Report of the Panel on Implementing Recommendations from New Worlds, New Horizons Decadal Survey

Panel on Implementing Recommendations from New Worlds, New Horizons Decadal Survey; National Research Council

ISBN: 0-309-16374-9, 36 pages, , (2010)

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Panel on Implementing Recommendations from New Worlds, New Horizons Decadal Survey
Board on Physics and Astronomy
Space Studies Board
Division on Engineering and Physical Sciences

NATIONAL RESEARCH COUNCIL
OF THE NATIONAL ACADEMIES

THE NATIONAL ACADEMIES PRESS
Washington, D.C.
www.nap.edu

THE NATIONAL ACADEMIES PRESS 500 Fifth Street, N.W. Washington, DC 20001

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This study was supported by Contract NNX08AN97G between the National Academy of Sciences and the National Aeronautics and Space Administration, Contract AST-0743899 between the National Academy of Sciences and the National Science Foundation, and Contract DE-FG02-08ER41542 between the National Academy of Sciences and the U.S. Department of Energy. Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the authors and do not necessarily reflect the views of the agencies that provided support for the project.

Cover:

International Standard Book Number-13: 978-0-309-XXXXX-X
International Standard Book Number-10: 0-309-XXXXX-X

Available in limited quantities from:

Board on Physics and Astronomy
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Printed in the United States of America

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PANEL ON IMPLEMENTING RECOMMENDATIONS FROM NEW WORLDS, NEW HORIZONS DECADAL SURVEY

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Preface

The National Research Council (NRC) Panel on Implementing Recommendations from the New Worlds, New Horizons Decadal Survey was requested by the Office of Science and Technology Policy to address the following:

> With the overall goal of ensuring that the scientific priorities of *New Worlds, New Horizons in Astronomy and Astrophysics* ("the decadal survey program") be pursued in as effective and timely a manner as possible, the NRC will organize a workshop that will feature invited presentations and discussion, to consider the implications of the following points:
>
> 1. The changes in the current budgetary and programmatic outlook for NASA's astrophysics program from the scenarios outlined in the decadal survey report.
> 2. The current status of NASA's implementation of the Wide-Field IR Survey Telescope (WFIRST) recommendation.
> 3. The current status of the ESA-Euclid mission, including any discussions of U.S. partnership in the mission.
> 4. The possible synergies and complementarities between the proposed NASA-WFIRST and ESA-Euclid science goals.
>
> In the context of the implications of these items and through a short report following the workshop, the panel will describe several strategic options for pursuing the science priorities of the decadal survey program. For each option the panel will outline the associated pros and cons from the perspective of achieving the decadal science goals in a timely manner.

The assembled panel comprised former members of the Committee for Decadal Survey of Astronomy and Astrophysics and other individuals involved in relevant aspects of the 2010 decadal survey process. All had an intimate knowledge of the survey itself and the rationales behind the strategy and various recommendations incorporated in the integrated plan outlined in the recently released report of the survey, *New Worlds, New Horizons* (NWNH). The panel invited to the open session of a meeting held November 7, 2010 stakeholders from both Europe and the United States and from the relevant agencies (NASA, ESA, NSF, DOE, and OSTP) and the scientific community (see Appendix A). On short notice, these individuals graciously agreed to attend (either in person or remotely) and (1) made presentations in response to questions prepared in advance by the panel and the NRC, (2) answered additional questions from the panel members, and (3) provided their own candid observations on relevant matters.

Having organized its workshop and considered the issues outlined in the charge, the panel concluded that its role was to review and assess the possibility of U.S. participation in the European Space Agency's (ESA's) dark energy project Euclid in light of the strategy developed as a result of the Astro2010 survey process and recommended in NWNH. Specifically, the charge, as interpreted by the panel, was to investigate the potential impact of both (1) U.S. participation in the ESA Euclid project and (2) the current budgetary situation at NASA with respect to the prospects for realizing NWNH priorities.

In particular, the panel interpreted its charge to be to assess whether a NASA commitment in the upcoming FY 2012 budget request to participate in the Euclid project at a level of approximately 20 percent of Euclid's costs would be consistent with achieving the priorities, goals, and recommendations, and with pursuing the science strategy, articulated in NWNH. The panel also investigated what impact such participation, as well as the current budgetary situation, might have on the prospects for the timely realization of the Wide-Field Infrared Survey Telescope (WFIRST) recommended by NWNH.

During the panel's deliberations, the report of the JWST Independent Cost Review Panel (ICRP) was made public. The ICRP reported that the James Webb Space Telescope (JWST) can be launched no earlier than the fourth quarter of 2015 and at a minimum additional expense of $1.4 billion.[1] As of the time the present panel's report was completed, it had still not been made clear how or whether the JWST cost and schedule overrun would be addressed. This panel's report should thus be read in the context of this new development and uncertainty, which nevertheless also serves to highlight the timely nature of this panel's conclusions.

In its deliberations, the panel made use not only of the testimony before it by external participants (see Appendixes A and B), but also of the decadal survey report NWNH itself. NWNH was the primary resource used by the panel in arriving at its conclusions, and the panel was careful not to contradict NWNH, either on particulars or on strategy, as it dissected the issues and pursued its charge.

Adam S. Burrows, *Co-Chair*
Charles F. Kennel, *Co-Chair*
Panel on Implementing Recommendations from the New Worlds, New Horizons Decadal Survey

[1] J. Casani, et al., "James Webb Space Telescope Independent Comprehensive Review Panel: Final Report" October 29, 2010 (publicly released on November 10, 2010).

Acknowledgment of Reviewers

This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the Report Review Committee of the National Research Council (NRC). The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their review of this report:

Dr. Roger D. Blandford, Stanford University
Dr. Martha P. Haynes, Cornell University
Dr. Robert C. Kennicutt, Jr., University of Cambridge
Dr. Jonathan I. Lunine, University of Arizona and University of Rome Tor Vergata
Dr. Christopher McKee, University of California, Berkeley
Dr. Marcia J. Rieke, University of Arizona
Dr. Paul L. Schechter, Massachusetts Institute of Technology
Dr. David N. Spergel, Princeton University
Dr. Scott D. Tremaine, Institute for Advanced Study
Dr. Michael S. Turner, The University of Chicago

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations, nor did they see the final draft of the report before its release. The review of this report was overseen by William Press, The University of Texas at Austin.

Appointed by the NRC, he was responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring panel and the institution.

Contents

Executive Summary

The 2010 Astronomy and Astrophysics Decadal Survey report, *New Worlds, New Horizons in Astronomy and Astrophysics* (NWNH), outlines a scientifically exciting and programmatically integrated plan for both ground- and space-based astronomy and astrophysics in the 2012-2021 decade.[1] However, late in the survey process, the budgetary outlook shifted downward considerably from the guidance that NASA had provided to the decadal survey. And since August 2010—when NWNH was released—the projections of funds available for new NASA Astrophysics initiatives has decreased even further because of the recently reported delay in the launch of the James Webb Space Telescope (JWST) to no earlier than the fourth quarter of 2015 and the associated additional costs of at least $1.4 billion. [2] These developments jeopardize the implementation of the carefully designed program of activities proposed in NWNH. In response to these circumstances, NASA has proposed that the United States consider a commitment to the European Space Agency (ESA) Euclid mission at a level of approximately 20 percent.[3] This participation would be undertaken in addition to initiating the planning for the survey's highest-ranked, space-based, large-scale mission, the Wide-Field Infrared Survey Telescope (WFIRST).

The Office of Science and Technology Policy (OSTP) requested that the National Research Council (NRC) convene a panel to consider whether NASA's Euclid proposal is consistent with achieving the priorities, goals, and recommendations, and with pursuing the science strategy, articulated in NWNH. The panel also investigated what impact such participation might have on the prospects for the timely realization of the WFIRST mission and other activities recommended by NWNH in view of the projected budgetary situation.[4]

The Panel on Implementing Recommendations from the New Worlds, New Horizons Decadal Survey convened its workshop on November 7, 2010, and heard presentations from NASA, ESA, OSTP, the Department of Energy, the National Science Foundation, and members of the domestic and foreign astronomy and astrophysics communities. Workshop presentations identified several tradeoffs among options: funding goals less likely versus more likely to be achieved in a time of restricted budgets; narrower versus broader scientific goals; and U.S.-only versus U.S.-ESA collaboration. The panel captured these tradeoffs in considering four primary options.[5]

Option A: Launch of WFIRST in the Decade 2012-2021

The panel reaffirms the centrality to the overall integrated plan articulated in NWNH of embarking in this decade on the scientifically compelling WFIRST mission. If WFIRST development and launch are significantly delayed beyond what was assumed by NWNH, one of the key considerations that led to this relative ranking is no longer valid. However, until there is greater clarity on how and when WFIRST can be implemented, it is difficult to determine whether the relative priorities of NWNH should be reconsidered. These issues may well require consideration by the decadal survey implementation advisory committee (DSIAC) recommended in NWNH.[6]

[1] National Research Council, *New Worlds, New Horizons in Astronomy and Astrophysics*, The National Academies Press, Washington, D.C., 2010 (prepublication version).

[2] J. Casani, et al., "James Webb Space Telescope Independent Comprehensive Review Panel: Final Report," October 29, 2010 (publicly released on November 10, 2010).

[3] At the November 7, 2010 workshop NASA said that the current participation level on Euclid is planned at 20% of the estimated mission development cost (see Appendix B for more information).

[4] The panel's statement of task is given in this report's Preface. Information on the workshop is provided in Appendixes A and B.

[5] The four options are not ranked in any particular order.

[6] In NWNH, the recommended DSIAC was charged to "monitor progress toward reaching the goals recommended in [NWNH], and to provide strategic advice to the agencies over the decade of implementation" (p. 1-5).

Option B: A Joint WFIRST/Euclid Mission
If the budget constraints that have emerged since delivery of the NWNH report are not adequately addressed and a timely WFIRST as originally conceived is not possible (see Option A), one option to accomplish WFIRST's goals would be a single, international mission, combining WFIRST and ESA's Euclid. Either a U.S.-led mission or an ESA-led mission could be consistent with the NWNH report, contingent on whether or not the United States plays "a leading role" and "so long as the committee's recommended science program is preserved and overall cost savings result" (p. 1-6). Therefore, it would be advantageous for NASA, in collaboration with ESA, to study whether such a joint mission is feasible. Waiting to decide on a significant financial commitment to such a partnership, whatever its form, would allow time for such studies and for the DSIAC to be established and provide guidance on this issue.

Option C: Commitment by NASA of 20 percent Investment in Euclid prior to the M-class decision
A 20 percent investment in Euclid as currently envisioned and as presented by NASA is not consistent with the program, strategy, and intent of the decadal survey. NWNH stated the following if the survey's budget assumption cannot be realized: "In the event that insufficient funds are available to carry out the recommended program, the first priority is to develop, launch, and operate WFIRST, and to implement the Explorer program and core research program recommended augmentations" (p. 7-40). A 20 percent plan would deplete resources for the timely execution of the broader range of NWNH space-based recommendations and would significantly delay implementing the Explorer augmentation, as well as augmentations to the core activities that were elements in the survey's recommended first tier of activities in a less optimistic budget scenario. A 20 percent contribution would also be a non-negligible fraction of the resources needed for other NWNH priorities.

Option D: No U.S. Financing of an Infrared Survey Mission This Decade
If neither options A nor B are viable due to budget constraints (or if option A is not viable and option B is not possible due to programmatic difficulties), and option C is rejected, the panel concluded that to be consistent with the overall plan in NWNH, any existing budget wedge could go to other NWNH priorities: the next-ranked large recommendation (augmentation of the Explorer program), technology development for future missions, and the high-priority medium and small recommended activities, possibly with the omission of WFIRST. Although an extremely unfortunate outcome with severely negative consequences for the exciting science program advanced by NWNH, this option seems consistent with NWNH, which did not prioritize between its large, medium, and small recommended activities. However, such a major change of plan should first be reviewed by the recommended DSIAC.

Providing strategic advice under current conditions is extremely challenging. The question of whether today's changing conditions fundamentally alter the long-term approach of the decadal survey might understandably be asked. However, the panel emphasizes that the 2010 decadal survey provided integrated advice that was explicitly designed to be robust for the entire decade. The survey anticipated that fiscal and scientific conditions would change. NASA's rapidly changing budgetary landscape highlights the urgency of establishing a mechanism such as the DSIAC to ensure that appropriate community advice is available to the government. The NWNH recommendations remain scientifically compelling, and this panel believes that the decadal survey process remains the most effective way to provide community consensus to the federal government to assist in its priority setting for U.S. astronomy and astrophysics.

1
Introduction

The Astronomy and Astrophysics Decadal Survey report, *New Worlds, New Horizons in Astronomy and Astrophysics* (NWNH), outlines a scientifically exciting and programmatically integrated plan for both ground- and space-based astronomy and astrophysics in the 2012-2021 decade.[7] The survey involved hundreds of astronomers in 9 panels and 6 study groups that reported to one overarching committee whose task was to integrate numerous specific scientific and technical goals into a resilient strategy for research over the decade. For the first time in a decadal survey, the panels and study groups evaluated technical and cost issues along with science. NWNH has achieved a new level of realism in advice provided by the National Research Council to the astronomical research agencies. However, the budgetary guidance that NASA provided to the decadal survey shifted downward considerably in the two years (fall 2008-August 2010) during which the survey operated. Since August 2010—when NWNH was released—projections of funds available for new NASA Astrophysics initiatives have been reduced even further. The recently reported delay in the launch of the James Webb Space Telescope (JWST) to no earlier than the fourth quarter of 2015 and the associated additional costs of at least $1.4 billion jeopardize the implementation of the carefully designed program of activities proposed in NWNH.[8]

Before NWNH was released, NASA had been considering a commitment to the European Space Agency (ESA) Euclid mission at a level of approximately 20 percent of its costs in its forthcoming FY 2012 budget request.[9] According to NASA, participation in Euclid could provide the U.S. research community with access to dark energy science data, which is one component of the science program proposed for the Wide-Field Infrared Survey Telescope (WFIRST)—NWNH's top-ranked, large-scale, space-based mission. Euclid is proposed for launch in 2018, while NASA has reported that, under the current circumstances, WFIRST might launch no earlier than 2022.[10] NWNH envisioned WFIRST to launch in 2020 following a 2013 start.

Given the apparent differences between the Euclid and WFIRST proposals, the Office of Science and Technology Policy requested that the NRC convene a panel and organize a workshop to consider whether NASA's Euclid participation proposal is consistent with achieving the priorities, goals, and recommendations, and with pursuing the science strategy, articulated in NWNH. The panel also investigated what impact such participation might have on the prospects for the timely realization of WFIRST mission and other activities recommended by NWNH in view of the projected budgetary situation.[11]

The panel convened its workshop on November 7, 2010 and heard presentations from NASA, DOE, NSF, ESA, OSTP, and members of the domestic and foreign astronomy and astrophysics communities (see Appendixes A and B). Workshop presentations identified several tradeoffs among options: less versus more likely to achieve funding goals in a time of restricted budgets; narrower versus broader scientific goals; and U.S.-only versus U.S.-ESA collaboration.

[7] National Research Council, *New Worlds, New Horizons in Astronomy and Astrophysics*, The National Academies Press, Washington, D.C., 2010 (prepublication version).
[8] J. Casani, et al., "James Webb Space Telescope Independent Comprehensive Review Panel: Final Report" October 29, 2010 (publicly released on November 10, 2010).
[9] Based on input received from ESA at the panel's November 7, 2010 meeting. The panel assumed that the ~20 percent share in question would equal approximately $170 million to $200 million.
[10] Based on input received from ESA and NASA at the panel's November 7, 2010 meeting.
[11] The panel's statement of task is given in this report's Preface.

2

Discussion

The discussion in the sections below is derived from text in the decadal survey, information conveyed to the panel at its November 7, 2010 meeting (see Appendixes A and B), and the panel's own deliberations.

THE BALANCED PROGRAM RECOMMENDED IN ASTRO2010

New Worlds, New Horizons in Astronomy and Astrophysics (NWNH)[13] prioritized a set of missions and activities to advance the set of science priorities identified by the Science Frontier Panels. It is important to note that, while the program was organized according to three science objectives—cosmic dawn, new worlds, and the physics of the universe, these science objectives themselves were not ranked. Rather, a program was constructed to optimize science return and to ensure progress on a much broader front as well (see table[14]), while also fostering unanticipated discovery. Importantly, NWNH does not recommend *any* specific science goal as its top priority.

TABLE Summary of Science Frontiers Panels' Findings

Panel	Science Questions		Area(s) of Unusual Discovery Potential
Cosmology and Fundamental Physics	CFP 1	How did the universe begin?	Gravitational Wave Astronomy
	CFP 2	Why is the universe accelerating?	
	CFP 3	What is dark matter?	
	CFP 4	What are the properties of neutrinos?	
Galactic Neighborhood	GAN 1	What are the flows of matter and energy in the circumgalactic medium?	Time-Domain Astronomy Astrometry
	GAN 2	What controls the mass-energy-chemical cycles within galaxies?	
	GAN 3	What is the fossil record of galaxy assembly from the first stars to the present?	
	GAN 4	What are the connections between dark and luminous matter?	
Galaxies Across Cosmic Time	GCT 1	How do cosmic structures form and evolve?	The Epoch of Reionization
	GCT 2	How do baryons cycle in and out of galaxies, and what do they do while they are there?	
	GCT 3	How do black holes grow, radiate, and influence their surroundings?	
	GCT 4	What were the first objects to light up the universe, and when did they do it?	
Planetary Systems and Star Formation	PSF 1	How do stars form?	Identification and Characterization of Nearby Habitable Exoplanets
	PSF 2	How do circumstellar disks evolve and form planetary systems?	
	PSF 3	How diverse are planetary systems?	
	PSF 4	Do habitable worlds exist around other stars, and can we identify the telltale signs of life on an exoplanet?	
Stars and Stellar Evolution	SSE 1	How do rotation and magnetic fields affect stars?	Time-Domain Surveys
	SSE 2	What are the progenitors of Type Ia supernovae, and how do they explode?	
	SSE 3	How do the lives of massive stars end?	
	SSE 4	What controls the mass, radius, and spin of compact stellar remnants?	

Moreover, NWNH prioritized missions and activities only within size categories, and not across

[13] National Research Council, *New Worlds, New Horizons in Astronomy and Astrophysics*, The National Academies Press, Washington, D.C., 2010 (prepublication version).
[14] Ibid., p. A-2.

them. For example, in space, the recommended priority order for the large-scale activities were: (1) the Wide-Field Infrared Survey Telescope (WFIRST); (2) the Explorer program augmentation; (3) the Laser Interferometer Space Antenna (LISA); and (4) the International X-ray Observatory (IXO). At the medium scale, the priorities were (1) a New Worlds Technology Development program; and (2) an Inflation Probe Technology Development program. NWNH does not state that large-scale activities should be done ahead of medium-scale activities, or that medium-scale activities should be done ahead of small-scale ones, nor that the top large-scale priority is the top *overall* priority of the program. NWNH also does not state that the list of priorities within a category necessarily means that the highest priority must be completed before the next priority begins.

A principle central to NWNH is the need for a *balanced* program, and thus small programs and core augmentations were also enumerated in NWNH.[15] Some examples of such programs are, "support of individual investigators, instrumentation, laboratory astrophysics, public access to privately operated telescopes, suborbital space missions, technology development, theoretical investigations, and collaboration on international projects."[16] These programs were not prioritized against medium or large activities.

Comparison of WFIRST and Euclid Capabilities and Science Goals

WFIRST is a 1.5-meter space telescope with a near-infrared (NIR) imager and a near-infrared spectrometer-camera. Its NIR detectors have some sensitivity in the visible red, but WFIRST is primarily an infrared platform. In conception, it combines three overarching goals: (1) to use the three primary methods that have emerged to investigate dark energy and the validity of general relativity in describing cosmic acceleration (Baryon Acoustic Oscillations [BAO], weak lensing, and Type Ia supernovae);[17] (2) to conduct a microlensing survey of exoplanets to derive the statistics of exoplanet system architectures; and (3) to provide a guest investigator mode to perform a deep-infrared survey of galaxies, quasars, and large-scale structure, and also a complete survey of the galactic plane. The panel notes that a guest investigator mode is a substantial addition to these IR surveys and one which makes WFIRST a community facility with a large potential "discovery space."[18]

By comparison, Euclid is a 1.2-meter space telescope with an emphasis on dark energy which uses the BAO and weak lensing approaches and foregoes the use of Type Ia supernovae. In the words of the "Yellow Book" on Euclid, it is a "precision cosmology mission with goals of dark matter, dark energy, initial conditions, tests of gravity and sharpening cosmological parameters." [19] Although Euclid has a NIR imaging capability, and NIR spectroscopic capability for BAO studies, it is primarily an optical instrument with CCDs with a pixel scale of 0.1 arcseconds. However, a byproduct of the Euclid mission will also be a NIR imaging and spectroscopic survey, and Euclid has a modest planet microlensing capability.

The multiple objectives of WFIRST—dark energy, microlensing planet search, infrared surveys, and the support of pointed observations proposed by guest investigators—are made possible by the large number of IR-detectors and the fine resolution with which they sample the excellent images afforded from space. Euclid as currently envisioned has a smaller primary mirror, fewer IR arrays, and much coarser imaging scale in the infrared, so it cannot meet the NWNH science goals. The WFIRST design has a great advantage over the Euclid design in the microlensing search for planets because its high-resolution pixels are in the infrared, where the galactic bulge stars that will be monitored are intrinsically brighter and less affected by dust. As explained in the report of the decadal survey's Panel on

[15] The need for a balanced program is also given in National Research Council, "A Performance Assessment of NASA's Astrophysics Program, National Academies Press, Washington, D.C., 2007.
[16] National Research Council, *New Worlds, New Horizons in Astronomy and Astrophysics*, National Academies Press, Washington, D.C., 2010 (prepublication version), p. ES-2
[17] National Research Council, *New Worlds, New Horizons in Astronomy and Astrophysics*, National Academies Press, Washington, D.C., 2010 (prepublication version), pp. 1-5 and 7-17.
[18] As noted by Roger Blandford at the November 7, 2010 meeting.
[19] European Space Agency, "Euclid Yellow Book."

Electromagnetic Observations from Space, of the missions considered, only WFIRST can build up a deep statistical sample that will adequately complement the Kepler mission's probe of Earth-sized planets close to their parent stars. For the program of dark energy research, another significant advantage of WFIRST is its capability for simultaneous spectroscopy and imaging.

The panel notes that a keystone of the integrated plan advocated in NWNH is exploration of dark energy over the full redshift range with multiple techniques and facilities.[20] Hence, it was concluded in NWNH that WFIRST and LSST would complement one another to improve overall accuracy and control systematics. The WFIRST and Euclid missions each have strengths and weaknesses with respect to the goals of a dark energy study, but NWNH concluded that the substantial advantages of the WFIRST configuration and its ability to address multiple priority science questions identified by the survey were decisive. Accordingly, NWNH ranked WFIRST highest in the large class of space-based activities.

SPECIFIC STATEMENTS IN NWNH CONCERNING EUCLID

The Astro2010 survey committee was aware of the preliminary discussions on possible U.S. participation in Euclid that were inaugurated between NASA and ESA before NWNH was released and considered options for collaborations in its overall deliberations, albeit late in the process.[21] There are three references in NWNH to possible U.S. collaboration on Euclid:

1. "The European Space Agency (ESA) is considering an M-class proposal, called Euclid, with related goals. Collaboration on a combined mission with the United States playing a leading role should be considered so long as the committee's recommended science program is preserved and overall cost savings result." (p.1-6).

2. "Euclid is a European mission concept aimed at cosmology and dark energy, which is competing for one of two M(edium)-class launch slots, with a decision expected in late 2011 and launches scheduled for 2018 and 2019.[22] The overlap in goals and scope between the proposed U.S. and European missions is significant, and there is potentially a grand partnering arrangement involving NASA, DOE, and ESA if the expanded scientific priorities set by Astro2010 for such a mission can be aligned among the partners, and assuming that the arrangement is consistent with the United States playing a clear leadership role." (p.3-14).

3. "There have been discussions between the U.S. agencies and ESA about mounting a joint mission, which could be a positive development if it leads to timely execution of a program that fully supports all of the key science goals of WFIRST (planet microlensing, dark energy science, general investigations) and leads to savings overall. It is expected that the United States will play a leading role in this top-priority mission." (p. 7-18).

As is clear from the quotes above, NWNH looked favorably on international participation with the Europeans on WFIRST/Euclid science, but only in the context of (1) "a clear leadership role" for the United States and (2) "a [timely] program that fully supports all of the key science goals of WFIRST (planet microlensing, dark energy science, general investigations) and leads to savings overall," as articulated above.

SPECIFIC STATEMENTS IN NWNH ON LARGE MISSION OVERRUNS

[20] As noted by Roger Blandford at the November 7, 2010 meeting.
[21] It is important to note that the Euclid mission was not proposed to the Program Prioritization Panels nor did it go through the cost, risk, and technical evaluation process.
[22] As heard from the European Space Agency at the November 7, 2010 meeting, there are two M-class mission launch opportunities within 2017-2018, and the current budget would allow an M-class mission launch in 2022, assuming the first large-class mission will be launched in 2020.

In the most restricted budget scenario considered by the Decadal survey committee, NWNH stated:

> "In the event that insufficient funds are available to carry out the recommended program, the first priority is to develop, launch, and operate WFIRST, and to implement the Explorer program and core research program recommended augmentations." (p. 7-40).

Even under such constrained circumstances, NWNH insisted on maintaining balance in the program and did not support sacrificing, or significantly delaying, any one element of the remaining components of its integrated plan for one large mission.

In addition, consistent with this theme and related to the current situation with JWST, NWNH clearly objected to the use of funds to address overruns in large and medium missions at the expense of core activities. One relevant paragraph in NWNH contains the words:

> "NASA's core research programs, from theoretical studies to innovative technology development, are fundamental to mission development and essential for scientific progress. . . Maintaining these core activities has a high priority for the survey committee, and the budget allocations should not be allowed to decrease to address overruns in the costs of large and medium missions." (p. 1-9).

3

Conclusions

The fiscal boundary conditions communicated to the NRC by NASA shifted considerably during the decadal survey process, and erosion since then has been continuing at an alarming pace. Providing strategic advice under these conditions is extremely challenging. The question may be asked whether these changing conditions fundamentally alter the context for the strategy developed by the decadal survey. The panel notes, however, that the decadal survey process was designed to produce advice robust to changing conditions, both fiscal and scientific, and the panel found that the recommendations made in NWNH remain scientifically compelling. Nevertheless, the decline in real purchasing power identified before NWNH was issued, and the recent increase in the cost of completing the James Webb Space Telescope (JWST),[23] together jeopardize the implementation of NWNH. In this context, and with a focus on the Euclid/WFIRST issue, the panel explored the pros and cons of the four primary options that emerged during its deliberations, and it drew conclusions for each as to whether they were consistent with NWNH recommendations.

Option A: Launch of WFIRST in the Decade 2012-2021

The panel reaffirms the centrality to the overall integrated plan articulated in NWNH of embarking in this decade on the scientifically compelling WFIRST mission. According to NWNH:

> "WFIRST addresses fundamental and pressing scientific questions and contributes to a broad range of astrophysics. It complements the proposed ground-based program in two key science areas: dark energy science and the study of exoplanets. It is an integral part of coordinated and synergistic programs in fields in which the United States has the leading role. It also presents opportunities for interagency and perhaps international collaboration that will tap complementary experience and skills. It also presents relatively low technical and cost risk, making it feasible to complete within the decade, even in a constrained budgetary environment. For these reasons, it is the top-priority recommendation for a space-based initiative. A 2013 new start should enable launch in 2020." (p. 7-18).

However, without additional funds to augment the projected NASA Astrophysics budget—for the express purpose of completing JWST—the carefully crafted program for space-based astrophysics recommended in NWNH may not be realized. It is clear from NASA and OSTP comments at the November 7, 2010 meeting that in the current budget climate WFIRST will be delayed by a delayed JWST (assuming that JWST will not be canceled). In recognition of tight budgetary constraints for the coming decade due to the continued development of JWST, the NWNH program for space astrophysics was more modest than the programs of the previous two decadal surveys.[24] That being the case, there is considerable concern in the astronomy and astrophysics community that even this modest program is jeopardized by the possibility of yet more cost and schedule growth in JWST which threatens to reduce still further the funding available for new astrophysics missions such as WFIRST and other activities recommended in NWNH. More broadly, this budget situation has serious consequences for elements of the program that address time-critical science opportunities and strive for a balanced and diverse program.

As the panel heard from the survey chair at its workshop, key to the WFIRST mission

[23] J. Casani, et al., "James Webb Space Telescope Independent Comprehensive Review Panel: Final Report" October 29, 2010 (publicly released on November 10, 2010).

[24] National Research Council, *New Worlds, New Horizons in Astronomy and Astrophysics*, National Academies Press, 2010 (prepublication version), p. 7-4.

recommendation is the possibility of its rapid development and thus launch within the decade.[25] Current estimates of a launch of 2022,[26] or even much later, substantially weaken NWNH's rationale for this mission, and would also postpone the development of future missions (in the 2020-2030 timeframe). NWNH states that WFIRST's relatively low technical risk makes it "feasible to complete within the decade, even in a constrained budgetary environment. *For these reasons* [emphasis added], it is the top-priority recommendation for the space-based initiative" (p. 3-14). NWNH considered LISA and IXO to be compelling, highly capable, and more ambitious flagship missions than WFIRST, but ranked them lower because of their required new technology development, higher cost, and technical risk, which, given NWNH's budget assumptions, make launch this decade or even early next decade highly unlikely. If WFIRST development and launch are significantly delayed beyond what was assumed by NWNH, one of the key considerations that led to this relative ranking is no longer valid.

The panel notes that the NWNH program also includes (1) key investments in technology development for future missions, (2) medium-scale activities (beyond such technology development), and (3) small-scale activities, all of which are jeopardized by the austere budgets now under consideration. While the advantages of appropriating the projected budget scenarios utilized in developing the NWNH-recommended astrophysics program are obvious, the panel recognizes the unique challenges that this option presents. However, until the issues associated with WFIRST (and JWST) are clarified, it is difficult to determine whether the relative priorities of NWNH should be reconsidered, or whether resources would be better invested in small and medium scale activities than on a significantly delayed WFIRST. The relative development schedules of Euclid and WFIRST may also be a factor in such considerations. Having heard the evidence presented at its workshop, the panel finds that the current situation is unclear and all of these issues may well require consideration by the decadal survey implementation advisory committee (DSIAC) recommended in NWNH when more information is available. This panel, echoing the assumption in NWNH that the mission would be available to address key science priorities in the decade ahead, strongly emphasizes that the success of JWST is central to U.S. space astronomy, but hopes that whatever means are found to address the JWST cost increases do not vitiate the exciting program put forward in NWNH.

Option B: A Joint WFIRST/Euclid Mission

If the budget constraints that have emerged since delivery of the NWNH report are not adequately addressed (see Option A) and a timely WFIRST as originally conceived is not possible, one option to accomplish WFIRST's goals would be a single, international mission, combining WFIRST and ESA's Euclid.[27] The panel affirms the scientific priority of a mission that accomplishes all the goals of WFIRST that would also accomplish the goals of Euclid. Although no path has yet been identified by the agencies toward a single international mission, such a mission may still be possible. Fitting the ESA and NASA processes together at this stage would be a challenge, but the scientific benefits are clear. Were a joint mission to remain on the ESA schedule for Euclid to launch within this decade, it would indeed be completely consistent with the NWNH plan for WFIRST.

The NWNH report recommended a leadership role for the U.S. in a joint mission. The panel interprets "a leadership role"[28] to mean (1) ensuring that the science requirements and observing plan, which are jointly designed and agreed upon, support all the primary WFIRST science goals specified in NWNH, namely planet microlensing, dark energy science (through the BAO, weak lensing, and SNIa methods), and the galactic survey/guest investigator program (p. 7-17);[29] (2) that the United States has a prominent role on the science team, whose members have full access to the data, and that the data are archived for the U.S. community to use; and (3) that the United States has sufficient involvement in mission development that can ensure that all the science requirements are met.

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[25] As described in Dr. Roger Blandford's presentation at the panel's November 7, 2010 meeting.
[26] As described by NASA at the panel's November 7, 2010 meeting.
[27] See number (3) in "Specific Statements in NWNH Concerning Euclid" above.
[28] National Research Council, *New Worlds, New Horizons in Astronomy and Astrophysics*, National Academies Press, 2010 (prepublication version), p. 3-14.
[29] Ibid., p. 7-17.

With the above conditions, either a U.S.-led mission or an ESA-led mission could be consistent with the NWNH report. Appropriately, NASA is pushing ahead with a WFIRST science definition team (SDT) to clarify mission details and is waiting for ESA to finish its M(edium)-class selection process before reopening negotiations on a possible partnership.[30] NASA could invite current Euclid scientists to participate in the WFIRST SDT, and solicitations for U.S. scientists to participate on the Euclid team could encompass the full suite of WFIRST goals. Should Euclid be selected, negotiations could proceed to merge the teams toward an optimized international mission.

The panel notes that at this stage it has too little information to determine whether the option of a transatlantic partnership on WFIRST/Euclid science can be crafted that comports with NWNH's overall integrated plan for U.S. astronomy. Therefore, the panel concludes that it would be advantageous for NASA to embark as soon as possible on the required studies, presumably in collaboration with ESA, to determine whether such a partnership is technically, financially, and politically feasible. Also, the panel notes that waiting to decide on a significant financial commitment to such a partnership, whatever its form, would allow time for such studies and for the decadal survey implementation advisory committee (DSIAC) recommended in NWNH to be established to "monitor progress toward reaching the goals recommended in [NWNH], and to provide strategic advice to the agencies over the decade of implementation" (p. 1-5). The current panel is very sympathetic to NASA's Science Mission Directorate as it attempts to implement NWNH in the current budgetary climate and expects that the DSIAC, once established, will work closely and productively with NASA to help realize the program articulated in NWNH within emerging budgetary constraints.

Option C: Commitment by NASA of 20 percent Investment in Euclid prior to the M-class decision

The panel heard from NASA about its proposal to join ESA in a partnership on the Euclid mission at a level of 20 percent. Having also heard details of the Euclid mission from ESA and the rationale for the decadal survey's WFIRST recommendation and its three science goals from Roger Blandford, the panel concluded that a 20 percent investment in Euclid as it is currently envisioned and as presented by NASA is not consistent with the program, strategy, and intent of the decadal survey. NASA's current position is that a down payment can be made on the dark energy science goals of WFIRST by making a 20 percent investment in Euclid, and that this approach would provide the opportunity for U.S. scientists to be involved sooner in space-based dark energy science, given that a launch of WFIRST would most likely be delayed significantly.[31] However, the two other WFIRST science goals outlined in NWNH, robust exoplanet microlensing and guest-observer-survey programs, would not be fully realized in the baseline mission of Euclid (although Euclid does include a modest microlensing capability). The Astro2010 survey committee was aware of Euclid, as it is currently configured, and the possibility of a minority partnership. However, a minority share in Euclid does not appear as an option in either budget scenario described in NWNH. Instead, NWNH stated that if the survey's budget assumption cannot be realized then, "In the event that insufficient funds are available to carry out the recommended program, the first priority is to develop, launch, and operate WFIRST, and to implement the Explorer program and core research program recommended augmentations" (p. 7-40). NWNH does not prioritize among these three recommendations and does not provide guidance on how to do so. The DSIAC may be able to weigh in on this matter should the need arise.

NASA has stated that a 20 percent investment in Euclid as described would be cost-neutral over the decade—owing to a complementary ESA contribution in WFIRST. However, the panel concludes that the 20 percent plan would deplete resources for the timely execution of the broader range of NWNH space-based recommendations and would significantly delay implementing the Explorer augmentation ($463 million), as well as augmentations to the core activities ($110 million) that were elements in the survey's first tier of activities for a less optimistic budget scenario. Moreover, the present panel emphasizes that a 20 percent share dedicated to Euclid would be a non-negligible fraction of the resources needed for these and other NWNH priorities (such as New Worlds [$100-200 million] and Cosmic Microwave Background/inflation [$60-200 million] technology development and theory and computation

[30] As described by NASA at the panel's November 7, 2010 meeting.
[31] As presented by NASA at the November 7, 2010 meeting.

networks [$50 million from NASA]), and would be spent in part during the period of greatest stress on the NASA budget due to JWST cost growth and delay. [32]

The NWNH program recommended for NASA also includes support for LISA pathfinder and IXO development—both LISA and IXO are candidates for ESA's L(arge)-class mission opportunity—which the panel highlights because ESA intends[33] to make a decision on its L-class and M-class missions on a similar timescale in 2011. The outcome of these ESA processes may be another key issue for the NWNH-recommended DSIAC to review in the context of extremely limited available resources.

Option D: No U.S. Financing of an Infrared Survey Mission This Decade

The impacts of the JWST cost overruns on the astrophysics budget are not currently known, but it is conceivable that their severity would have a crippling effect on the integrated program recommended in NWNH. If neither of options A nor B are viable due to budget constraints (or if option A is not viable and option B is not possible due to programmatic difficulties), and option C is rejected, the panel finds, consistent with the overall plan in NWNH, any existing budget wedge could go to other NWNH priorities: the next-ranked large recommendation (augmentation of the Explorer program), technology development for future missions, and the high-priority medium and small recommendations, possibly with the omission of WFIRST (p. 7-40). Although an extremely unfortunate outcome with severely negative consequences for the exciting science program advanced by NWNH, because NWNH did not prioritize between its large, medium, and small recommendations, this option would seem consistent with NWNH. However, such a major change of plan should first be reviewed by the DSIAC.

Final Remarks

In exploring the four options discussed above and reaching its conclusions, this panel was guided by the widely recognized community consensus that the decadal survey process is the most effective way to inform federal priority setting in astronomy and to ensure the continuance of the remarkable record of accomplishment in astronomy witnessed during the past fifty years. The recent decadal survey engaged a large number in the astronomy community for almost 2 years in a massive consensus-building exercise. Past surveys have always served astronomy and the federal agencies well as the "gold standard" for scientific and project advice. As charged, this panel has sought to interpret the integrated plan recommended in NWNH in the context of changing circumstances.[34] It did not view its role as altering or revisiting in any way the issues addressed by NWNH, nor as providing guidance beyond what is stated in NWNH.

[32] As presented by NASA at the November 7, 2010 meeting. Based on input received from ESA at this meeting, the panel assumed that the ~20 percent share in question would equal approximately $170 million to $200 million.
[33] As presented by ESA at the November 7, 2010 meeting.
[34] The recently-enacted NASA Authorization Act directs NASA "to take into account recommendations from the National Academies' decadal surveys when submitting their budget request," (Section 805).

Appendixes

Appendix A

Meeting of the Panel on Implementing Recommendations from New Worlds New Horizons Decadal Survey

November 7, 2010—Beckman Center, Huntington Room

OPEN SESSION

1230	Introduction	William Colglazier, NRC CEO
1240	Background and Agenda for Discussion	Charles Kennel and Adam Burrows, Panel Co-chairs
1245	Precision Cosmology and Dark Energy with Euclid: European Perspective	Alexandre Réfrégier, Euclid PI, Service d'Astrophysique, Saclay
1315	Status of ESA Plans for M-Class Missions	Fabio Favata, Head of ESA Science Planning and Community Coordination Office
1330	NASA-ESA Joint Plans for M/L-Class Collaboration	Jon Morse, NASA Astrophysics and Fabio Favata, ESA
1345	Discussion with Fabio Favata and Jon Morse	All
1405	Euclid Science: U.S. Perspective (including Q&A)	Steve Kahn, Stanford University
1425	WFIRST and Euclid	David Weinberg, Ohio State University
1445	The Astro2010 Program: An Integrated Plan for 2010-2021 (including Q&A)	Roger Blandford, Astro2010 Chair, Stanford University
1520	**Break**	
1535	The U.S. Plan for Implementation of WFIRST and Outlook for NASA Astrophysics (including Q&A)	Jon Morse, NASA Astrophysics
1605	Implementation of LSST and other complementary programs by DOE and NSF (including Q&A)	William F. Brinkman, DOE Science, Dennis Kovar, DOE High Energy Physics Vern Pankonin, NSF Astronomy
1620	OSTP Views (including Q&A)	Carl Wieman, Associate Director, Science, Office of Science and Technology Policy
1635	Public Comment	
1700	**Concluding Remarks**	Charles Kennel and Adam Burrows
1715	**Adjourn Public Session** (to be reconvened at 17.30)	

CLOSED SESSION

1730	**SESSION STARTS—**Panel Discussion	
2130	**SESSION ENDS**	

Appendix B

The panel held a workshop on November 7th at which a number of presentations were made as described in Appendix A. Below is a brief overview of each presentation made at the panel's workshop on November 7, 2010 in Irvine, California. See Appendix A for the agenda for the workshop. In order to help focus the presentations and in the interest of efficient data gathering, the committee prepared guiding questions which were delivered to the speakers prior to the workshop. These questions are reproduced alongside a short summary of each speaker's presentation. Additional questions not listed below were asked during the actual meeting. Speakers' viewgraphs are available, as provided, upon request through the NRC's Public Access Records Office.[35]

Dr. William Colglazier, Executive Officer of the National Research Council (NRC), opened the meeting by outlining the nature of the request to the NRC for this study from the Office of Science and Technology Policy. He thanked the panel for addressing this challenging task on such a rapid schedule. He noted that the U.S. Government is looking forward to the panel's perspective on the NASA proposal to participate in the European Space Agency's (ESA's) Euclid mission.

Dr. Adam Burrows and Dr. Charles Kennel, co-chairs of the panel, provided some opening remarks, and described the issues on which the panel wanted to focus. They noted the tight meeting agenda, and asked speakers to be efficient in their presentations and to leave time for questions. They concluded by remarking that both the Board on Physics and Astronomy and the Space Studies Board—of which they are chairs, respectively—had just earlier that morning being discussing the need for NRC stewardship of the space sciences decadal surveys and that this rapid panel and workshop activity only underscored that need.

Dr. Alexandre Réfrégier of the Service d'Astrophysique, Saclay, and Principal Investigator for Euclid, was given the following questions prior to his talk:
Q1: What are Euclid's primary (or Level 1) science requirements?
Q2: To what extent is U.S. technical involvement needed to deliver Euclid science?
Q3: To what extent is Euclid's science complementary to and/or synergistic with the science envisioned for WFIRST?
Q4: Given the NWNH recommendation and a potential NASA partnership, is there any consideration being given to scaling Euclid back to an optical-only mission, with the expectation that a WFIRST mission would carry out the infrared complement?
Q5: How might the Euclid design and mission be modified to incorporate microlensing?
Dr. Réfrégier delivered a presentation via teleconference entitled, "Euclid: Mapping the geometry of the Dark Universe." He outlined the outstanding questions in cosmology and then described the Euclid mission as being driven by science concerning the nature of the dark energy, nature of the dark matter, initial conditions (inflation physics), and modifications to gravity. He remarked that U.S. involvement is very welcome, but not necessary for Euclid to proceed, though that Euclid has involved U.S. scientists from the project's beginning, so continued involvement would allow U.S. scientists to participate in the project in a more formal way and give more programmatic margins to optimize the mission. He then described the Euclid mission baseline and technical specifications, as well as its figures of merit (FOMs). He also noted its anticipated synergies with other facilities and "legacy" through archival means, and said that, depending on WFIRST's actual manifestation, there may be a lot of scope for making Euclid and WFIRST's science complementary. He said that the incorporation of microlensing is possible from a hardware point of view and is being discussed, but the current nominal survey baseline does not include it. Finally, he provided the current Euclid mission schedule, which foresees launch in 2018, contingent on its selection in the M(edium)-class mission decision expected mid-2011.

Dr. Fabio Favata, Head of the ESA Science Planning and Community Coordination Office, was given the

[35] The Public Access Records Office provides access to project materials available to the public, and can be accessed online via the Current Projects System at http://www8.nationalacademies.org/cp/.

following questions prior to his talk:
Q1: What is ESA's reaction to the statement on Euclid in NWNH: "Collaboration on a combined mission with the United States playing a leading role should be considered so long as the committee's recommended [NWNH] science program is preserved and overall cost savings result."?
Q2: Is there any flexibility in the plans for the science of the Euclid mission? Could it be restructured to include all 3 components of a WFIRST mission? (specifically, for dark energy: weak lensing, BAO, and SNe; exoplanets via microlensing; and a guest investigator survey mode?)
Q3: What approach is ESA taking to secure independent cost and schedule estimates for the Euclid mission?
Q4: What is the current status of independent cost estimates for Euclid, and how confident is ESA that Euclid can stay within the 470 MEuro cost ceiling?
Q5: What is ESA's schedule for delivery of Euclid science, and to what extent does that schedule depend on U.S. involvement?
Dr. Favata delivered a presentation via teleconference on ESA program planning with respect to Euclid. He outlined the ESA long-term science program planning process and described the "Cosmic Vision 2015-2025"[36] process which resulted in the identification of four "Grand Themes."[37] He went on to discuss the Cosmic Vision 2015-2025 budget consideration and allocation process and the mission types and management processes created within the science program. He also outlined the Cosmic Vision project selection process and the current status of the process. He mentioned that Euclid will have to undergo selection in the M-class selection process next year and that it is competing with two strong competitors. He said that, at this stage in the competition, no significant changes to Euclid's configuration that would impact the project's readiness for the selection process would be possible. He noted that after the competition the agency could consider it if it had international partnerships. He said there was no consideration being given to scaling Euclid back to an optical-only mission, given an expectation that a WFIRST mission would carry out the infrared complement. Should there be a partnership with the U.S. then ESA could consider a different scenario after the Euclid selection, however this would need to go through the usual ESA advisory structure process. At the time of Dr. Favata's presentation to the panel, NASA has not communicated any final decision on Euclid, and ESA is continuing with Euclid as is. He noted it would be very difficult to modify the mission significantly and this state and keep with the launch date of 2018.

Dr. Jon Morse, Director of the NASA Astrophysics Division, and Fabio Favata, ESA, next took questions pertaining to ongoing NASA-ESA discussions regarding Euclid and a possible NASA minority partnership in the Euclid project and perhaps a reciprocal ESA involvement in the WFIRST program. They were given the following questions prior to their appearance:
Q1: When is the deadline for NASA and ESA to firm their commitments to Euclid?
Q2: How would a 1-year delay (or more) in a U.S. decision to join Euclid impact NASA's and ESA's decision on the mission and its scope?
Q3: Do you think it is possible to join Euclid in a leadership role, with all 3 components (exoplanets, guest investigator survey mode, and dark energy) included in the mission?
Q4: In what way is possible U.S. participation in Euclid seen as a part of a new era of wider U.S./European collaboration in space astrophysics?
Dr. Favata remarked that a U.S. commitment to Euclid, if made, should come as soon as possible. Dr. Morse said that ESA has asked the agency that ideally it should hold its competition and announce the U.S. science team in late-January 2011 if it plans to name scientists to the Euclid science team. Dr. Morse said that the situation with JWST, the FY 2011 budget, and the FY 2012 President's budget request will be clearer before June 2011. Dr. Morse commented that ESA has said that the deadline for committing to a 20 percent participation level in Euclid would be spring 2011, to ensure proper evaluation in the ESA Cosmic Vision downselect process. From NASA's perspective, the agency finalizes its FY 2012 budget request in mid-December; if NASA would be making announcements on Euclid in late-January or early-February the agency would need to incorporate them into the FY 2012 budget. He added that this is why

[36] See http://sci.esa.int/science-e/www/area/index.cfm?fareaid=100.
[37] See ESA publication BR-247.

the rapid schedule was needed for this panel to give its input to the agencies by mid-December. Dr. Favata later remarked via email that, "[ESA] believe[s] that to implement Euclid for a launch in 2018 ESA will need to start implementation phase in the third quarter of 2011. Hence by the middle of 2011 all contributions to the missions will need to be defined."

The panel heard from Dr. Steve Kahn, Stanford University, the Deputy Project Director for the Large Synoptic Survey Telescope (LSST) and a Co-Investigator of Euclid from the U.S. community. The following questions were given to him prior to the meeting:
Q1: What do you see as the advantages for U.S. scientists and science of possible U.S. participation in Euclid?
Q2: What are the scientific redundancies between Euclid and LSST?
Q3: To what extent might LSST and other synergistic programs depend on Euclid capabilities, and vice versa? Specifically, in what ways are they mutually dependent?
Q4: What does LSST need from WFIRST to optimize their joint scientific return?
Q5: Do DOE laboratories have technical contributions or hardware development activities that would benefit WFIRST?
Q6: What is the level of enthusiasm in the DOE science community for participation in WFIRST?
Dr. Kahn emphasized that U.S. researchers have played important roles in Euclid's scientific and technical development since the mission's beginning. He then spoke about the relationship between Euclid and LSST, noting that LSST and Euclid are complementary, in particular: "Each data set [from Euclid and LSST] will individually constrain the properties of dark energy at unprecedented levels." Dr. Kahn also commented that "LSST can achieve its scientific goals with respect to dark energy without relying on data from any other experiment or facility." Moving on to the relationship between LSST and WFIRST, he remarked that "LSST could benefit from complementary observations by WFIRST, depending on how WFIRST is designed." Dr. Kahn believed that DOE laboratories have technical contributions or hardware development activities that would benefit WFIRST, as evidenced by the role that LBNL, SLAC, and FNAL have played in past astrophysics concepts and experiments such as SNAP, JDEM, and Fermi. He thought relevant elements of the DOE science community would be "eager to participate" in WFIRST science and hardware. He wondered what additional benefit the U.S. community might derive from an increased share in Euclid beyond the proposed 20 percent, and concluded by stating that dark energy is a rich topic, with many distinct analyses that can be used to constrain parameters.

Dr. David Weinberg, Ohio State University, discussed the relative scientific reach of WFIRST and Euclid. He was given the questions below prior to the meeting:
Q1: JDEM Omega, the dark energy mission developed by a U.S. Science Definition Team, and Euclid have different designs and emphasize different wavebands. Could you comment on the relative strengths and weaknesses of the two approaches?
Q2: Is there a scientific rationale for the U.S. both to invest in Euclid and to pursue WFIRST, assuming it launches 5 years after Euclid?
Q3: Measuring weak lensing of distant galaxies constrains both models of dark energy and possible departures from the predictions of general relativity of gravity's behavior over the largest scales. LSST --- the highest ranked ground-based facility in NWNH --- is to make crucial observations of weak lensing: How important is WFIRST's near-IR photometry of vast galaxy samples to the success of the LSST effort?
Dr. Weinberg discussed the capabilities of WFIRST and how its three methods—supernovae, baryon acoustic oscillations, and weak lensing—would make substantial contributions to dark energy science. He also noted that WFIRST "would have a broad impact on high priority science" because of its insight to combine several activity proposals with different science ambitions but similar technology requirements into one mission. He also noted that WFIRST's IR capability would make "critical contribution to each of the three leading methods" and that those IR observations are only possible from space. Dr. Weinberg remarked that the absence of a wide-field IR space mission would result in a factor of several-to-ten decrease in dark energy discovery potential, and that "the LSST weak lensing survey will be systematics-limited by photo-z uncertainties at a level well above its statistical uncertainties." He then described Euclid's space-based optical weak lensing experiment as "powerful," and remarked that Euclid and LSST

are complementary because of their ability to provide cross-checks on measurements. He also said that Euclid's IR capabilities, while able to make contributions to dark energy science, will not be able to match WFIRST, nor can they achieve WFIRST's expected contributions to the three measurement methods identified earlier. Concluding, Dr. Weinberg outlined several best- and worst-case scenarios with respect to various Euclid and WFIRST outcomes. He also opined that "it may be hard to maintain U.S. community support for WFIRST following Euclid-IR, even though WFIRST is a factor of several more powerful, and that this problem gets worse if WFIRST slips later and is seen to be cutting into flexibility for the next decade."

Dr. Roger Blandford, Stanford University, and Chair of Astro2010, then described the NWNH survey process and its science objectives for the 2012-2021 decade. He was given the questions below prior to the meeting:
Q1: The top NWNH recommendations in large ground and space projects have a dark energy component. Can you explain the intended scientific and programmatic synergy between LSST and WFIRST and any time-critical elements?
Q2: How important is the timely execution of a microlensing survey to the overall NWNH strategy for exoplanets?
Q3: What is the major science to be achieved by the infrared surveys that motivated the NWNH recommendation for WFIRST and how time-critical is it?
Q4: How might NASA decisions on Euclid affect WFIRST science, as well as non-WFIRST science complementary to and/or synergistic with WFIRST science?
Q5: More broadly, how might early U.S. participation in Euclid affect other initiatives and recommendations of NWNH, as well as its overall integrated program?
Dr. Blandford described the budgetary context presented to and used by the committee, as well the cost, risk, and technical evaluation process which the committee implemented. He discussed the report's emphasis on balancing the program, and briefly listed the large-class space-based priorities. He also discussed the WFIRST mission and its complementarity with LSST, as well as the importance of WFIRST to dark energy science and the science enabled by WFIRST's microlensing and IR surveys. He noted that "LSST and WFIRST combine to measure properties of dark energy," that "multiple techniques are needed to explore the physics of dark energy over the full range of redshift, and that "combined observations improve accuracy and control systematics." Also, since Kepler and WFIRST are complementary, Dr. Blandford stated that the timely execution of a microlensing survey is important to the overall NWNH strategy for exoplanets. He added that the IR surveys enabled by WFIRST would contribute much to galactic and extragalactic astronomy, and the guest investigator program would add "much discovery space." With the exception of the coordinated monitoring programs, he did not believe most of this survey-enabled science was time-critical. On the proposed NASA participation in Euclid, Dr. Blandford thought a "comprehensive, joint program could get the science faster and cheaper and retain strong U.S. presence in fields it currently leads," and that he believed that "[a] Euclid, with or without NASA, that executes much of the WFIRST science program on schedule will likely obviate a later WFIRST mission under constrained economic circumstances with possible consequences." He noted the "danger of surrendering U.S. leadership in dark energy and exoplanets." Going on, Dr. Blandford commented that a minority role in Euclid is not among NWNH recommendations. If alternatively, "Euclid (with U.S. participation) only executes some of the program and there is a clear commitment to start WFIRST at a later date, then this will significantly impact the implementation of the second ranked Explorer augmentation and the integrated and time-critical mission development recommendations on LISA, IXO, NW, IP and 'small' programs." He added that no U.S. space mission has been started to exploit either the discovery of exoplanets in 1995 and of cosmic acceleration in 1998. Dr. Blandford stated that "Euclid is primarily a cosmology mission" and currently has more ambitious instrumentation than does WFIRST.

Jon Morse, NASA Astrophysics, gave the next talk and had been presented the following questions prior to the meeting:
Q1: What is the present budget outlook for NASA Astrophysics? How is it expected to change? How does it impact the suite of large, medium, and small missions and activities recommended in NWNH?

Q2: If we are involved with Euclid and it does only the dark energy component, how would this impact the goals of a WFIRST mission that would come later?
Q3: If we join Euclid at the 20 percent level now, even if it were cost-neutral, how would that expenditure affect the implementation of the Explorer Recommendation, LISA and IXO, and the new medium and small priorities articulated in NWNH?
Q4: Please describe the funding profile (particularly in the years before the JWST launch) that you imagine for a 20 percent US share of Euclid, and compare it with what would be required to 1) build WFIRST for a 2020 launch, or 2) build it later in the next decade?
Dr. Morse stated that the budget profile and schedule for JWST dominate considerations of when WFIRST development may begin, adding that, as communicated to the Astro2010 decadal committee and acknowledged in the report, significant funds for the next astronomy flagship mission will not become available until after JWST launches. In his talk, Dr. Morse emphasized that participation in Euclid by NASA may be the only way, under the reduced future funds anticipated due to a JWST launch delay, that the U.S. astronomy community might participate this decade in large-area space-based dark-energy studies. He said that NASA has discussed with ESA that NASA would participate in Euclid in a cost-neutral way, such that whatever funding is spent on Euclid, ESA would contribute a like amount towards WFIRST. Dr. Morse said that the current participation level on Euclid is planned at 20% of the estimated mission development cost, based on ESA's invitation to NASA in early 2010 and recent feedback from NASA's advisory committees. While that expenditure would defer some WFIRST planning activities beyond the launch of JWST, the resulting delay to the WFIRST launch would be small. The panel heard that NASA had issued a "dear colleague" letter inviting participation in a science definition team as a first step in the WFIRST program. The panel also heard that, since WFIRST would follow JWST, a launch of the top priority large space mission from the decadal would happen no earlier than 2022 under current projections. NASA has also made a call for U.S. scientists to participate in the Euclid science team, but the call reserves the right of the agency to defer or terminate any investigations dependent on "the outcome of decisions informed by an assessment of the proposed ESA-NASA Euclid collaboration."[38] Project offices have been established for the Euclid and WFIRST projects. Dr. Morse stated that NASA is working on its initial response to all of the decadal survey priorities as part of the next budget cycle and will communicate the response in the February release of the FY 2012 President's budget request.

The panel heard brief remarks from William F. Brinkman, DOE Science, Dennis Kovar, DOE High Energy Physics, and Vern Pankonin, NSF Astronomy. They were given the following questions prior to the meeting:
Q1: What are NSF and DOE plans for implementing LSST, and other programs synergistic with WFIRST science?
Q2: Does the DOE see any role for it in Euclid?
Q3: Could DOE comment on its position concerning possible contributions of either hardware or scientific personnel to WFIRST?
The panel heard that with the termination of the Joint Dark Energy Mission, DOE is no longer currently involved in a space-based dark energy project. On Euclid, DOE stated that it sees no role for it in Euclid, though "DOE HEP will support our scientists on the Euclid science team (if selected), and if our community proposes an effort on Euclid, we will then investigate participation, depending on funding availability." On WFIRST, DOE HEP said it "will support our scientists on the WFIRST Science Definition Team (if selected)," and that, "after the WFIRST concept is developed, DOE HEP will explore possible contributions if appropriate (consistent with PASAG criteria) and depending on funding availability." DOE does remain a partner in the decadal survey's priority large, ground-based activity, LSST. NSF gave a brief update on the LSST progress towards a construction start in 2014 at the very earliest. On November 5, 2010, the NSF MPS Advisory Committee unanimously recommended LSST to advance to PDR. DOE and NSF are working to coordinate their schedules and funding for LSST.

Dr. Carl Wieman, Associate Director for Science at OSTP, made several comments to conclude the day's

[38] National Aeronautics and Space Administration, "Solicitation for NASA Science Team Members for ESA's Euclid Mission," Solicitation Number NNH11ZDA006J, October 7, 2010.

open session activities. Dr. Wieman was provided the questions below prior to the meeting:
Q1: What are the motivations for this NRC activity?
Q2: How can the Panel help the Administration?
Q3: What is OSTP's view of the possibility that the entire NASA program could be dependent in large measure on international collaboration?
Dr. Wieman remarked that OSTP's motivation in requesting the panel to conduct its business was to preserve the integrity of the decadal survey process, and to obtain NRC advice on NWNH recommendations in light of rather different budget scenarios. He recognized the unprecedented community effort that the most recent survey represents. He looked forward to receiving the panel's analysis of the various options for implementing the survey recommendations as laid out in the panel's charge. In response to the question asking if he was comfortable with having all major NASA missions be international collaborations, Dr. Wieman commented that, while not the preferred option, international collaboration on NASA astronomy missions may be the only choice available in the near future given the current budget environment. Dr. Wieman mentioned that OSTP wants more resources available for astrophysics in a larger fiscal environment. He said that OSTP sees the gains in the FY2011 topline budget (assuming it is passed and signed as requested) difficult to sustain in the current fiscal environment going forward. He noted that it is not realistic to expect significant adjustment for astrophysics in the future. OMB and OSTP concurred with NASA's assessment that JWST's problems will make a WFIRST launch unlikely in the early 2020's. Also, they concurred with NASA that funding for Euclid at the 20 percent level would not substantially impact either JWST or WFIRST launch dates, though it would impact other activities. He asked the report be ready by mid-December so it could inform the final stages of the budget process leading up to the President's FY 2012 budget request due to be released in early February 2011.