Presentation to:
Committee on Strategic NASA Science Missions
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Part I: Perspective from the Midterm Assessment

Part 2: Perspective from a university-based astrophysics research center

# 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)

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# 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. [Kepler = Discovery mission (small/medium)]
- 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. [Hubble space telescope = flagship]

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.

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# 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.

# Summary of New Worlds New Horizons Recommendations for large space activities

| Recommendation | Launch Date[b] | Science | Technical Risk[c] | Appraisal of Costs[a] | |
|---|---|---|---|---|---|
| | | | | Total (U.S. Share) | U.S. Share, 2012-2021 |
| 1. WFIRST —NASA/DOE collaboration | 2020 | Dark energy, exoplanets, and infrared survey-science | Medium low | $1.6B | $1.6B |
| 2. Augmentation to Explorer Program | Ongoing | Enable rapid response to science opportunities; augments current plan by 2 Medium-scale Explorer (MIDEX) missions, 2 Small Explorer (SMEX) missions, and 4 Missions of Opportunity (MoOs) | Low | $463M | $463M |
| 3. LISA —Requires ESA partnership[d] | 2025 | Open low-frequency gravitational-wave window for detection of black-hole mergers and compact binaries and precision tests of general relativity | Medium[e] | $2.4B ($1.5B) | $852M |
| 4. IXO —Partnership with ESA and JAXA[d] | 2020s | Black-hole accretion and neutron-star physics, matter/energy life cycles, and stellar astrophysics | Medium high | $5.0B ($3.1B) | $200M |

Summary of New Worlds New Horizons Recommendations for medium space activities

TABLE ES.4 Space: Recommended Activities—Medium-Scale (Priority Order)

| Recommendation | Science | Appraisal of Costs[a] | Cross-Reference in Chapter 7 |
|---|---|---|---|
| 1. New Worlds Technology Development Program | Preparation for a planet-imaging mission beyond 2020, including precursor science activities | $100M to $200M | Page 215 |
| 2. Inflation Probe Technology Development Program | Cosmic microwave background (CMB)/ inflation technology development and preparation for a possible mission beyond 2020 | $60M to $200M | Page 217 |

[a] The survey's cost appraisals are in FY2010 dollars and are committee-generated and based on available community input.

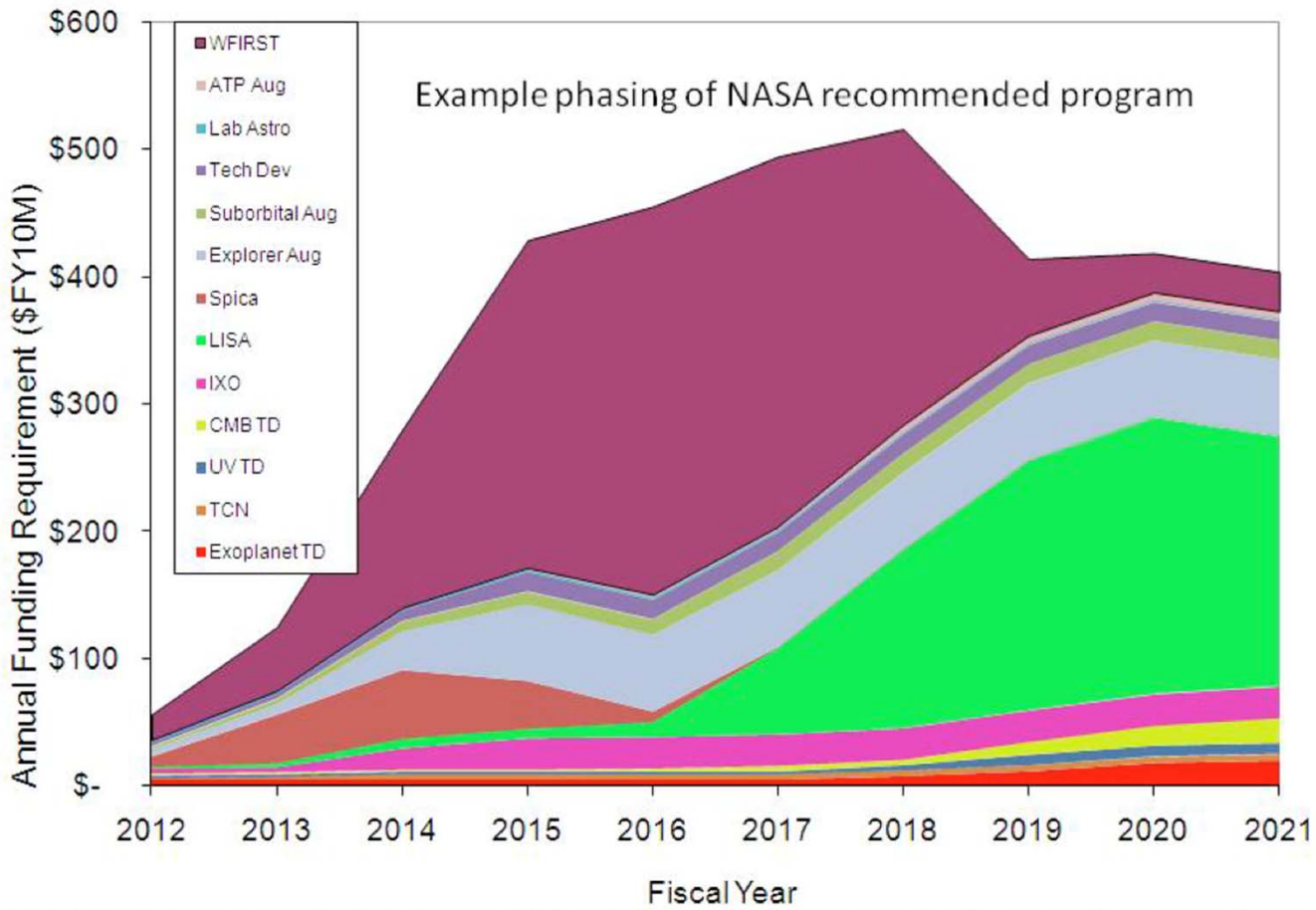


***FIGURE 7.12 NASA recommended program. This sandchart is the outcome of a committee exercise carried out in FY2010 dollars to show that the phased program recommended would fit within the budget constraints adopted by the committee in the setting of its recommendations. The profiles and budget costs will vary on a project-by-project and program-by-program basis and should not be taken as representing a literal recommended program. The sandcharts are presented here to show, as an existence proof, that the recommended NASA SMD spending on Astro2010-recommended new initiatives and program augmentations are implementable.***

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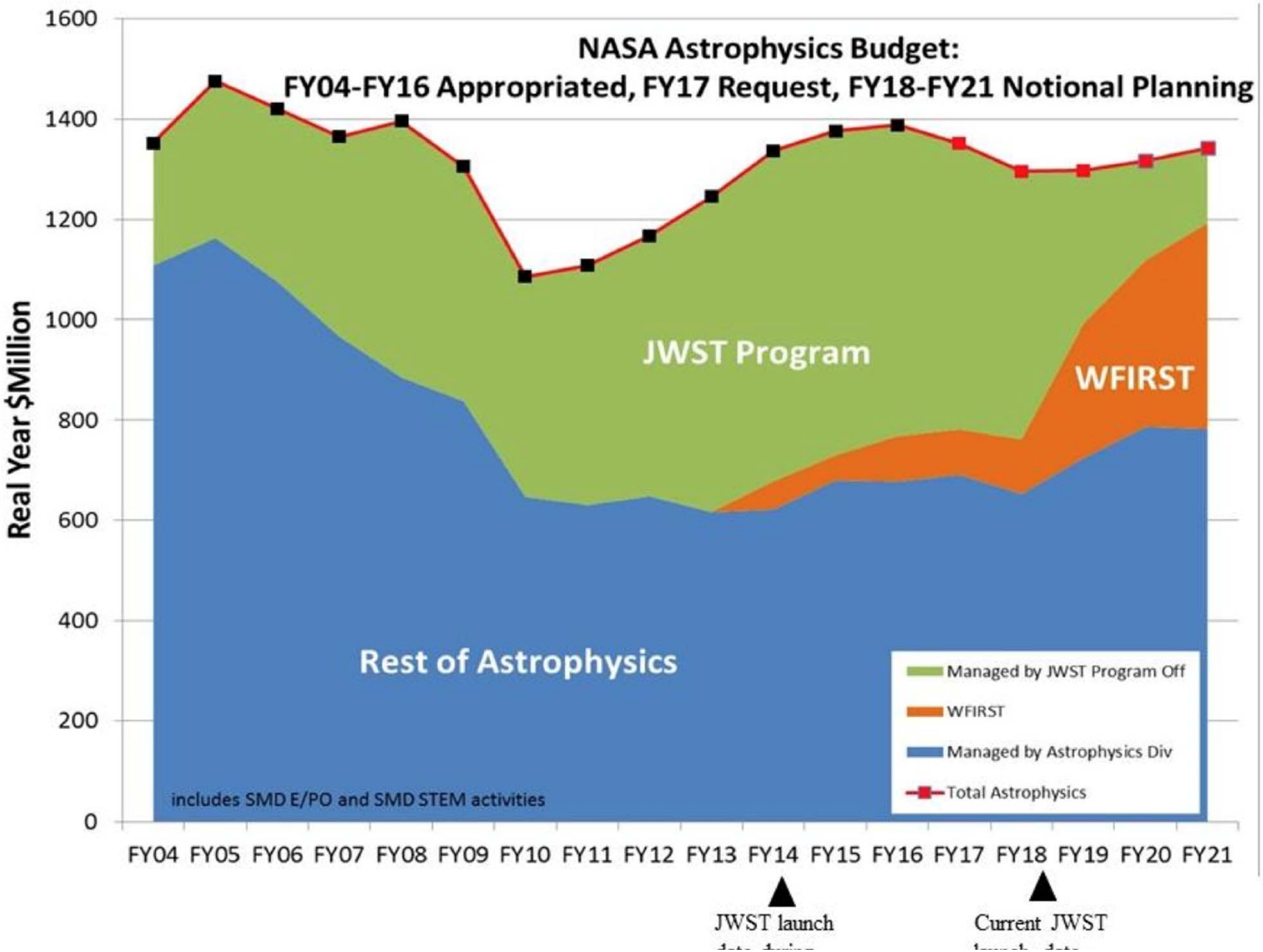
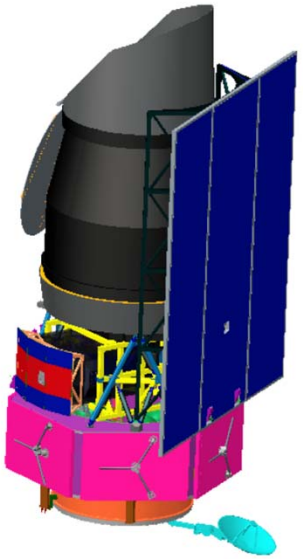


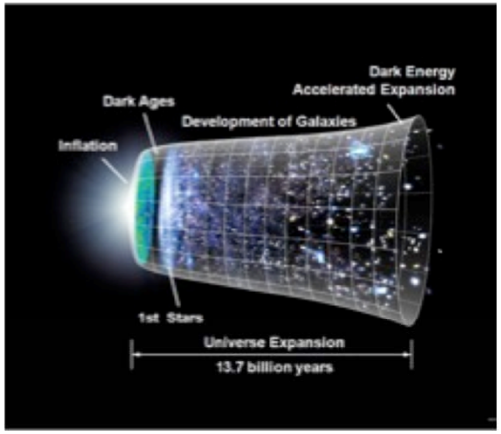
Recommendation #1: WFIRST WideField InfraRed Survey Telescope

Implementation different from NWHH

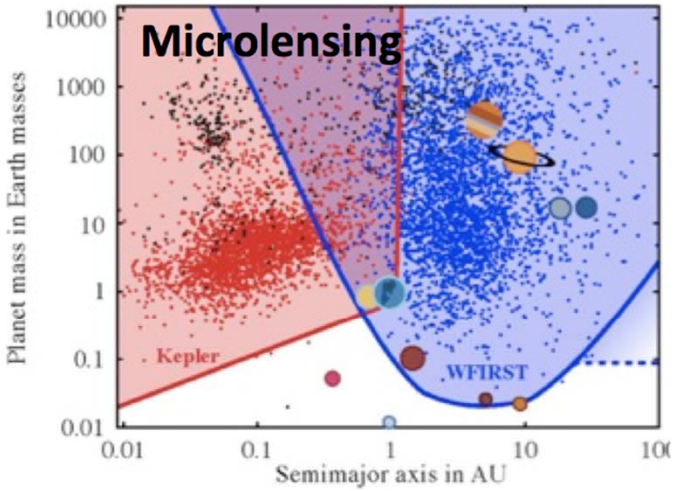


- 2.4m mirror
- Widefield imager/spectro meter and integral field unit
- Coronagraph

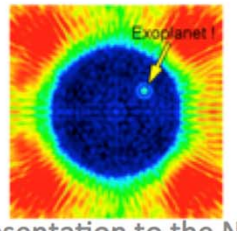
## Dark Energy



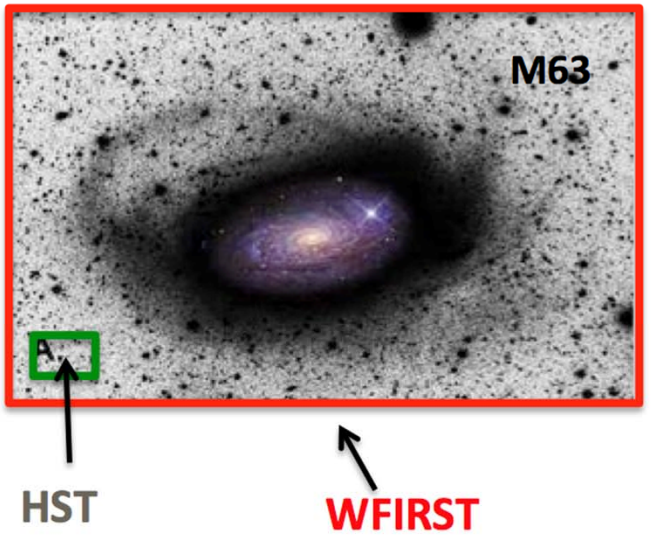

## Exoplanets




Coronagraph

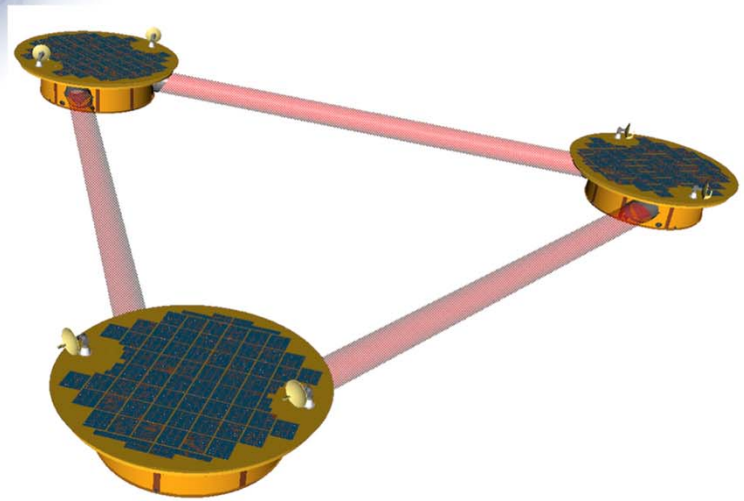


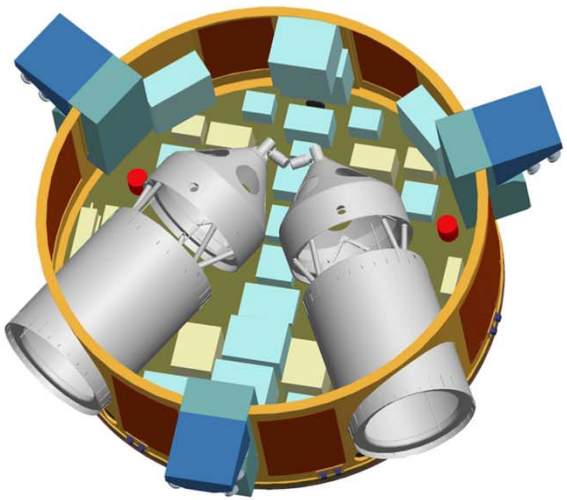

## Astrophysics



# Recommendation #3: LISA
# Laser Interferometer Space Antenna

## Current ESA plan is significantly less capable





- A time-varying strain in space-time is measured by interferometrically monitoring relative displacements in the three arms.
- Three interacting spacecraft in an equilateral triangle with 5 million km arms make up the "science instrument"
- Each spacecraft follows an independent orbit around the sun, with the plane of the triangle inclined at 60 degrees to the ecliptic

- Each spacecraft hosts two optical assemblies consisting of a
  - Telescope
  - Optical bench
  - Gravitational Reference Sensor (GRS) containing a proof mass
- The spacecraft protects its two proof masses from all external disturbances.

As presented to Decadal Survey

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# 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.

TABLE 4.2 Changes to WFIRST Since *New Worlds, New Horizons in Astronomy and Astrophysics*

| Reference Mission | Projected Cost (FY2015 dollars) |
|---|---|
| JDEM-Omega Design—2010 | $1.8 billion |
| 1.5 m on-axis telescope | |
| 36 H2RG detectors: 1 imaging array + 2 spectroscopic arrays | |
| 2.0 μm long wavelength cutoff | |
| L2 orbit, Atlas V launch vehicle | |
| Interim Design Reference Mission—2011 | $1.8 billion |
| 1.5 m on-axis telescope → 1.3m off-axis telescope | |
| Design Reference Mission 1—2012 | $1.8 billion |
| 3 focal plane arrays → 1 larger array with grism in filter wheel | |
| 2.0 μm cutoff → 2.4 μm cutoff | |
| WFIRST-AFTA 2013 Design Reference Mission—2013 | $1.9 billion to $2.1 billion |
| 1.3 m telescope → 2.4 m AFTA telescope (on-axis) | (includes GO) |
| 36 H2RG detectors → 18 H4RG detectors | |
| 2.4 μm cutoff → 2.0 μm cutoff | |
| Supernova IFU *option* → *baseline* | |
| GO program increased to 25-30% of observing time | |
| On-axis coronagraph as an *option* (with 6-year prime mission) | |
| L2 orbit → inclined GEO orbit | |
| WFIRST-AFTA 2015 Design Reference Mission—2015[a] | $2.0 billion to $2.3 billion |
| Coronagraph (with 6-year prime mission) *option* → *baseline* | (includes coronagraph) |
| Coronagraph development and technology downselect | |
| 2025 launch | |
| Atlas V launch vehicle → Delta IV Heavy | |
| WFIRST at KDP-A—2016[b] | |
| 2024 launch | $2.3 billion to $2.5 billion |
| 2025 launch | $2.6 billion to $2.8 billion |
| Inclined GEO orbit → L2 | |

[a] Paul Hertz, NASA, "NASA Astrophysics: Progress toward New Worlds, New Horizons," presentation to committee on October 8, 2015.

[b] Paul Hertz, NASA, "Astrophysics," presentation to committee February 26, 2016.

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# 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.

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# The Space-Based Program – Key Findings and Recommendations

# 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.

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# 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.

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# 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.

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# 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.

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# 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.

•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.

# JNH Comments post-Midterm Assessment

- Certain important (even transformational) science REQUIRES flagship-scale missions
- Extremely important rapid-response astrophysics has been done by smaller missions – eg., COBE, WMAP, Swift, Kepler...
- Maintaining program balance (i.e. small-medium-large) is critical for scientific productivity, engagement with university community, training of scientists and engineers
- Enthusiastic community endorsement of NASA/AST implementation of NWNH program to date (given JWST and other budget constraints)
- There is a history of cost growth in flagship missions
- Community call to NASA/AST to manage costs and scope of current flagship mission to preserve program balance
- Endorse creating competed Probe mission class (~$500M)
- To the extent this is a discussion about workforce, it should be a discussion about the NASA centers *and* the research universities

# Exoplanet Missions

JWST

AFTA

TESS

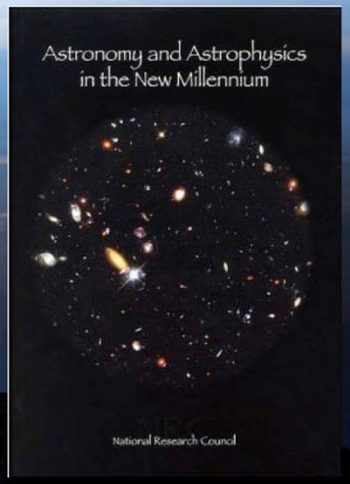
Kepler

New Worlds Telescope

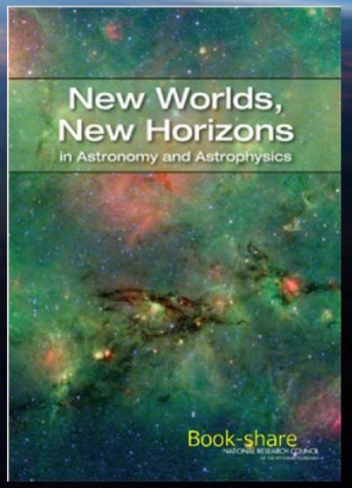
Spitzer

Hubble

Ground-based Observatories




**2001** Decadal Survey




**2010** Decadal Survey

THANK YOU