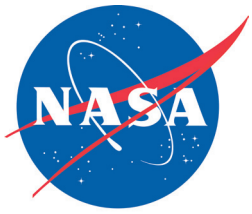
National Aeronautics and Space Administration



Astrophysics Implementation Plan

Astrophysics Division
Science Mission Directorate
NASA Headquarters

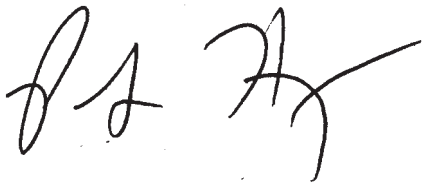
December 2012

Revision 1: typographical errors corrected 12/20/12

Revision 2: typographical omissions corrected 4/15/13

The 2010 decadal survey in astronomy and astrophysics, *New Worlds, New Horizons in Astronomy and Astrophysics*, recommended a coordinated program of research, technology development, ground-based facilities, and space-based missions to be implemented during 2012–2021 to address the most compelling science questions. However, the budgetary environment does not allow the recommendations of the decadal survey to be implemented as written. This *Astrophysics Implementation Plan* has been prepared by the Astrophysics Division of NASA's Science Mission Directorate to describe the activities currently being undertaken by the Astrophysics Division to respond to the decadal survey recommendations within the current budgetary constraints. One important goal of the Astrophysics Division is to begin a strategic mission, subject to the availability of funds, which follows from the decadal survey and is launched after the James Webb Space Telescope.

This is the Implementation Plan of the Astrophysics Division in the Science Mission Directorate at NASA Headquarters



Paul Hertz, Astrophysics Division Director

Contents

Figures and Tables

Figures

Tables

1. Introduction

NASA's astrophysics program is the space-based implementation of the Nation's astrophysics science goals and objectives. NASA's astrophysics program has been tremendously successful at advancing the frontiers of scientific understanding. It began with the first orbiting astronomical observatories in the 1960s, and it has continued into the current era of the Great Observatories. NASA's next large space observatory will be the James Webb Space Telescope (JWST), currently under development for launch in late 2018.

The 2010 decadal survey in astrophysics, *New Worlds, New Horizons in Astronomy and Astrophysics*[1] (hereafter the Decadal Survey), defined the Nation's astrophysics science priorities by producing a set of 20 high-priority scientific questions. The Decadal Survey went on further to recommend research and analysis activities, theory and computational networks, technology development areas, ground-based facilities, and space missions for addressing these scientific questions.

The policy and budgetary environment that has come to pass since the release of the Decadal Survey in August 2010 is very different from the one that was assumed for the purpose of formulating the implementation recommendations in the Decadal Survey. The result is that the overall budget level, and particularly any future funding for new missions, available to implement Decadal Survey recommendations is significantly reduced from that assumed in the Decadal Survey.

This *Astrophysics Implementation Plan* articulates the NASA Astrophysics Division's near term plans (2013–2017) for achieving Decadal Survey science and priorities within current budget constraints. It briefly describes the context within which the Astrophysics Division is operating, including the substantive changes since the release of the Decadal Survey. It then describes how the Astrophysics Division is responding to the Decadal Survey recommendations within the current planning budget (the FY 2013 President's budget request[2]) and the process being used to inform that response. A key goal of the Astrophysics Division is to begin a new, strategic mission in 2017, subject to funding availability, which will follow JWST and be responsive to the recommendations of the Decadal Survey. Since it cannot be assumed that the authority to start a new large mission will be granted by 2017, concepts for moderate cost missions that cost no more than approximately $1B must also be considered. All mission concept studies being studied derive from the science objectives of the Decadal Survey's prioritized activities.

This *Astrophysics Implementation Plan* describes the studies and other activities that are being undertaken in support of this goal. Section 2 describes the Astrophysics Division and its programs. Section 3 summarizes the Decadal Survey's recommended program of activities. Section 4 explains the strategy that the Astrophysics Division has used to develop a near-term implementation plan in response to the Decadal Survey's recommendations. Sections 5 through 7 lay out that near-term implementation plan: Section 5 addresses the recommendations leading to future space missions, Section 6 addresses the recommendation for an enhanced Explorer Program, and Section 7 addresses the recommendations for the core program and other small activities. Section 8 summarizes the document.

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1 *New Worlds, New Horizons in Astronomy and Astrophysics* (NRC, 2010); http://www.nap.edu/catalog.php?record_id=12951.

2 FY 2013 President's Budget Request for NASA; http://www.nasa.gov/news/budget/.

2. Astrophysics at NASA

2.1 Astrophysics Science

The scope of NASA's astrophysics science program flows from Goal 2 of the 2011 NASA Strategic Plan[3]. *"Expand scientific understanding of the Earth and the universe in which we live."* Specifically, the astrophysics science program addresses Outcome 2.4, to *"Discover how the universe works, explore how it began and evolved, and search for Earth-like planets."* Three broad scientific questions stated in the 2010 NASA Science Plan[4] emanate from this goal:

- How do matter, energy, space, and time behave under the extraordinarily diverse conditions of the cosmos?
- How did the universe originate and evolve to produce the galaxies, stars, and planets we see today?
- What are the characteristics of planetary systems orbiting other stars, and do they harbor life?

Responsibility for Outcome 2.4 and its broad science questions resides in the Astrophysics Division of NASA's Science Mission Directorate (SMD)[5].

The Astrophysics Division carries out the NASA astrophysics science program in a manner that reflects SMD's guiding principles[6]. These principles include:

- Substantial progress on the science priorities and objectives in the Decadal Survey is a measure of success.
- Investment choices are based on scientific merit via peer review and open competition.
- Active participation by the research community beyond NASA in planning and executing the program is critical to success.
- Effective international and interagency partnerships leverage NASA resources and extend the reach of our science results.
- A balanced portfolio of space missions and mission-enabling programs sustains progress toward NASA's science goals.
- The NASA mandate includes broad public communication.

The Astrophysics Division's science strategy is guided by recommendations from the Decadal Survey and from other studies conducted by the National Research Council (NRC).

3 *The 2011 NASA Strategic Plan*; http://www.nasa.gov/news/budget/.
4 *2010 Science Plan for NASA's Science Mission Directorate*; http://science.nasa.gov/about-us/science-strategy/.
5 Further information on the NASA Astrophysics Division; http://science.nasa.gov/astrophysics/.
6 *2010 Science Plan for NASA's Science Mission Directorate*, Section 3.1; ibid.

2.2 Astrophysics Science

The Astrophysics Division implements its astrophysics science through three focused and two cross-cutting programs. The three focused programs address the three broad scientific questions stated in the 2010 NASA Science Plan (see Section 2.1) and provide an intellectual framework for advancing science and strategic planning.

- Physics of the Cosmos[7]: This Program aims to understand how the universe works, starting with the basic building blocks of our existence—matter, energy, space, and time—and exploring how they behave under the extreme physical conditions that characterize the evolving Universe.
- Cosmic Origins[8]: This Program seeks to understand the many phenomena and processes associated with galaxy, stellar, and planetary system formation and evolution from the earliest epochs to today.
- Exoplanet Exploration[9]: This Program advances our understanding of exoplanets[10], with the goal to ultimately detect habitable, Earth-like planets around other stars, to determine how common such planets are, and to search for indicators that they might harbor life.

The two cross-cutting programs complement the focused programs by developing and launching smaller missions through the Astrophysics Explorers Program and by supporting basic and applied research activities through the Astrophysics Research Program. The Astrophysics Research Program includes suborbital investigations, theoretical research, technology development, data analysis, and laboratory investigations, which are solicited through the Research Opportunities in Space and Earth Sciences (ROSES) NASA Research Announcement[11]; these are essential for maximizing scientific return, pioneering new approaches to advancing the science objectives, and training the workforce required to ensure future competitiveness.

Astrophysics Focused Programs	Astrophysics Cross-cutting Programs
• **Physics of the Cosmos (PCOS) Program** *How does the universe work?*	• **Astrophysics Explorer (APEX) Program** *Focused, PI-led, competitively selected missions*
• **Cosmic Origins (COR) Program:** *How did we get here?*	• **Astrophysics Research Research Program:** *Basic and applied research activities solicited through ROSES*
• **Exoplanet Exploration (ExEP) Program:** *Are we alone?*	

Table 1—Structure of Programs in the Astrophysics Division. *The three focused Programs are listed, along with the driving questions that serve to delineate their content. The two cross-cutting programs are differentiated from the focused Programs by scope, but ultimately share in their science objectives.*

7 Physics of the Cosmos Program; http://pcos.gsfc.nasa.gov/.
8 Cosmic Origins Program; http://cor.gsfc.nasa.gov/.
9 Exoplanet Exploration Program; http://exep.jpl.nasa.gov/.
10 Exoplanets, a name derived from "extrasolar planets," are planetary bodies in systems around other stars.
11 *Research Opportunities in Space and Earth Sciences* (ROSES); http://go.nasa.gov/ROSES12.

2.3 Advisory Structure and Community Input to the Astrophysics Division

In planning its science programs, the Astrophysics Division receives key strategic guidance from the priorities defined by decadal surveys. The decadal surveys are complemented by additional studies that are requested by NASA and conducted by the NRC. For each of these other studies, the NRC appoints an ad hoc committee to gather broad community input and to write a report that provides findings and recommendations.

The Astrophysics Division also receives ongoing tactical-level advice from the science community through the Astrophysics Subcommittee[12]. The Astrophysics Subcommittee has three Program Analysis Groups (PAGs), one for each of the three focused programs within the Astrophysics Division: PhysPAG (Physics of the Cosmos PAG), COPAG (Cosmic Origins PAG), and ExoPAG (Exoplanet Exploration PAG). Each PAG is steered by an Executive Committee whose Chair is a member of the Astrophysics Subcommittee. The Executive Committee's responsibilities include collecting and summarizing community input with subsequent reporting to the Astrophysics Subcommittee. The PAGs provide a means for soliciting and coordinating analysis from the scientific community in support of their respective program objectives. Much of the work of each PAG is conducted by ad hoc Study Analysis Groups (SAGs) on specific topics (see Table 2).

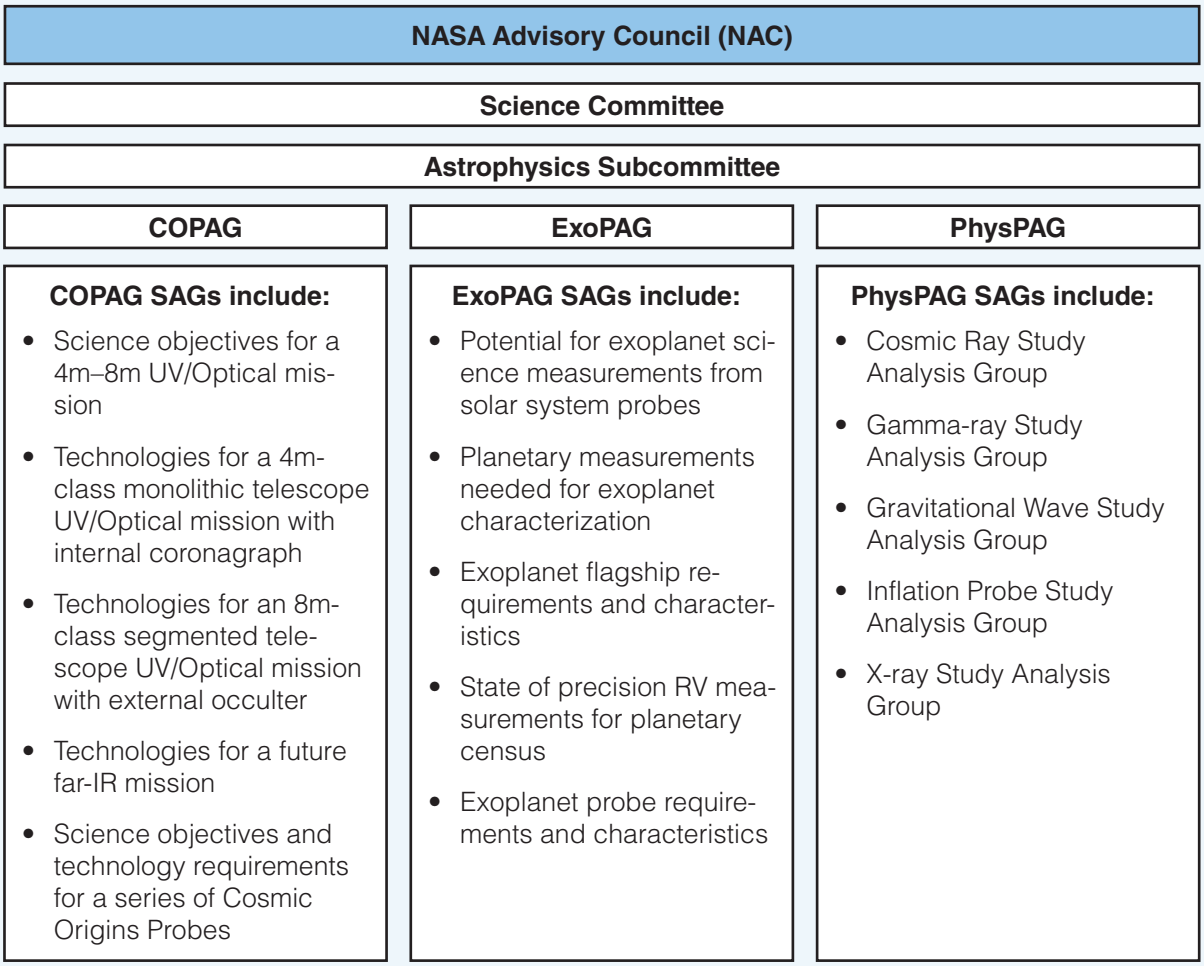

Table 2—Analysis Groups. *Structure of Program Analysis Groups (PAGs) and Study Analysis Groups (SAGs) reporting to the Astrophysics Subcommittee.*

12 The Astrophysics Subcommittee reports to the Science Committee of the NASA Advisory Council; information on the Astrophysics Subcommittee, including presentations and minutes from the meetings, can be accessed at http://science.nasa.gov/science-committee/subcommittees/nac-astrophysics-subcommittee/.

All interested scientists can contribute to the PAGs and SAGs by participating in their meetings and by giving input. In this way, the PAGs enable direct and regular communication through public meetings, giving the community opportunities to provide scientific and programmatic analysis to the Astrophysics Division[13].

Strategic advice to the Astrophysics Division is provided by the Boards of the NRC; the NRC is the operational unit of the National Academies of Science. The Committee on Astronomy and Astrophysics[14] (CAA) is a joint standing committee of the Space Studies Board (SSB) and the Board on Physics and Astronomy (BPA). The CAA's overarching purpose is to support scientific progress in astronomy and astrophysics and assist the Federal government in integrating and planning programs in these fields. The CAA has been charged with serving some of the purposes of a decadal survey implementation advisory committee (DSIAC) by providing strategic guidance to the Astrophysics Division regarding its implementation of the Decadal Survey[15]. The CAA's statement of task[16] requires it to monitor the progress in implementation of the recommendations of the Decadal Survey and to formulate and oversee ad hoc studies related to the implementation of the Decadal Survey. One such ad hoc study will be the Mid-Decade Review (see Section 5.6).

Finally, the Astronomy and Astrophysics Advisory Committee[17] (AAAC) advises the National Science Foundation (NSF), NASA, and the U.S. Department of Energy (DOE) on selected issues within the fields of astronomy and astrophysics that are of mutual interest and concern to the agencies.

13 Information on the PAGs and SAGs, including currently active SAGs and information on meetings and studies, may be found at http://science.nasa.gov/science-committee/subcommittees/nac-astrophysics-subcommittee/analysis-groups/.

14 Committee on Astronomy and Astrophysics; http://sites.nationalacademies.org/BPA/BPA_048755.

15 Decadal Survey, page 15: "NASA … should on a regular basis request advice from an independent standing committee constituted to monitor progress toward reaching the goals recommended in the decadal survey of astronomy and astrophysics, and to provide strategic advice to the agencies over the decade of implementation."

16 CAA Statement of Task; http://sites.nationalacademies.org/BPA/BPA_048755#SOT.

17 Astronomy and Astrophysics Advisory Committee; http://www.nsf.gov/mps/ast/aaac.jsp.

3. The Decadal Survey

3.1 *New Worlds, New Horizons in Astronomy and Astrophysics*

Decadal surveys represent the broad consensus of the Nation's scientific communities, and thus they are the starting point for NASA's strategic planning process in astrophysics.

The NRC Committee for a Decadal Survey of Astronomy and Astrophysics was charged "to survey the field of space and ground-based astronomy and astrophysics, recommending priorities for the most important scientific and technical activities of the decade 2010-2020." The committee was asked to formulate a research strategy with recommendations for initiatives in priority order within different categories (related to the size of the projects and their home agencies). The survey was also instructed to consider and make recommendations relating to the allocation of future budgets and to address choices that the agencies may face, given a range of budget scenarios, including criteria on which the recommendations depend.

The resulting report, *New Worlds, New Horizons in Astronomy and Astrophysics: A Survey for the Decade 2012-2021*, was released in August 2010. The accompanying panel reports[18] were released in 2011.

3.2 Summary of the Decadal Survey Recommended Program

The Decadal Survey assumed in all cases that we complete, launch, and operate JWST, the highest priority of the 2000 decadal survey[19]. In addition, the prioritization process for the 2010 Decadal Survey considered projects that had been recommended in previous decadal surveys but had not had a formal start, in addition to research activities that have emerged more recently from the research community.

The decadal committee built a recommended program of activities for astronomy and astrophysics to realize the science of the high priority activities identified in the survey. They developed the following program for space-based astronomy with ranked large and medium activities, and unranked smaller activities.

Priority	Activity	Science
1	Wide Field Infrared Survey Telescope (WFIRST)	Dark energy; exoplanets; infrared survey science
2	Augmentation to Explorer Program	Enable rapid response to science opportunities
3	Laser Interferometer Space Antenna (LISA)	Open low frequency gravitational wave window for detection of black hole mergers and compact binaries, and precision tests of General Relativity
4	International X-ray Observatory (IXO)	Black hole accretion and neutron star physics; matter/energy life cycles, and stellar astrophysics

Table 3.1—Recommended New Space Activities: Large Scale *(From Table ES.5 of the Decadal Survey.*

18 *Panel Reports—New Worlds, New Horizons in Astronomy and Astrophysics* (NRC, 2011); http://www.nap.edu/catalog.php?record_id=12982.
19 *Astronomy and Astrophysics in the New Millennium* (NRC, 2001); http://www.nap.edu/catalog.php?record_id=9839.

The Explorer Augmentation recommendation increases the budget to enable 2 Medium-scale Explorer (MIDEX) missions[20], two Small Explorer (SMEX) missions, and four Missions of Opportunity (MO) during the decade. The LISA and IXO recommendations both require a partnership with and prioritization by the European Space Agency (ESA); in addition, the LISA recommendation requires success of the LISA Pathfinder, and the IXO recommendation depends on a partnership with the Japanese Space Agency (JAXA).

Priority	Activity	Science
1	New Worlds Technology Development Program	Preparation for a planet imaging mission beyond 2020, including precursor science activities
2	Inflation Probe Technology Development Program	Cosmic microwave background (CMB)/inflation technology development and preparation for a possible mission beyond 2020

Table 3.2—Recommended New Space Activities: Medium Scale *(From Table ES.4 of the Decadal Survey..*

For the first item in the medium scale activities, the Decadal Survey's proposed program is designed to allow a habitable exoplanet imaging mission to be well formulated in time for consideration by the 2020 decadal survey. Similarly, the second item depends on the near-term measurements of ongoing CMB polarization investigations to trigger the targeted technology investment.

Activity	Science
(Augmentation to) Astrophysics Theory Program	Broad
(Definition of) a future ultraviolet-optical space capability to succeed HST	Technology development benefitting a future ultraviolet telescope to study hot gas between galaxies, the interstellar medium, and exoplanets
(Augmentation to) Intermediate Technology Development	Broad; targeted at advancing the readiness of technologies at technology readiness levels[21] (TRL) 3 to 5
(Augmentation to) Laboratory Astrophysics	Basic nuclear, ionic, atomic, and molecular physics to support interpretation of data from JWST and future missions
(U.S. contribution to JAXA-led) SPICA mission	Understanding the birth of galaxies, stars, and planets; cycling of matter through the interstellar medium
(Augmentation to) the Suborbital Program	Broad, but including especially CMB and particle astrophysics
Theory and Computation Networks	Broad; targeted at high priority science through key projects

Table 3.3—Recommended New Space Activities: Small Scale *(Alphabetical order; unranked) (From Table ES.1 of the Decadal Survey).*

Note that the recommendation for Theory and Computation Networks includes additional funding from NSF and DOE.

20 The term MIDEX refers to medium-class Explorer missions that were launched on Delta 2 launch vehicles. Current medium-class Explorer mission are called EX missions and will be restricted to the available launch vehicles.

21 Technology readiness levels; http://www.nasa.gov/topics/aeronautics/features/trl_demystified.html.

3.3 Decadal Survey Budget Assumptions and Priorities

3.3.1 Baseline budget: Optimistic Scenario

The program recommended by the Decadal Survey for NASA was constrained to fit within a budget for the Astrophysics Division that is flat in FY 2010 dollars over the decade and assumed a 2014 launch of JWST. These assumptions yielded $3.7B available for new initiatives and augmentations to existing programs (including extensions of currently operating missions) within the decade 2012-2021. The resulting budget notionally would have allowed NASA to carry out the program given in Tables 3.1-3.3 above which includes launching WFIRST by 2020; enhancing the Explorer program; making a good start on LISA or IXO if selected by ESA for development this decade and otherwise carrying out technology development programs for them; carrying out technology programs for New Worlds and Inflation Probe; making essential augmentations to the core research programs; and contributing to SPICA.

3.3.2 Reduced Budget Scenario

NASA also charged the decadal committee to consider plans for a more conservative budget projection based on extrapolating the President's FY 2011 budget submission, which projected about $700M less funding over the decade. With the resulting $3B available over the decade, the full recommended program could not be carried out. In this situation, the committee set the first priority activities as follows: develop, launch, and operate WFIRST; implement the recommended Explorer program augmentations; implement the recommended core research program augmentations. The second priority activities are: pursue the New Worlds Technology Development Program as recommended, to a mid-decade review; start LISA as soon as possible (assuming a successful Pathfinder and ESA partnership); and invest in IXO technology development or possibly accelerate it. The third priority activities are to pursue the CMB Technology Development Program as recommended, to mid-decade review. This more conservative budget scenario does not permit NASA participation in the JAXA SPICA mission unless that mission's development phase is delayed.

Priority in Constrained Budget Scenarios	Activities
1	• Develop, launch, operate WFIRST • Explorer Program Augmentations • Core Research Program Augmentations
2	• New Worlds Technology Development Program • Start LISA • Invest in IXO technology development
3	• CMB Technology Development Program
Not Recommended	• Participation in SPICA

Table 4—Recommended New Space Activities: Small Scale *Constrained Budget Scenario (from the Decadal Survey, page 237).*

4. Astrophysics Division Implementation Strategy

4.1 Guiding Principles for Implementation Strategy

The Astrophysics Division is responsible for the stewardship of the Nation's capabilities in space astrophysics and for advancing the Nation's space astrophysics goals and objectives. The guiding principles used by the Division in implementing its strategy for meeting those responsibilities include:

- Enable the science and priorities identified by the Decadal Survey with new activities as well as through ongoing missions, including large missions, medium missions, and Explorers.
- Invest in the Astrophysics Research Program for developing the science cases and technologies of new missions and for maximizing the scientific return from operating missions.
- Receive community guidance and advice through the APS and its associated PAGs, the CAA, and the AAAC, and use this guidance and advice to inform decisions made by the Division.
- Implement the program through choices made by the Astrophysics Division in the context of the science and prioritized activities identified by the Decadal Survey, and work with the Science Mission Directorate, NASA Administrator's office, and White House Office of Management and Budget (OMB) to move those choices into budget realities.
- Use processes that are as transparent as possible.
- Preserve and nurture core capabilities at NASA Centers and throughout the Nation.
- Maintain flexibility needed in an environment that is constantly changing.

4.2 Key Developments since the Release of the Decadal Survey

The Decadal Survey was released in August 2010. Since then, several important developments have transpired which affect the Astrophysics Division's strategy for implementing its recommendations. These include:

- A new launch date of no earlier than 2018 was established for JWST, with a new life-cycle cost commitment of $8.8B, an increase of $3.1B over the previous commitment. The Administration has made the successful completion and launch of JWST one of NASA's priorities at the Agency level. NASA has committed funding with adequate reserves to JWST development to ensure a launch in 2018. No new strategic astrophysics mission can be started before funds become available near the completion and launch of JWST.
- The budget environment assumed by the Decadal Survey has not been realized. The Decadal Survey assumes $3.7B of available funding over the decade in its optimistic budget scenario, and the Survey's constrained budget scenario assumes $3.0B of available funding over the decade. However, neither of these assumptions has been realized. Although the total funding for astrophysics is higher than either of those scenarios, the increased cost of JWST has left less than $1B of available astrophysics funding over the decade to address the Decadal Survey recommendations for new projects and activities.

- Consistent with the recommendations of the NRC report on Assessment of a Plan for U.S. Participation in Euclid[22], a strategic partnership was established with ESA in 2012 to participate in ESA's Euclid mission. This partnership includes contribution of sensor chip systems for the mission's Near Infrared Spectrometer and Photometer, at a cost of approximately $50M, and selection of U.S. scientists to the Euclid Consortium and the Euclid Science Team.

- Neither LISA nor IXO was selected as the first large mission to go forward by the Decadal Survey nor as the first large mission in the ESA Cosmic Vision Programme; as a result the partnership between NASA and ESA was ended for these missions. In May 2012, ESA selected the Jupiter Icy moons Explorer (JUICE) mission over European-only X-ray and gravitational wave observatory missions as the first large mission in its Cosmic Vision 2015-2025 Programme.

- In June 2012, NASA announced that the National Reconnaissance Office (NRO) had made available two 2.4m telescope systems for NASA's use. In August 2012, NASA started two studies of potential uses of these telescope assets, to be completed and reported to the NASA Administrator in April 2013. Specifically:

    - The Astrophysics Division will conduct a focused mission concept study to assess the possible astrophysical use of the telescope assets to address the science priorities described in the Decadal Survey for a wide field infrared survey telescope. The study will also consider an optional second instrument, i.e. a coronagraph to address the Decadal Survey's priorities for direct imaging and characterization of exoplanets. This study is called the Astrophysics Focused Telescope Assets (AFTA) study and it was initiated in October 2012.

    - SMD will lead a broad study to assess a range of potential uses of these telescope assets across the SMD portfolio including Heliophysics, Planetary Science, and Astrophysics beyond the Decadal Survey priorities. Human Exploration and Space Technology will be active partners in this study, taking into account higher risk mission architectures, advanced technologies, and lower cost. This study includes a February 2013 community workshop.

4.3 Support for Decadal Survey Recommendations in the FY 2013 Budget

The Astrophysics Division goal is to start a new strategic mission[23] in FY 2017, subject to the availability of funds as JWST approaches launch. The Decadal Survey has stated that the highest priority for a new large strategic mission in this decade is WFIRST. The cost and schedule growth that occurred on JWST has led to concern about project management and control for large missions. It is important that NASA successfully deliver JWST within its rebaselined cost and schedule commitments. It is also important that all future missions proposed for new starts have well understood technical, cost, and schedule estimates in order to prevent cost overruns. Several GAO studies on past NASA missions find that a robust program of technology development is an effective way to retire cost risks.[24]

Since it cannot be assumed that the authority to start a new large mission will granted by 2017, concepts for strategic moderate cost missions that cost no more than approximately $1B (hereafter referred to as "probes"[25]) must also be considered. The Astrophysics Division has begun studies to identify candidates for such probes that derive from the activities prioritized in the Decadal Survey and are responsive to the Decadal Survey science questions. See Section 5 for details. The Astrophysics Division is also conducting the AFTA study during 2013 to assess the

22 *Assessment of a Plan for U.S. Participation in Euclid* (NRC, 2012); http://www.nap.edu/catalog.php?record_id=13357.

possible scientific benefits and cost estimates of using the 2.4m telescope assets for advancing the science of the high priority activities recommended in the Decadal Survey.

In addition, progress on Decadal Survey science and priorities is maintained through sustaining and enhancing the core research program, continued operation of existing missions and their Guest Observer (GO) programs, growing use of the suborbital programs, and more frequent Explorer opportunities. Funding for all of these programs is maintained in the President's FY 2013 budget request. Note that, at the time this document is written, the Congress has not acted on the President's FY 2013 budget request for NASA.

The President's FY 2013 budget request for the Astrophysics Division includes:

- An Astrophysics Explorer Program that can support four mission selections and four Missions of Opportunity (MO) selections over a decade (depending on the cost caps chosen and launch vehicle availability). The Astrophysics Explorer Program budget has been augmented in response to the Decadal Survey to support this cadence of missions. One EX-class mission and one Mission of Opportunity from the November 2010 Announcement of Opportunity (AO), both to be downselected in Spring 2013, are funded. An AO for another MO was released in September 2012; in addition, a FY 2014 AO for a SMEX-class mission, and a FY 2015 AO for an EX-class mission and a MO are planned.

- Extensions of astrophysics operating missions and their associated GO programs. In response to the 2012 Senior Review of Operating Missions[26], extensions were approved and funding was allocated through at least FY 2014 for Chandra, Fermi, Hubble, Kepler, Spitzer, and Swift. Continuation of NASA funding for U.S. participation consistent with JAXA or ESA's plans was allocated for Herschel, Planck, Suzaku, and XMM-Newton.

- Continued development and operation of the SOFIA airborne observatory. Development of SOFIA is continued to enable Cycle 1 GO science observations beginning in mid 2013. An instrument upgrade will begin in 2013, and an AO for new instrumentation is planned for 2014. The SOFIA Observatory will formally transition from development to operations by 2014 after at least four instruments are commissioned for the use of guest observers.

- A new program for mid-TRL level technology development. In response to the Decadal Survey, the Strategic Astrophysics Technology (SAT) program has been established. Through the SAT program, the Astrophysics Division solicits and provides funding for mid-level technology that addresses the highest technology development priorities in all three focused programs (PCOS, COR, ExEP). In support of the SAT program, all three focused programs annually survey their communities for technology needs that are required to advance the Decadal Survey priorities, and this survey is published in the Program Annual Technology Reports.

- An augmented competitive Astrophysics Research Program that maintains growth realized in FY 2012. The funding available for competed research investigations was increased by 10% from FY 2010 to FY 2012, and this higher funding level is maintained in the FY 2013 President's budget request. This supports increased funding for all of the competitive research programs (ADAP, APRA, ATP, OSS) and is responsive to Decadal Survey

23 A strategic mission is one that is identified other than through an Announcement of Opportunity for PI-led mission proposals. In the Astrophysics Division, all non-Explorer missions are strategic missions.

24 *NASA: Assessments of Large-Scale Projects* (GAO-12-207SP); http://www.gao.gov/products/GAO-12-207SP.

25 The Astrophysics Division is currently operating three missions that could be considered probe-class based on their development and operation costs: the Spitzer Space Telescope, the Fermi Gamma Ray Space Telescope, and the Kepler Space Telescope.

26 2012 Senior Review of Astrophysics Division Operating Missions; http://nasascience.nasa.gov/astrophysics/2012-senior-review/.

recommendations regarding the Astrophysics Theory Program and suborbital payloads and investigations in the Astrophysics Research and Analysis program.

- New research opportunities. In response to recommendations in the Decadal Survey and from the APS, new proposal opportunities are being offered and funded for Theory and Computation Networks (in partnership with NSF), laboratory astrophysics consortia, and the Nancy Grace Roman Technology Fellowships for early career researchers.

Following the formulation of the President's FY 2013 budget request, an NRC study[27] endorsed a small investment in Euclid as a valuable first step toward meeting one of the science goals of the WFIRST mission. The committee found that this contribution is consistent with the recommendations of the Decadal Survey in maintaining a U.S. leadership role in dark energy studies only in combination with moving forward with the WFIRST mission's dark energy program and its broader goals. NASA has undertaken a partnership with ESA and agreed to provide a contribution of detector subsystems for the Near Infrared Spectrometer Photometer (NISP) instrument on the Euclid mission in exchange for appointing NASA-selected members for full participation in the Euclid Consortium and the Euclid Science Team.

A summary of some of the items in the FY 2013 President's budget request which respond directly to Decadal Survey recommendations is provided in Table 5.[28]

27 *Assessment of a Plan for U.S. Participation in Euclid*, (NRC, 2012); http://www.nap.edu/catalog.php?record_id=13357..

28 In February 2012, the APS conducted an assessment of the Astrophysics Division's response to the Decadal Survey recommendations included in the FY 2013 President's budget request; see the Chair Letter of the February 2012 meeting at http://science.nasa.gov/science-committee/subcommittees/nac-astrophysics-subcommittee/.

Scale	Decadal Survey Recommendation	Response included in the FY 2013 President's Budget Request
Large	WFIRST	SDT and DRMs in FY 2011 and FY 2012; AFTA study in FY 2013; technology investments in detectors through SAT program; participation in Euclid
Large	Explorer Augmentation	Augment budget to support selection of 2 EX missions, 2 SMEX missions, and 4 Missions of Opportunity over a decade; MO AO in 2012, SMEX AO in 2013/2014, and EX AO in 2015
Large	LISA	Complete ST-7/LISA Pathfinder mission; technology investments through SAT program; Community Science Team (CST) study in 2012
Large	IXO	Technology investments through SAT program; CST study in 2012; potential probe study
Medium	New Worlds Technology	Technology investments through technology testbeds and SAT program; probe studies in FY 2013 and FY 2014
Medium	Inflation Probe Technology	Technology investments through APRA program including three suborbital balloon payloads; complete Planck mission and data analysis; potential probe study after Planck results
Small	Astrophysics Theory Program Augmentation	Small augmentation starting in FY 2012 and maintained
Small	(Definition of) a future UV-optical space capability	Technology investments through SAT program; science driver studies in FY 2012 and responsive mission studies in FY 2013 leading toward next decadal survey
Small	Intermediate Technology Development Augmentation	Initiated SAT program in FY 2010
Small	Laboratory Astrophysics Augmentation	Augmentation to select laboratory consortia
Small	SPICA (U.S. contributions to JAXA-led)	Not supported as a strategic contribution; candidate for Explorer Mission of Opportunity
Small	Suborbital Program Augmentation	Small augmentation for payloads; augmentation to support development of ULDB platforms and WASP
NA	Additional core program augmentations	Initiated Nancy Grace Roman Technology Fellows program; small augmentation for ADAP program; small augmentation for APRA program

Table 5—FY 2013 response to Decadal Survey. *Astrophysics Division programs and activities included in the FY 2013 President's budget request that respond to Decadal Survey recommendations.*

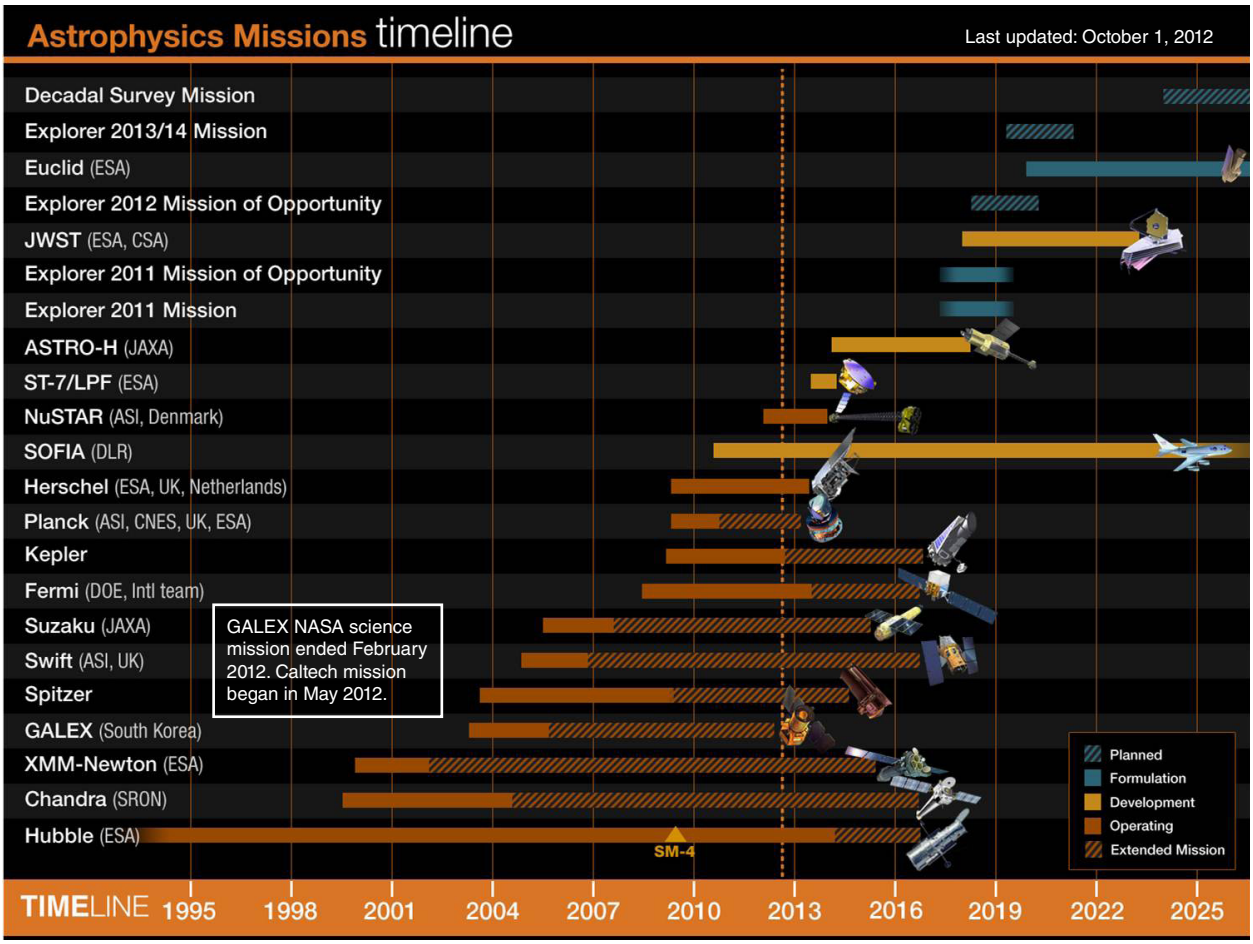

Figure 1. *Astrophysics mission timeline through the early 2020s.*

4.4 Astrophysics Implementation Plan

The Astrophysics Division will use the science of the high priority activities identified by the Decadal Survey to guide strategy and inform choices going forward into this decade and in preparing for the next decadal survey.

There is, however, inadequate available budget to implement all the Decadal Survey recommendations (cf. Sections 3.2 and 3.3). In particular, a new start for a large mission will be possible only when the spending on JWST begins to decrease in FY 2017. In the interim, progress on decadal priorities will be made through the core research program, through the continued operation of existing missions and their Guest Observer (GO) programs, through the suborbital program, and through frequent Explorer opportunities.

To prepare for a new mission, the Astrophysics Division is undertaking a near-term program of mission concept studies and technology development, with the goal of informing a mid-decade decision on a mission which could begin formulation starting as early as FY 2017. These include studies of a large strategic mission, WFIRST. Since funding availability for a large mission cannot be guaranteed, moderate missions ("probes") are also being studied to begin formulation as early as mid-decade.

Note that all mission concept studies must derive from the science objectives of the prioritized activities in the Decadal Survey. Table 6 provides a summary of these mission concept studies, including probes that may address the WFIRST science objectives.

Strategic Mission Concepts	Derived from Decadal Survey Recommendation	Status of Studies	Plan for Future
WFIRST: Large Strategic Mission (DRM1)	Large 1st priority: WFIRST	Completed in 2012	Candidate large mission for mid-decade
WFIRST: Probe-size Strategic Mission (DRM2)	Large 1st priority: WFIRST	Completed in 2012	Candidate probe for mid-decade
Use of the 2.4m telescope assets to advance the science of WFIRST (study includes an optional second instrument to advance exoplanet science)	Large 1st priority: WFIRST (Medium 1: New Worlds Technology)	Started in 2012	Candidate large mission for mid-decade
Gravitational Wave missions to advance the science of LISA	Large 3rd priority: LISA	Completed in 2012	Candidate large mission for next decade; candidate for international partnership
X-ray missions to advance the science of IXO	Large 4th priority: IXO	Completed in 2012; under consideration for study in 2014	Candidate probe for mid-decade; candidate large mission for next decade; candidate for international partnership
Exoplanet probes to advance the science of a planet characterization and imaging mission	Medium 1st priority: New Worlds Technology	Planned for 2013	Candidate probe for mid-decade; candidate large mission for next decade
Cosmic Microwave Background Polarization Probe	Medium 2nd priority: Inflation Probe Technology	Study under consideration for study in 2015	Candidate probe or large mission for next decade
Science and technology drivers for a UV/Visible mission	Small: (Definition of) a future UV-optical space capability	Started in 2012	Candidate probe or large mission for next decade

Table 6—*Mission concept studies being conducted or considered.*

An FY 2017 new start, followed by efficient development for the selected mission, requires mature technology by the end of this decade. The mission concept studies shown in Table 6 will identify technology requirements, and these will be used to guide technology investments during this decade.

Sections 5 through 7 provide more details about the overall Astrophysics Division implementation plan for the near term. The processes and activities pertaining to the Division's response to the Decadal Survey's recommendations for the next strategic mission are presented in Section 5. The plan for addressing the recommendation for the Explorer Program augmentation is detailed in Section 6, and the responses to recommendations for the Core Research program and other small-scale items are given in Section 7.

5. Astrophysics Implementation Plan: Toward the Next Strategic Mission

5.1 Overview

The Decadal Survey recommended WFIRST as the top priority for the next large space mission. Given that ESA is not proceeding with LISA or IXO in this decade, WFIRST is the only large space mission prioritized by the Decadal Survey still under consideration for a start in this decade. However, since funding availability for starting a large space mission this decade cannot be guaranteed, moderate-sized ("probe") mission concepts are also being considered. All such probe mission concepts must derive from the prioritized recommendations in the Decadal Survey.

The near-term implementation of the strategy calls for completing the following activities by the end of FY 2014:

- Continue mission concept studies and technology development for WFIRST to be prepared for a potential new start this decade.
- Guided by other Decadal Survey prioritized recommendations (see Tables 3.1 and 3.2), identify mission concepts that can be developed within a probe-class budget while addressing the science objectives of Decadal Survey prioritized recommendations.
- For the mission concepts thereby identified (see Table 6), develop a technology development plan so that the schedule and cost of maturing the technologies to TRL- 6[29] can be established and verified through the independent technology management boards of the three Astrophysics Division focused program offices.
- Map the technology funding requirements from the above exercise to the available funding in this decade.
- Identify opportunities for international partnerships in order to reduce NASA's cost of the mission concepts identified and to advance the science objectives of the Decadal Survey in addition to WFIRST or probe-class missions.

Although technology development plans exist in all three focused program areas[30], not all potentially important areas of technology can be advanced within the near term. With the above data in hand, priorities can be set and decisions can be made for high priority, focused investments in

- technologies for the missions with highest potential to be the next mission to start;
- technologies that can facilitate a partnership with another agency;

and/or

- technologies for missions competing in the 2020 decadal review.

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29 NASA space flight project management processes require that technologies necessary for a space flight project must be matured to TRL-6 prior to the Preliminary Design Review (PDR); see NASA Procedural Requirements (NPR) 7120.5E, *NASA Space Flight Program and Project Management Requirements,* in the NASA Online Directives Information System (NODIS) at http://nodis3.gsfc.nasa.gov/.

30 Cosmic Origins Program Annual Technology Report (PATR) at http://cor.gsfc.nasa.gov/technology/; Exoplanet Exploration Program Technology Plan at http://exep.jpl.nasa.gov/technology/; Physics of the Cosmos PATR at http://pcos.gsfc.nasa.gov/technology/.

The Astrophysics Division strategy for selecting and starting the next strategic mission is shown schematically in Figure 2. Further details about the steps along this path are given in the subsections below.

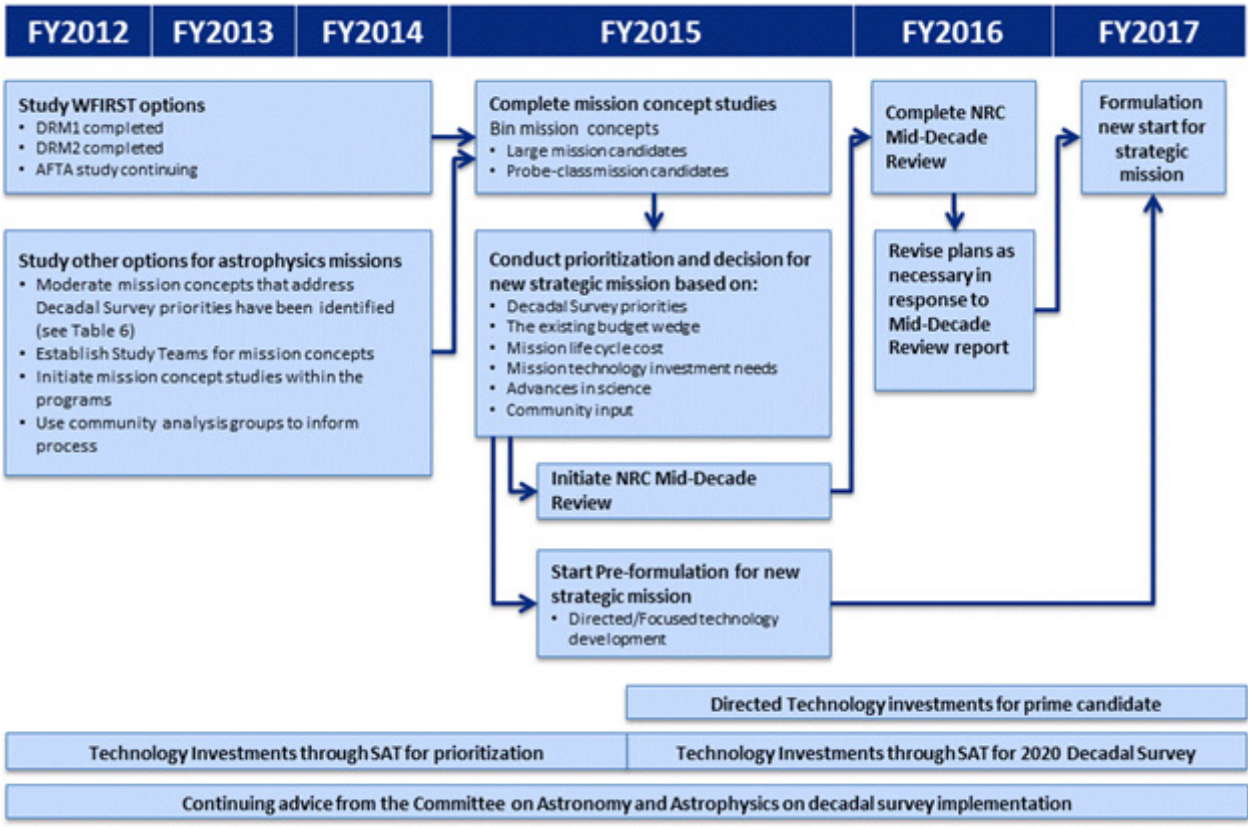

Figure 2. *Schematic plan for starting a strategic mission in 2017.*

5.2 WFIRST

5.2.1 DRM1: full size WFIRST

The WFIRST Science Definition Team (SDT) was formed in 2011 to refine the science case for the mission, optimize the design and implementation, and develop two Design Reference Missions (DRMs) to serve as the basis for further programmatic and technical review. The first DRM (DRM1) was scoped to meet all of the scientific and observational requirements outlined in the Decadal Survey. It utilizes existing, proven technology, and could move into design and development immediately if a new start were to be approved.

DRM1 utilizes infrared sensors based on current technology and fits within a medium lift class launch vehicle fairing. DRM1 assumes that WFIRST will be deployed in an Earth-Sun L2 libration point orbit, and have a prime mission of 5 years, but will have no design elements (e.g., propellant supply) that intrinsically limit the lifetime to less than 10 years.

The report of the SDT is available at http://wfirst.gsfc.nasa.gov/.

5.2.2 DRM2: probe-size WFIRST

In late 2011, the Astrophysics Division requested the WFIRST SDT to produce a second Design Reference Mission (DRM2) in response to ESA's selection of the Euclid dark energy mission, which is scheduled to launch in 2019 or 2020. DRM2 is designed to be non-duplicative with the capabilities of the Euclid mission, JWST, and/or planned ground based facilities such as the Large Synoptic Survey Telescope (LSST). It also is a lower cost alternative to DRM1, though with a reduced science return in its prime mission compared to DRM1. To reduce mission costs, DRM2 employs a smaller telescope than DRM1, fields a smaller number of higher performance infrared sensors that require technology development, uses an observatory design with only selective redundancy, and fits within a lower cost launch vehicle. The DRM2 design also assumes that WFIRST will be deployed in an Earth-Sun L2 libration point orbit, but would have a prime mission of 3 years. With the improved sensors, DRM2 has similar sensitivity to DRM1 for a fixed observation time, and can achieve many, but not all, of the Decadal Survey science objectives within its 3 year design lifetime, and could carry out all of them in an extended mission. It is assumed that the actual observing plan for a WFIRST utilizing the DRM2 mission concept will be optimized based on the data available at that time.

The report of the SDT is available at http://wfirst.gsfc.nasa.gov/.

5.2.3 AFTA: use of 2.4m telescope assets to advance the science of WFIRST

In October 2012, the Astrophysics Division began the Astrophysics Focused Telescope assets (AFTA) study by selecting members of a SDT to assess the possible scientific use of the 2.4m telescope assets acquired from NRO for advancing the science of the high priority activities identified by the Decadal Survey.

The SDT is to provide science requirements, investigation approaches, key mission parameters, and scientific studies needed to support the definition of an optimized space mission concept DRM for the use of one of the telescope assets by the Astrophysics Division to further the science priorities described in the Decadal Survey for a wide field infrared survey telescope. The study will include an optional second instrument and will estimate the cost for such an option: an internal coronagraph has been designated as the proxy second instrument in response to the Decadal Survey recommendation for the detection and study of exoplanets. The SDT, working with the WFIRST Study Office at GSFC, will produce a baseline DRM which would use one of the telescope assets. The overall mission cost is to be kept as low as possible while still achieving all or part of the science priorities of WFIRST. The findings of the SDT will be provided in a final report no later than April 30, 2013. The charter and other information on the AFTA study are available at http://wfirst.gsfc.nasa.gov/.

5.3 Studies of Moderate-sized Missions

5.3.1 Gravitational Wave Mission Concepts to Advance LISA Science

During FY 2012, the Astrophysics Division through its PCOS Program Office initiated a study of gravitational wave mission concepts to advance the science of the LISA mission, responsive to the Decadal Survey recommendation for LISA. The purpose of the study was to develop mission concepts that would accomplish some or all of the LISA science objectives at lower cost. The science performance of these mission concepts was evaluated against the LISA science endorsed by the Decadal Survey. The study explored how architecture choices in gravitational wave

mission concepts impact the science return, the risk and the cost. The study was conducted by a Study Team, consisting of a Core Team of scientists and engineers, a Community Science Team representing the gravitational wave, astrophysics, and fundamental physics communities, and a Science Task Force—approximately 40 people in all.

The study found that scientifically compelling mission concepts can be carried out for somewhat less than the full LISA cost. No concepts were found near or below $1B. Owing to the nature of the measurements needed to detect and characterize gravitational waves, the scientific performance of mission concepts decreases far more rapidly than cost as the concepts are scaled down. The study found no technology that can make a dramatic reduction in cost; however, investment in specific technologies is required to enable participation by the U.S. in a possible future international gravitational wave observatory that is responsive to the Decadal Survey recommendation for the science return for LISA.

The final report and other information on the gravitational wave observatory study are available at http://pcos.gsfc.nasa.gov/studies/gravitational-wave-mission.php.

To move forward with the required investment in critical technologies, during FY 2013 the PCOS Program Office will create a Technology Development Plan (TDP) that captures the costs and schedule needed to advance the TRL of current technologies that would be needed for U. S. participation in a future international gravitational wave observatory or for a US-led observatory to be considered by the 2020 decadal survey. In succeeding years, the TDP will be used to guide gravitational wave technology investments, both through the SAT program that is completed through ROSES and through directed technology efforts. The Astrophysics Division will also continue to support the ST-7 Disturbance Reduction System (DRS) payload and the LISA Pathfinder mission.

5.3.2 X-ray Mission Concepts to Advance IXO Science

During FY 2012, the Astrophysics Division through its PCOS Program Office initiated a study of X-Ray mission concepts to advance the science of the IXO mission, responsive to the Decadal Survey recommendations for IXO technology development and for the NASA cost of IXO to be kept below $2B. The purpose of the study was to develop mission concepts that would accomplish some or all of the IXO science objectives at lower cost. The science performance of these mission concepts was evaluated against the IXO science endorsed by the Decadal Survey. The study explored how architecture choices in X-ray mission concepts impact the science return, the risk and the cost. The study was conducted by a Study Team, consisting of a Core Team of scientists and engineers and a Community Science Team representing the X-ray astrophysics community. The goal was to assess the fraction of IXO science that can be performed versus mission cost.

The study found that scientifically compelling mission concepts can be carried out for less than the full IXO cost. In particular, the IXO science objectives can be largely achieved at a cost of below $2B, and a significant share of these objectives can be achieved by a probe-class mission with a cost of $1B or less. Investment in critical technologies is required to enable any of the X-ray astrophysics missions that are responsive to the Decadal Survey recommendation for the science return for IXO. The mission concepts studied would be candidates for prioritization by the 2020 Decadal Survey as a mission to follow WFIRST; if a large mission like WFIRST cannot be started this decade, then any X-ray probe-class mission concept that is technologically ready would be a candidate for a probe to start this decade.

The final report and other information on the X-ray mission study are available at http://pcos.gsfc.nasa.gov/studies/x-ray-mission.php.

To move forward with the required investment in critical technologies, during FY 2013 the PCOS Program Office will create a TDP that captures the costs and schedule needed to mature current technologies for both a probe-class mission that might be started this decade and for a larger mission that could be considered by the 2020 decadal survey for a start in the next decade. In the following years, the TDP will be used to guide X-ray technology investments, both through the SAT program that is competed through ROSES and through directed technology efforts. In the mid-decade time frame, the Astrophysics Division may engage the science community to refine the definition of a probe-class mission that pursues the IXO science objectives that might be started this decade, and later on to define a larger class mission that would be a candidate for prioritization by the 2020 decadal survey as either an international partnership or a U.S.-led mission.

5.3.3 Concept studies for Exoplanet probes to advance the science of a planet characterization and imaging mission

During FY 2013, the Astrophysics Division through its Exoplanet Exploration Program Office will initiate mission concept studies of probe-class missions to advance the science of a planet characterization and imaging mission as prioritized in the Decadal Survey. The highest priority Decadal Survey medium scale recommendation is a New Worlds Technology Development Program in preparation for planet imaging mission beyond 2020, including precursor science activities. The mission concepts studied would be candidates for prioritization by the 2020 Decadal Survey as a mission to follow WFIRST; if a large mission like WFIRST cannot be started this decade, then an exoplanet probe which is technologically ready would be a candidate for a probe to start this decade.

The mission concept studies will be dedicated primarily to probe-scale exoplanet mission concepts for direct imaging using starlight suppression with the aim of validating their affordability within a $1B cost cap. Starlight-suppression missions will require technology development, and the concept studies will be used to assess technical maturity and refine the related technology plans. At least two studies will be conducted for direct-imaging missions: an internal coronagraph, and an external occulter. Astrometry concepts that augment the capability of a starlight suppression mission, or concepts that provide cross-Program support for Cosmic Origins science, may also be considered as part of the above two studies. A possible outcome of this effort is that sufficiently compelling direct-imaging missions may not fit convincingly within the probe-mission cost cap, so an additional study or studies may be conducted to consider high priority probe-scale mission concepts that require no new technology.

The Astrophysics Division will select science and technology definition teams (STDTs) in early 2013 through a “Dear Colleague” letter to carry out the exoplanet mission concept studies. The STDTs will be active starting in spring 2013. Each STDT will deliver a Baseline Mission Concept Report, in which it will identify the likely science return from a cost-driven probe-scale mission. The reports will identify needed technologies to be developed through approximately 2019.

5.3.4 Concept studies, following technology development and observations, for an Inflation Probe

In a constrained budget environment, the Decadal Survey places investment in an Inflation Probe at a lower priority than investments in other prioritized activities (see Section 3.3.2). Consistent with Decadal Survey recommendations, NASA continues investment in Planck data analysis as well as suborbital and ground-based programs of technology development and observations to pursue detection of primordial B-mode polarization of the cosmic microwave background, a key precursor for an Inflation Probe mission. Planck is expected to release temperature data in 2013 and polarization data in 2014. Other suborbital investigations are underway with the promise of returning polarization measures on a similar timescale. The Astrophysics Division plans to initiate studies in 2015 to develop concepts for a CMB polarization mission, giving astrophysicists one year to sift through the complete Planck data set and to incorporate related measurements from other projects. The Inflation Probe community has produced a Technology Roadmap[31]. This roadmap would be updated as a result of the new concept studies.

5.3.5 Studies of UV/Visible science objectives to drive concepts and technology that advance the science of a future UV/Visible telescope

The Decadal Survey recommended a small program of technology development and mission concept studies benefitting a future ultraviolet/visible telescope to study hot gas between galaxies, the interstellar medium, the evolution of normal stars and galaxies, and exoplanets. The Astrophysics Division is responding to this recommendation by identifying the detailed science drivers for a future ultraviolet/visible space telescope that could considered in the 2020 decadal survey. This will be followed by identification of the technology drivers necessary for realizing the required capability, and then investment in the requisite technologies. Although the plan outlined above is consistent with the spirit of the Decadal Survey recommendations, the Astrophysics Division is not aiming toward a particular mission concept or aperture size in anticipation of a more refined determination of science requirements. In May 2012, the Astrophysics Division released a Request for Information (RFI) soliciting community input for compelling science drivers for future ultraviolet/visible missions. At a September 2012 workshop, the science community discussed responses to the RFI and assessed traceability to the Decadal Survey[32]. Current plans are for a second RFI to be released in FY 2013 to solicit mission concepts and mission enabling technologies. A second workshop will be held to discuss the responses to the second RFI and identify notional mission concepts and technology requirements for candidate missions at various classes (probe and large scale). Some mission trade studies are envisioned which will drive technology investment decisions during the latter half of the decade. Technology investments will be made through competition, via the APRA or SAT programs, or through targeted technology funding.

5.4 Technology Development

The Astrophysics Division invests in the technology necessary to realize science results through several complementary pathways; these pathways are differentiated by the TRL endpoint of the technology development effort and by the mission need for the technology itself.

Basic technology research (at TRL 1-3) is funded through the Astrophysics Research and Analysis (APRA) program in response to competitively solicited and peer reviewed proposals submitted through ROSES. APRA includes the balloon and sounding rocket suborbital programs,

31 Inflation Probe Technology Roadmap; http://pcos.gsfc.nasa.gov/sags/ipsag/docs/IP_techdoc_v13All.pdf.

32 UV/Visible Request for Information (RFI); http://cor.gsfc.nasa.gov/RFI2012.

which often take detector technology to TRL 6-7. Mid-level technology development for TRL 3-5 is funded through the Strategic Astrophysics Technology (SAT) program in response to competitively solicited and peer reviewed proposals submitted through ROSES. The Astrophysics Division has also funded targeted technology and technology testbeds, such as the high-contrast imaging testbeds at JPL in support of exoplanet technology development investigations, and specific technologies necessary for observatories such as LISA and IXO. Finally, technology development for strategic missions in development is funded through the flight project itself.

Plans for making technology investments in Decadal Survey recommended areas are summarized in Table 5.

5.5 Selection Process and Timescale

Although not fully developed, the decision criteria for determining the next strategic mission are expected to include the following key elements:

- Any approved mission must be responsive to the stated intent of the Decadal Survey taking into account the budgetary and other constraints governing the Astrophysics Division and its programs. Simply stated, the selected mission must logically derive from the science objectives addressed by the prioritized activity recommendations of the Decadal Survey.
- The required funding profile, including technology developments, must be compatible with the Astrophysics Division's planning budget for technology and mission development; this planning budget is given in the President's FY 2013 budget request and will evolve annually. Any technology development funding required to bring the necessary technology to TRL 6 before the mission PDR must be affordable within the planning budget.
- The risk posture of the selected mission must be well understood, including programmatic, technical, and institutional risks. In the current environment where significant attention is paid to cost performance for NASA projects, high confidence is required that the mission life cycle cost is within the budgetary constraints mentioned above.

The following constraints will be used to guide the identification of the next strategic mission:

- If a large strategic astrophysics mission is approved to follow JWST, a mission that addresses the Decadal Survey science objectives of WFIRST remains the highest priority.
- If only a probe-class mission is possible, the candidates for this mission will be determined by the studies outlined in Table 6.
- Before the probe-size version of WFIRST (see Section 5.2.2) could be adopted, it must be established that its 3-year mission is responsive to the Decadal Survey recommendation, that its cost-saving design meets NASA requirements for mission assurance, and that its new detector technology can be matured in a timely manner.
- If the strategic mission that follows JWST is a probe mission, a large mission like WFIRST would remain under consideration as a future mission subject to budget availability.

During the period leading up to the decision on determining the next astrophysics strategic mission, the Astrophysics Division will consult regularly with the Committee on Astronomy and Astrophysics; see Section 2.3. This will include presentation of the mission concept studies to

the CAA. Among the questions which will be discussed with the CAA, or with an ad hoc study committee formulated and overseen by the CAA, are whether the priorities of the Decadal Survey are still valid in the context of ongoing advances in science and programmatic changes[33] and whether the mission concepts under consideration for a mid-decade decision, including the probe-size version of WFIRST (see Section 5.2.2), are responsive to the recommendations of the Decadal Survey.

During this period, community input on the tactical process of identifying and prioritizing the candidate missions will be provided through the APS.

5.6 Role of the Mid-Decade Review

The NASA Authorization Act of 2005 requires NASA to have the National Academy of Sciences conduct performance reviews of the NASA science divisions every five years. Thus each science division sponsors a Decadal Survey and, about 5 years later, follows with a Mid-Decade Review. The first Mid-Decade Review was conducted in astrophysics in 2006, since then there have been Mid-Decade Reviews in the other three NASA science divisions. Astrophysics will be the first NASA science division to undertake a second Mid-Decade Review.

The charter to the Committee conducting the 2006 Mid-Decade Review of Astrophysics was to study the alignment of NASA's Astrophysics Division with the 2000 decadal survey and other NRC reports. Specifically that Committee was charged to address the following: (1) How well NASA's program addresses the strategies, goals, and priorities outlined in the Decadal Survey and other NRC reports; (2) Progress toward realizing these strategies, goals and priorities; and (3) Any actions that could be taken to optimize the scientific value of the program in the context of current and forecasted resources available to it. That Committee was not charged to revisit nor to alter the scientific priorities or mission recommendations provided in the Decadal Survey or other reports, but rather to provide guidance about implementing the recommended mission portfolio leading toward the next decadal survey.

The Astrophysics Division, in partnership with the NSF's Division of Astronomical Sciences, currently intends to request a Mid-Decade Review beginning in 2015 and concluding in 2016. Consistent with its practices, the NRC will appoint an ad hoc committee to conduct the Mid-Decade Review and write a report. The charter is likely to be similar to the charter from the previous decade: assess the Astrophysics Division's response to the Decadal Survey, but do not alter the recommendations.

At the time of the writing of this document, it is the intent of the Astrophysics Division that a decision regarding the strategic mission to follow JWST will have been taken and made public prior to the Mid-Decade Review conducting its assessment. A key aspect of the Mid-Decade Review will be an assessment by the review committee on whether NASA's astrophysics program, including the decision regarding the strategic mission to follow JWST, aligns with the Decadal Survey science questions and recommended, prioritized activities in the context of current and forecasted resources available to the Astrophysics Division.

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33 Subsequent to the Decadal Survey, the NRC *Report of the Panel on Implementing Recommendations from the New Worlds, New Horizons Decadal Survey* stated that "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."; http://www.nap.edu/catalog.php?record_id=13045.

34 *A Performance Assessment of NASA's Astrophysics Program*, (NRC, 2007); http://www.nap.edu/openbook.php?record_id=11828..

6. Astrophysics Implementation Plan: Astrophysics Explorers

The Astrophysics Explorer Program is one of two cross-cutting Programs, spanning across all science areas in the astrophysics portfolio. The goal of the Astrophysics Explorer Program is to provide frequent flight opportunities for high quality, high value, focused astrophysics science investigations that can be accomplished under a not-to-exceed cost cap and developed relatively quickly. This competitive, cost-efficient program supports small-class (SMEX) and medium-class (EX, formerly called MIDEX) missions and missions of opportunity (MOs). Competitive selection ensures that the most current and compelling science will be accomplished.

In its prioritization, the Decadal Survey treated the entire Astrophysics Explorer Program of small missions as a single large activity. Under its optimistic budget scenario, the Decadal Survey recommended, as its second priority in the large-scale space-based projects category, an augmentation of the Astrophysics Explorer Program to support the selection of two new astrophysics MIDEX missions, two new astrophysics SMEX missions, and at least four astrophysics MOs over the coming decade. They further recommended that Explorer AOs should be released on a predictable basis as close to annually as possible, to facilitate coordination of MOs. They also encouraged allowing the inclusion of suborbital payloads as MOs, if they are shown to offer compelling scientific returns. To accommodate this plan, the Decadal Survey recommended that an annual budget increase of $60M be implemented by 2015. Even under its more conservative budget projection, in the event that insufficient funds were available to carry out the recommended program, the Decadal Survey retained the augmentation of the Explorer program in its set of "first priorities."

The Astrophysics Division is implementing the recommendations of the Decadal Survey to the extent that the budget allows.

An AO for EX missions, which are comparable to MIDEX missions, was released in November 2011. From that solicitation, two EX mission proposals (TESS and FINESSE) were selected for Phase A concept studies. One of these two missions is anticipated to be selected in Spring 2013 for flight, with launch expected by 2017 or 2018. At the same time that the EX solicitation was released, a solicitation was released for MO proposals. From that solicitation, two MO proposals (NICER and GUSSTO) were selected for Phase A concept studies. One of these two MOs is anticipated to be selected in Spring 2013 for flight, with launch expected by 2017.

A solicitation for MO proposals was released in September 2012, with proposals due in December 2012 and a selection expected by June 2013. From this solicitation it is anticipated that one MO will be selected with launch expected by 2018, though more than one proposal could be selected if together the total investment fits within the available budget.

An AO for SMEX missions is planned for late 2013/early 2014. The AO following that is planned to solicit an EX[35] mission as well as another MO. The exact date will depend upon the available funding; if the runout of the President's FY 2013 budget request is realized, the EX AO could come as soon as late 2014/early 2015.

35 To differentiate the MIDEX missions that were launched on Delta 2 launch vehicles from future medium-class Explorer missions, future medium-class Explorer mission are called EX missions..

7. Astrophysics Implementation Plan: The Core Program and Other Small Recommendations

The Decadal Survey contained a number of recommendations for small programs that are directed to NASA. These recommendations are generally oriented toward the core research and analysis programs within the Astrophysics Division.

The Astrophysics Research Program encompasses the Division's research and analysis programs (ADAP, APRA, ATP, OSS, RTF, TCAN; see Acronym List), the balloon program, and the astrophysics data archives. In response to the Decadal Survey, the total level of the research and analysis programs was increased by approximately 10% between FY 2010 and FY 2012, and this increased level of funding is retained in the President's FY 2013 budget request.

The specific recommendations of the Decadal Survey, and the implementation of those requests within the President's FY 2013 budget request, are as follows.

- Astrophysics Theory Program (ATP) Augmentation: Starting in FY 2012, the ATP has been augmented by a small amount; ATP is competed through ROSES.
- (Definition of) a future UV-optical space capability: See Section 5.3.
- Intermediate Technology Development Augmentation: Starting in FY 2011, a Strategic Astrophysics Technology (SAT) program has been established within each of the Cosmic Origins, Exoplanet Exploration, and Physics of the Cosmos programs; SAT is competed through ROSES.
- Laboratory Astrophysics Augmentation: Laboratory astrophysics is a subelement of the Astrophysics Research and Analysis (APRA) program; APRA is competed through ROSES. Laboratory Astrophysics has been augmented to support the opportunity for large consortia within the laboratory astrophysics subelement, with the first selection being awarded in 2012.
- SPICA (U.S. contributions to JAXA-led): Consistent with the Decadal Survey recommendations for a constrained budget environment, no funding is available for a U.S. contribution to SPICA within the President's FY 2013 budget request. However a U.S. contribution to SPICA may be proposed as an Explorer Mission of Opportunity.
- Suborbital Program Augmentation: Astrophysics suborbital payloads for both balloons and sounding rockets are funded through the APRA program; the balloon program is funded as part of the Astrophysics Research Program and the sounding rocket program is funded outside of the Astrophysics Division as part of the Heliophysics Research Program. The funding for astrophysics suborbital payloads has been augmented by a small amount. Additional platforms continue to be developed, including ultra-long duration balloons within the balloon program, an arcsecond pointer for balloon-borne telescopes within the balloon program, and new sounding rocket motors within the sounding rocket program.

- Theory and Computation Networks (NASA, NSF, DOE): The Astrophysics Division and NSF's Division of Astronomical Science are jointly establishing the Theory and Computational Networks (TCAN) program with annual funding of $1.5M/yr each. A joint NSF/NASA solicitation for the first TCAN proposals was released in November 2012.

Two additional Core program augmentations were made to ensure continued scientific return on operating missions and to develop the workforce required to ensure future competitiveness:

- The Nancy Grace Roman Technology Fellowships (RTF) for early career researchers has been established within the Astrophysics Research Program. The first Nancy Grace Roman Technology Fellow candidates were selected in 2012; the RTF program is competed through ROSES.
- The Astrophysics Data Analysis Program (ADAP) has been augmented to accommodate new data sets from Kepler and other astrophysics missions; ADAP is competed through ROSES.

8. Summary

This *Astrophysics Implementation Plan* lays out the steps that the Astrophysics Division is taking to respond to the recommendations of the 2010 Decadal Survey within the budgetary reality that constrains its planning. The current budget projection differs from the planning budget used in the Decadal Survey.

Other changes that impact the Decadal Survey recommendations include ESA's decision not to select either LISA or IXO as the first large mission in the Cosmic Vision Programme, the NRO making two 2.4m telescope assets available to NASA, and NASA's decision to partner with ESA on the Euclid mission.

In addition, authority to start a large strategic mission, like WFIRST, to follow JWST cannot be assumed. The Astrophysics Division is therefore initiating studies of moderate-sized missions, called probes, to make the potential future astrophysics mission portfolio more robust to future budget uncertainty.

The Astrophysics Division has responded to the Decadal Survey by augmenting the Explorer Program; augmenting the core research program; and initiating studies that will lead to the start of a strategic astrophysics mission in 2017, if funds are available. These studies include several versions of WFIRST as well as probe-class missions that flow from the Decadal Survey recommendations. As these studies identify the new technology development that is required to enable them, the Astrophysics Division will prioritize its technology investments to advance the readiness of these mission candidates.

These mission studies will be discussed with the CAA and the APS to obtain guidance on the timing and order of potential strategic astrophysics missions within the context of the Decadal Survey recommendations. The studies and the advisory committee guidance will inform a mid-decade decision as to which new strategic mission will be started following JWST. That decision will be subject to review by the NRC Mid-Decade Review Committee. In addition, these studies will help advance mission candidates for the 2020 decadal survey and future international partnerships.

Acronyms

AAAC	Astronomy and Astrophysics Advisory Committee
ADAP	Astrophysics Data Analysis Program
AO	Announcement of Opportunity
APEX	Astrophysics Explorer
APRA	Astrophysics Research and Analysis program
AFTA	Astrophysics Focused Telescope Assets
ATP	Astrophysics Theory Program
BPA	Board on Physics and Astronomy
CAA	Committee on Astronomy and Astrophysics
CMB	Cosmic Microwave Background
COPAG	Cosmic Origins Program Analysis Group
COR	Cosmic Origins
CST	Community Science Team
DOE	Department of Energy
DRM	Design reference Mission
DRS	Disturbance Reduction System
DSIAC	Decadal Survey Implementation Advisory Committee
ESA	European Space Agency
EX	Explorer-class
ExEP	Exoplanet Exploration
ExoPAG	Exoplanet Exploration Program Analysis Group
FINESSE	Fast Infrared Exoplanet Spectroscopy Survey Explorer
FY	Fiscal Year
GAO	Government Accountability Office
GO	Guest Observer
GSFC	Goddard Space Flight Center
GUSSTO	Galactic/extragalactic ULDB Spectroscopic/Stratospheric THz Observatory
HST	Hubble Space Telescope
IR	Infrared
IXO	International X-ray Observatory
JAXA	Japanese Space Agency
JDEM	Joint Dark Energy Mission
JPL	Jet Propulsion Laboratory
JUICE	Jupiter Icy moon Explorer
JWST	James Webb Space Telescope
LISA	Laser Interferometer Space Antenna
LSST	Large Synoptic Survey Telescope
MIDEX	Medium-class Explorer
MO	Mission of Opportunity
NAC	NASA Advisory Council
NASA	National Aeronautics and Space Administration
NICER	Neutron star Interior Composition Explorer
NISP	Near Infrared Spectrometer Photometer
NODIS	NASA Online Directives Information System
NPR	NASA Procedural Requirements

NRC	National Research Council
NRO	National Reconnaissance Office
NSF	National Science Foundation
NWNH	New Worlds, New Horizons (the Decadal Survey)
OMB	Office of Management and Budget
OSS	Origins of Solar Systems program
PAG	Program Analysis Group
PATR	Program Annual Technology Report
PCOS	Physics of the Cosmos
PDR	Preliminary Design Review
PhysPAG	Physics of the Cosmos Program Analysis Group
PI	Principal Investigator
RFI	Request for Information
ROSES	Research Opportunities in Space and Earth Sciences
RTF	Nancy Grace Roman Technology Fellowship program
SAG	Study Analysis Group
SAT	Strategic Astrophysics Technology
SDT	Science Definition Team
SMD	Science Mission Directorate
SMEX	Small-class Explorer
SOFIA	Stratospheric Observatory for Infrared Astronomy
SPICA	Space Infrared Telescope for Cosmology and Astrophysics
SSB	Space Studies Board
ST-7	Space Technology 7
STDT	Science and Technology Definition Team
TCAN	Theory and Computational Networks program
TDP	Technology Development Plan
TESS	Transiting Exoplanet Survey Satellite
TRL	Technology readiness Level
ULDB	Ultra-long Duration Balloon
UV	Ultraviolet
WASP	Wallops Arcsecond Pointer
WFIRST	Wide Field Infrared Survey Telescope
XMM	X-ray Multi-Mirror Mission.

References

NRC Committees and Reports:

Committee on Astronomy and Astrophysics	http://sites.nationalacademies.org/BPA/BPA_048755
Astronomy in the New Millennium (NRC, 2001)	http://www.nap.edu/catalog.php?record_id=9839
Astrophysics Mid-Decade Review (NRC, 2007)	http://www.nap.edu/openbook.php?record_id=11828
New Worlds, New Horizons in Astronomy Astrophysics (NRC, 2010)	http://www.nap.edu/catalog.php?record_id=12951
NWNH Panel Reports (NRC, 2011)	http://www.nap.edu/catalog.php?record_id=12982
NRC Study on Implementing NWNH (NRC, 2011)	http://www.nap.edu/catalog.php?record_id=13045
NRC Study on Euclid Participation (NRC, 2012)	http://www.nap.edu/catalog.php?record_id=13357

NASA Websites and Documents:

2010 NASA Science Plan	http://science.nasa.gov/about-us/science-strategy/
2011 NASA Strategic Plan	http://www.nasa.gov/news/budget/
2012 Astrophysics Senior Review	http://nasascience.nasa.gov/astrophysics/2012-senior-review/
FY 2013 President's Budget Request	http://www.nasa.gov/news/budget/
AFTA study information	http://wfirst.gsfc.nasa.gov/
Assessments of Large-Scale Projects	http://www.gao.gov/products/GAO-12-207SP
Astronomy and Astrophysics Advisory Committee	http://www.nsf.gov/mps/ast/aaac.jsp
Astrophysics Analysis Groups	http://science.nasa.gov/science-committee/subcommittees/nac-astrophysics-subcommittee/analysis-groups/
Astrophysics Subcommittee	http://science.nasa.gov/science-committee/subcommittees/nac-astrophysics-subcommittee/
Cosmic Origins Program	http://cor.gsfc.nasa.gov/
Exoplanet Exploration Program	http://exep.jpl.nasa.gov/
Gravitational Wave CST Report	http://pcos.gsfc.nasa.gov/studies/gravitational-wave-mission.php
Inflation Probe Technology Roadmap	http://pcos.gsfc.nasa.gov/sags/ipsag/docs/IP_techdoc_v13All.pdf
NASA Online Directives Information System	http://nodis3.gsfc.nasa.gov/
Physics of the Cosmos Program	http://pcos.gsfc.nasa.gov/
ROSES-12 NASA Research Announcement	http://go.nasa.gov/ROSES12
Technology Readiness Levels	http://www.nasa.gov/topics/aeronautics/features/trl_demystified.html
UV/Visible Request for Information	http://cor.gsfc.nasa.gov/RFI2012
X-ray CST Report	http://pcos.gsfc.nasa.gov/studies/x-ray-mission.php
WFIRST SDT Report	http://wfirst.gsfc.nasa.gov/