National Aeronautics and Space Administration

NASA Astrophysics: Progress toward New Worlds, New Horizons

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

October 8, 2015

Astrophysics

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Science Mission Directorate

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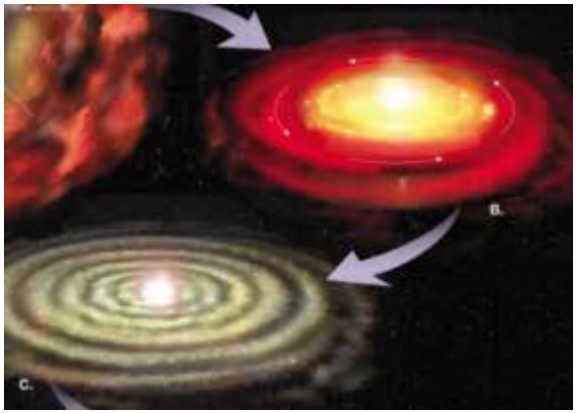
www.nasa.gov

Why Astrophysics?

Astrophysics is humankind's scientific endeavor to understand the universe and our place in it.

1. How did our universe begin and evolve?

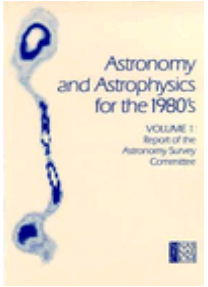


2. How did galaxies, stars, and planets come to be?

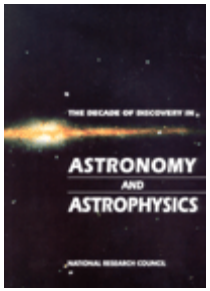
3. Are We Alone?

These national strategic drivers are enduring

1972



1982



1991

2001

2010

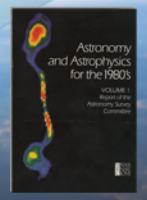
Summary

- The 2010 Decadal Survey recommended a coordinated program of research, technology development, ground-based facilities, and space-based missions to address the most compelling science questions.
- The budget environment does not allow the recommendations of the Decadal Survey to be implemented as written.
  - Choices have been made.
  - NASA Astrophysics has kept the community informed of our progress through Town Halls, Implementation Plan Updates, and Newsletters.
  - NASA Astrophysics obtains frequent community input via advisory committees (CAA, AAAC, APS) and community groups (e.g., PAGs, SAGs, CSTs, SDTs, SWGs, etc.).
- NASA Astrophysics is addressing all of the recommendations in the Decadal Survey. Substantial progress is being made toward Decadal Survey priorities.
  - The James Webb Space Telescope (JWST) remains on schedule and within budget for a launch in October 2018.
  - Preformulation for the Wide-Field Infrared Survey Telescope (WFIRST) using Astrophysics Focused Telescope Assets (AFTA) is well underway.
  - Explorer AOs are being issued every 2-3 years.
  - Highly leveraged partnerships with the European Space Agency (ESA) are advancing the science of LISA and IXO.
  - Investments in technology, suborbital investigations, core research, and other Decadal Survey priorities are yielding science in this decade and preparing for the next decade.

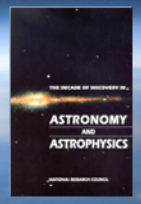
ASTROPHYSICS

Decadal Survey Missions

1972
Decadal Survey
Hubble



1982
Decadal Survey
Chandra



1991
Decadal Survey
Spitzer, SOFIA

2001
Decadal Survey
JWST

2010
Decadal Survey
WFIRST

Outline

Overview of NASA Astrophysics

- Strategic and Management Processes
- Changes in the Mission Suite since the 2010 Decadal Survey
- Budget Summary: past, present, planning
- Near-term milestones

NASA's Response to the 2010 Decadal Survey

- Overall Strategy
- Progress toward Decadal Survey Priorities
- Response to Decadal Survey Recommendations
  - DSIAC; Balanced Program
  - Large Activity: WFIRST; Explorers Program; LISA; IXO
  - Medium Activity: New Worlds Technology; Inflation Probe Technology
  - Small Activity: SPICA; Core Research Programs; Astrophysics Theory Program; Future UV-Optical Space Capability; Intermediate Technology Development; Laboratory Astrophysics; Suborbital Program
  - International Collaboration; Societal Benefits

Preparing for the 2020 Decadal Survey

- Large Mission Concept Studies

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

- Jaqueline N. Hewitt, MIT (Chair) [NWNH – PPP]
- Adam S. Burrows, Princeton [Implement]
- Neil J. Cornish, Montana State [NWNH – SFP]
- Andrew W. Howard, U. Hawaii-Manoa
- Bruce Macintosh, Stanford [CAA, NWNH – PPP]
- Richard F. Mushotzky, U. Maryland [NWNH – SFP]
- Angela V. Olinto, U. Chicago [NWNH – PPP]
- Steven M. Ritz, UCSC [CAA, NWNH, Implement]
- Alexey Vikhlinin, Harvard-Smithsonian CfA [CAA]
- David H. Weinberg, Ohio State [NWNH – SFP]
- Rainer Weiss, MIT
- Eric M. Wilcots, U. Wisconsin [CAA, NWNH – SFP]
- Edward L. Wright, UCLA
- A. Thomas Young, Lockheed Martin, retired [CAA, NWNH, Implement, AFTA, LLBP]

CAA - Committee on Astronomy and Astrophysics
NWNH – New Worlds, New Horizons in Astronomy and Astrophysics (Blandford, 2010)
Implement – Implementing Recommendations from the New Worlds, New Horizons Decadal Survey (Burrows & Kennel, 2011)
Euclid – Assessment of a Plan for U.S. Participation in Euclid (Spergel, 2012)
AFTA – Evaluation of the Implementation of WFIRST/AFTA in the Context of New Worlds, New Horizons in Astronomy and Astrophysics (Harrison, 2014)
OIR – Optimizing the U.S. Ground-Based Optical and Infrared Astronomy System (Elmegreen, 2015)
LLBP – The Space Science Decadal Surveys: Lessons Learned and Best Practices (Dressler, 2015)

Questions from the Mid-Term Committee

1	What do you see as significant scientific discoveries and technical advances impacting space-based astrophysics since the publication of the decadal survey?	N/A
2	How does NASA's current budget and outlook for astronomy and astrophysics compare to what was given to the decadal survey committee?	Slide 26
3	How have NASA's programs addressed the priorities outlined in the decadal survey, and what is NASA's plan to address the priorities in the future?	Slides 35-36 Slides 37-91
4	What is your degree of confidence in the JWST budget and schedule and how might overruns affect NASA's ability to respond to the NWNH recommendations?	Oral
5	What is the current cost estimate for WFIRST-AFTA and what will be NASA's approach to managing cost overruns should they occur?	Slide 45
6	If B-mode polarization in the CMB produced in the epoch of reionization is detected, how does NASA plan to respond?	Oral
7	How has NASA responded to the recommendations from the NRC "Implementation" report (2010), the "Euclid" report (2012), and the "WFIRST-AFTA" report (2014)? What is the rationale for the Euclid budget level?	Slides 40-50
8	What are the plan, budget, and schedule for US involvement in Athena (if not covered in #3 above)?	Slides 57-59
9	What are the plan, budget, and schedule for US involvement in e-LISA (if not covered in #3 above)?	Slides 54-56
10	Have the funding levels for the Astronomy and Physics Research and Analysis remained the same or increased? Please provide separate information on research and analysis and on technology development.	Slides 67-70 Slides 76-79
11	Proposal success rates in research and analysis have declined sharply, and there is evidence this is having significant impact on research productivity (e.g., recent AAAC report). How does NASA plan to respond to this development?	Oral
12	What plans has NASA made to prepare for the next decadal survey? What is NASA's anticipated timeline for the next decadal survey? Which aspects of NWNH have been the most useful, and which have not been useful?	Slides 92-98

National Aeronautics and Space Administration

Overview of NASA Astrophysics: Strategy, Missions, and Budget

www.nasa.gov

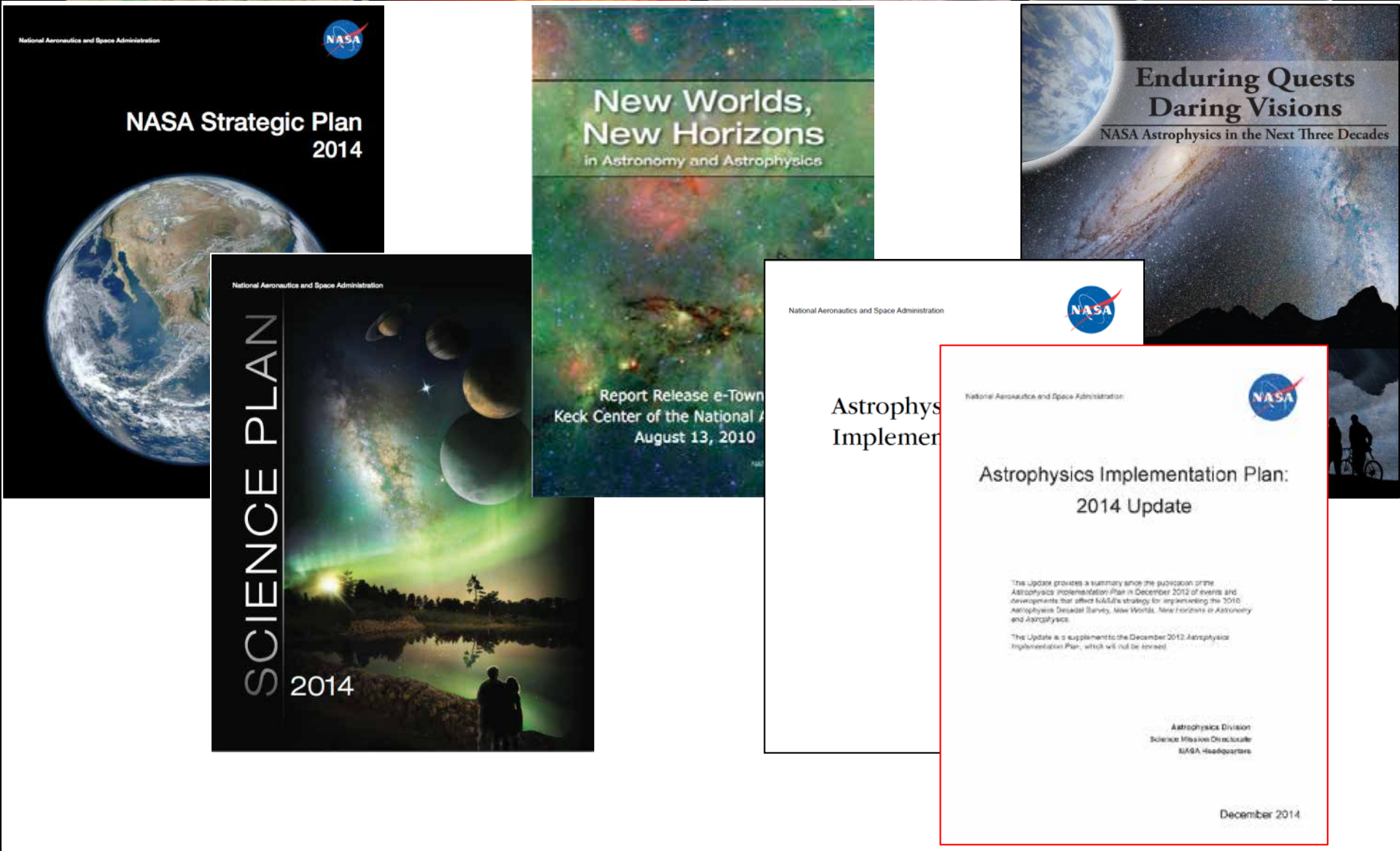
NASA Astrophysics Division Overview

Strategic Objective: Discover how the universe works, explore how it began and evolved, and search for life on planets around other stars.

Major activities:

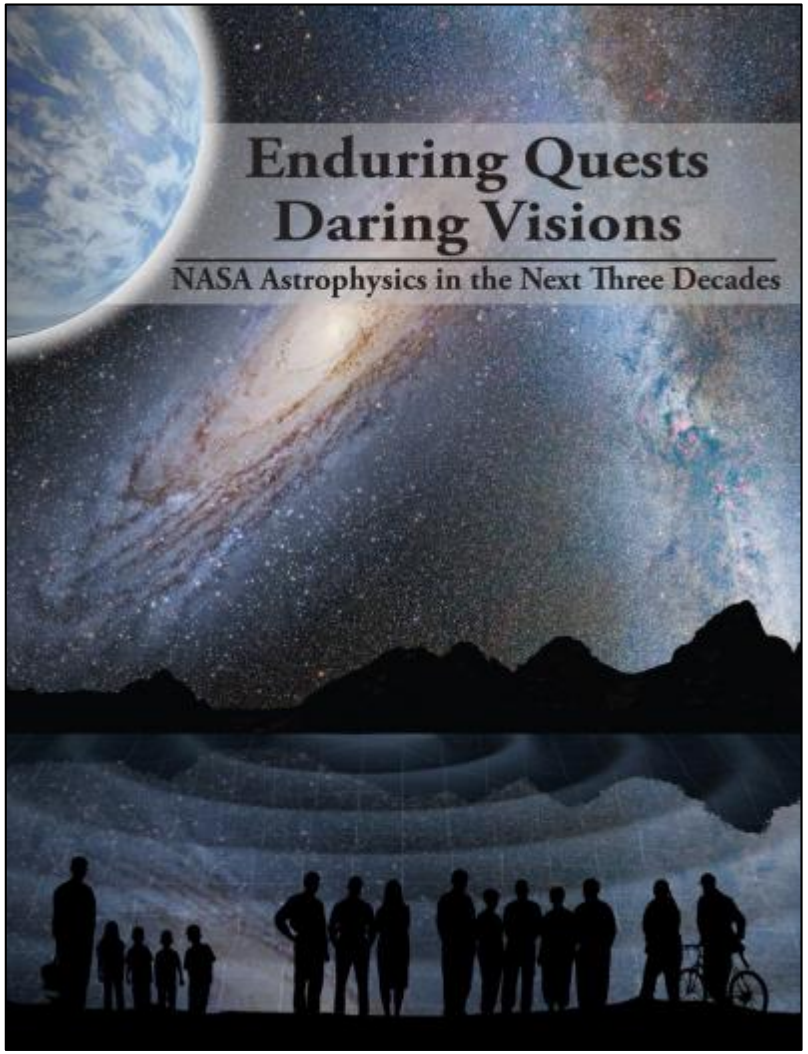
- Building, launching, and operating space observatories, many with international partners.
- Developing technologies to enable future observatories.
  - Basic research as well as focused technology development.
- Conducting and sponsoring cutting-edge research; supporting research, enabling technology, and workforce development.
  - Suborbital-class projects using scientific balloons, sounding rockets, International Space Station, and other platforms.
  - Basic and applied technology development.
  - Analysis of data from NASA and international partner space observatories.
  - Theoretical and computational investigations.
  - Laboratory experiments in support of astrophysical understanding.
  - Fellowships and other hands-on experience.

Astrophysics Driving Documents

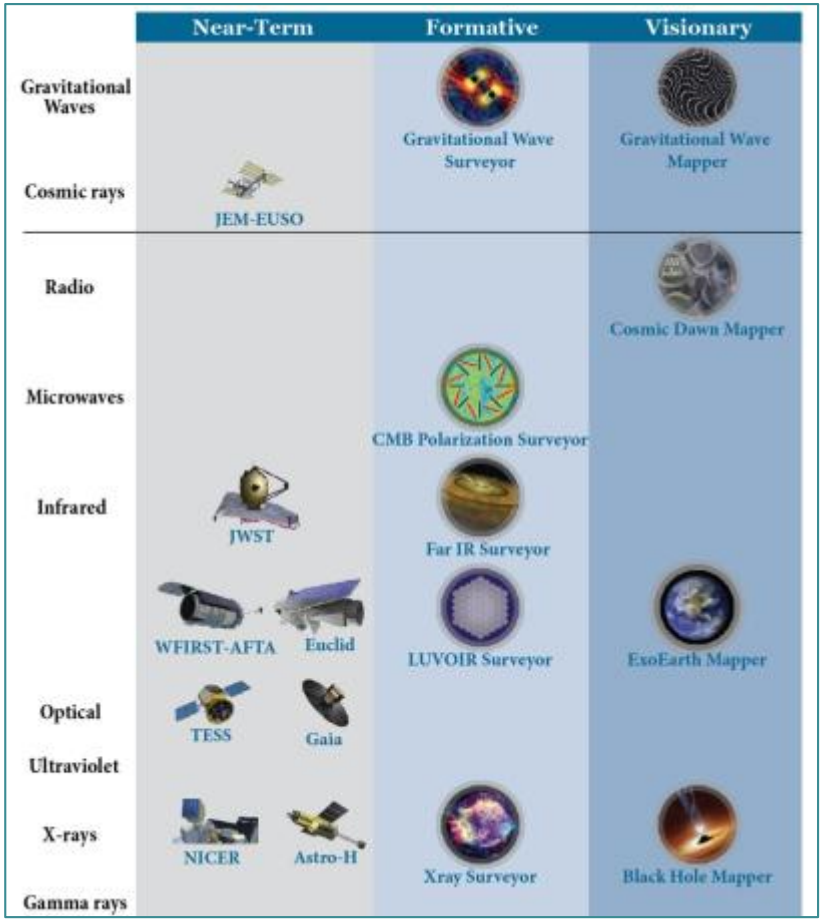


http://science.nasa.gov/astrophysics/documents

Enduring Quests, Daring Visions



- A 30 year vision to address the enduring questions:
  - Are we alone?
  - How did we get here?
  - How does the universe work?



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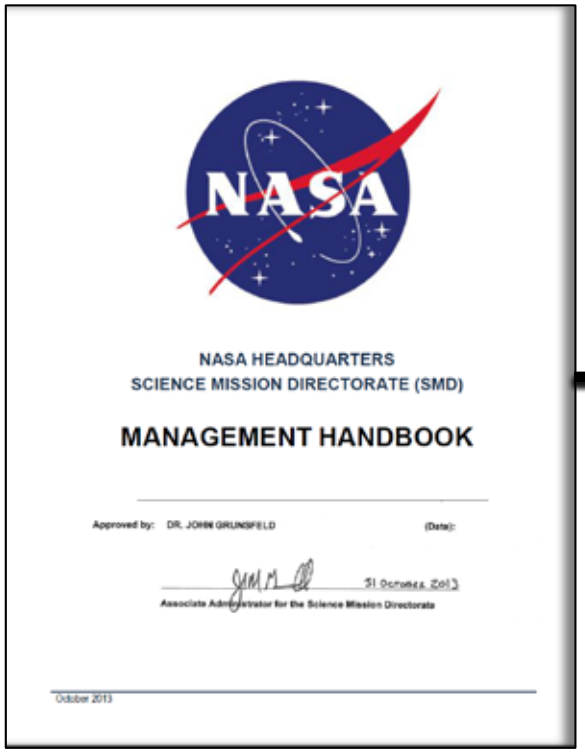
SMD Management Practices


NASA HEADQUARTERS
SCIENCE MISSION DIRECTORATE (SMD)

MANAGEMENT HANDBOOK

Approved by: DR. JOHN GRUNSFELD (Date):

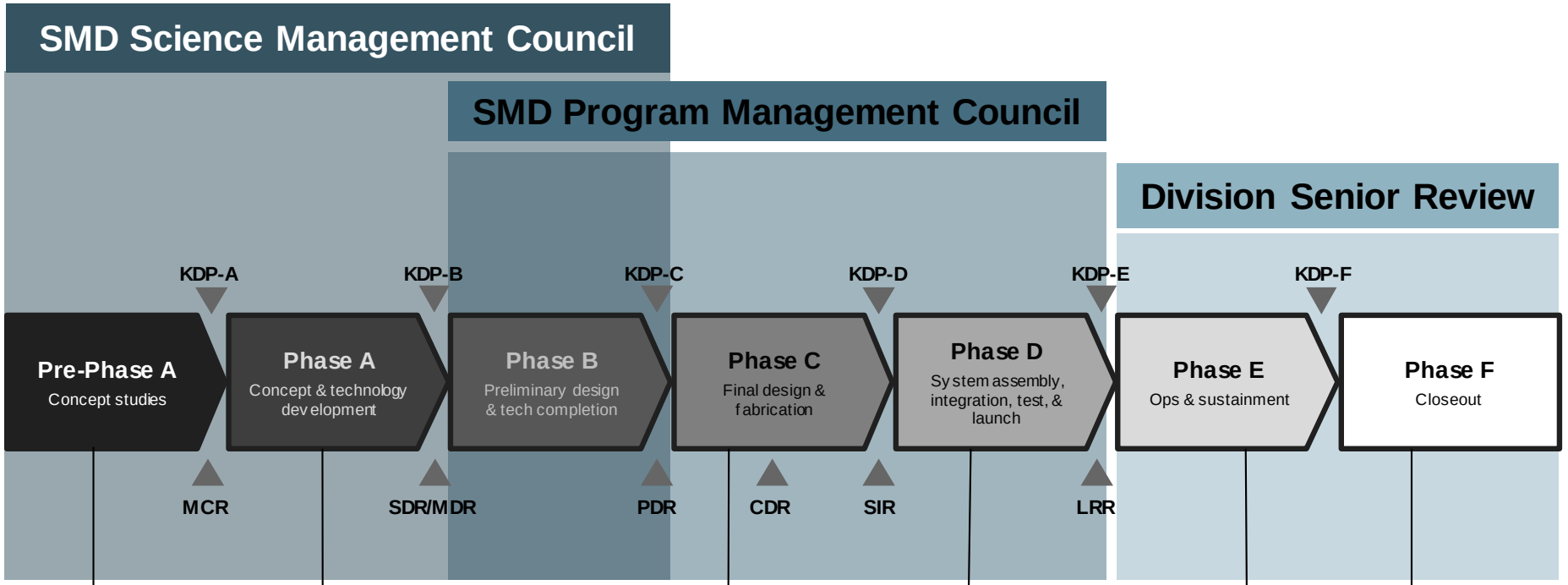
31 Oct 2013

Associate Administrator for the Science Mission Directorate

October 2013

- Flight Missions
- Research & Analysis
- Technology Development
- Senior Reviews
- AO Solicitations
- STEM Outreach
- Comms & Public Engagement

SMD Decisional Process for Missions



WFIRST-AFTA
Athena

SMEX x 3
MO x 2

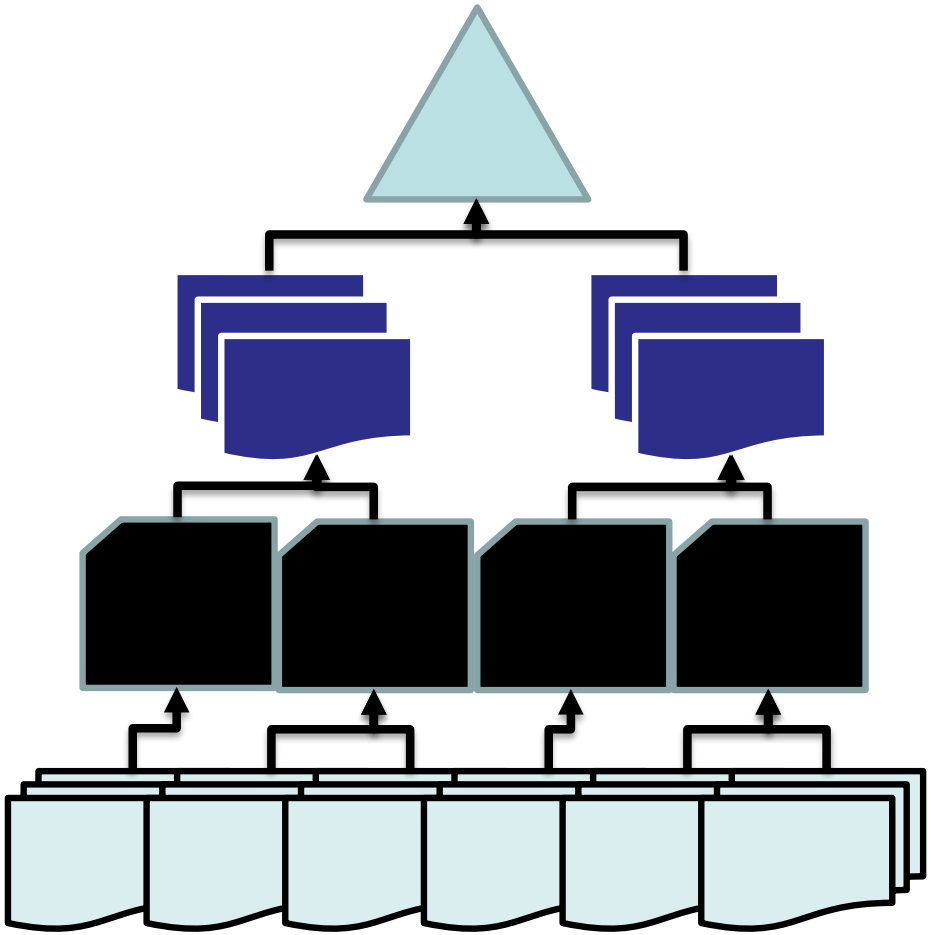
NICER
TESS
Webb
Euclid

LISA Pathfinder
ASTRO-H

Herschel
Kepler/prime
Planck
Suzaku

Chandra, Fermi, Hubble, Kepler/K2, NuSTAR, SOFIA, Spitzer, Swift, XMM-Newton

SMD Research and Analysis Management



Division Research Program

Managed by Research Director (Division Director or Division Associate Director for Research)

Discipline Areas (one of more program elements)

Managed by Research Manager, supported by Portfolio Managers and Discipline Chiefs

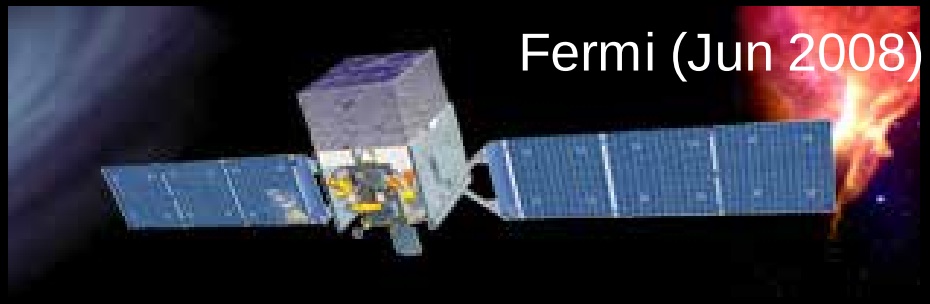
Program Elements (commonly solicited and managed investigations)

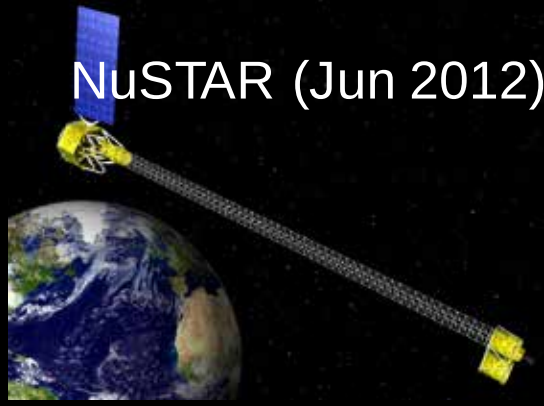
Managed by Program Officer

Investigations (selected proposals)

Managed by Principal Investigator

Astrophysics Missions Launched Recently

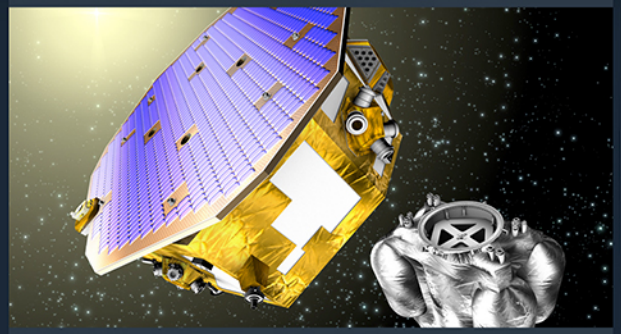




Astrophysics Missions in Development

LISA Pathfinder
11/2015

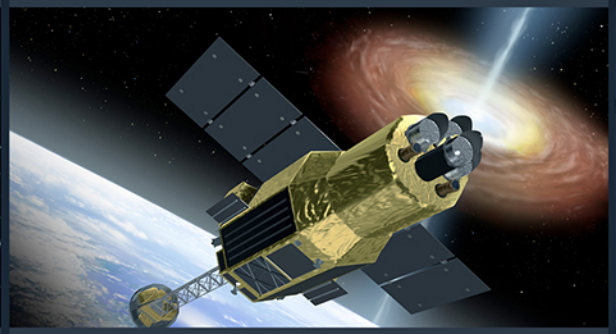
ESA-led Mission



NASA supplied the ST7/Disturbance Reduction System (DRS)

ASTRO-H
11/2015

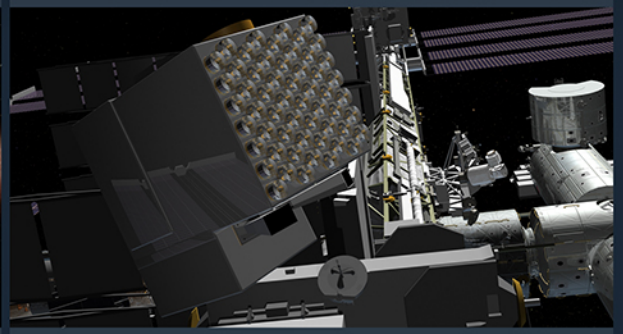
JAXA-led Mission



NASA supplied the Soft X-ray Spectrometer (SXS) instrument

NICER
8/2016

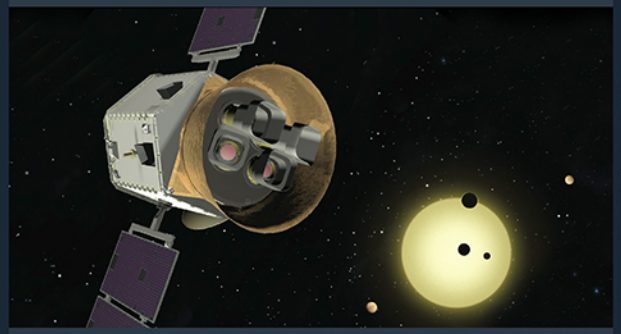
NASA Mission



Neutron Star Interior Composition Explorer

TESS
8/2017

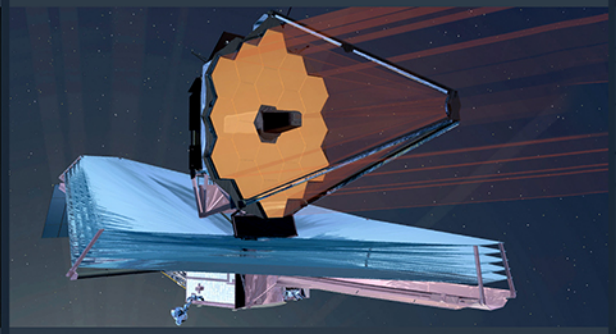
NASA Mission



Transiting Exoplanet Survey Satellite

JWST
10/2018

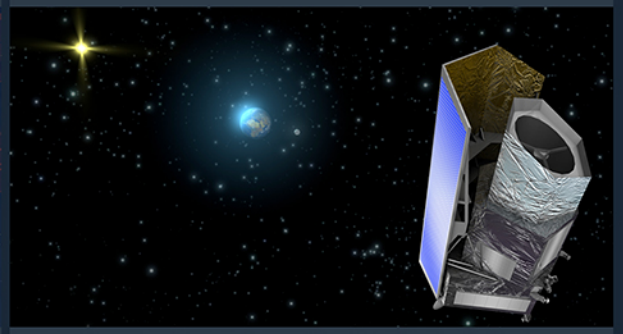
NASA Mission



James Webb Space Telescope

Euclid
2020

ESA-led Mission



NASA is supplying the NISP Sensor Chip System (SCS)

Astrophysics Missions in Pre-Formulation

SMEX / MO – 2019/2020
see next chart for list of selections

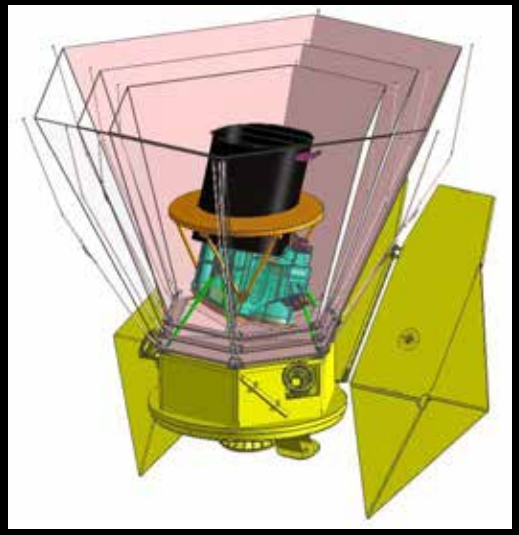
MIDEX / MO – 2022/2023

WFIRST-AFTA – NLT 2026

Athena – 2028

All launch dates notional

Astrophysics SMEX/MO Missions in Formulation



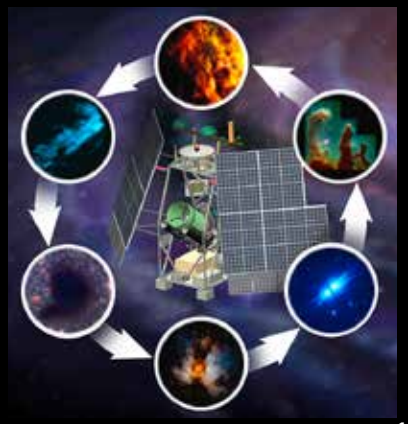
SPHEREx
PI: J. Bock, Caltech
An All-Sky Near-IR Spectral Survey

PRAXyS
PI: K. Jahoda, GSFC
Polarimeter for Relativistic Astrophysical X-ray Sources

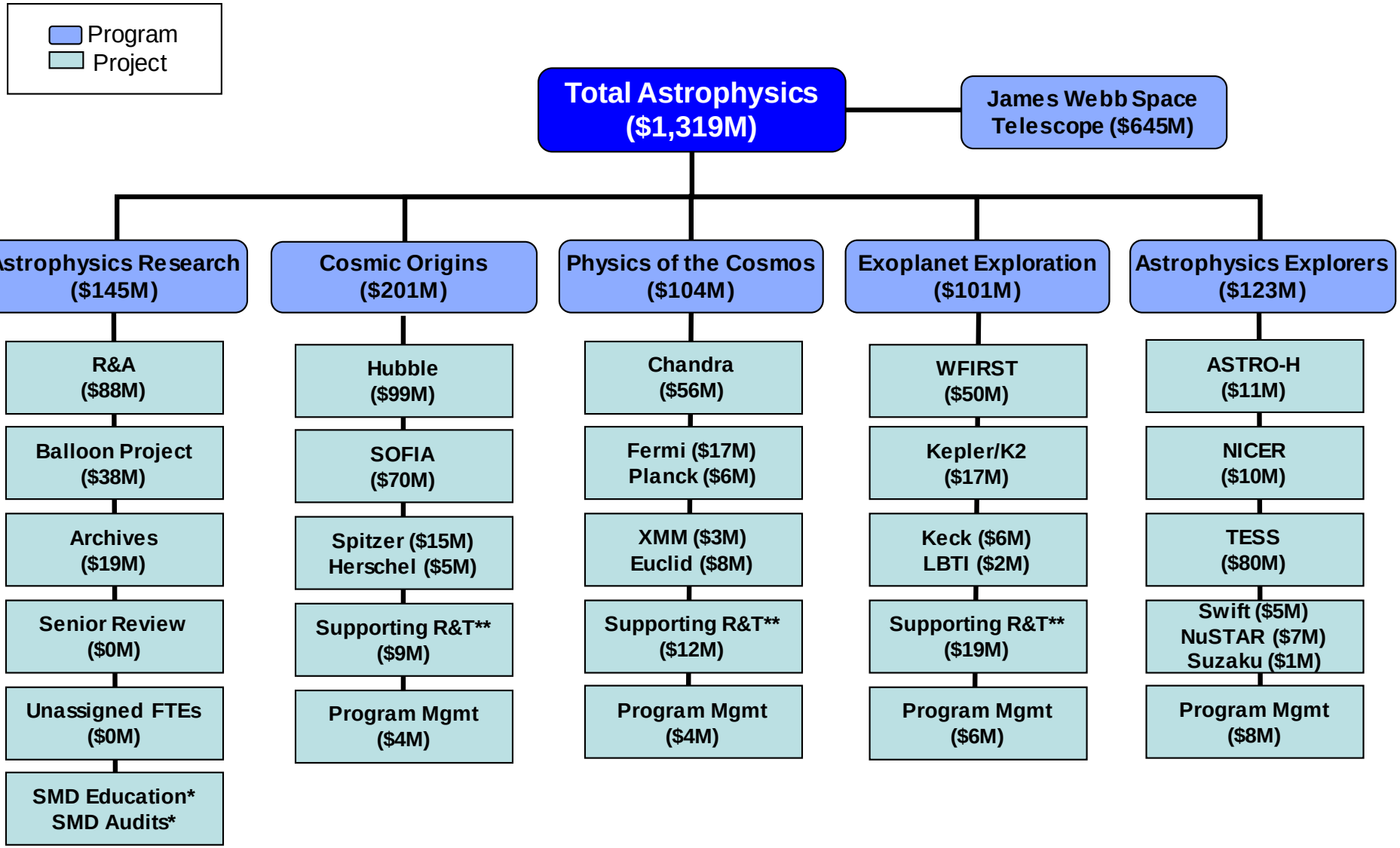
IXPE
PI: M. Weisskopf, MSFC
Imaging X-ray Polarimetry Explorer

PI: A. Lee, UC Berkeley
US Participation in JAXA's LiteBIRD CMB Polarization Survey

PI: C. Walker, U. Arizona
GUSTO: Gal/Xgal U/LDB Spectroscopic - Stratospheric Terahertz Observatory



Astrophysics Programs - FY15 Appropriations



* subtracted from total

** SR&T includes SAT, Fellows, ST-7/LPF, Athena, EPDS/NN-EXPLORE, NExScI, NAI, mission studies

FY16 President's Budget Request

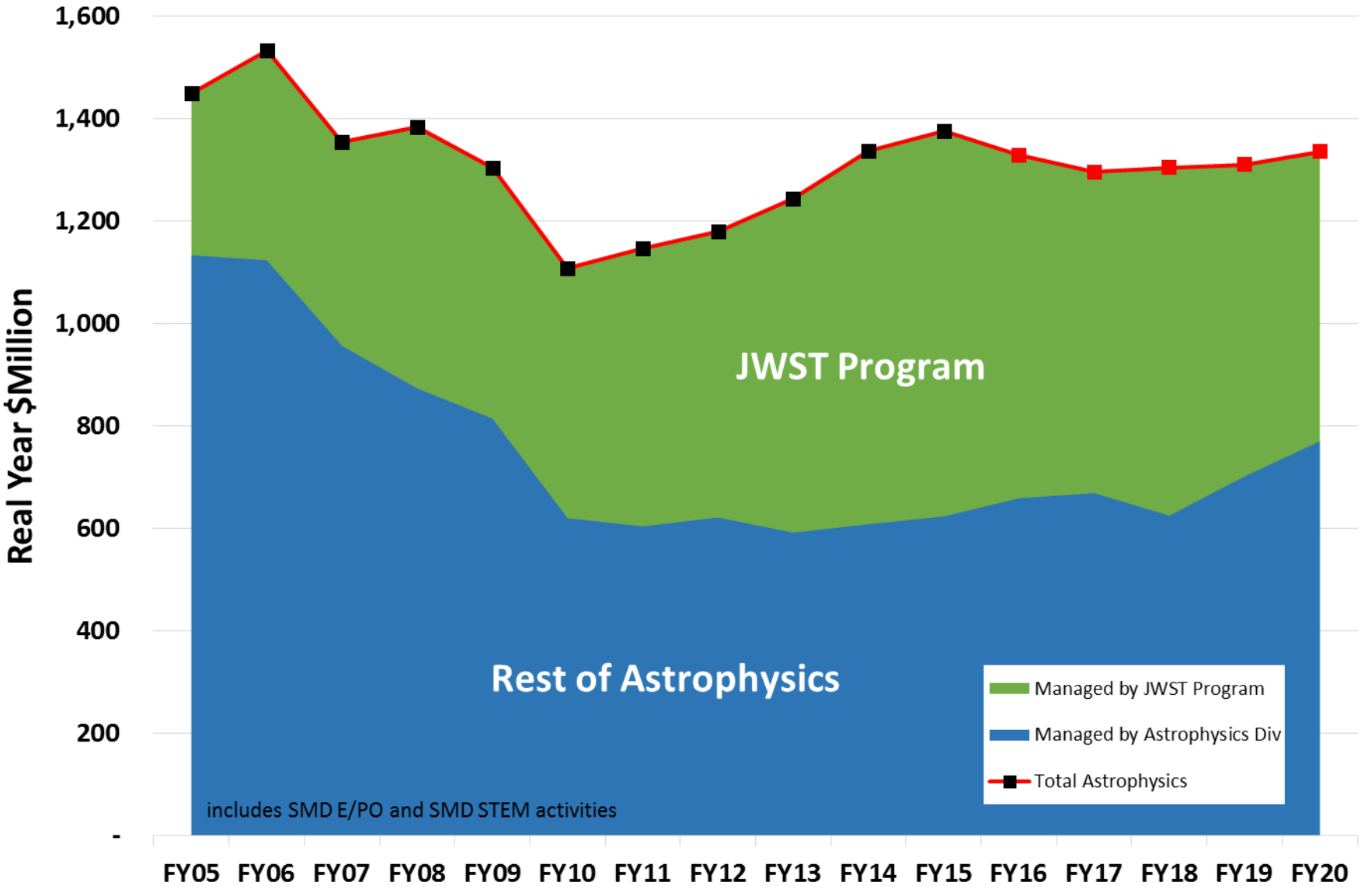
Outyears are notional planning from FY16 President's budget request

($M)	2014	2015	2016	2017	2018	2019	2020
Astrophysics*	$678	$685	$689	$707	$750	$986	$1,118
JWST	$658	$645	$620	$569	$535	$305	$198

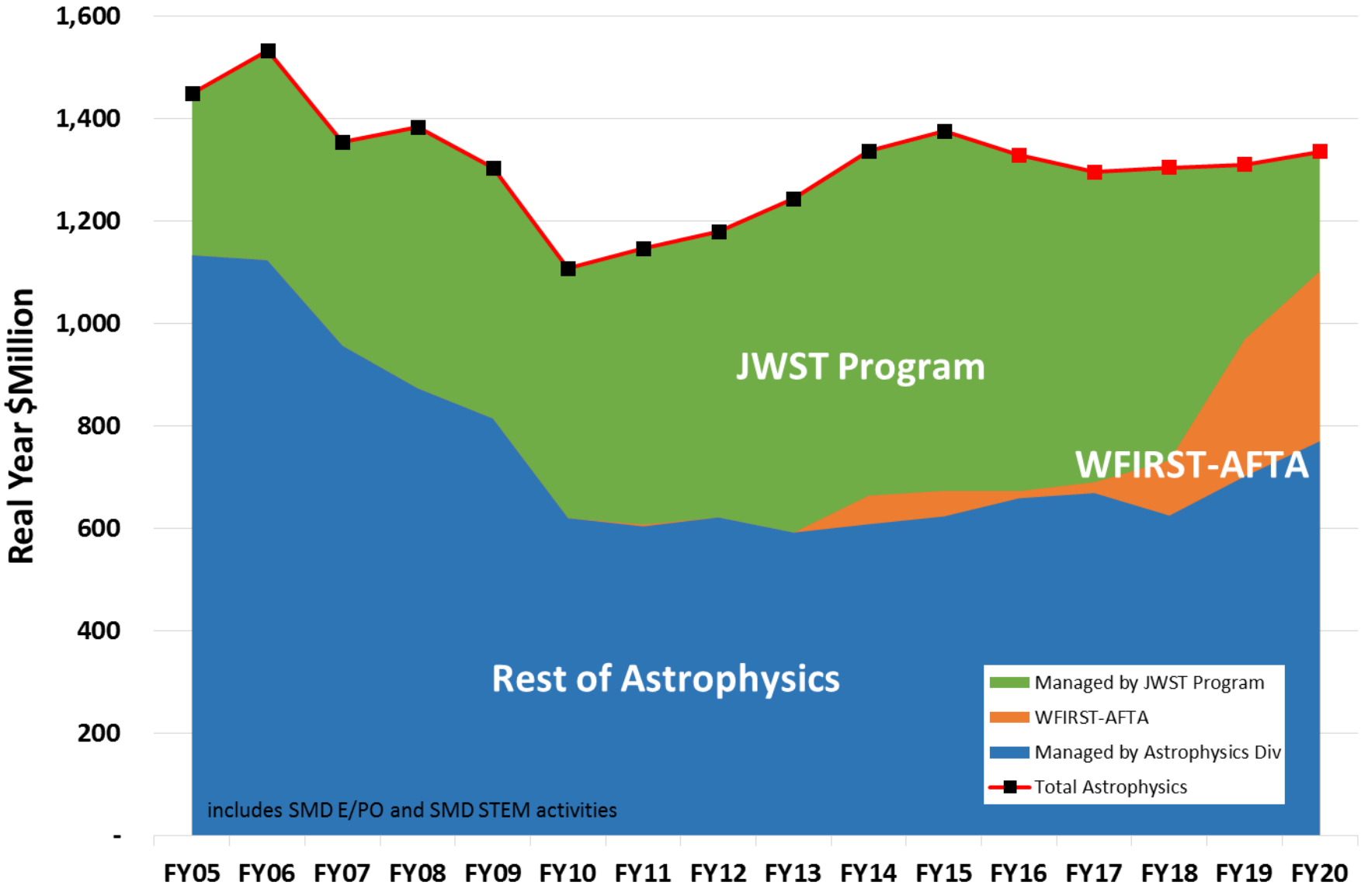
- Continues preformulation of WFIRST-AFTA as the "Astrophysics Decadal Strategic Mission."
- Grows Astrophysics Research and Analysis (including Astrophysics Data Analysis Program) from ~$80M/yr to ~$90M/yr in FY16.
- Supports completion of missions under development, including LPF/ST7, ASTRO-H, NICER, TESS, and Euclid.
- Enables selection of a SMEX mission and an Explorer Mission of Opportunity from the 2014 AO, and notional release of a MIDEX AO in late CY16/early FY17.
- Provides full funding for SOFIA operations and places SOFIA into the 2016 Astrophysics Senior Review. (Subsequently SOFIA was deferred to the 2018 Senior Review.)
- Plans for the 2016 Astrophysics Senior Review.
- Plans for continued Hubble operations through FY20 providing overlap with JWST.
- Plans for mission concept studies and technology development (within the three Program SR&T budgets) leading up to the 2020 Decadal Survey.

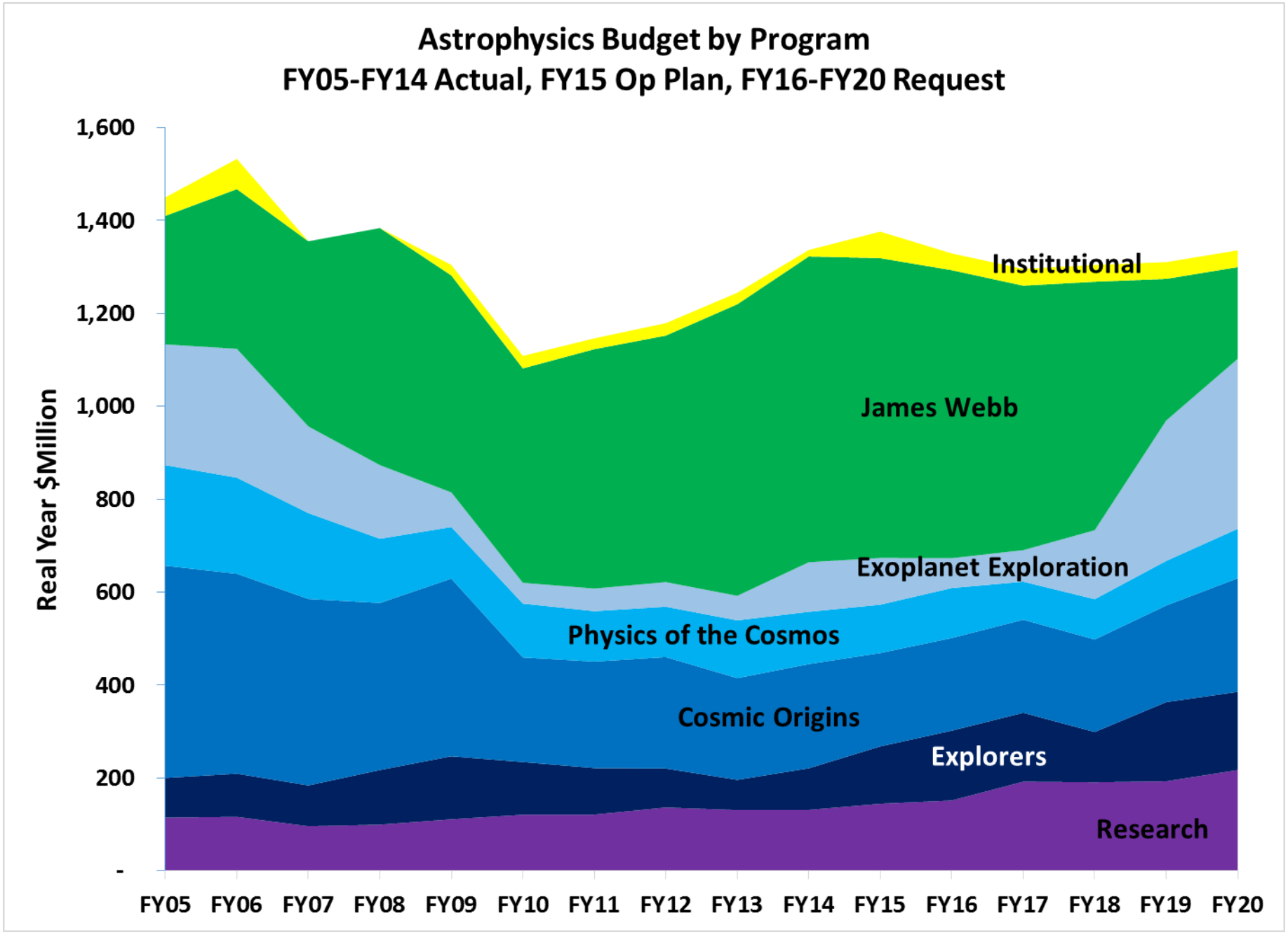
* Excludes "SMD STEM Activities" in all years.

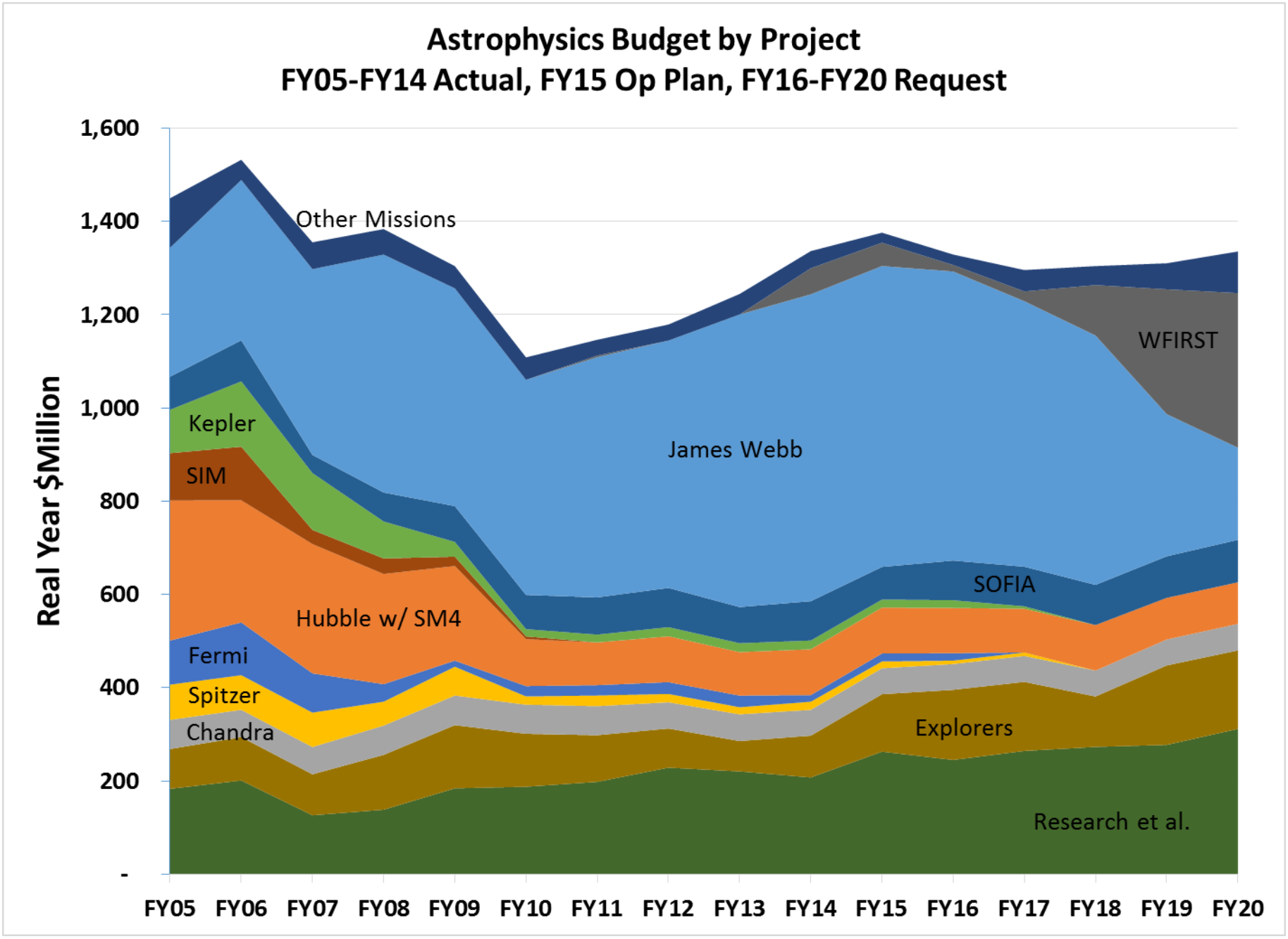
Astrophysics Budget by Project
FY05-FY14 Actual, FY15 Op Plan, FY16-FY20 Request



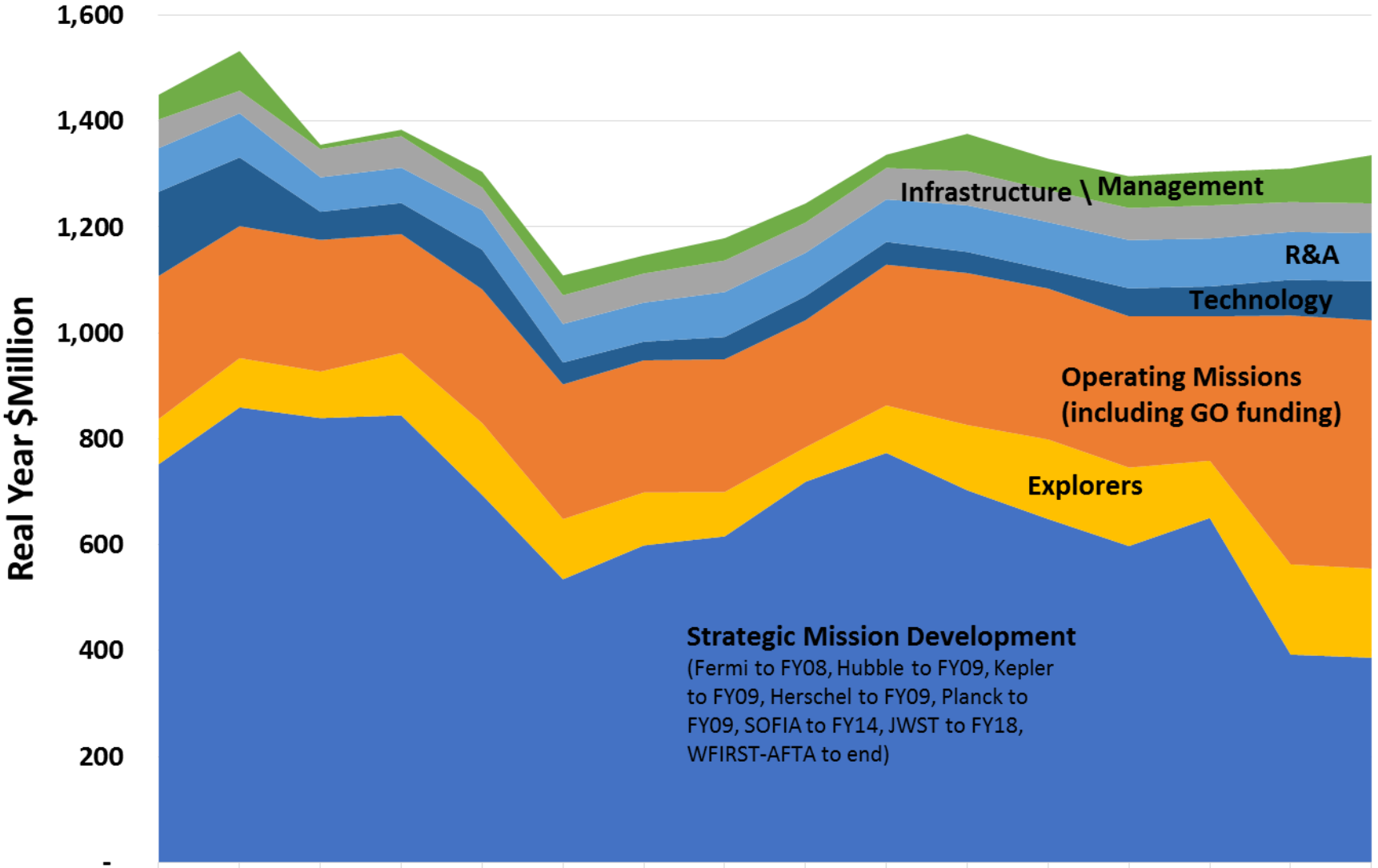
Astrophysics Budget by Project
FY05-FY14 Actual, FY15 Op Plan, FY16-FY20 Request



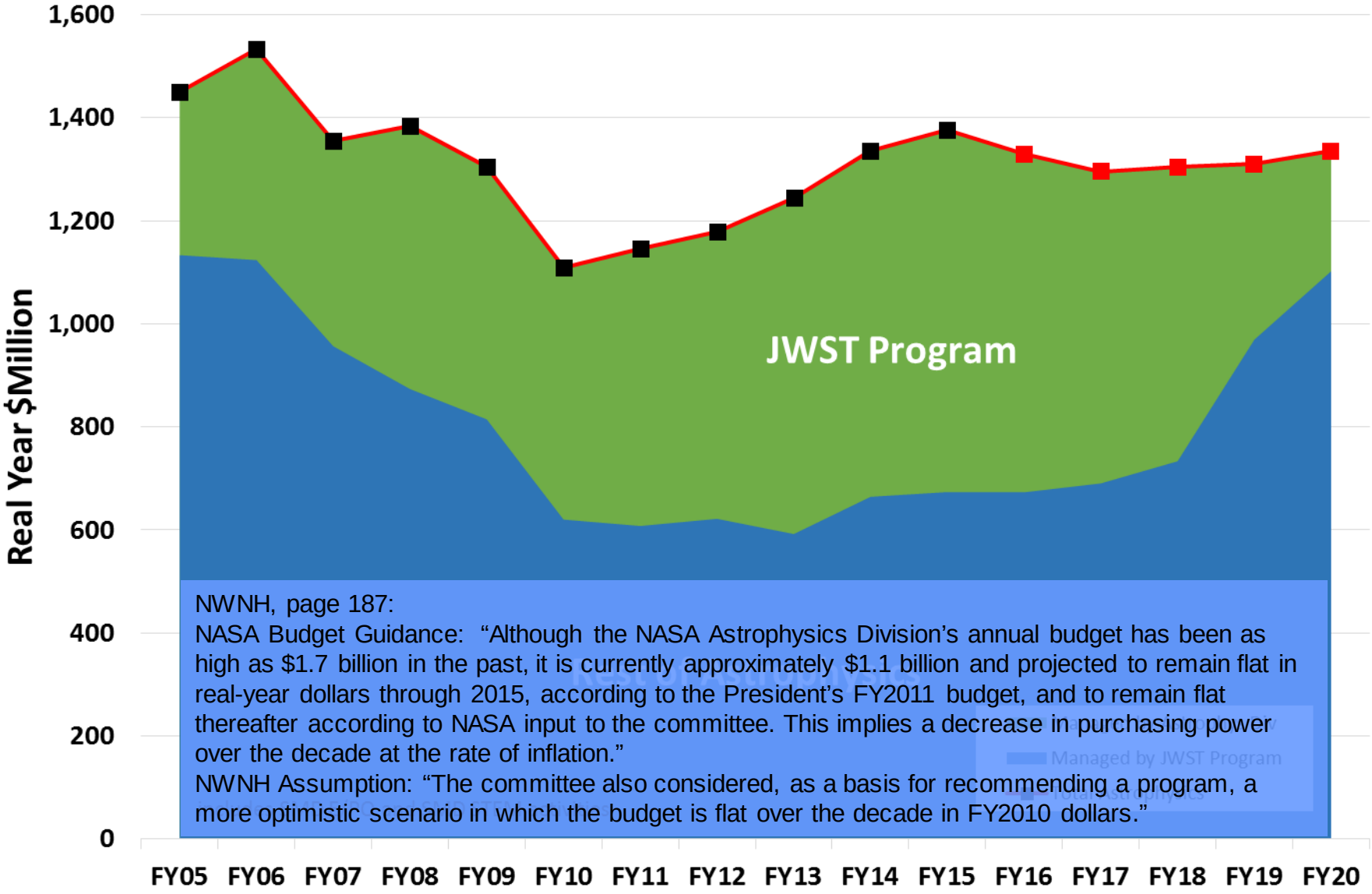

Astrophysics Budget by Program
FY05-FY14 Actual, FY15 Op Plan, FY16-FY20 Request
Real Year $Million
1,600
1,400
1,200
1,000
800
600
400
200
-
Institutional
James Webb
Exoplanet Exploration
Physics of the Cosmos
Cosmic Origins
Explorers
Research
FY05
FY06
FY07
FY08
FY09
FY10
FY11
FY12
FY13
FY14
FY15
FY16
FY17
FY18
FY19
FY20


Astrophysics Budget by Project
FY05-FY14 Actual, FY15 Op Plan, FY16-FY20 Request
Real Year $Million
1,600
1,400
1,200
1,000
800
600
400
200
-
Other Missions
Kepler
SIM
Hubble w/ SM4
Fermi
Spitzer
Chandra
James Webb
WFIRST
SOFIA
Explorers
Research et al.
FY05
FY06
FY07
FY08
FY09
FY10
FY11
FY12
FY13
FY14
FY15
FY16
FY17
FY18
FY19
FY20

Astrophysics Budget by Function
FY05-FY14 Actual, FY15 Op Plan, FY16-FY20 Request



Astrophysics Budget by Project
FY05-FY14 Actual, FY15 Op Plan, FY16-FY20 Request



NWNH, page 187:
NASA Budget Guidance: "Although the NASA Astrophysics Division's annual budget has been as high as $1.7 billion in the past, it is currently approximately $1.1 billion and projected to remain flat in real-year dollars through 2015, according to the President's FY2011 budget, and to remain flat thereafter according to NASA input to the committee. This implies a decrease in purchasing power over the decade at the rate of inflation."
NWNH Assumption: "The committee also considered, as a basis for recommending a program, a more optimistic scenario in which the budget is flat over the decade in FY2010 dollars."

FY16 Congressional Appropriation Markups

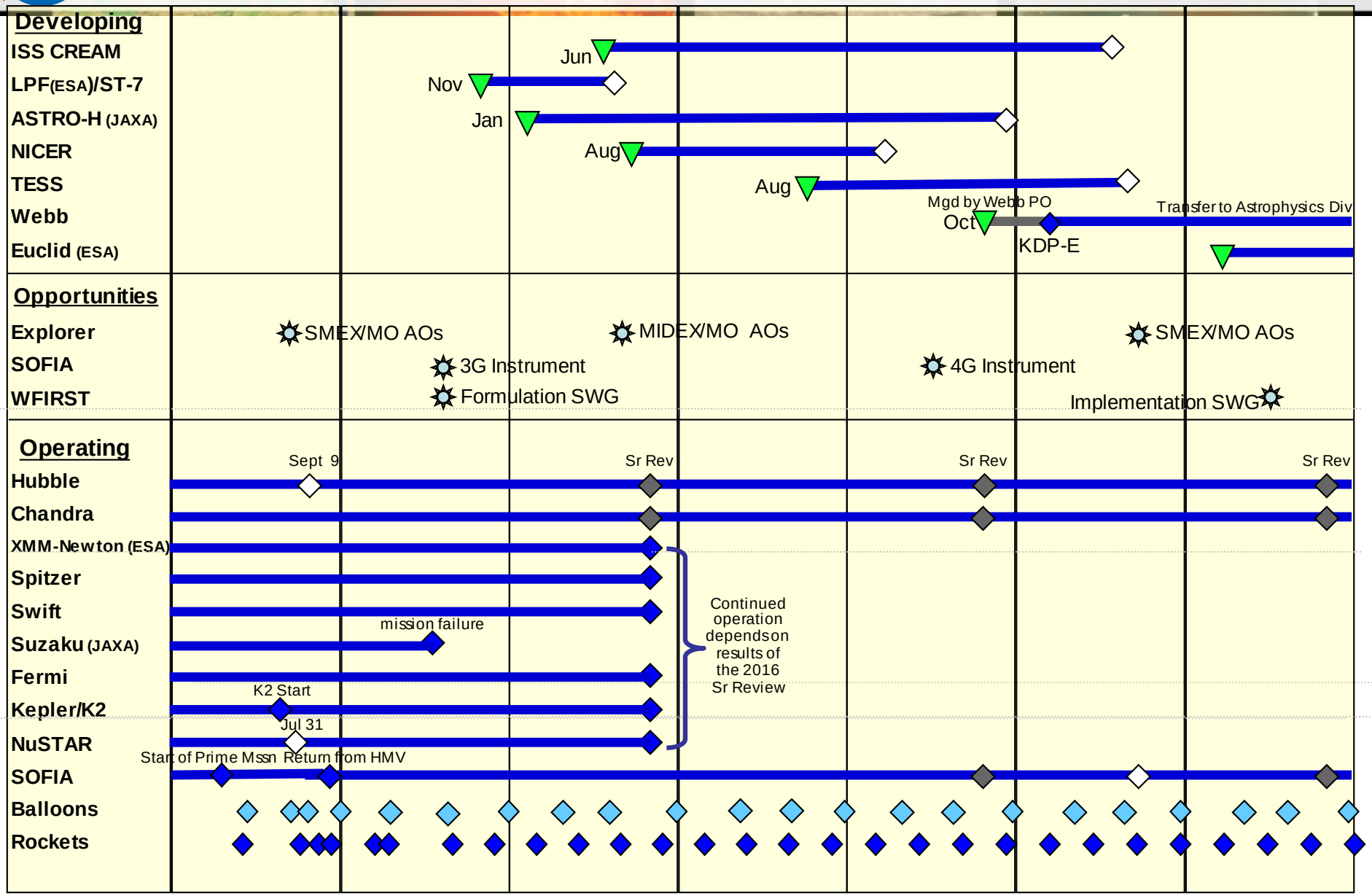
$M	FY15 Approp	FY16 Pres Request	FY16 House Budget	Delta House vs Request	FY16 Senate Budget	Delta Senate vs Request
Status			Appropriation passed full House		Appropriation sent from Committee to Senate	
NASA	18,010.2	18,529.1	18,529.1	0	18,289.5	-239.6
SMD	5,244.7	5,288.6	5,237.5	-51.1	5,295.0	+6.4
JWST	645.4	620.0	620.0	0	620.0	+0
Astrophysics w/ SMD Education	726.8	709.1	735.6	+26.5		
Astrophysics w/out SMD Ed	684.8	689.1			730.6	+41.5
WFIRST	50.0	14.0	49.8	+35.8	90.0	+76.0
Hubble	98.6	97.1			98.3	+1.2
SOFIA	70.0	85.2			85.2	+0
Rest of Astrophysics	634.8	675.1	653.8	-21.3	653.8	-35.7
SMD Education	42.0	20.0	32.0	+12.0	42.0	+22.0

FY16 Congressional Appropriation Markups

Astrophysics Project	House Language (paraphrased)	Senate Language (paraphrased)
All	Follow the Decadal Survey	Follow the Decadal Survey
JWST	Do not overrun	Do not overrun
WFIRST	Include coronagraph; accelerate exoplanet program	Accelerate formulation start, with goal of KDP-A by January 15, 2016
Hubble		Hubble is wonderful
SOFIA	Do not put SOFIA in 2016 Senior Review; do not terminate SOFIA	Any SOFIA participation in 2016 Senior Review is only for practice
Explorers		Increase AO frequency to at least every 3 years with goal of every 2 years
Kepler		Kepler has revolutionized the pace of planet finding
SMD Education	Reallocate funds among Divisions	APD should administer SMD-wide education activities

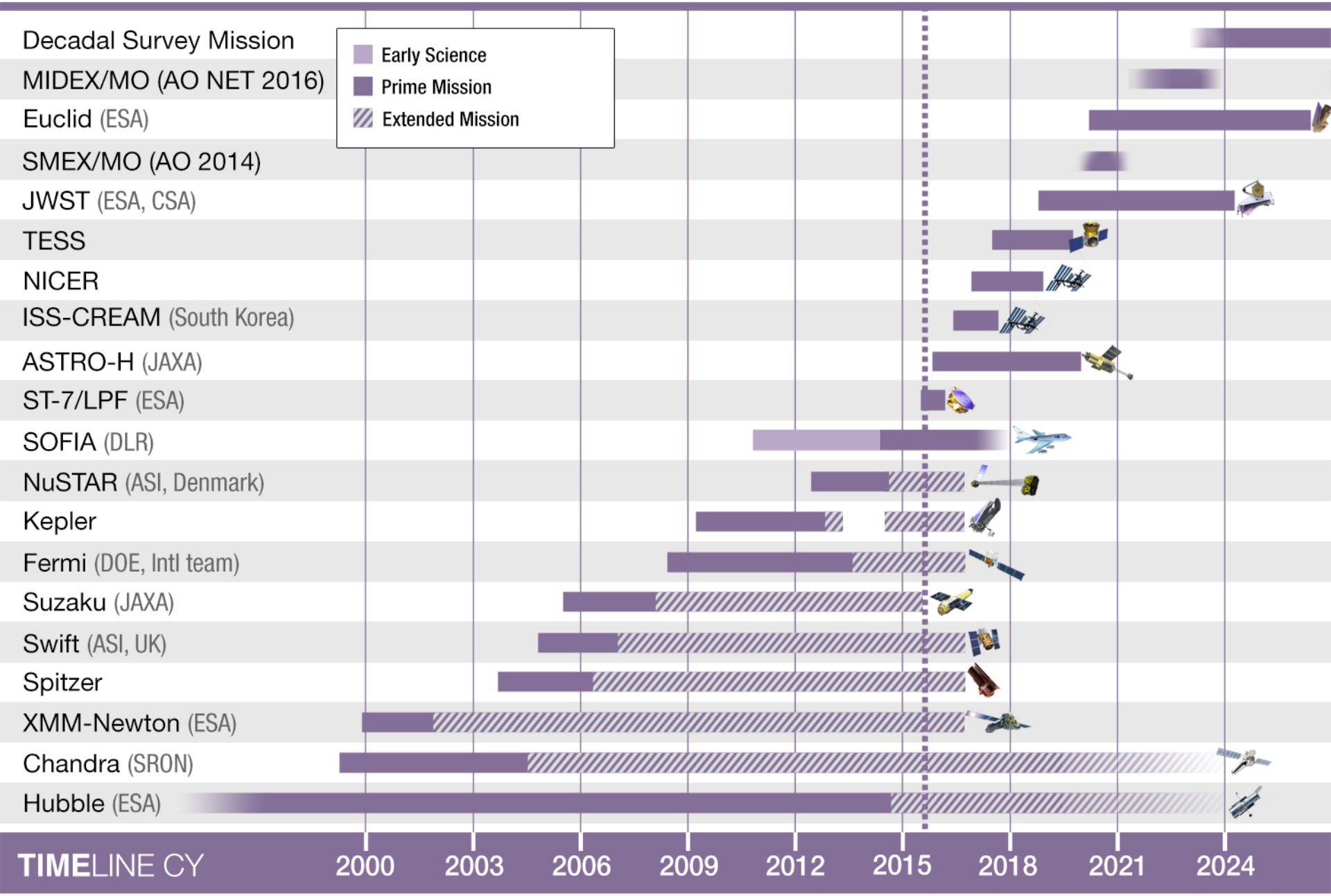
Astrophysics Science Mission Events

Last updated: August 29, 2015



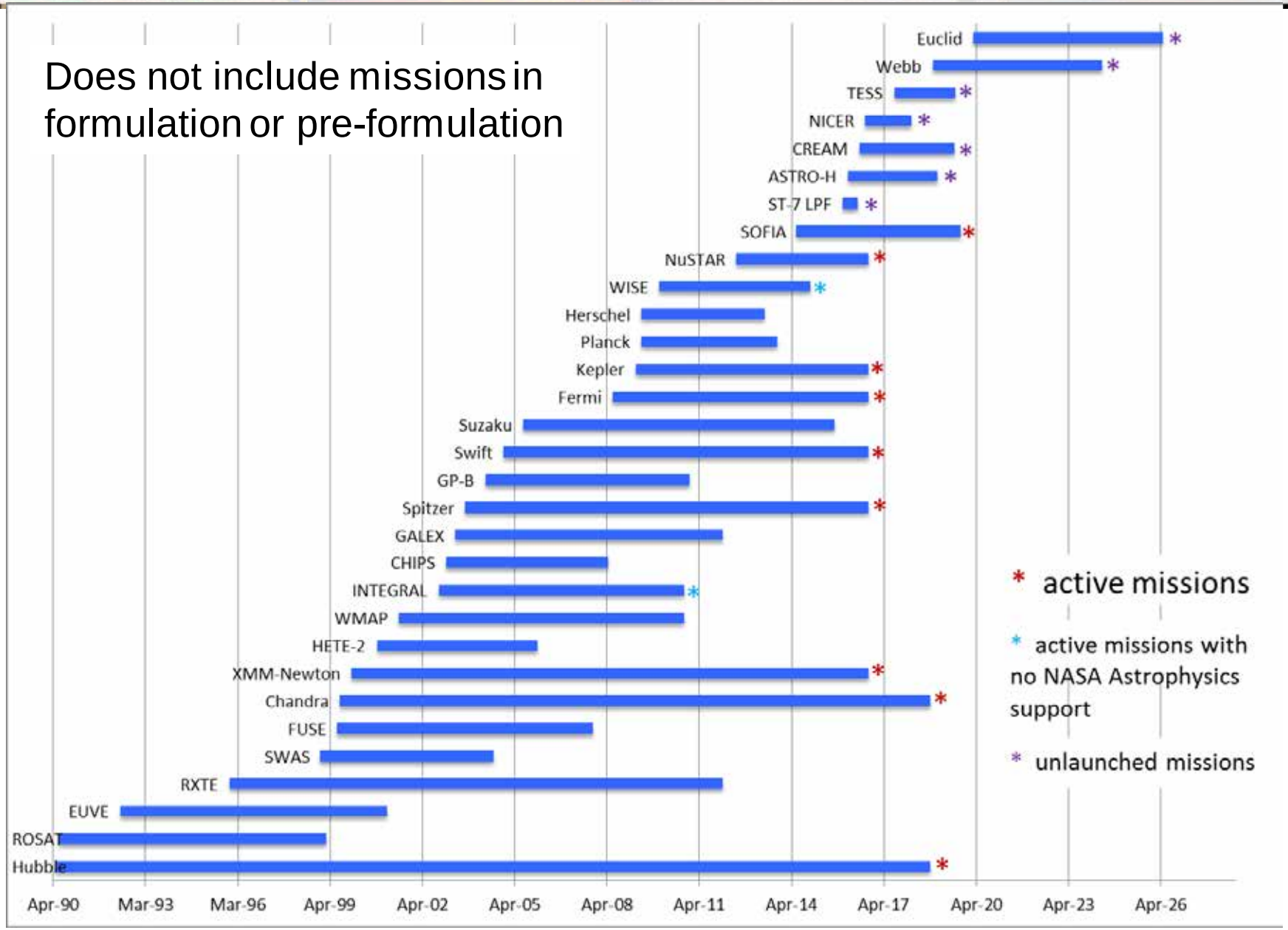
Launch Date (mission 'working to' date) **Event Date** **End of Prime Mission** **Balloon Campaigns** **AO Release** (future is notional)

Astrophysics Timeline



Dates beyond 2016 are contingent upon the results of the 2016 Senior Review

Astrophysics Mission Timeline



National Aeronautics and Space Administration

NASA's Response to the 2010 Decadal Survey in Astronomy and Astrophysics

www.nasa.gov

Overall Strategy

- Complete JWST, within budget, for launch in October 2018
- Highest priority is starting a new mission to follow JWST
  - Must be responsive to NWNH
  - On track to start WFIRST-AFTA
- Driver for all planning is addressing NWNH priorities and recommendations within the available funding
  - All recommendations of NWNH are being addressed in some way
  - Many recommendations are not being addressed exactly as in NWNH
  - Also responsive to subsequent NRC studies (Implementing NWNH, Participating in Euclid, Assessing WFIRST-AFTA)
- Coordination and collaboration across organizational boundaries
  - International (ESA, JAXA, CSA, CNES, ASI, DLR, etc.), Interagency (NSF, DOE, NRO), Interdirectorate (HEOMD, STMD, OEd), Interdivision (PSD, ESD, HPD)
- Clear and frequent communication to the community regarding NASA's progress and plans
  - AAS Town Halls, continuous reporting to CAA/AAAC/APS, biennial publication of Astrophysics Implementation Plan and White Papers, use of Program Analysis Groups (PAGs), use of community based study and review teams (SAGs, CSTs, SDTs, STDTs, SWGs, etc.)

Decadal Survey Recommendations

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Progress Toward Decadal Survey Priorities

The NASA FY15 Appropriation, the President's FY16 Budget Request, and the notional out year budget planning guidance in the President's FY16 Budget Request, support:	
Complete JWST	JWST remains within budget guidelines and on track for an October 2018 launch.
Large-scale 1. WFIRST	Preformulation and focused technology development for WFIRST-AFTA (a 2.4m version of WFIRST with a coronagraph) are underway to enable a new start. Budget line established for an Astrophysics Decadal Strategic Mission.
Large-scale 2. Augmentation to Explorer Program	Astrophysics Explorers planned budget increased to support cadence of four AOs per decade including SMEX AO in Fall 2014 and MIDEX AO in late 2016/early 2017.
Large-scale 3. LISA	Discussing partnership on ESA's L3 gravitational wave observatory and participating in ESA-led assessments in 2014-2015. Strategic astrophysics technology (SAT) investments plus support of LISA Pathfinder.
Large-scale 4. IXO	Pursuing a partnership on ESA's L2 Athena X-ray observatory; the Athena study phase, with U.S. participation, is underway. Strategic astrophysics technology (SAT) investments.
Medium-scale 2. Inflation Probe Technology Development Prog	Balloon-borne investigations plus strategic astrophysics technology (SAT) investments. Studying partnership on JAXA's LiteBIRD.

Progress Toward Decadal Survey Priorities

The NASA FY15 Appropriation, the President's FY16 Budget Request, and the notional out year budget planning guidance in the President's FY16 Budget Request, support:	
Medium-scale 1. New Worlds Technology Development Program	Focused technology development for a coronagraph on WFIRST, strategic astrophysics technology (SAT) investments, and exoplanet probe mission concept studies. Established partnership with NSF to develop extreme precision Doppler spectrometer as facility instrument. Exozodi survey using LBTI.
Small-scale. Research Program Augmentations	Increased annual R&A budget by 10% from FY10 to FY12 and another 10% from FY14 to FY16. Within R&A: established Theoretical and Computational Astrophysics Networks (TCAN) program with NSF; funding available for astrophysics theory; funding available for lab astrophysics; funding available for suborbital payloads.
Small-scale. Intermediate Technology development Augmentation	Established competed Strategic Astrophysics Technology (SAT) program element; directed technology funding for WFIRST and other large-scale decadal priorities (e.g., WFIRST coronagraph, Athena).
Small-scale. Future Ultraviolet-Visible Space Capability	Strategic Astrophysics Technology (SAT) and Astrophysics R&A (APRA) investments; mission concept studies.
Small-scale. SPICA (U.S. contribution to JAXA-led)	Not supported as a strategic contribution; candidate for Explorer Mission of Opportunity.

Response to Recommendations: DSIAC

- Decadal Survey (New Worlds, New Horizons in Astronomy and Astrophysics; 2010)

"NASA, NSF, and DOE 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. Such a decadal survey implementation advisory committee (DSIAC) should be charged to produce Annual reports to the agencies, the Office of Management and Budget, and the Office of Science and Technology Policy, as well as a mid-decade review of the progress made. The implementation advisory committee should be independent of the agencies and the agency advisory committees in its membership, management, and operation (p. 15)."

- NASA views the work of the CAA and AAAC as fulfilling the "regular basis" portion of this recommendation.
  - The AAAC does submit annual reports to the Agencies, OMB, and OSTP on progress against the Decadal Survey.
  - The CAA does not issue reports.
- NASA views the work of this Midterm Committee as fulfilling the "mid-decade review" portion of the recommendation.

Response to Recommendations: Balanced Program

- Decadal Survey (New Worlds, New Horizons in Astronomy and Astrophysics; 2010)

"A successful program must be balanced (pp 14-15). A major recommendation of this report, directed to both the ground and the space programs, is that more support should be directed toward activities of intermediate scale. For the space program, both NASA's Explorer program and its Suborbital program are recommended in Chapter 7 for funding increments (p. 148). Success rests on a diversified portfolio including large flagship missions, smaller more focused Explorer missions, and suborbital, data analysis, theory, technology development, and laboratory astrophysics programs. Maintain balance between support for the development and operation of missions and the support for the archiving, analysis, and scientific interpretation of the data realized from the missions, including theoretical and computational modeling (pp 174-175)."

- NASA Response
  - NASA has made difficult choices to address multiple Decadal Survey recommendations including maintaining a balanced program within a constrained budget environment.
  - The current and planned portfolio includes all of the elements in the definition of a balanced program provided by NWNH.

Response to Recommendations: WFIRST

- Decadal Survey (New Worlds, New Horizons in Astronomy and Astrophysics; 2010)

"[The highest priority, large-scale space activity is a] Wide-Field Infrared Survey Telescope (WFIRST)—an observatory designed to settle essential questions in both exoplanet and dark energy research, and which will advance topics ranging from galaxy evolution to the study of objects within our own galaxy (p. 3). The independent cost appraisal is $1.6 billion, not including the guest investigator program. The recommended schedule has a launch date of 2020 with a 5-year baseline mission. The European Space Agency (ESA) is considering an M-class proposal, called Euclid, with related goals. Collaboration on a combined mission with the United States playing a leading role should be considered so long as the committee's recommended science program is preserved and overall cost savings result (p. 17). WFIRST is a 1.5-meter telescope that will orbit the second Lagrange point (L2), 1.5 million kilometers from Earth. It will image the sky at near-infrared wavelengths and perform low-resolution infrared spectroscopy (p. 206). This continuing interagency collaboration [with DOE] on the proposed WFIRST is important both scientifically and technically (p. 207)."

- NASA Response
  - NASA has conducted multiple pre-formulation studies for a WFIRST mission and is currently proceeding toward a new start for WFIRST-AFTA.
  - NASA has agreed to provide the sensor chip systems for the NISP instrument on ESA's Euclid mission and is planning to support U.S. participation in the mission.

Response to Recommendations: WFIRST

- FY10-FY11
  - NASA proposes to provide substantive contribution to Euclid in exchange for substantive ESA contribution to WFIRST.
  - First NRC Euclid study (Report of the Panel on Implementing Recommendations from the New Worlds, New Horizons Decadal Survey; December 2010) rejects this proposal.
- FY11-FY12:
  - NASA appoints the first WFIRST Science Definition Team (SDT) co-chaired by James Green and Paul Schechter (November 2010).
  - First WFIRST SDT develops IDRM (quick version of WFIRST as described in Decadal Survey) (July 2011 report).
  - Second NRC Euclid study (Assessment of a Plan for U.S. Participation in Euclid; February 2012) recommends a limited contribution to Euclid in exchange for US participation in the mission.
  - First WFIRST SDT then develops DRM1 (improved design for WFIRST) and DRM2 (minimal cost for a delayed WFIRST) (August 2012 report).
- FY13:
  - NASA enters into agreement with ESA to provide the sensor chip systems for the NISP instrument on Euclid in exchange for US participation in the mission (January 2013 MOU).

Response to Recommendations: WFIRST

- FY12-FY13
  - NASA receives 2.4m telescope assembly from another Government agency (announced June 2012). NASA Administrator requests study on application of 2.4m telescope assembly as Astrophysics Focused Telescope Assets (AFTA) for WFIRST or for use advancing other NASA priorities (August 2012).
  - NASA appoints second WFIRST SDT co-chaired by David Spergel and Neil Gehrels (October 2012).
  - Second WFIRST SDT develops science case for WFIRST-AFTA (May 2013 report). NASA Administrator approves continued preformulation of WFIRST-AFTA using 2.4m telescope assembly (June 2013).

Response to Recommendations: WFIRST

- FY13-FY15:
  - NASA appoints WFIRST-AFTA SDT co-chaired by David Spergel and Neil Gehrels (July 2013).
  - NASA is appropriated~$50M/year in FY14 and FY15 to support WFIRST-AFTA preformulation study and technology development. NASA HQ assigns the work to a WFIRST-AFTA Study Office at GSFC with significant support from JPL.
  - NRC WFIRST-AFTA study (Evaluation of the Implementation of WFIRST-AFTA in the Context of New Worlds, New Horizons in Astronomy and Astrophysics; March 2014) endorses WFIRST-AFTA science but is cautious regarding cost and risk; the study recommends NASA mature design and technology, obtain independent cost and technology assessment, and monitor impact of mission on astrophysics balance.
  - WFIRST-AFTA SDT develops baseline DRM using AFTA and including a widefield instrument with advanced detectors and a coronagraph instrument (March 2015 report).
  - NASA contracts Aerospace Corporation to conduct a cost and technical assessment (CATE) of the WFIRST-AFTA DRM (February 2015).

Response to Recommendations: WFIRST

- Harrison Report (Evaluation of the Implementation of WFIRST-AFTA in the Context of NWNH; 2014)

"Recommendation 2-1: NASA should move aggressively to mature the coronagraph design and develop a credible cost, schedule, performance, and observing program so that its impact on the WFIRST mission can be determined. Upon completion of this activity, and a cost and technical evaluation of WFIRST-AFTA with the coronagraph, an independent review focused on the coronagraph should be convened to determine whether the impact on WFIRST and on the NASA astrophysics program is acceptable or if the coronagraph should be removed from the mission."

- NASA Response
  - The report of the WFIRST Science Definition Team (March 2015) presents a baseline coronagraph plan and design that is mature enough to develop a credible cost, schedule, performance, and observing program. The SDT report includes an assessment of the impact on the WFIRST-AFTA mission.
  - An independent CATE of the cost of both the baseline WFIRST-AFTA mission including the coronagraph and the descoped mission without the coronagraph was conducted by the Aerospace Corporation.
  - The Midterm Committee will determine whether the impact on the astrophysics program is acceptable.

Response to Recommendations: WFIRST

- Harrison Report (Evaluation of the Implementation of WFIRST-AFTA in the Context of NWNH; 2014)

"Recommendation 3-1: NASA should sponsor an external technical and cost review of the WFIRST-AFTA mission that NASA plans to propose as a new start. This review should be independent of NASA's internal process. The objective of the review should be to ensure that the proposed mission cost and technical risk are consistent with available resources and do not significantly compromise the astrophysics balance defined in the 2010 National Research Council report New Worlds, New Horizons in Astronomy and Astrophysics. This review should occur early enough to influence the exercising of a rescoping of the mission if required."

- NASA Response
  - The independent CATE of the DRM serves as the external cost and technical review prior to KDP-A.
  - Per standard NASA practices, a Standing Review Board will be appointed for WFIRST-AFTA once it enters formulation. The SRB will develop a range of costs prior to KDP-B based on the mission concept. The SRB will develop joint cost and schedule confidence limits prior to KDP-C based on the preliminary design. NASA can direct rescopings at any time up to KDP-C; NASA can direct descopings following KDP-C.
  - Members of the science community serve on SRBs.

Response to Recommendations: WFIRST

The Design Reference Mission (DRM) as specified in the SDT report was used.

NASA est.	FY10$	FY15$	RY$
DRM w/ coronagraph	$1.8-2.1B	$2.0-2.3B	$2.5-2.8B
Cost of including coronagraph	~$0.32B	~$0.35B	
NWNH estimate	$1.6B*		

Summary of the Aerospace CATE of WFIRST-AFTA

- Aerospace's independent cost validated the projects estimate – was approximately 10% higher.
- Aerospace identified $150M in potential design threats based on the fact that WFIRST-AFTA is in pre-formulation.
  - NASA believes that because the funding level for WFIRST-AFTA over FY14-17 will be in excess of $150M, the design threats are significantly mitigated.
  - Aerospace's position is that the design threats go away later in formulation.
  - This accounts for most of the 10% difference.
- The Aerospace cost assessment of design threats has decreased substantially since 2013; the investments made in pre-formulation have already realized a reduction in the Aerospace assessed risk of cost growth.

* NWNH estimate does not include GO program; NASA estimate includes GO program

Response to Recommendations: WFIRST

NASA conclusions from the preformulation Aerospace CATE:

- The Aerospace independent assessment validates the NASA estimated cost for WFIRST-AFTA.
- The cost of WFIRST-AFTA without the coronagraph is comparable to the cost of WFIRST in NWNH, thereby validating NASA's expectation that the cost of a larger telescope is offset by the savings of using an existing telescope.
- The substantial pre-formulation investments in technology development and design trades have substantially reduced the "design threats" in the CATE since 2013, and are expected to reduce them to zero by the end of formulation.

Response to Recommendations: WFIRST

Current status of WFIRST-AFTA:

- Currently in pre-formulation phase.
  - Activities include technology development for detectors and coronagraph (with STMD), assessment of the 2.4m telescopes including risk mitigation, mission design trades, payload accommodation studies, and observatory performance simulations.
- Maturing key technologies by FY17.
  - H4RG infrared detectors for widefield imager.
  - Internal coronagraph for exoplanet characterization.
- Preparing for Phase A
  - Selected 17 teams for funding in the WFIRST Preparatory Science program on February 3 to conduct WFIRST-specific simulations and models.
  - SDT report made public March 2015 and available online at http://wfirst.gsfc.nasa.gov.
  - RFI for industry engagement released July 7; expected to lead to RFP to study major elements of WFIRST hardware that could be provided; responses received July 28.
  - Solicitation for members of Formulation Science Working Group (F-SWG) released July 29; proposals due August 17.

Notional schedule for WFIRST-AFTA	Consistent with FY16 budget request	Continued $50M Congressionally directed funding
KDP-A (new start)	NET October 1, 2016	NET January 2016
LRD (launch date)	Fall 2026	Spring 2025

WFIRST - AFTA

Wide-Field Infrared Survey Telescope with Astrophysics Focused Telescope Assets

Coronagraph Technology Milestones		
1	Shaped Pupil mask fabricated with reflectivity of 10^{-4} and 20 μm pixel size.	7/21/14 ü
2	Shaped Pupil Coronagraph demos 10^{-8} raw contrast with narrowband light.	9/30/14 ü
3	PIAACMC mask fabricated with 10^{-8} raw contrast with 10% broadband light.	12/15/14 ü
4	Hybrid Lyot Coronagraph demos 10^{-8} raw contrast with narrowband light.	2/28/15 ü
5	Occulting Mask Coronagraph demos 10^{-8} raw contrast with 10% broadband light.	9/15/15 ü
6	Low Order Wavefront Sensing provides jitter sensing better than 0.4 mas rms.	9/30/15 ü
7	Spectrograph read-out demo to have low dark current and read noise.	8/25/16
8	PIAACMC coronagraph demos 10^{-8} raw contrast with 10% broadband light.	9/30/16
9	Occulting Mask Coronagraph demos 10^{-8} raw contrast with 10% broadband light.	9/30/16

Widefield Detector Technology Milestones		
1	Produce, test, and analyze 2 candidate passivation techniques in banded arrays.	7/31/14 ü
2	Produce, test, and analyze 1 additional candidate passivation techniques in banded arrays.	12/30/14 ü
3	Produce, test, and analyze full arrays with operability > 95%.	9/15/15 ü
4	Produce, test, and analyze final selected recipe in full arrays demonstrating a yield > 20% with operability > 95%.	9/15/16
5	Complete environmental testing of one sensor chip assembly, as per NASA test standards.	12/1/16

Response to Recommendations: Euclid

Current status of NASA contribution to Euclid:

- NASA Euclid project was established in 2012 and is currently in Phase C.
- NASA signed MOU with ESA in January 2013 to provide sensor chip systems for NISP instrument in exchange for US participation on the Euclid consortium and making the Euclid data available to the US community.
- The NASA Euclid project, managed by JPL, consists of the following activities
  - Acquire 16 flight and 4 flight spare sensor chip systems from Teledyne; the sensor chip system consist of the sensor chip assembly (detector), cryo-flex cable, and sensor chip electronics (ASIC)
  - Test and characterize the sensor chip systems in the Detector Characterization Lab (DCL) at GSFC before delivering to ESA
  - Develop the US node for the Euclid Science Consortium Ground System, the Euclid NASA Science Center at IPAC (ENSCI)
  - Support the NASA-selected members of the Euclid Consortium, who were selected through an open competition
  - (Later) Support US general observers and archival researchers, who will be selected through an open competition, in using Euclid and its data set to conduct compelling research

Response to Recommendations: Euclid

- Assessment of a Plan for U.S. Participation in Euclid (NRC, 2012)

"Recommendation 1. NASA should make a hardware contribution of approximately $20 million (FY12$) to the Euclid mission to enable U.S. participation. This investment should be made in the context of a strong U.S. commitment to move forward with the full implementation of WFIRST in order to fully realize the decadal science priorities of the NWNH report."

- NASA is providing the NISP sensor chip system, consistent with the hardware contribution described in the NRC report.
- NASA has made a strong commitment to move forward with pre-formulation of WFIRST; a decision for full implementation is pending.

"Recommendation 2. In exchange for this small, but crucial contribution, NASA should secure through negotiation with the European Space Agency both a U.S. position on the Euclid Science Team with full data access and the inclusion of a team of U.S. scientists in the Euclid Consortium that would be selected by a peer-reviewed process with full data access as well as authorship rights consistent with Euclid policies still to be formulated."

- Done.

"Recommendation 3. NASA should seek independent community review of any financial commitment for hardware expenditures beyond $30 million for Euclid."

- Within NASA Euclid project, hardware acquisition expenditures are currently less than $30M.

Response to Recommendations: Explorers

- Decadal Survey (New Worlds, New Horizons in Astronomy and Astrophysics; 2010)

"NASA should support the selection of two new astrophysics MIDEX missions, two new astrophysics SMEX missions, and at least four astrophysics Missions of Opportunities (MoOs) over the coming decade. AOs should be released on a predictable basis as close to annually as possible, to facilitate MoOs. Further, the committee encourages inclusion of suborbital payload selections, if they offer compelling scientific returns. To accommodate this plan, an annual budget increase would be required for the astrophysics portion of the program from its current average value of about $40 million per year to a steady value of roughly $100 million by 2015 (pp 18, 209)."

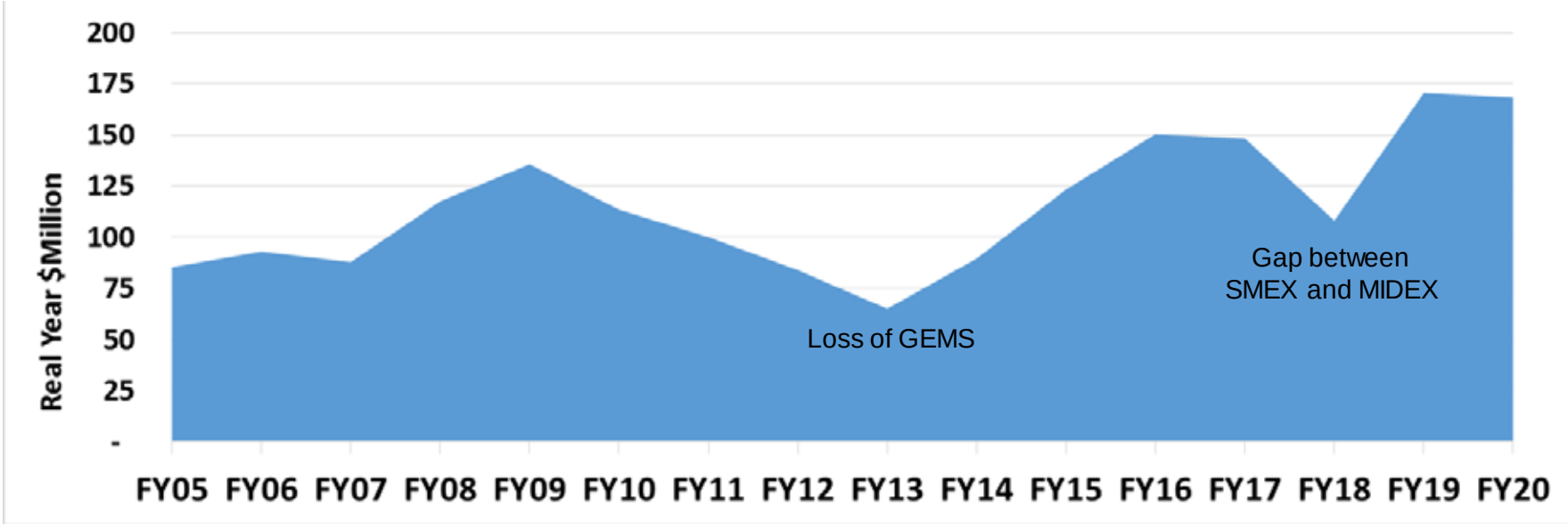
Response to Recommendations: Explorers

- Explorer budget augmented to support 4 AOs per decade
  - 2 SMEX AOs w/ PI-managed cost cap ~$125M
  - 2 MIDEX AOs w/ PI-managed cost cap ~$200M (TBR)
  - 1 MO per AO w/ PI-managed cost cap ~$65M
- Prior year spending, FY15 appropriation, and FY16 budget request support the following AO schedule

AO Type	AO Date	Launch Date	Missions
SMEX + MO	February 2003	June 13, 2012	NuSTAR
			No MO downselected
SMEX + MO	September 2007		GEMS; mission non-confirmed
		NET Nov 2015	SXS on ASTRO-H (Partner MO)
MIDEX + MO	November 2010	August 2017	TESS
		August 2016	NICER (Small mission MO)
MO-only	September 2012		No selection made
SMEX+ MO	September 2014	~2020	IXPE, PRAXyS, or SPHEREx
		TBD	LiteBIRD or GUSTO
MIDEX + MO	~Late 2016	~2023	
SMEX + MO	~2019 (TBC)	~2025	
MIDEX + MO	~2021 (TBC)	~2028	

Response to Recommendations: Explorers

- Explorer budget augmented to support 4 AOs per decade
  - 2 SMEX AOs w/ PI-managed cost cap ~$125M
  - 2 MIDEX AOs w/ PI-managed cost cap ~$200M (TBR)
  - 1 MO per AO w/ PI-managed cost cap ~$65M
- Astrophysics Explorers budget
  - FY05-FY14 actual, FY15 Op Plan, FY16-FY20 proposed
  - Includes all Astrophysics Explorers missions for all phases (development, operations), funding for future selections, cost of program (program management, cost of AO evaluations and multiple Phase A awards).
  - Does not include funding for mission extensions beyond FY16 (that funding is in the Senior Review budget line).



Response to Recommendations: LISA

- Decadal Survey (New Worlds, New Horizons in Astronomy and Astrophysics; 2010)

"In recommending LISA for continued development, the committee identified two key decision points. First, the LPF mission must be successful. LISA is a partnership with ESA, and so its schedule is dependent on ESA's selection of the next L-class mission opportunity. Second, ESA must assign LISA it highest priority as an L-class mission. If either of these conditions is not satisfied, the committee recommends that a DSIAC be tasked to review the status of LISA mid-decade, in consultation with ESA, and to reconsider LISA's prioritization relative to other opportunities. If … a roughly equal partnership is not possible, the committee recommends that NASA request advice from a decadal survey implementation advisory committee (DSIAC) to review the situation mid-decade (pp 18-19, 213). Further investment is needed in systems engineering and life-testing of components for the LISA Pathfinder mission, which is designed to demonstrate a number of LISA's critical technologies (p 155)."

Response to Recommendations: LISA

- 2012: ESA does not select LISA for the L1 opportunity as the first large mission in the Cosmic Vision Programme.
- 2012: Community Study Team examines options for a GW observatory in three cost bins (small, medium, large)
  - CST concluded that only viable option for realizing GW science is a LISA-like mission with cost ~$2B or more
  - http://pcos.gsfc.nasa.gov/studies/gravitational-wave-mission.php
- 2013: NASA announces intent to partner on ESA GW mission
- 2014: ESA selects GW mission for the L3 opportunity as the third large mission in the Cosmic Vision Programme, launching in 2034.
  - US representation on ESA's Gravitational Observatory Advisory Team (GOAT)
  - Preliminary report http://www.cosmos.esa.int/web/goat
- Technology investments toward a future GW mission
  - 2013: Gravitational Wave Mission Technology Roadmap http://pcos.gsfc.nasa.gov/docs/
  - 2010-2015: Support to technology development through SAT awards of ~$6M or 20% of total PCOS SAT (http://pcos.gsfc.nasa.gov/technology/)
  - NASA negotiations with ESA concerning possible L3 partnership for a GW Observatory with launch in 2034
- Continued support of LPF/ST7 for launch in late 2015
- Possible technology and science study in preparation for the 2020 Decadal and to inform NASA's contributions to L3

Response to Recommendations: LISA

- Path forward (2015-2020)
  - Support LISA Pathfinder mission and data analysis
  - Support GOAT process and determine
    - Notional GW Observatory technology and architecture
    - Notional assignment of technologies (and potential mission responsibilities) among ESA member nations, U.S., and other parties
    - US technology interests are described in Gravitational Wave Mission Technology Roadmap (http://pcos.gsfc.nasa.gov/docs/)
  - Support U.S. involvement in a response to ESA's L3 mission concept AO
  - Support GW technology needed for a GW Observatory through the SAT program
- Based on report of the Midterm Committee, NASA will prioritize investments in GW technology against other competing priorities

Response to Recommendations: IXO

- Decadal Survey (New Worlds, New Horizons in Astronomy and Astrophysics; 2010)

"If IXO is selected for the first L-class launch, NASA should request that a decadal survey implementation advisory committee review the IXO case and examine progress in the mission design and readiness. If the review is favorable, NASA should be prepared to invest immediately in technology development at a high level, and work with the project to define the partnership agreements (p 214). [There are] significant technology development needs for IXO, primary among them being the selection and demonstration of the critical X-ray optics (p 155)."

Response to Recommendations: IXO

- 2012: ESA does not select IXO for the L1 opportunity as the first large mission in the Cosmic Vision Programme.
- 2012: Community Study Team examines options for an X-ray observatory under $1B
  - CST identifies three possible X-ray Probe architectures that each deliver a fraction of IXO's science
  - http://pcos.gsfc.nasa.gov/studies/x-ray-probe-2013-2014.php
- 2013: NASA announces intent to partner on ESA large X-ray mission
- 2014: ESA selects Athena mission for the L2 opportunity as the 2nd large mission in the Cosmic Vision Programme, launching in 2028.
  - US representation on Athena Science Team and community-based Athena Science Working Groups
  - Formulation of the mission by ESA is underway, and a strawman design mission was completed in 2014. ESA plans an instrument AO in CY2016.
  - NASA appointed a US scientist to the Athena Science Study Team and US scientists to the Athena Science Working Groups.
- 2014: NASA issued RFI to assess interest by U.S. organizations in providing hardware for the Athena mission

Response to Recommendations: IXO

- 2015: NASA is pursuing a partnership with ESA to provide up to $100-150M in components of the two instruments and/or the observatory.
  - NASA will provide the sensor array for the X-ray Integral Field Unit (microcalorimeter).
  - NASA is considering a proposal for contributions to the Wide Field Instrument (imager).
  - NASA is considering providing use of test facilities, specifically the X-ray Cryogenic Facility (XRCF) at MSFC.
  - NASA also plans for funding US members of the Athena science team, a US science data center, and US general observers during operation.
- NASA is budgeting for participation in the Athena mission, but such budgets come at an "opportunity cost" from other Astrophysics budget lines within a constrained budget.
- Based on report of the Midterm Committee, NASA will prioritize investments toward a role in Athena against other competing priorities

Response to Recommendations: New Worlds Tech

- Decadal Survey (New Worlds, New Horizons in Astronomy and Astrophysics; 2010)

"NASA and NSF should support an aggressive program of ground-based high-precision radial velocity surveys of nearby stars to identify potential candidates. In the first part of the decade NASA should support competed technology development to advance multiple possible technologies for a next-decade planet imager, and should accelerate measurements of exozodiacal light levels that will determine the size and complexity of such missions. If, by mid-decade, a DSIAC review determines that sufficient information has become or is becoming available on key issues such as planet frequency and exozodiacal dust distribution, a technology down-select should be made and the level of support increased to enable a mission capable of studying nearby Earth-like planets to be mature for consideration by the 2020 decadal survey, with a view to a start early in the 2020 decade (p 20). From the above considerations, a budget of $4 million per year is recommended in the first several years of the decade, in addition to the generally available technology development funds. If the scientific groundwork has been laid and the design requirements for an imaging mission have become clear by the second half of this decade, a technology down-select should be made. Furthermore, mission development should be supported at an appropriate level for the mission design and scope to be well understood. [The] committee therefore recommends that a decadal survey implementation advisory committee be convened mid-decade to review progress both scientifically and technically to determine the way forward, and in particular whether an increased level of support associated with mission-specific technology development should commence (p 216)."

Response to Recommendations: New Worlds Tech

- 2010: Technology Development for Exoplanet Missions (TDEM) element of Strategic Astrophysics Technology (SAT) program (introduced June 2009) is refocused to support New Worlds Technology Development priorities.
  - TDEM solicitations have been solicited in each ROSES except ROSES-11
  - Technology areas include coronagraph starlight suppression demonstrations, starshade technology, wavefront sensing & control of scattered starlight, coronagraph modeling and model validation, and other technologies
  - List of awards at http://exep.jpl.nasa.gov/technology/
- 2013: Decision to include a coronagraph technology demonstration instrument on WFIRST-AFTA
  - Identified primary and backup coronagraph technologies in 2013
  - Coronagraph technology development is funded by Astrophysics (through WFIRST study) and STMD (through Game Changing Program)
  - Coronagraph is in WFIRST-AFTA baseline DRM

Response to Recommendations: New Worlds Tech

- 2013-2015: Exoplanet Probe Studies
  - Established DRMs and science yields for $1B class exoplanet characterization missions with internal occulter (coronagraph) and external occulter (starshade).
- 2014: Established NN-EXPLORE partnership with NSF to develop a facility radial velocity spectrometer for the WIYN telescope
  - NOAO share of WIYN telescope dedicated to exoplanet research
  - NSF provides NOAO share of WIYN telescope
  - NASA provides facility spectrometer, research funding, data archiving
- 2015: LBTI passed Operational Readiness Review
  - Plan to complete in 2017 the HOSTS survey of exozodiacal dust in the habitable zones of nearby main sequence stars
- 2015: Starshade Readiness Working Group will establish investments and activities necessary to attain TRL-6 for a starshade
- 2016-2019: Mission concept studies for two exoplanet characterization missions (HabEx and LUVOIR)

Response to Recommendations: New Worlds Tech

- Estimated spending on New Worlds technology including precursor science, FY11-FY20
  - WFIRST-AFTA coronagraph, technology development and formulation/design ~$100M
  - Technology Demonstration for Exoplanet Missions (TDEM) element of Strategic Astrophysics Technology (SAT) ~$52M
  - NN-EXPLORE initiative with NSF including Extreme Precision Doppler Spectrometer (EPDS) for WIYN telescope ~$17M
  - Long Baseline Telescope Interferometer, complete development, commissioning, HOSTS exozodiacal dust survey ~$16M
  - Exoplanet Research Program (XRP) and exoplanet-relevant technology in Astrophysics R&A (APRA) program ~$50M
  - Exoplanet probe studies ~$6M
  - Total (FY11-FY20, est. planned) ~$240M
- Based on report of the Midterm Committee, NASA will prioritize increased investments toward mission-specific New Worlds Technology against other competing priorities

Response to Recommendations: Inflation Probe Tech

- Decadal Survey (New Worlds, New Horizons in Astronomy and Astrophysics; 2010)

"The committee recommends a technology program to advance detection techniques at an annual funding level of $1 million to $2 million (p. 20). NASA through the APRA program, as described below, should augment support for CMB technology development at a modest level. … If the combined space and ground-based program is successful in making a positive detection of B-modes from the epoch of inflation, it is further recommended that NASA should then embark on an enhanced program of technology development, with a view to preparing a mature proposal for a dedicated space mission to study inflation through CMB observations for consideration by the 2020 decadal survey. If this observational goal is not met, then the suborbital programs and the broad technology development programs should continue to be supported at the same early-decade level with the goal of further improving detection limits (p. 217)."

Response to Recommendations: Inflation Probe Tech

- Planck extension and support of data analysis for third archival release in 2015
- Suborbital (balloon) Investigations:
  - E and B Experiment (EBEX), PI: S. Hanany (U. Minnesota). Flew in Antarctica in 2012-2013
  - SPIDER, PI. W. Jones (Princeton). Flew in Antarctica in 2014-2015; hope to refly in 2016-2017 (currently on the ice awaiting recovery)
  - Primordial Inflation Polarization Explorer (PIPER), PI: A. Kogut (GSFC). Scheduled to fly in Ft. Sumner in Fall 2016
- Technology investments (detectors and other systems):
  - APRA: total funding in 2010-2015 of $14.2M for 27 investigations; does not include ROSES-14 selections for FY16 new starts
  - SAT: total funding in 2010-2015 of $3.4M for 2 investigations; does not include ROSES-14 selections for FY16 new starts
- Selection in 2015 for a Phase A study of U.S. Participation in the Japanese LiteBIRD Mission as an Explorer Mission of Opportunity, PI: A. Lee (UC Berkeley)
- Pending the report from the Midterm Committee, the rest of the decade might include:
  - Continued investments in detector technology and suborbital investigations
  - Consider any Inflation Probe proposals submitted to the 2016 MIDEX AO
  - Possible downselect of LiteBIRD for flight in both Japan and U.S.
  - Consider U.S. participation proposed for a European Inflation Probe (possible M5)
  - Possible study of an Inflation Probe strategic mission for the 2020 Decadal Survey

Response to Recommendations: SPICA

- Decadal Survey (New Worlds, New Horizons in Astronomy and Astrophysics; 2010)

U.S. Contribution to the JAXA-ESA SPICA Mission. "A competed U.S. science and instrument contribution at an estimated level of $150 million over the decade is recommended (p. 21). Instrumentation for the SPICA mission is a third area where specific technology development funds are needed during this decade (p. 155). The committee recommends that the United States should join this project by contributing infrared instrumentation, which would exploit unique U.S. expertise and detector experience …… the committee urges NASA to work with JAXA to determine the optimal phasing of an Announcement of Opportunity for contributions. A notional budget of $150 million, including operations over the decade, is recommended (p. 218)."

"In the event that insufficient funds are available to carry out the recommended Program … it is unfortunate that this reduced budget scenario would not permit participation in the JAXA-SPICA mission unless that mission's development phase is delayed (p.237-238)."

- NASA Response
  - A U.S. contribution to SPICA is not supported in the budget as a strategic contribution; it is a candidate for an Explorer Mission of Opportunity proposal.
  - JAXA has restructured SPICA as a joint JAXA/ESA mission; whether it proceeds depends on ESA selecting its contribution to SPICA as its M5 mission.
  - ESA M5 AO is planned for 2016; this is well timed with the 2016 MIDEX AO for a potential proposal for a U.S. contribution as a Mission of Opportunity.

Response to Recommendations: Core Research

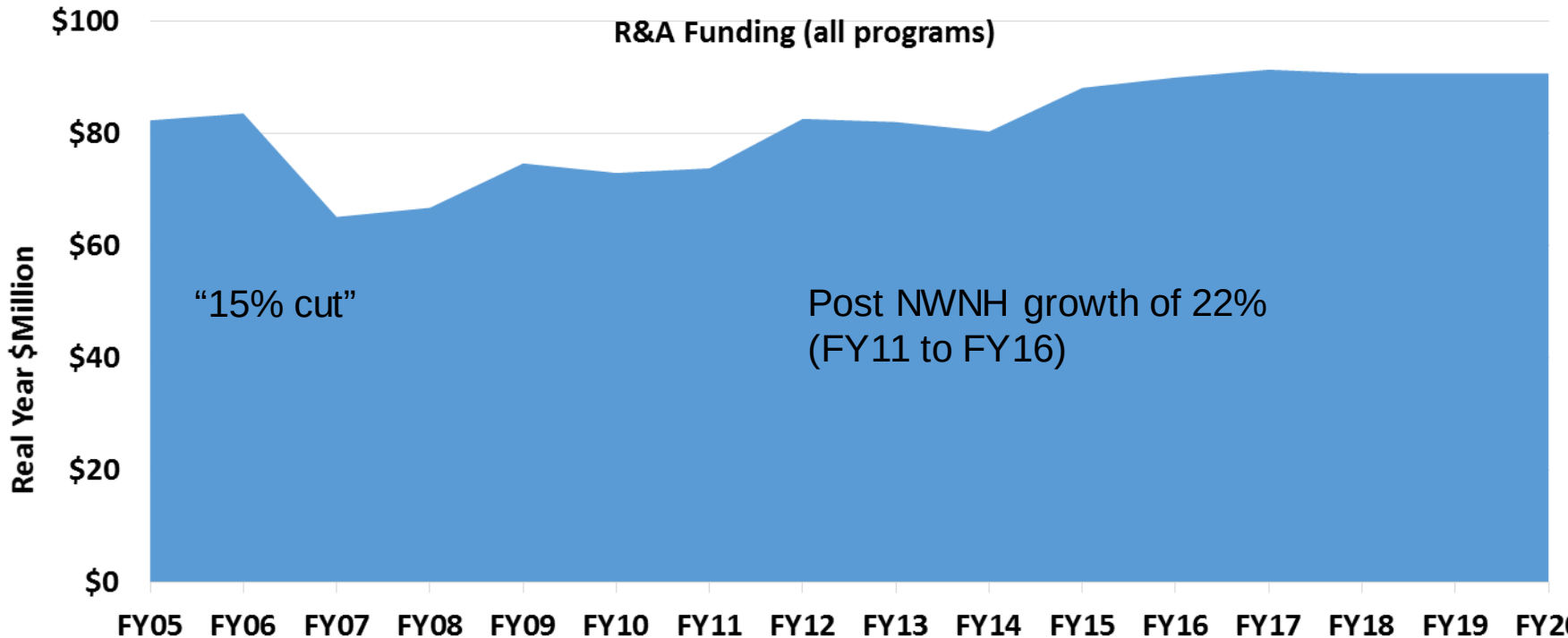
- Decadal Survey (New Worlds, New Horizons in Astronomy and Astrophysics; 2010)

Core Research Programs. "Maintaining these core activities has a high priority for the survey committee, and the budget allocations should not be allowed to decrease to address overruns in the costs of large and medium missions (p. 21). In the committee's judgment, it is absolutely necessary for the health of the whole astronomy and astrophysics enterprise to increase the support of individual investigators: those who write the papers, who train the students and other junior researchers, and who in the end produce the results to drive the field forward and ignite the public's imagination. Reallocation of resources may have to come at the expense of support of existing missions/facilities and new projects (p. 134)."

- NASA Response
  - Core research programs have not been decreased to address overruns in large and medium missions.
  - Core R&A programs (APRA, ADAP, ATP+TCAN, XRP/OSS, RTF) have grown in funding since the Decadal Survey.
  - GO funding has decreased as funding is reduced for missions in extended phase relative to same missions in prime phase; will grow in future as new missions are launched.

Response to Recommendations: Core Research

- Core R&A Funding includes
  - Astrophysics Research and Analysis (APRA): all years
  - Astrophysics Data Analysis Program (ADAP): all years
  - Astrophysics Theory Program (ATP): all years
  - Exoplanet Research Program (XRP), was Origins of Solar Systems (OSS): all years
  - Theoretical and Computational Astrophysics Networks (TCAN): FY14+
  - Nancy G. Roman Technology Fellowships (RTF): FY12+
  - Long Term Space Astrophysics (LTSA): through FY09, then into ADAP
  - Beyond Einstein Foundation Science (BEFS): through FY06, then into ATP
  - Does not include WFIRST Preparatory Science (WPS) or mission-funded theory



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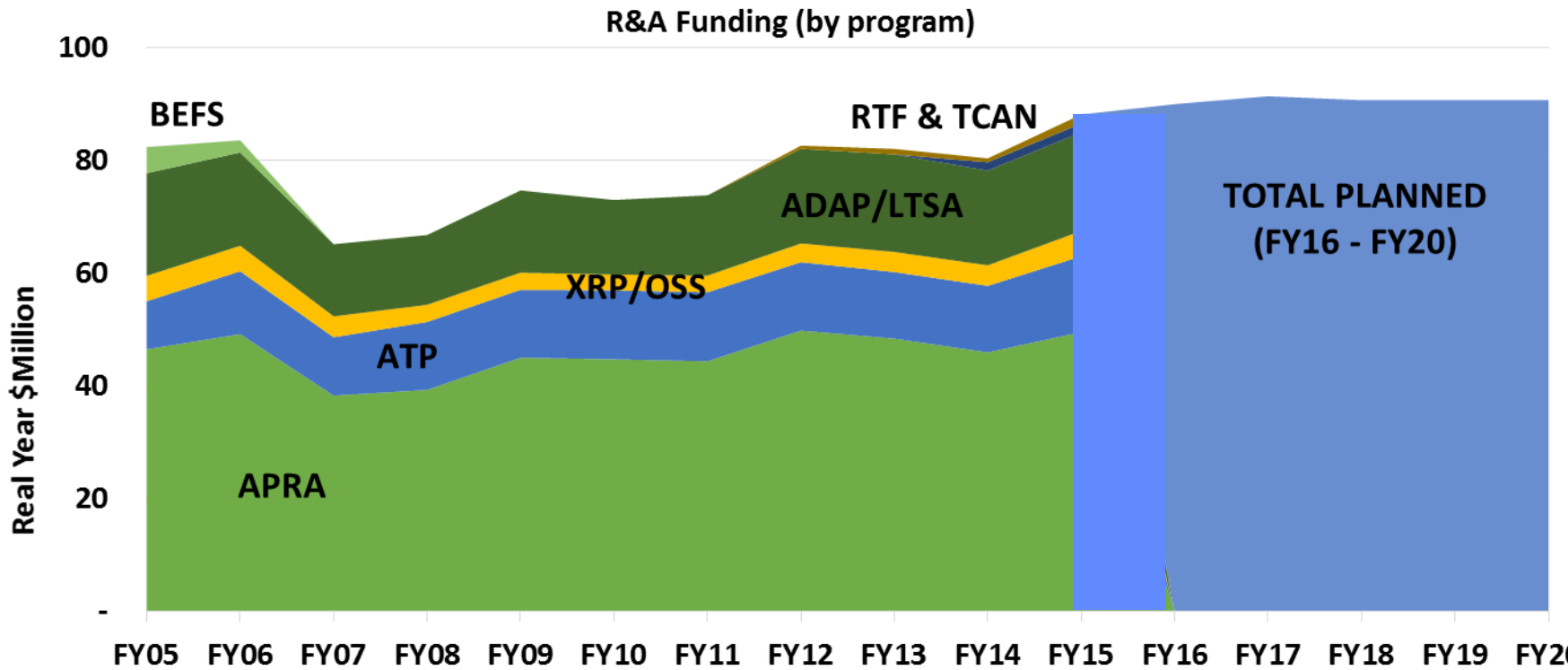
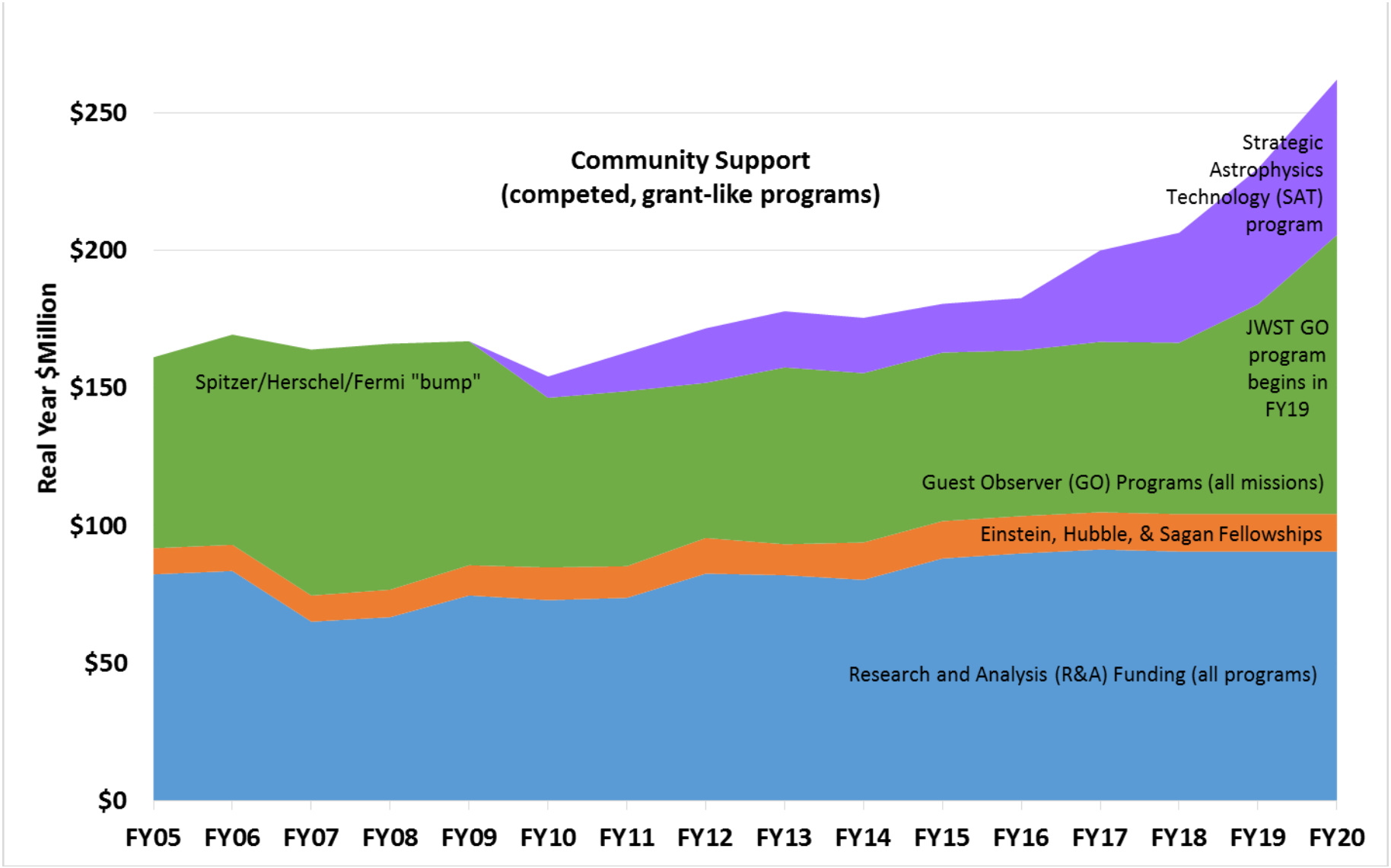


Response to Recommendations: Core Research



Response to Recommendations: Astrophys Theory

- Decadal Survey (New Worlds, New Horizons in Astronomy and Astrophysics; 2010)

Astrophysics Theory Program. "An augmentation of $35 million to the current funding level recommended (p. 21). A new program of Research Networks in Theoretical and Computational Astrophysics should be funded by DOE, NASA, and NSF. The program would support research in six to eight focus areas that cover major theoretical questions raised by the survey's Science Frontiers Panels (p. 31). The committee proposes a new competed program to support coordinated theoretical and computational research—particularly that of fundamental relevance to upcoming space observatories. For NASA an annual budget of $5 million is recommended (p. 32). Selection criteria would include the degree of cross-institutional synergy in the network and its planned role in training and mentoring the next generation of researchers. Funding would normally be for a 5-year period, and the entire program would be subject to a senior review after 5 years (p. 142)."

- NASA Response
  - ATP funding level has remained approximately constant since FY08 at $12M/year.
  - TCAN augments program starting in FY14 at $1.5M/year from NASA for three years, matched by NSF. TCAN will be reviewed in 2015 for a continuation decision per NWNH.
  - WPS augments program by $4.9M total during FY15-FY17 (funding is from WFIRST study, not from Research Program); at least 50% of WPS is theory. No repeat of WPS is planned.

Response to Recommendations: Future UV-Optical

- Decadal Survey (New Worlds, New Horizons in Astronomy and Astrophysics; 2010)

Definition of a Future Ultraviolet-Optical Space Capability. "To prepare for a future major ultraviolet mission to succeed the Hubble Space Telescope, it will be necessary to carry out a mission-definition program. A budget of roughly $40 million over the decade for mission studies and initial technology development is recommended (p. 21). No more servicing missions are planned, and NASA intends to deorbit HST robotically at the end of the decade. The committee endorses this decision (p. 219). The committee highly recommends a modest program of technology development to begin mission trade-off studies, in particular those contrasting coronagraph and star-shade approaches, and to invest in essential technologies such as detectors, coatings, and optics, to prepare for a mission to be considered by the 2020 decadal survey. A notional budget of $40 million for the decade is recommended (p. 220)."

- NASA response
  - 2012 May: NASA issued an RFI soliciting science objectives for a future UV/visible space observatory. http://cor.gsfc.nasa.gov/studies/
  - 2012 September: NASA held a workshop to discuss potential science drivers for a future UV/visible mission.
  - Based on these activities, NASA and the community have responded with in several ways (see next chart):
    - Technology investments
    - Mission concept studies

Response to Recommendations: Future UV-Optical

- Technology investments relevant to a future UV/visible mission
  - NASA conducts annual technology prioritization reviews, based on community input, to review and prioritize gaps between currently available technology and what is needed to achieve our science goals. The 2014 Cosmic Origins Program Annual Technology Report (PATR) includes the following as the highest priority technologies:
    - o High-Reflectivity Optical Coatings for UV/Vis/NIR;
    - o High-QE, Large-Format UV detectors;
    - o Photon-Counting, Large-Format UV Detectors;
    - o Affordable, Light-Weight, Large-Aperture Optics;
    - o Wavefront Sensing and Control at the Nanometer Level; and
    - o High-Efficiency UV Multi-Object Spectrometers.

    http://cor.gsfc.nasa.gov/technology/
  - NASA invests in relevant technologies through three programs:
    - o Strategic Astrophysics Technology (SAT)
    - o Astrophysics R&A (APRA)
    - o Space Technology Mission Directorate (STMD) programs (none currently funded by STMD in this topic area)
  - The SAT portfolio is available at http://cor.gsfc.nasa.gov/technology/quadcharts/COR_Tech_Dev_Quadcharts_8-15.pptx

Response to Recommendations: Future UV-Optical

- Technology investments relevant to a future UV/visible mission
  - APRA UV/Visible portfolio (FY10-FY15) supports efforts in:
    - Gratings, MCP detectors, solid-state detectors, multi-object spectroscopy, coronagraph technology, star-shades, numerous science topics
    - Includes basic technology, sounding rocket payloads, and balloon payloads.
    - Includes10 efforts geared towards exoplanets
    - Includes 9 suborbital payloads (sounding rockets, balloons)
    - Includes 4 basic technology efforts (detectors, multi-object spectrographs)
    - $39M selected to date, $25M dispersed (during FY10-FY15), $14M committed for FY16 and beyond, does not include ROSES-14 selections for FY16 new starts
    - Estimated spending FY11-FY20 is ~$54M

Response to Recommendations: Future UV-Optical

- Mission concept studies relevant to a future UV/visible mission
  - ATLAST: Using institutional funds, a study team led by GSFC, with STScI, JPL, and MSFC, has continued to mature the ATLAST mission concept that was considered by the 2010 Decadal Survey.
  - HDST: AURA has sponsored a mission concept study for a High Definition Space Telescope (HDST); the AURA report was issued in early 2015.
  - LUVOIR: NASA will conduct up to four mission concept studies to inform the 2020 Decadal Survey. One of the concepts under consideration for study is the Large Ultraviolet/Optical/Infrared Surveyor (LUVOIR).
    - A LUVOIR STDT and Study Team would draw upon the work done by the ATLAST and HDST studies.
    - Technologies required for any of the pre-decadal mission concept studies will be candidates for funding from SAT starting in FY17.

Response to Recommendations: Intermediate Tech

- Decadal Survey (New Worlds, New Horizons in Astronomy and Astrophysics; 2010)

Intermediate Technology Development. "An augmentation beginning at $2 million per year and increasing to $15 million per year by the end of the decade would address this imbalance is recommended (p. 22). The committee recommends that funding for such medium-term technology development be augmented at the level of $2 million per year starting early in the decade, ramping up to an augmentation of $15 million per year by 2021 (p. 220)."

- NASA Response
  - NASA's Strategic Astrophysics Technology (SAT) program supports low and mid TRL technology development that is specifically directed at future strategic missions.
    - "SAT supports the maturation of key technologies to the point at which they are feasible for implementation in space flight missions."
  - SAT supports several classes of technology investments, including
    - Competed investigations, selected in response to a peer reviewed ROSES proposal;
    - Directed investigations, assigned to a PI when competition is not warranted; and
    - Testbeds and other infrastructure available to the technology community.

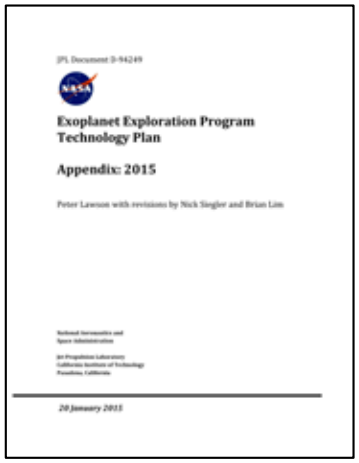
Response to Recommendations: Intermediate Tech

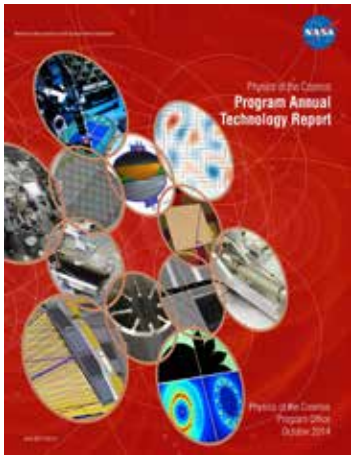
- Technology gaps are identified and prioritized in the Program Annual Technology Reports (PATRs).
  - PATRs are developed with considerable community input including an open call for identification of technology gaps and use of community based Program Analysis Groups and Technology Assessment Committees to prioritize technology gaps.
  - Gap lists serve to identify where technology development is needed.

http://cor.gsfc.nasa.gov/technology/

http://exep.jpl.nasa.gov/technology/

http://pcos.gsfc.nasa.gov/technology/





Response to Recommendations: Intermediate Tech

- NASA Response
  - NASA initiated the SAT program in ROSES 2009 with a solicitation for Technology Development for Exoplanet Missions (TDEM).
  - In ROSES 2010, SAT was expanded to also include Technology Development for Physics of the Cosmos Program (TPCOS) and Technology Development for the Cosmic Origins Program (TCOP).
  - The SAT solicitation in ROSES 2010 was amended in December 2010 to explicitly link SAT priorities to NWNH recommendations.
  - The SAT solicitation in ROSES 2015 will be amended to explicitly add the decadal mission concept studies to the SAT priorities.
  - Occasionally, SAT's scope has been narrowed depending on the strategic needs of the Astrophysics portfolio or in response to budget shortfalls.
  - Technology development that is initiated within SAT is transitioned to a study or project budget when that technology is adopted for a mission.
    - Coronagraph technology for WFIRST-AFTA is being funded within the WFIRST-AFTA study budget.
    - X-ray microcalorimeter technology for Athena will be transitioned from SAT to an Athena budget line when the Athena project is created.

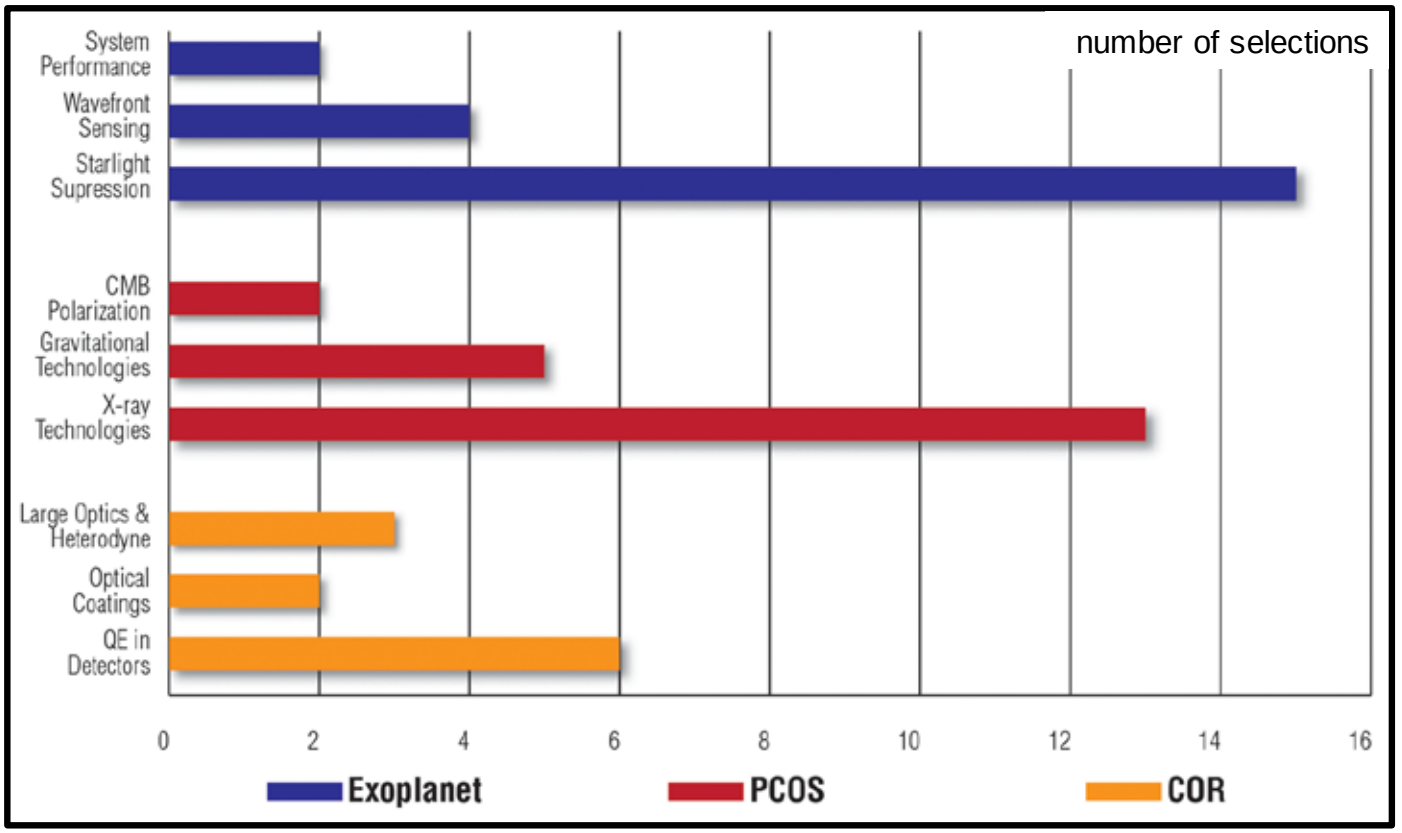
Response to Recommendations: Intermediate Tech

- SAT Selections Summary
  - TDEM: http://exep.jpl.nasa.gov/technology/
  - TPCOS: http://pcos.gsfc.nasa.gov/technology/
  - TCOP: http://cor.gsfc.nasa.gov/technology/

TDEM

TPCOS

TCOP



$17 M	$29M	$18M

Total Investment on Technology Maturation: $64M (FY10-FY15)

Response to Recommendations: Lab Astro

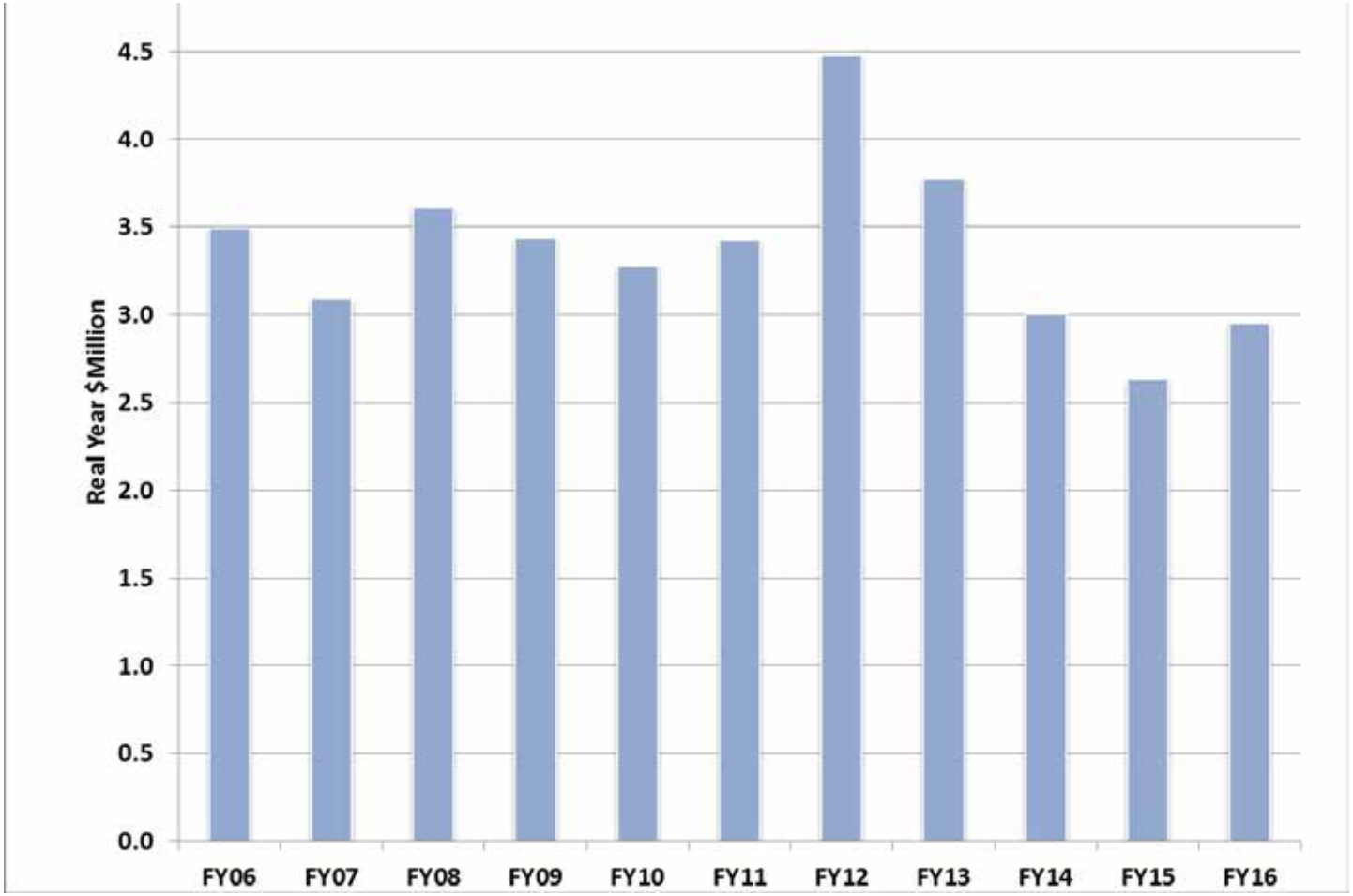
- Decadal Survey (New Worlds, New Horizons in Astronomy and Astrophysics; 2010)

Laboratory Astrophysics. "An increase by $2 million per year in the funding of the present program is recommended (p. 21). NASA and NSF support for laboratory astrophysics under the Astronomy and Physics Research and Analysis (APRA) and the Astronomy and Astrophysics Research Grants programs, respectively, should continue at current or higher levels over the coming decade because these programs are vital for optimizing the scientific return from current and planned facilities (pp 32, 162). Funding through APRA that is aimed at mission-enabling laboratory astrophysics should be augmented at a level recommended by [a NASA/DOE] scientific assessment. While the costs of obtaining the data that will be needed in the coming decade are difficult to estimate, an increase of 25 percent over the current budget, or a notional budget increment of $20 million over the decade, may be required (p. 222)."

- NASA Response
  - No targeted earmark for the NASA astrophysics research budget was earmarked for Laboratory Astrophysics. Laboratory Astrophysics shared in the ~$5.5M/yr (13%) increase in APRA from FY11 to FY16.
  - ROSES-2010 included solicitation for consortium proposals addressing the grand challenge of understanding carbon in the universe. One proposal was selected for funding in FY12-FY14.
  - For the past two years, NASA selected every Laboratory Astrophysics proposal that did very well in peer review (E/VG or better).

Response to Recommendations: Lab Astro

- NASA Response



- Laboratory Astrophysics Funding in FY06 through FY16. The bump in FY12 is due to the 'Carbon Cycle in the Universe' large consortium project. Number of ongoing programs ranges from 6 to 11 in each year.

Response to Recommendations: Suborbital

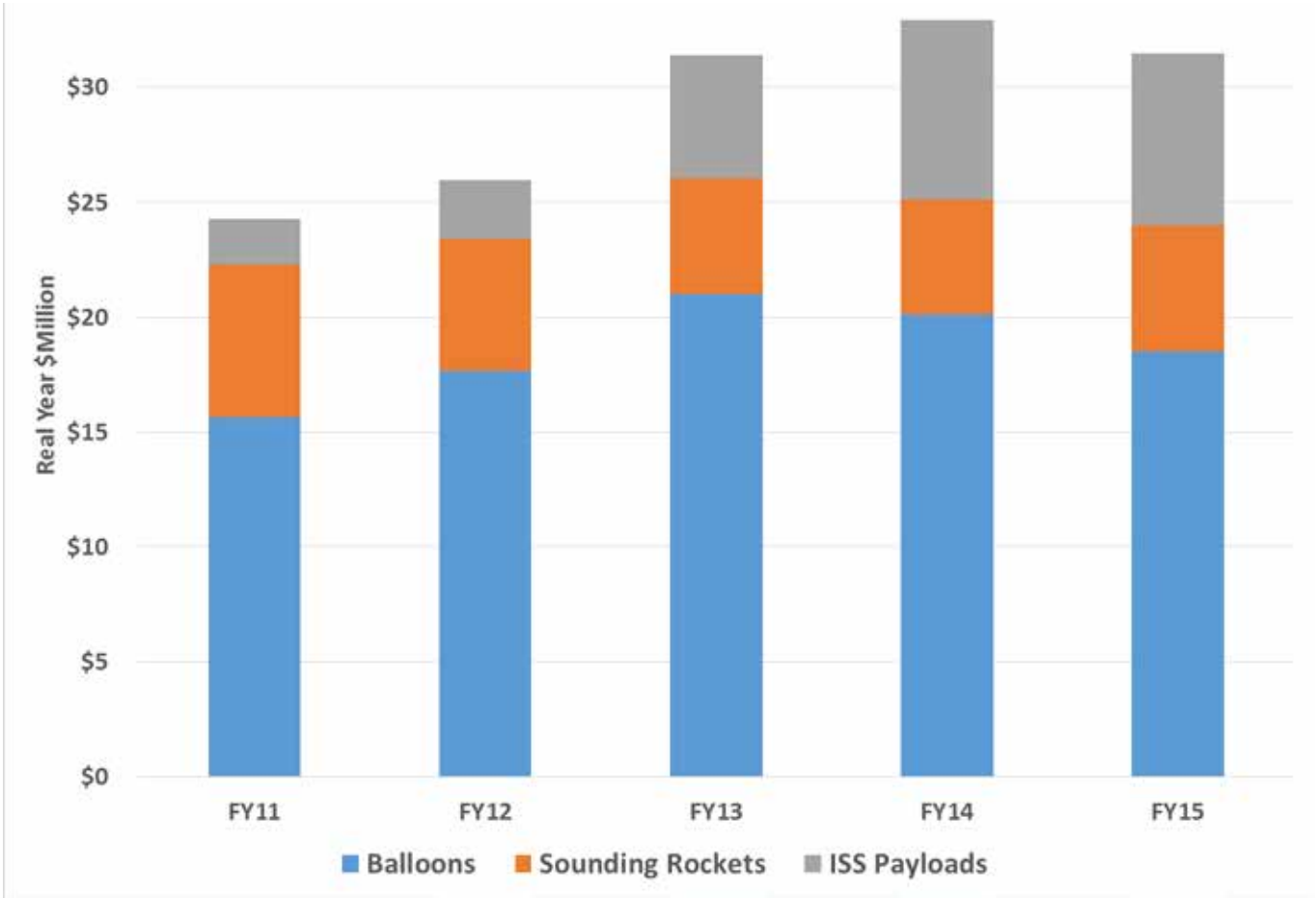
- Decadal Survey (New Worlds, New Horizons in Astronomy and Astrophysics; 2010)

Suborbital Program. "A growth in the budget by $15 million per year is recommended (p. 32). The ultralong-duration balloon (ULDB) program is attractive, because it provides about a factor-of-three more observing time than Antarctic long-duration balloons (LDBs) as well as mid-latitude long-duration flights, but it is expensive. One of this survey's priority science areas, the CMB, along with related dark matter and cosmic-ray detection experiments, has primary requirements for frequent access and increased total observing. If it is more cost-effective per observing day to expand the LDB program and improve its facilities and recovery reliability, then this should have the highest priority (p. 222). NASA should investigate and, if practical and affordable, implement the orbital sounding rocket capability described by NASA's Astrophysics Sounding Rocket Assessment Team (p. 222)."

- NASA Response
  - NASA has continued to invest in suborbital payloads (balloon, sounding rocket) through the APRA program.
  - NASA has invested in suborbital-class payloads for the International Space Station through the APRA program element to realize orbital-class science for a suborbital cost.
  - NASA has invested in additional balloon capabilities, including ULDB flights from New Zealand, to expand the science attainable with scientific balloons.
  - NASA has invested in a new sounding rocket motor, the Peregrine.
  - NASA has investigated orbital sounding rocket capability, and it is not practical and affordable at this time.

Response to Recommendations: Suborbital

- NASA has continued to invest in suborbital-class payloads (balloons, sounding rockets, ISS) through the APRA program: figure shows fiscal year amounts for balloons, rockets, ISS.
  - $32M/yr over FY13-FY15
  - Increase by $7M/yr over FY11-FY12



Response to Recommendations: Suborbital

- NASA has invested in additional balloon capabilities, including mid-latitude Ultra-Long Duration Balloon (ULDB) flights from New Zealand, to expand the science attainable with scientific balloons.
  - Super pressure balloons (SPBs) have been developed by NASA to support LDB flights through diurnal cycles at mid-latitudes: SPBs have been tested from multiple sites, including Sweden, Antarctica, and New Zealand.
  - Long duration ballooning from a mid-latitude site (New Zealand) was demonstrated in 2015 with a 32-day, around-the-world, balloon test.
  - Arc-second pointing capabilities are now available with the facility Wallops Arc Second Pointer (WASP).
  - A second payload integration building has been funded for assembly at McMurdo Station, Antarctica, where three Long Duration Balloon (LDB) flights per season are now standard.
  - A NASA payload recovery plane is being procured for Antarctica.
  - NASA is studying a Balloon Guidance System (BGS) to ensure that Antarctic flights remain over the continent and that mid-latitude flights do not go over densely populated areas.
- Balloon budget has been increased
  - Average $23.4M/yr (FY05-FY09)
  - Average $30.5M/yr (FY10-FY14)
  - Average $36.4M/yr (FY15-FY20, planned)

Response to Recommendations: Suborbital

- NASA has invested in a new sounding rocket motor, the Peregrine.
  - In order to mitigate reliability and availability concerns with current commercial sounding rocket motors, NASA developed a design for a new rocket motor, the Peregrine motor. Development will continue with a goal of attaining a TRL-5 design.
  - The Peregrine project began in 2011; test firings of the Peregrine motor were conducted in February 2015, and the project should attain TRL-5 in FY16.
- NASA has investigated orbital sounding rocket capability, and it is not practical and affordable at this time.
  - Astrophysics Sounding Rocket Assessment Team Study (2009) concluded that small payloads (up to 400 kg) could be launched for 30 day missions at a cost of $10M plus sounding rocket-class payload plus launch vehicle.
  - An orbital sounding rocket program relies on the availability of inexpensive rockets capable of attaining orbit. The 2009 study assumed the availability of the Falcon 1 rocket at a cost of $10M; neither that rocket nor a comparable, low-cost rocket is currently available.
  - The concept can be revisited if small, low cost rockets become available in the future; several companies have announced their intention to develop such rockets, but none have been demonstrated and none are available.

Response to Recommendations: Suborbital

- NASA invested in suborbital-class payloads for the International Space Station via the APRA program element to realize orbital-class science for a suborbital cost.
  - Transportation to ISS and accommodation on ISS (power, communications) are provided by the ISS Program.
  - CALET: U.S. contribution to Japan-led project, U.S. PI: J. Wefel (LSU), launched to ISS in August 2015.
  - ISS-CREAM: Conversion of successful long duration balloon payload to ISS payload, PI: E.-S. Seo (U. Maryland), delivered to KSC in August 2015, scheduled for launch to ISS in June 2016.
  - JEM-EUSO: U.S. contributions to European-led project proposed for ISS, U.S. PI: A. Olinto (U. Chicago); U.S. technology demonstrated on ground prototype (2013) and overnight balloon with helicopter under-flight (2014).

Response to Recommendations: Internat'l Collab

- Decadal Survey (New Worlds, New Horizons in Astronomy and Astrophysics; 2010)

International Collaboration. "In this new era it is imperative that planning for the U.S. research enterprise be done in an international context. (p. 81). An important goal for the U.S. agencies is to place appropriate value on reciprocity arrangements in providing access to foreign astronomical facilities and data sets for U.S. researchers. (p. 85)"

- NASA Response
  - "Principles for Access to Large Federally Funded Astrophysics Projects and Facilities" developed in conjunction with AAAC, OSTP, NSF, and DOE
  - All of NASA's international partnerships include access for U.S. scientists and public release of mission data sets. These conditions are included in the MOUs that NASA signs with its international partners.
  - Examples include Herschel, Planck, XMM-Newton, Suzaku, ASTRO-H, Euclid.

Response to Recommendations: Societal Benefits

- Decadal Survey (New Worlds, New Horizons in Astronomy and Astrophysics; 2010)

Societal Benefits. "Agencies, astronomy departments, and the community as a whole need to refocus their efforts on attracting members of underrepresented minorities to the field (p. 30). The committee believes that NASA's important investments in informal education and public outreach at the current level of 1 percent of each mission's cost should be continued (p. 110)."

- NASA Response
  - NASA has removed education activities from missions, but left missions responsible for communication and public outreach.
  - SMD will manage a competed education program of approximately the same size as the legacy program that it replaces ($42M in FY15).

Response to Recommendations: Societal Benefits

- On September 25, NASA announced that it has selected 27 organizations from across the United States to begin negotiations for cooperative agreement awards totaling $42 million to implement a new strategic approach to more effectively engage learners of all ages on NASA science education programs and activities.
  - Selections were made by the agency's Science Mission Directorate (SMD) in Washington through the Science Education Cooperative Agreement Notice announced in February. Agreement awards can run up to five years, with an additional five-year option. Selectee activities will support Earth science, astrophysics, planetary science and heliophysics.
  - 27 of 73 proposals selected (37%) for negotiations leading to cooperative agreement awards.
    - 15 are from "Legacy" institutions (56% retention rate).
    - Underserved areas, a Community College, expansion of National Science Foundation network, and a Space Grant member are all included in selections.
    - 3 selections support the 2017 Total Solar Eclipse, allowing for one full academic year of preparation.

Response to Recommendations: Societal Benefits

- 15 of 27 selected proposals use astrophysics mission content and/or address astrophysics-related education goals and standards.
- 3 of 27 selected proposals are specifically focused on Astrophysics
  - Space Telescope Science Institute – Baltimore, MD. Denise Smith, Principal Investigator for "NASA's Universe of Learning: An Integrated Astrophysics STEM Learning and Literacy Program"
  - SETI Institute – Mountain View, CA. Edna DeVore, Principal Investigator for "Reaching for the Stars: NASA Science for Girl Scouts"
  - SETI Institute – Mountain View, CA. Dana Backman, Principal Investigator for "Airborne Astronomy Ambassadors (AAA)"
- Full list of 27 selectees is in Backup

Spending: Recommendations vs Planned

Priority	NWNH Spend 2012-2021	NASA Spend 2011-2020	Comments
WFIRST	$1.6B	$853M	Later start, w/ AFTA
Explorers Program	$463M	$1.3B	4 AOs per decade
LISA	$852M	>$10M to FY17	Toward ESA L3
IXO	$200M	>$25M to FY20	Toward ESA Athena
New Worlds Technology	$100M to $200M	~$240M	See slide 61
Inflation Probe Technology	$60M to $200M	~$65M	APRA and SAT
SPICA	$150M	zero	
Astrophysics Theory Prog	$35M additional	$1.5M/yr add'l	TCAN program
Future UV-Opt Space Cap	$40M	$54M	APRA and SAT
Intermediate Tech Dev	$2M/yr to $15M/yr	$17M/yr FY15, $30M/yr FY18	SAT program
Laboratory Astrophysics	$2M/yr additional	flat	
Suborbital Program	$15M/yr add'l	$20M/yr add'l	Payload and balloon
Theory and Comp Networks	$5M/yr NASA	$1.5M/yr NASA	50/50 w/ NSF

National Aeronautics and Space Administration

Preparing for the 2020 Decadal Survey in Astronomy and Astrophysics

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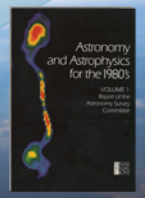
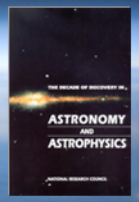
ASTROPHYSICS

Decadal Survey Missions

1972
Decadal Survey
Hubble



1982
Decadal Survey
Chandra

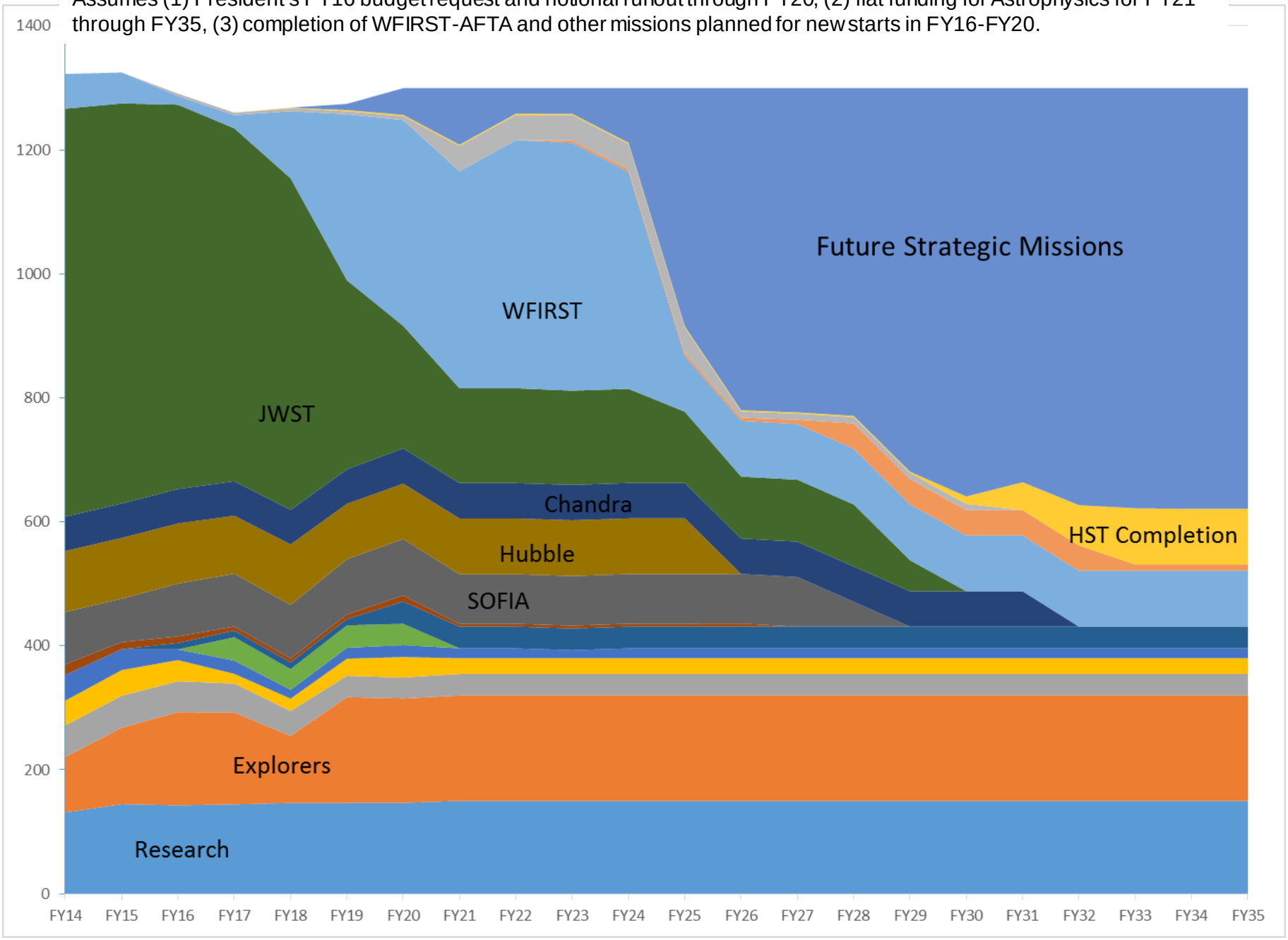


1991
Decadal Survey
Spitzer, SOFIA

2001
Decadal Survey
JWST

2010
Decadal Survey
WFIRST

Assumes (1) President's FY16 budget request and notional runout through FY20, (2) flat funding for Astrophysics for FY21 through FY35, (3) completion of WFIRST-AFTA and other missions planned for new starts in FY16-FY20.



Preparing for the 2020 Decadal Survey
Large Mission Concepts

- Study 3-4 large mission concepts as candidate prioritized large missions
  - Science case
  - Technology assessment
  - Design reference mission with strawman payload
  - Cost assessment
- Charge to the PAGs (January 2015)
  - "I am charging the Astrophysics PAGs to solicit community input for the purpose of commenting on the small set [of large mission concepts to study], including adding or subtracting large mission concepts."
- NASA Plan for Community Input
  - 2015: PAGs gather community input on selecting concepts for study

Preparing for the 2020 Decadal Survey
Large Mission Concepts

Community workshops

- January 3, 2015: PAGs charged @ AAS, Seattle. All PAGs meet.
- February 10-11, 2015: ExoPAG SIG #1 meeting @ JPL, Pasadena
- March 10, 2015: COPAG Virtual Town Hall
- March 19, 2015: Joint PAG EC meeting @ STScI, Baltimore
- April 11-14, 2015: PhysPAG SIGs meet @ Am Phys Soc, Baltimore
- June 2, 2015: ExoPAG Virtual Meeting
- June 3-5, 2015: COPAG Far-IR Workshop @ Pasadena
- June 13-14, 2015: ExoPAG meeting @ AbSciCon, Chicago
- June 25-26, 2015: COPAG UV/Vis SIG meeting @ Greenbelt
- July 1, 2015: PhysPAG session @ HEAD Symposium, Chicago
- July 3, 2015: Joint PAG EC Chair telecon
- July 13, 2015: Joint PAG EC Chair telecon with Paul Hertz
- July 14, 2015: ExoPAG Virtual Meeting
- August 7, Joint PAG Splinter Session @ IAU GA, Honolulu
- August 18, 2015: ExoPAG Virtual Meeting
- August 20, 2015: COPAG Virtual Town Hall
- August 31, 2015: Joint PAG Present @ AIAA Space 2015 Pasadena
- October 7, 2015: Deliver reports to Hertz
- October 21-22, 2015: Astrophysics Subcommittee Meeting

Preparing for the 2020 Decadal Survey
Large Mission Concepts

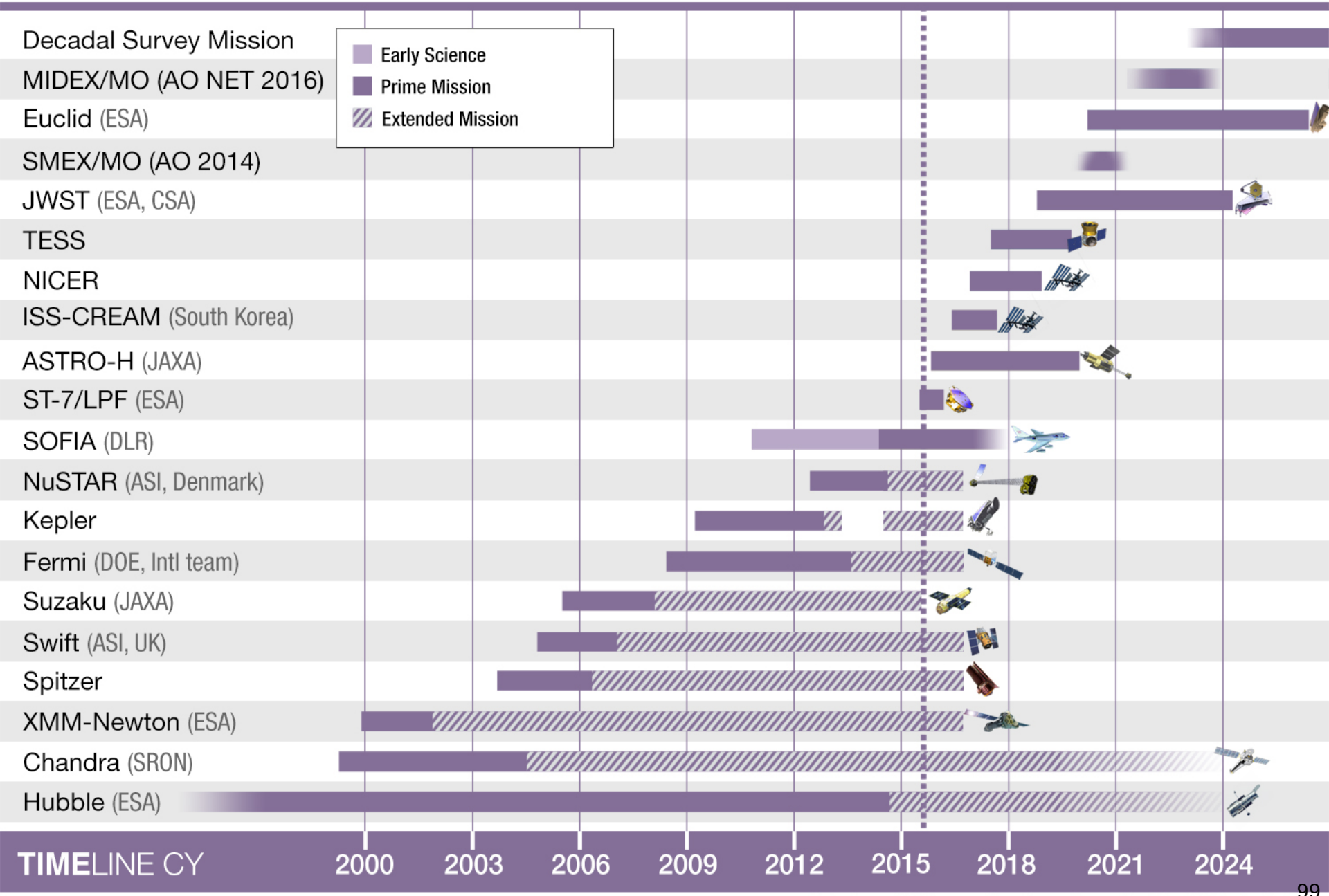
The initial short list (in alphabetical order):

- **FAR IR Surveyor** – The Astrophysics Visionary Roadmap identifies a Far IR Surveyor as contributing through improvements in sensitivity, spectroscopy, and angular resolution.
- **Habitable-Exoplanet Imaging Mission** – The 2010 Decadal Survey recommends that a habitable-exoplanet imaging mission be studied in time for consideration by the 2020 Decadal Survey.
- **UV/Optical/IR Surveyor** –The Astrophysics Visionary Roadmap identifies a UV/Optical/IR Surveyor as contributing through improvements in sensitivity, spectroscopy, high contrast imaging, astrometry, angular resolution and/or wavelength coverage. The 2010 Decadal Survey recommends that NASA prepare for a UV mission to be considered by the 2020 Decadal Survey.
- **X-ray Surveyor** – The Astrophysics Visionary Roadmap identifies an X-ray Surveyor as contributing through improvements in sensitivity, spectroscopy, and angular resolution.

Preparing for the 2020 Decadal Survey
Large Mission Concepts

- Study 3-4 large mission concepts as candidate prioritized large missions
  - Science case
  - Technology assessment
  - Design reference mission with strawman payload
  - Cost assessment
- Charge to the PAGS (December 2014)
  - "I am charging the Astrophysics PAGs to solicit community input for the purpose of commenting on the small set [of large mission concepts to study], including adding or subtracting large mission concepts."
- NASA Plan for Community Input
  - 2015: PAGs gather community input on selecting concepts for study
  - 2016: Appoint STDT and Center study office, STDT assesses technology
  - 2017: Fund technology development through SAT, STDT develops DRM
  - 2018: STDT submits DRM for cost assessment
  - 2019: STDT issues report and provides input to Decadal Survey

Astrophysics Timeline

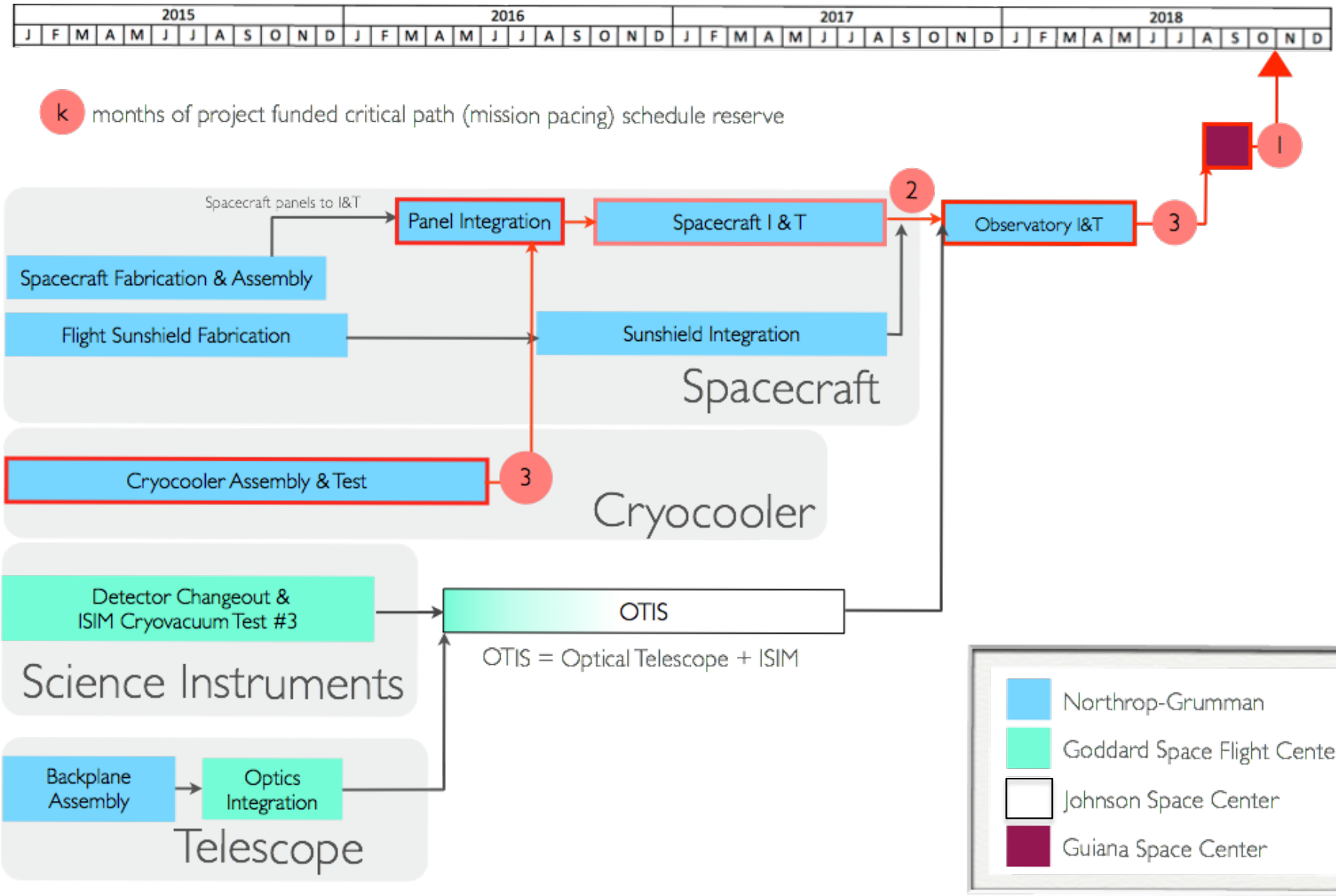


Dates beyond 2016 are contingent upon the results of the 2016 Senior Review

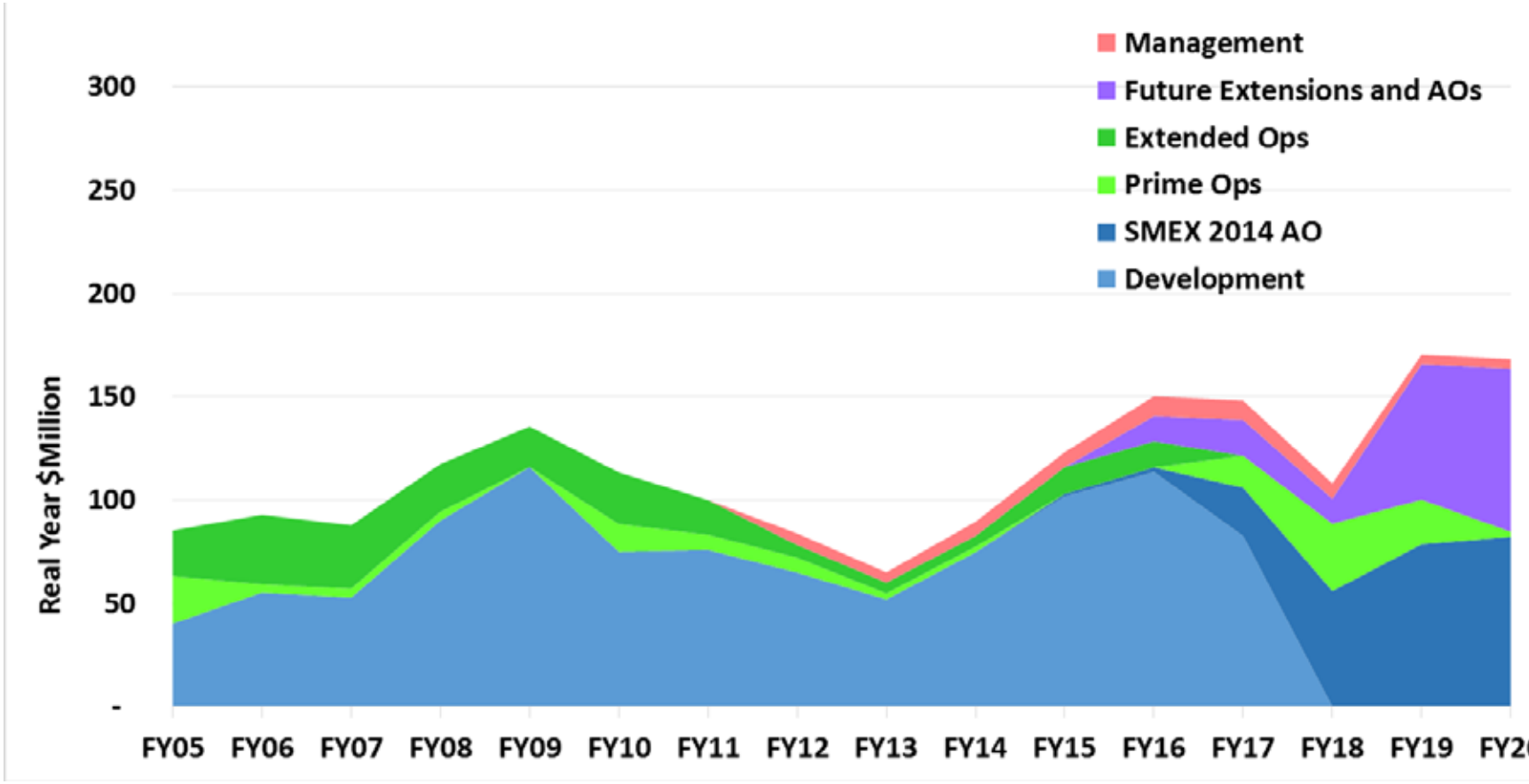
Backup

- Science education selections
- List of Acronyms

JWST Simplified Schedule



Response to Recommendations: Explorers



Map of NASA Science Mission Directorate Science Education Selections

List of Science Education Partners for NASA STEM Agreements

- The organizations selected to enter into negotiations leading to cooperative agreements are:
  - Alabama Space Science Exhibit Commission – Huntsville, AL. Deborah Barnhart, Principal Investigator for "Space Racers: Educating the Next Generation of Explorers about NASA's Missions"
  - American Museum of Natural History - New York City, NY. Rosamond Kinzler, Principal Investigator for "OpenSpace: An Engine for Dynamic Visualization of Earth and Space Science for Informal Education and Beyond"
  - Arizona State University – Tempe, AZ. Linda Elkins-Tanton, Principal Investigator for "NASA SMD Exploration Connection"
  - Challenger Center for Space Science Education - Washington, DC. Stephanie Hall, Principal Investigator for "CodeRed: My STEM Mission"
  - Gulf of Maine Research Institute - Portland, ME. Leigh Peake, Principal Investigator for "Real World, Real Science: Using NASA Data to Explore Weather and Climate"
  - Institute for Global Environmental Strategies – Arlington, VA. Theresa Schwerin, Principal Investigator for "NASA Earth Science Education Collaborative"
  - Jet Propulsion Laboratory – Pasadena, CA. Michelle Viotti, Principal Investigator for "NASA Active and Blended Learning Ecosystem (N-ABLE)"

List of Science Education Partners for NASA STEM Agreements (2)

- NASA Goddard Space Flight Center - Greenbelt, MD. C. Alex Young, Principal Investigator for "Heliophysics Education Consortium: Through the Eyes of NASA to the Hearts and Minds of the Nation"
- National Institute of Aerospace Associates – Hampton, VA. Shelley Spears, Principal Investigator for "NASA eClips 4D Multi-Dimensional Strategies to Promote Understanding of NASA Science: Design, Develop, Disseminate and Discover"
- Northern Arizona University - Flagstaff, AZ. Joelle Clark, Principal Investigator for "PLANETS (Planetary Learning that Advances the Nexus of Engineering, Technology, and Science)"
- Science Museum of Minnesota – Saint Paul, MN. Paul Martin, Principal Investigator for "NASA Space and Earth Informal Science Education Network (SEISE-Net)"
- SETI Institute - Mountain View, CA. Edna DeVore, Principal Investigator for "Reaching for the Stars: NASA Science for Girl Scouts"
- SETI Institute –Mountain View, CA. Dana Backman, Principal Investigator for "Airborne Astronomy Ambassadors (AAA)"
- Southern Illinois University, Edwardsville – Edwardsville, IL. Pamela Gay, "CosmoQuest: Engaging Students & the Public through a Virtual Research Facility"

List of Science Education Partners for NASA STEM Agreements (3)

- Space Science Institute – Boulder, CA. Paul Dusenbery, Principal Investigator for "NASA@ My Library: A National Earth and Space Science Initiative that Connects NASA, Public Libraries and their Communities"
- Space Telescope Science Institute - Baltimore, MD. Denise Smith, Principal Investigator for "NASA's Universe of Learning: An Integrated Astrophysics STEM Learning and Literacy Program"
- University of Alaska, Fairbanks – Fairbanks, AK. Elena Sparrow, Principal Investigator for "Impacts and Feedbacks of a Warming Arctic: Engaging Learners in STEM using NASA and GLOBE Assets"
- University of Colorado, Boulder – Boulder, CO. Douglas Duncan, Principal Investigator for "Enhancement of Astronomy and Earth Science Teaching Using High Resolution Immersive Environments"
- University of Michigan, Ann Arbor – Ann Arbor, MI. Jon Miller, Principal Investigator for "Demonstration of the Feasibility of Improving Scientific Literacy and Lifelong Learning through a Just-in-Time Dissemination Process"
- University of Texas, Austin – Austin, TX. Wallace Fowler, Principal Investigator for "STEM Enhancement in Earth Science"
- University of Toledo – Toledo, OH. Kevin Czajkowski, Principal Investigator for "Mission Earth: Fusing GLOBE with NASA Assets to Build Systemic Innovation in STEM Education"

List of Science Education Partners for NASA STEM Agreements (4)

- University Of Washington, Seattle – Seattle, WA. Robert Winglee, Principal Investigator for "Northwest Earth and Space Sciences Pipeline (NESSP)"
- Wayne County Intermediate School District – Wayne, MI. David Bydlowski, Principal Investigator for "AEROKATS and ROVER Education Network (AREN)"
- WGBH Educational Foundation – Boston, MA. Rachel Connolly, Principal Investigator for "NASA and WGBH: Bringing the Universe to America's Classrooms"

- Of the 27, three organizations are selected to support the science education associated with the upcoming 2017 total solar eclipse over North America:
  - Association of Universities for Research in Astronomy, Inc. – Tucson, AZ. Matthew Penn, Principal Investigator for "Geographically Distributed Citizen Scientist Training for the 2017 Citizen CATE Experiment"
  - Exploratorium – San Francisco, CA. Robert Semper, Principal Investigator for "Navigating the Path of Totality"
  - Southwestern Community College – Sylva, NC. Lynda Parlett, Principal Investigator for "Smoky Mountains STEM Collaborative: Bridging the Gaps in the K-12 to Post-Secondary Education Pathway"

Acronym List

- 3G Third Generation
- 4G Fourth Generation
- AAAC Astronomy and Astrophysics Advisory Committee
- AAS American Astronomical Society
- ADAP Astrophysics Data Analysis Program
- AFTA Astrophysics Focused Telescope Asset
- AO Announcement of Opportunity
- APD Astrophysics Division
- APRA Astrophysics Research and Analysis
- APS Astrophysics Subcommittee
- ASI Italian Space Agency
- ASIC Application Specific Integrated Circuit
- ASTRO-H not an acronym
- ATHENA Advanced Technology High Energy Astrophysics
- ATLAST Advanced Technology Large Area Space Telescope
- ATP Astrophysics Theory Program
- AURA Association of Universities for Research in Astronomy
- BEFS Beyond Einstein Foundation Science
- BGS Balloon Guidance System
- CAA Committee on Astronomy and Astrophysics
- CALET Calorimetric Electron Telescope
- CATE Cost and Technical Evaluation
- CDR Critical Design Review
- CHIPS Cosmic Hot Interstellar Plasma Spectrometer
- CMB Cosmic Microwave Background
- CNES French Space Agency
- COPAG Cosmic Origins Program Analysis Group
- COR Cosmic Origins Program
- CREAM Cosmic Ray Energy and Mass
- CSA Canadian Space Agency
- CST Community Science Team
- CXO Chandra X-ray Observatory
- DCL Detector Characterization Lab
- DOE Department of Energy
- DRM Design Reference Mission
- DRS Disturbance Reduction System
- DSIAC Decadal Survey Implementation Advisory Committee
- EBEX E&B Experiment
- EC Executive Committee
- ENSCI Euclid NASA Science Center at IPAC
- ESA European Space Agency
- ESD Earth Science Division
- EUSO Extreme Universe Space Observatory
- EUVE Extreme Ultraviolet Explorer

Acronym List

- EXEP Exoplanet Exploration Program
- EXOPAG Exoplanet Exploration Program Analysis Group
- FGST Fermi Gamma-ray Space Telescope
- FIR Far Infrared
- FTE Full Time Equivalent
- FUSE Far Ultraviolet Spectroscopic Explorer
- FY Fiscal Year
- GAIA not an acronym
- GALEX Galaxy Explorer
- GEMS Gravity and Extreme Magnetism Small Explorer
- GO Guest Observer
- GOAT Gravitational Observatory Advisory Team
- GP-B Gravity Probe B
- GSFC Goddard Space Flight Center
- GUSTO Gal/Xgal U/LDB Spectroscopic-Stratospheric Terahertz Observatory
- GW Gravitational Wave
- HabEx Habitable Exoplanet Imaging Mission
- HDST High Definition Space Telescope
- HEOMD Human Exploration and Operations Mission Directorate
- HETE High Energy Transient Explorer
- HMV Heavy Maintenance Visit
- HOSTS Hunt for Observable Signatures of Terrestrial Systems
- HPD Heliophysics Division
- HQ Headquarters
- HST Hubble Space Telescope
- INTEGRAL International Gamma-Ray Laboratory
- IPAC Infrared Processing and Analysis Center
- IR Infrared
- ISS International Space Station
- IXO International X-ray Observatory
- IXPE Imaging X-ray Polarimetry Explorer
- JAXA Japan Aerospace Exploration Agency
- JEM Japanese Experiment Module
- JPL Jet Propulsion Laboratory
- JWST James Webb Space Telescope
- K2 Second Kepler Mission
- KDP Key Decision Point
- L1 ESA First Large Mission
- L2 ESA Second Large Mission
- L2 Second Earth-Sun Lagrangian Point
- L3 ESA Third Large Mission
- LBTI Large Binocular Telescope Interferometer
- LDB Long Duration Balloon

Acronym List

- LISA Laser Interferometer Space Antenna
- LPF LISA Pathfinder
- LRD Launch Readiness Date
- LRR Launch Readiness Review
- LTSA Long Term Space Astrophysics
- LUVOIR Large Ultraviolet/Visible/Infrared
- M5 ESA Fifth Medium Mission
- MCP Microchannel Plate
- MCR Mission Concept Review
- MDR Mission Design Review
- MIDEX Medium-class Explorer
- MO Mission of Opportunity
- MOU Memorandum of Understanding
- MSFC Marshall Space Flight Center
- NASA National Aeronautics and Space Administration
- NET No Earlier Than
- NICER Neutron star Interior Composition Explorer
- NIR Near Infrared
- NISP Near Infrared Spectroscopic Photometer
- NN-EXPLORE NASA-NSF Exoplanet Research Program
- NOAO National Optical Astronomy Observatory
- NRC National Research Council
- NRO National Reconnaissance Office
- NSF National Science Foundation
- NuSTAR Nuclear Spectroscopic Telescope Array
- NWNH New Worlds, New Horizons in Astronomy and Astrophysics
- OMC Occulting Mask Coronagraph
- OEd Office of Education
- OMB Office of Management and Budget
- OSS Origins of Solar Systems program
- OSTP Office of Science and Technology Policy
- PAG Program Analysis Group
- PCOS Physics of the Cosmos Program
- PDR Preliminary Design Review
- PhysPAG Physics of the Cosmos Program Analysis Group
- PIAACMC Phase Induced Amplitude Apodization Complex Mask Coronagraph
- PIPER Primordial Inflation Polarization Explorer
- PO Program Office
- PPP Program Prioritization Panel
- PRAXyS Polarimeter for Relativistic Astrophysical X-ray Sources
- PSD Planetary Science Division

Acronym List

- QE Quantum Efficiency
- R&A Research and Analysis
- R&T Research and Technology
- RFI Request for Information
- RFP Request for Proposals
- ROSAT Roentgen Satellite
- ROSES Research Opportunities in Space and Earth Science
- RTF Nancy Grace Roman Technology Fellowship program
- RXTE Rossi X-ray Timing Explorer
- RY Real Year
- SAG Science Analysis Group
- SAT Strategic Astrophysics Technology
- SCS Sensor Chip System
- SDR System Definition Review
- SDT Science Definition Team
- SFP Science Frontier Panel
- SIG Science Interest Group
- SIR System Integration Review
- SMD Science Mission Directorate
- SMEX Small Explorer
- SOFIA Stratospheric Observatory for Infrared Astronomy
- SPB Super Pressure Balloon
- SPHEREx Spectro-Photometer for the History of the Universe, Epoch of Reionization, and Ices Explorer
- SPIDER not an acronym
- SPICA Space Infrared Telescope for Cosmology and Astrophysics
- SR&T Supporting Research and Technology
- SRB Standing Review Board
- SST Spitzer Space Telescope
- ST-7 Space Technology 7
- STDT Science and Technology Definition Team
- STEM Science Technology Engineering and Math
- STMD Space Technology Mission Directorate
- STScI Space Telescope Science Institute
- SWAS Submillimeter Wave Astronomy Satellite
- SWG Science Working Group
- SXS Soft X-ray Spectrometer
- TCAN Theoretical and Computational Astrophysics Networks program
- TCOP Technology Development for Cosmic Origins Program
- TDEM Technology Development for Exoplanet Missions

Acronym List

- TESS Transiting Exoplanet Survey Satellite
- TPCOS Technology Development for Physics of the Cosmos Missions
- TRL Technology Readiness Level
- ULDB Ultra Long Duration Balloon
- US United States
- UV Ultraviolet
- WASP Wallops Arc Second Pointer
- WFIRST Wide-Field Infrared Survey Telescope
- WISE Widefield Infrared Survey Explorer
- WIYN Wisconsin Indiana Yale NOAO
- WMAP Wilkinson Microwave Anisotropy Mapper
- WPS WFIRST Preparatory Science
- XMM X-ray Multi-Mirror Mission
- XRP Exoplanet Research Program