National Aeronautics and Space Administration

Astrophysics Update

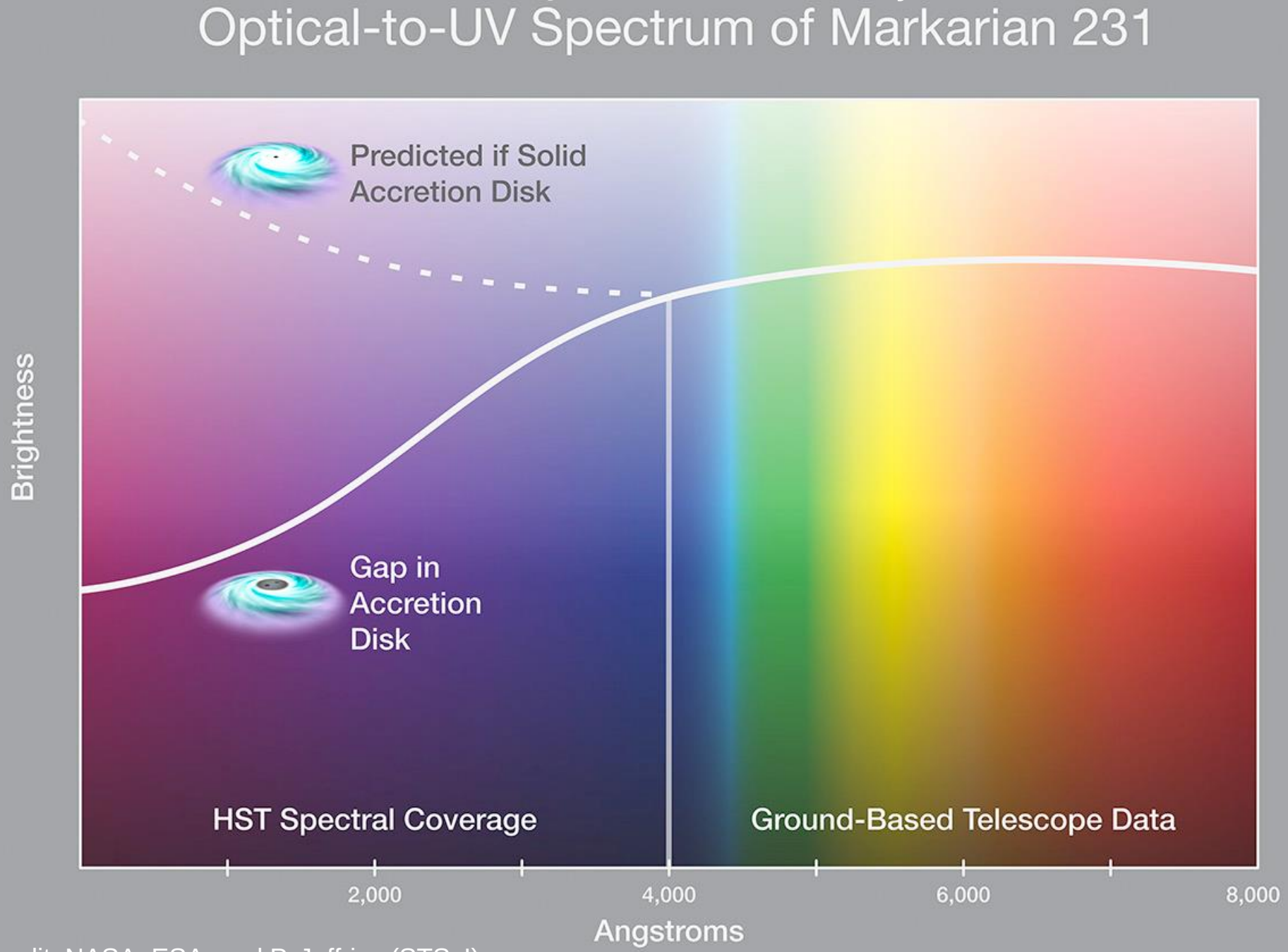
Astrophysics

Paul Hertz
Director, Astrophysics Division
Science Mission Directorate
@PHertzNASA

Astrophysics Subcommittee
October 22, 2015

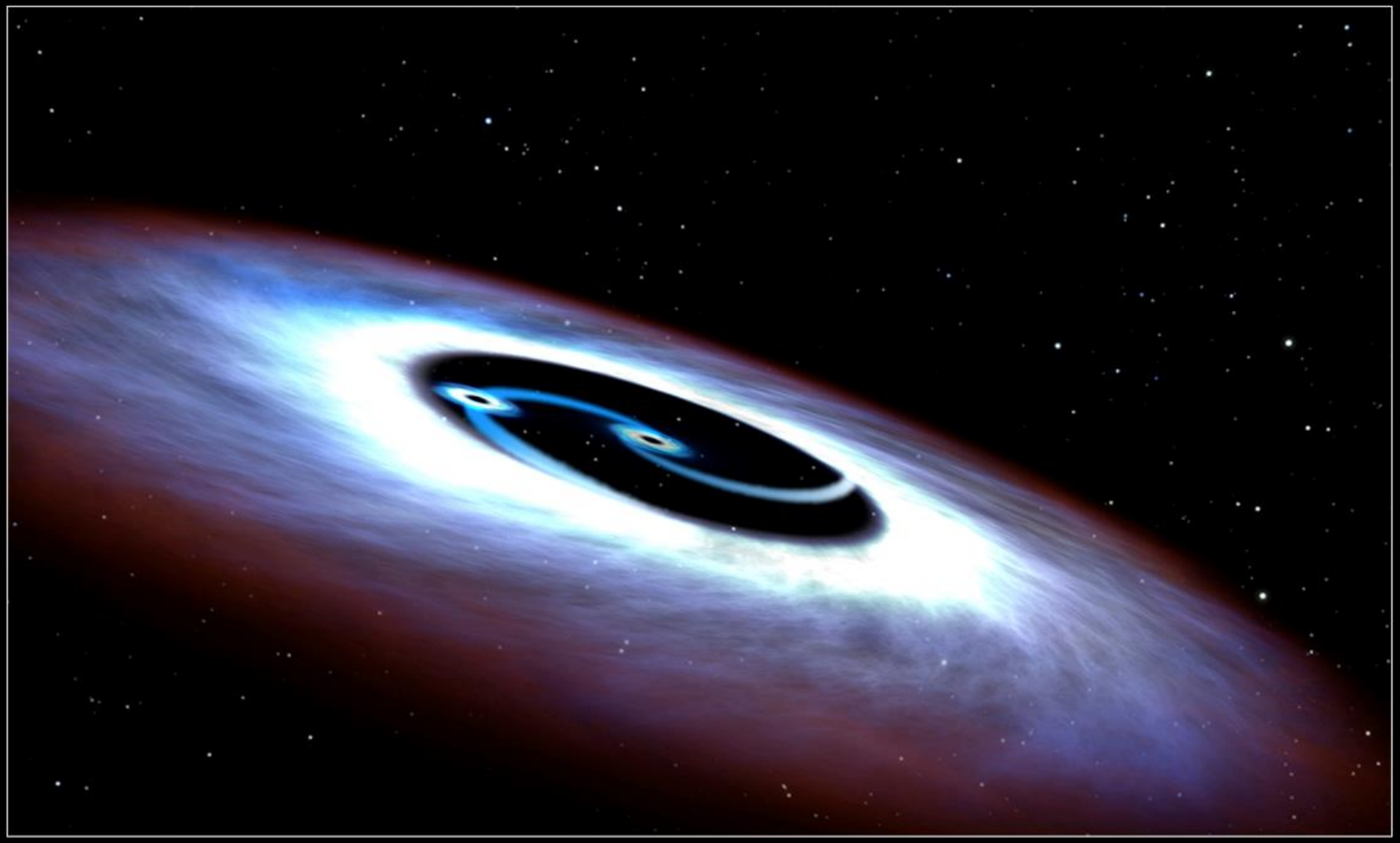
www.nasa.gov

Hubble Finds That the Nearest Quasar is Powered by a Double Black Hole



Credit: NASA, ESA, and P. Jeffries (STScI)

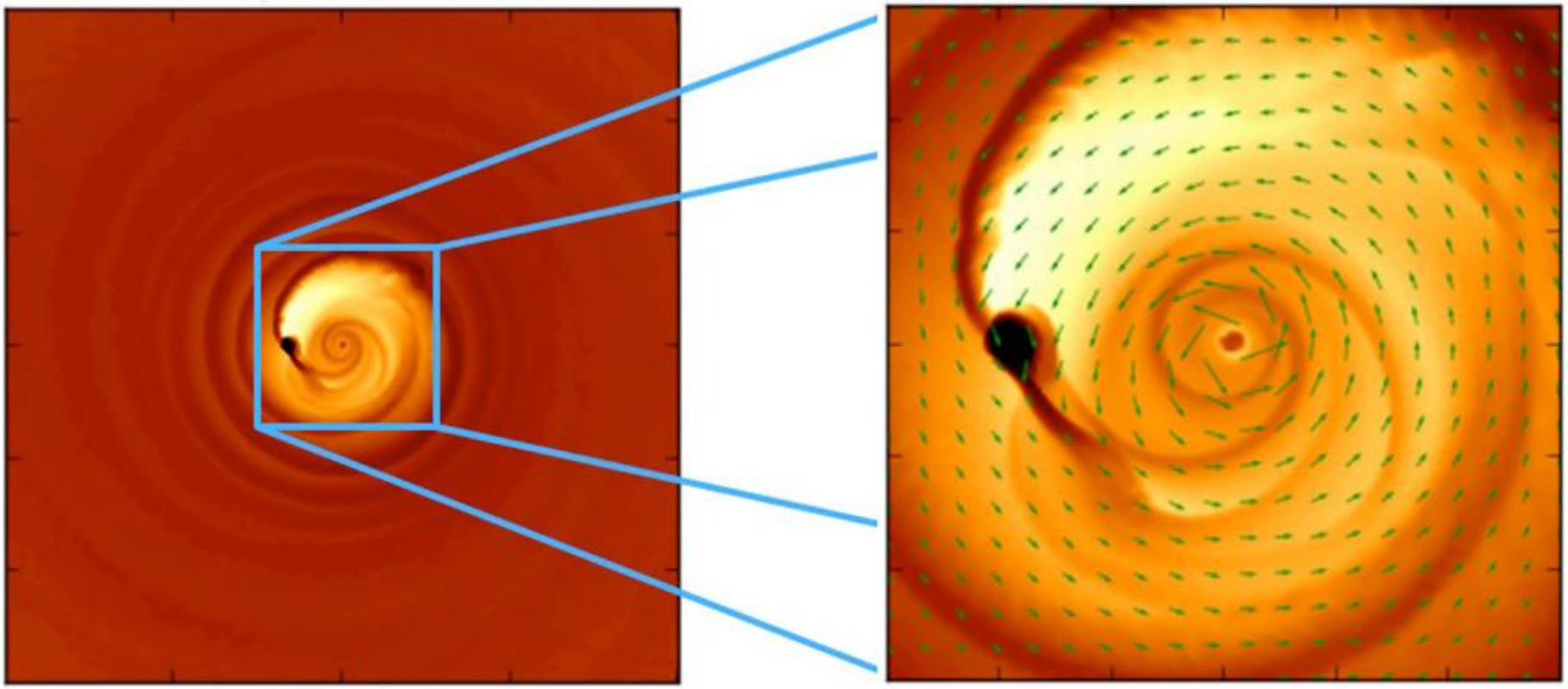
Hubble Finds That the Nearest Quasar is Powered by a Double Black Hole



Artist's View of a Binary Black Hole

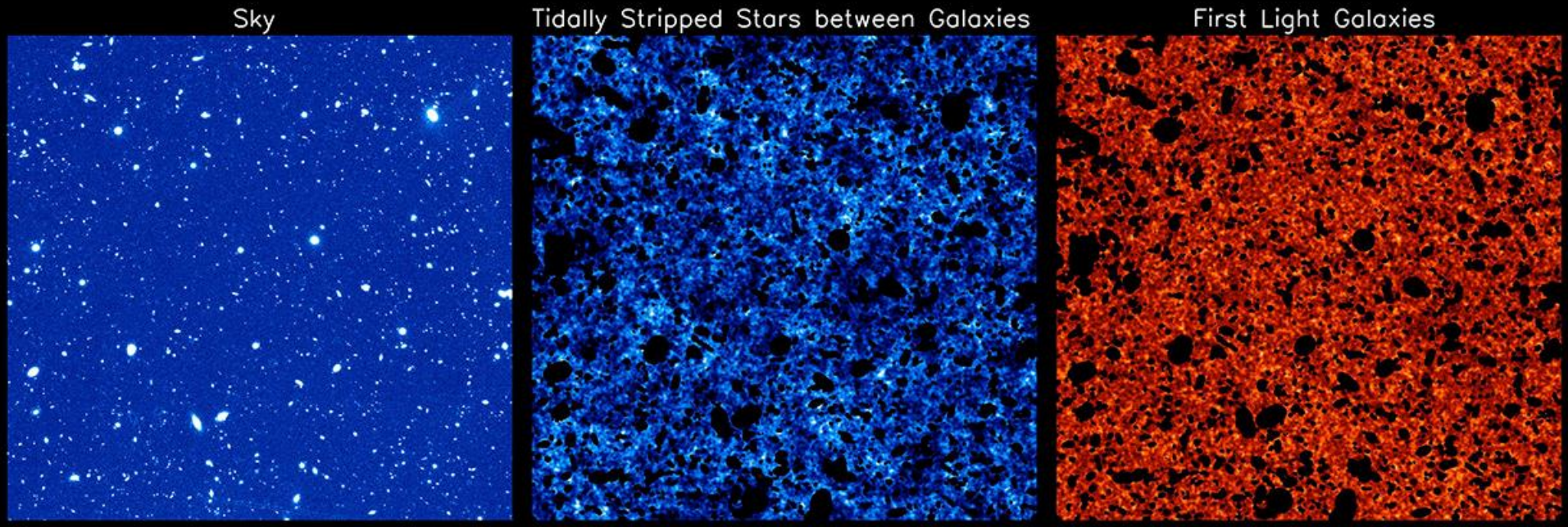
NASA and ESA ▪ STScI-PRC15-31a

Funky Light Signal From Colliding Black Holes Explained (GALEX, Hubble)



Simulation: Columbia University

Hubble Uncovers Clues of Earliest Galaxies



Credit: NASA, ESA, and K. Mitchell-Wynne (University of California, Irvine)

A Precocious Black Hole (in CID-947)

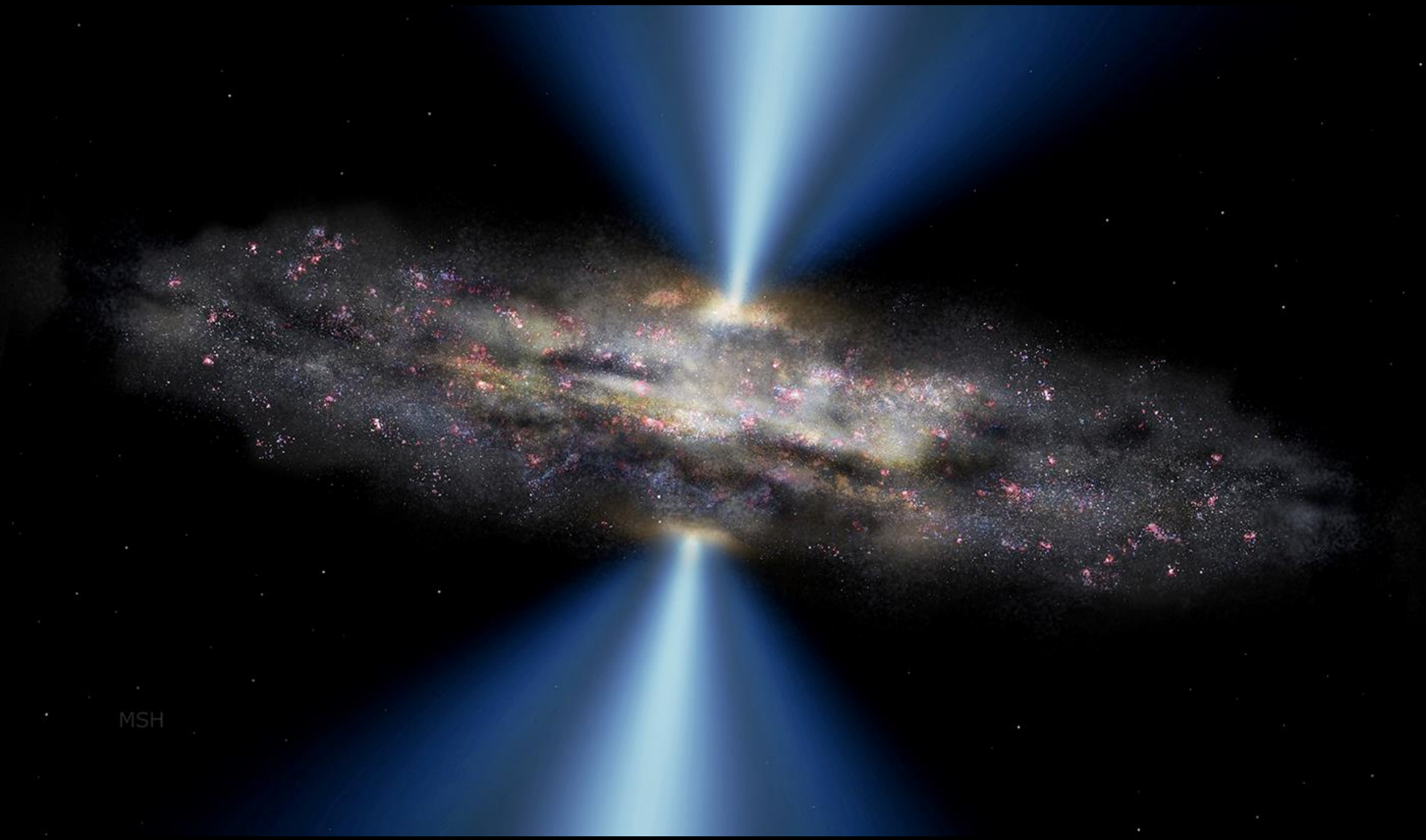
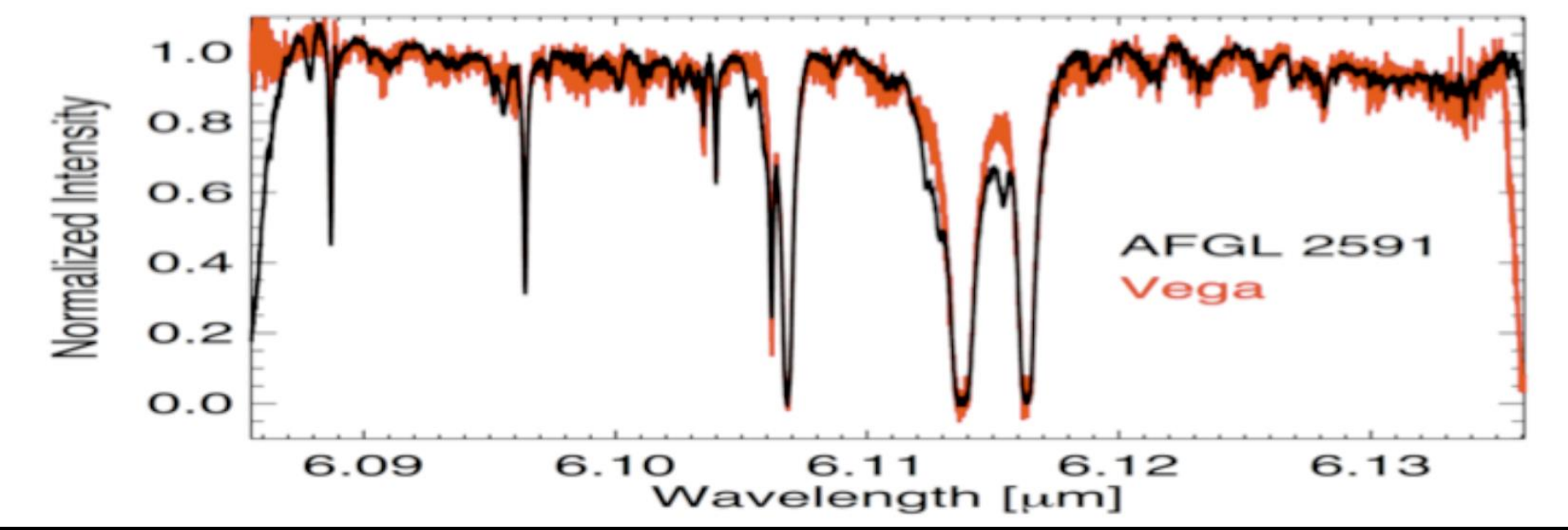


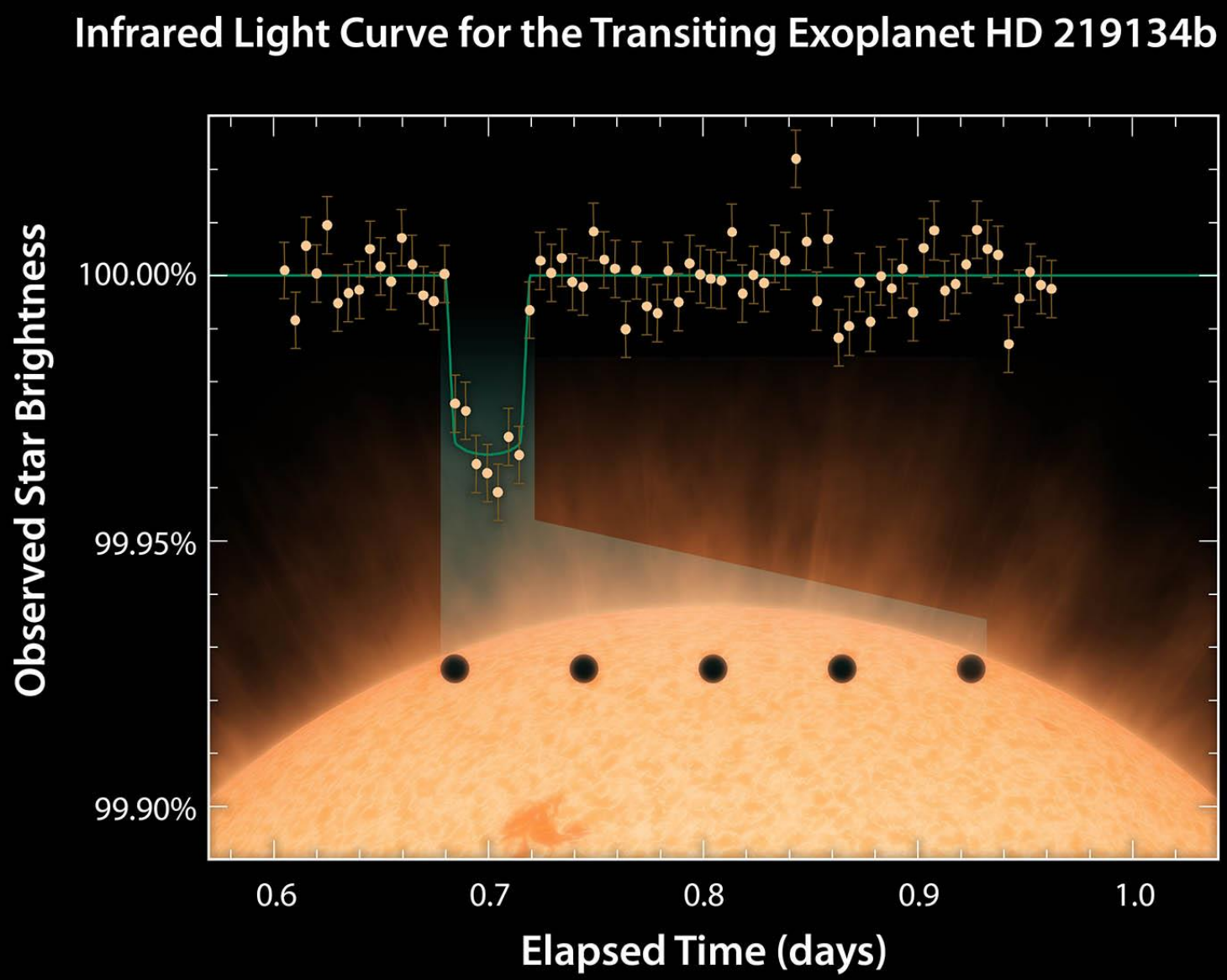
Illustration: M. Helfenbein, Yale University / OPAC

SOFIA observes Water Around the Protostar AFGL 2591



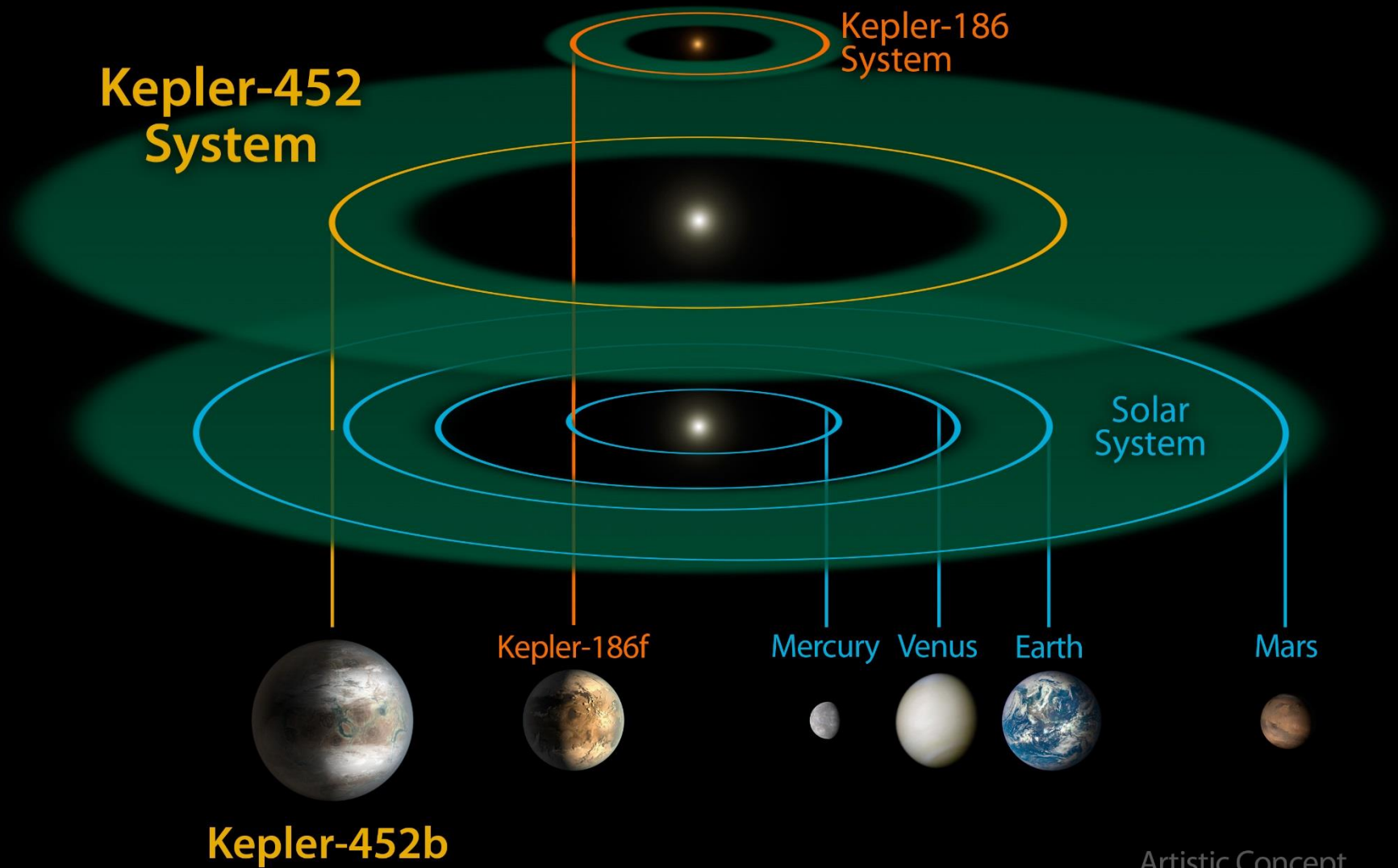
Credit: indriolo et al.

Spitzer Confirms Closest Rocky Exoplanet



Credit: NASA/JPL-Caltech

Kepler Mission Discovers Bigger, Older Cousin to Earth



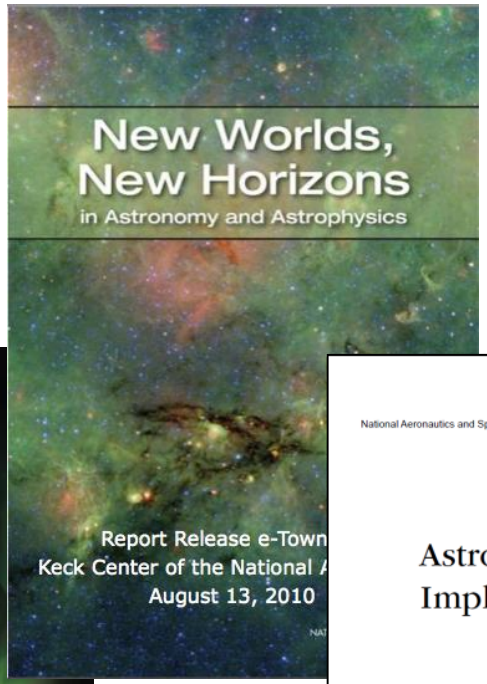
Credits: NASA/JPL-Caltech/R. Hurt

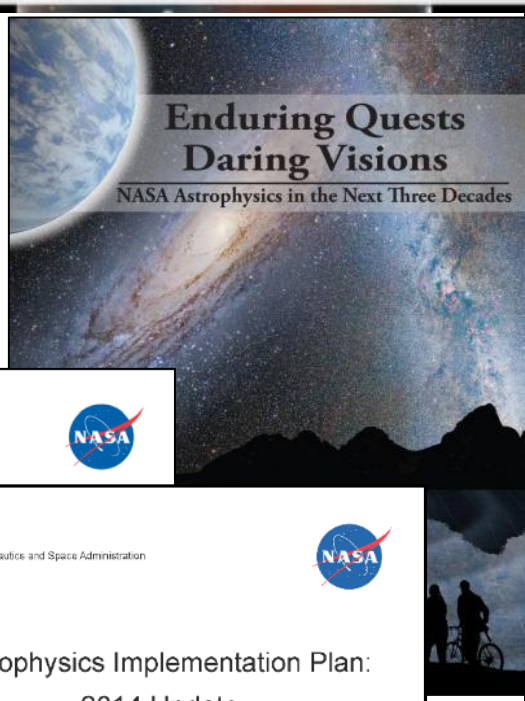
EXOPLANETS 20/20

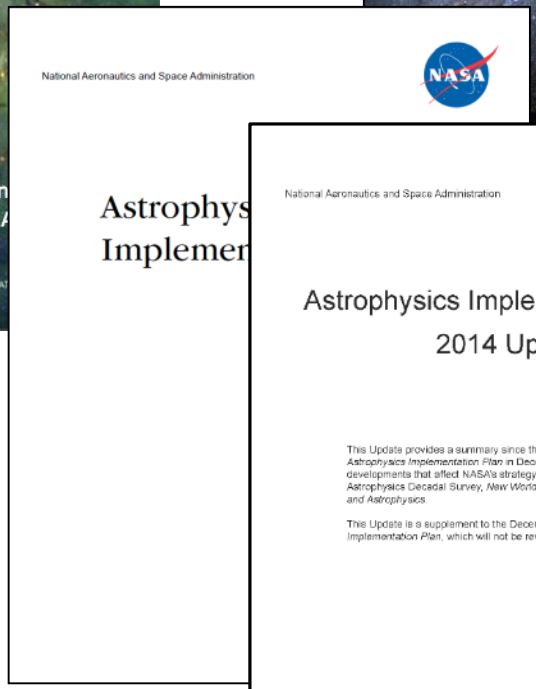
Celebrating the last 20 years–and imagining the next 20 years–of exoplanet exploration

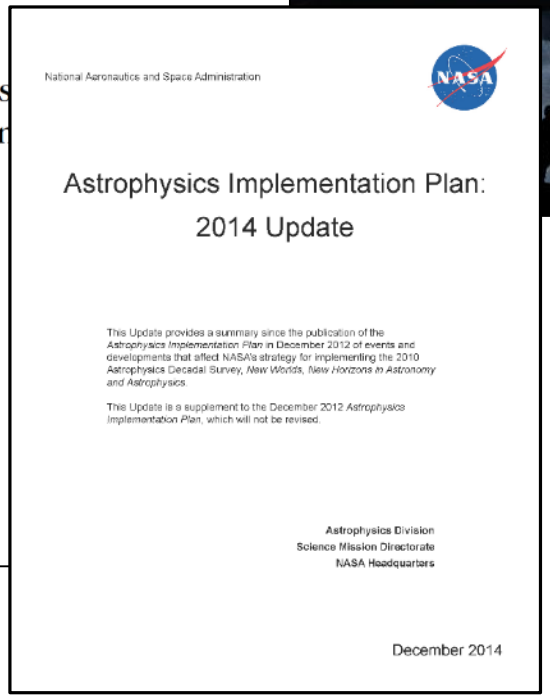
October 10-11, JPL Open House with Exoplanet Theme
October 19, NASM What's New in Aerospace Forum: "Exploring Alien Atmospheres."
October 20, Congressional Staffers Lunch and Learn: "The Search for Planets, Habitability, Life in Our Galaxy."
October 20, NASM Exoplanets 20/20–Celebrating 20 Years of Exoplanet Exploration, Imagining the Next 20 Years
October 21, Carnegie Capital Science, "Hunting Planets: Celebrating 20 Years of Exoplanets."
October 22, Reditt "Ask Me Anything" on Exoplanets
October 22-23, Thursday-Friday, Astrophysics Subcommittee Meeting at GSFC

Astrophysics Driving Documents







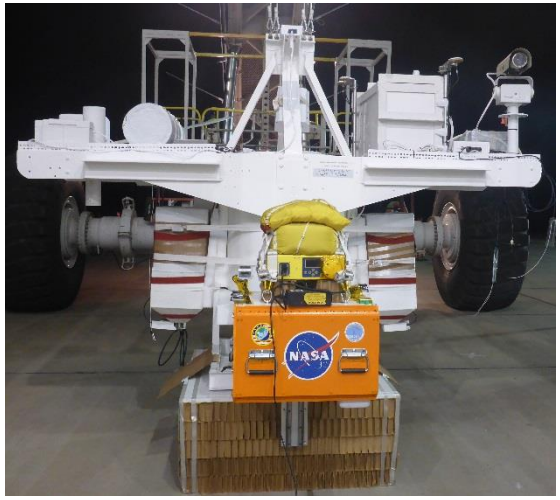


http://science.nasa.gov/astrophysics/documents

Astrophysics - Big Picture

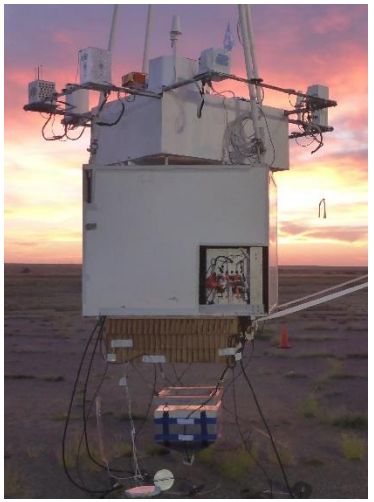
- **The FY16 budget request provides funding for NASA astrophysics to continue its programs, missions, and projects as planned**
  - The total funding (Astrophysics including JWST) is flat at ~$1.3B through FY20
  - Fully fund JWST to remain on plan for an October 2018 launch
  - Fund continued pre-formulation and technology work leading toward WFIRST; rate of progress depends on FY16 appropriation level
- **The operating missions continue to generate important and compelling science results, and new missions are under development for the future**
  - Chandra, Fermi, Hubble, Kepler/K2, NuSTAR, Spitzer, Swift, XMM-Newton all operating well; next Senior Review is Spring 2016 for FY17+; Suzaku mission ended
  - SOFIA is in prime operations as of May 2014; Senior Review is Spring 2018
  - Missions on track for launch include LISA Pathfinder (2015), ASTRO-H (2015/2016), ISS-CREAM (2016), NICER (2016), TESS (2017), JWST (2018), Euclid (2020)
  - WFIRST being studied, next Explorers being selected (SMEX in 2015, MIDEX in 2017), NASA joining ESA's Athena and ESA's L3 gravitational wave observatory
- **Progress being made against recommendations of the 2010 Decadal Survey**
  - Update to the Astrophysics Implementation Plan released in December 2014
  - NRC Mid Decade Review (with NSF, DOE) underway; Jackie Hewitt (MIT) is chair; report expected in May 2016
  - NASA initiating large mission concept studies as input for 2020 Decadal Survey
- **All ongoing work continuing under FY16 Continuing Resolution**

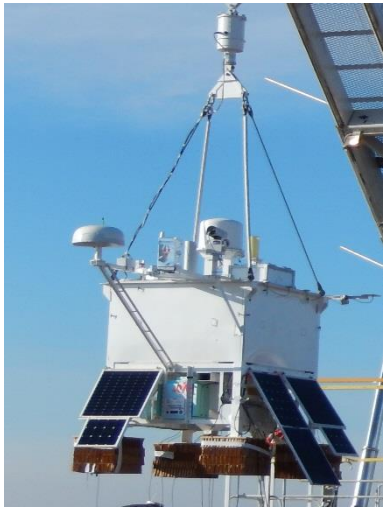
FY 2015 Fort Sumner Balloon Campaign



Test Flight I – Robert Salter, CSBF
Launch Date: September 4, 2015 /14:55 Z
Flight Duration: 7 hrs 45 min

High Altitude Student Platform (HASP) – Dr. Greg Guzik, Louisiana State Univ.
Launch Date: Sept. 7, 2015 /13:47 Z
Flight Duration: 26 hrs 31 min





RaD-X – Dr. Chris Mertens, LaRC
Launch Date: Sept. 25, 2015 /17:05:39 Z
Flight Duration: 21 hrs 52 min

Test Flight II – Bryan Stilwell, CSBF
Launch Date: Oct. 10, 2015 /14:51:47 Z
Flight Duration: 11 hrs 27 min

Upcoming Suborbital Launches

- Fall/Winter FY16 Sounding Rocket Launches @ White Sands NM
  - Planet Imaging Concept Testbed Using a Rocket Experiment (PICTURE); S. Chakrabarti, U. Massachusetts at Lowell (Nov 2015)
  - Diffuse X-ray emission from the Local galaxy (DXL); M. Galeazzi, U. Miami (Dec 2015)
  - Far-UV Off Rowland-circle Telescope for Imaging and Spectroscopy (FORTIS); S. McCandliss, Johns Hopkins U. (Dec 2015)
  - Colorado High-resolution Echelle Stellar Spectrograph (CHESS); K. France, U. Colorado (Feb 2015)
  - Micro-X; E. Figueroa, M.I.T. (Mar 2015)
- Winter FY16 Long Duration Balloon Campaign @ McMurdo Antarctica
  - Gamma-Ray Imager/Polarimeter for Solar Flares (GRIPS); P. Saint-Hilaire, U.C Berkeley (Dec 2015)
  - Stratospheric Terahertz Observatory (STO-II); C. Walker, U. Arizona (Dec 2015)
- Spring FY16 Ultra Long Duration Balloon Campaign @ Wanaka NZ
  - Compton Spectrometer and Imager (COSI); S. Boggs, U.C. Berkeley (Apr 2015)

2016 Senior Review (SR) Plans

	LRD	EOPM	
Hubble	1990		Delta SR; Hubble Panel
Chandra	1999		Delta SR; Chandra Panel
XMM (ESA)	1999		Standard SR; Main Panel
Spitzer	2003		Standard SR; Main Panel
Swift	2004		Standard SR; Main Panel
Suzaku (JAXA)	2005		No review; EOM plan approved
Fermi	2008	2013	Standard SR; Main Panel
Kepler/K2	2009	2013	Standard SR; Main Panel
NuSTAR	2012	2014	Standard SR; Main Panel
SOFIA	2014	2019	Review NET 2018
LISA Pathfinder (ESA)	2015	2016	Out of cycle review, if needed
ASTRO-H (JAXA)	2016	2019	Review NET 2018
NICER	2016	2018	Review NET 2018
TESS	2017	2019	Review NET 2018

NASA's Evolving Communications Policy

The role of science missions in NASA communications has evolved since missions were directed to propose and spend 1% of their total budget on education and public outreach (EPO). In 2014:

- NASA's policy documents established new definitions for communications.
  - Traditional news and social media, multimedia and public outreach and engagement were consolidated.
- EPO funding was removed from mission budgets.
- Education activities and funding were consolidated within SMD, under the Director for Science Engagement and Partnerships (see K. Erickson presentation)
  - Activities and funding were restructured along science disciplines, not missions.
  - The Director for Science Engagement and Partnerships has responsibility for integrated education strategies within SMD.

NASA's Definition of Communications

NASA has defined communications as follows:

- A comprehensive set of activities to effectively convey, and provide an understanding and inspiration about NASA's work, its objectives and benefits to target audiences, the public and other stakeholders, including NASA employees.
- These activities are intended to promote interest and foster participation in NASA's endeavors, and to develop exposure to, and appreciation for, Science, Technology, Engineering, and Math (STEM).

NOTE: This SMD policy does not cover technical communications directed at the scientific and technical community including scientific papers, technical reports, and web sites serving mission data and other technical information.

Roles and Responsibilities

NASA Center or JPL Office of Communications

- Missions must use the communications office of a NASA center or JPL to manage the communications plan and activities.
- These communications offices will be responsible for leading, coordinating, and executing mission communications activities -- in coordination with the mission's Principal Investigator (PI) for PI-led missions -- and with approval of Headquarters SMD and Office of Communications.
- The communications office develops the communications plan with the project and PI during Phase B of the mission.
- Mission-related communications are funded from the project budget (not within the PI's mission cost cap).

Roles and Responsibilities

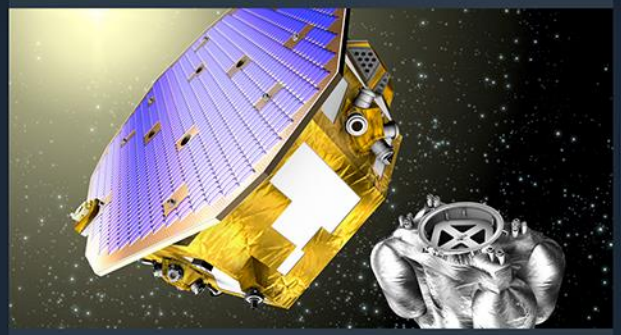
Principal Investigators

- The PI is a key spokesperson for the mission – along with NASA officials -- and is integral in communicating mission updates, science, and new discoveries.
- The PI provides content, analysis, and context for communications activities to convey an understanding of the mission, its objectives and benefits to target audiences, the public, and other stakeholders.
- The PI coordinates with the designated NASA center communications office for all mission-related communications activities.
- All mission news releases are reviewed by the PI (or designee).
- In the case of incompatible views, NASA has final decision on release of public products, while ensuring that scientific and technical information remains accurate and unfiltered.

Astrophysics Missions in Development

LISA Pathfinder
12/2015

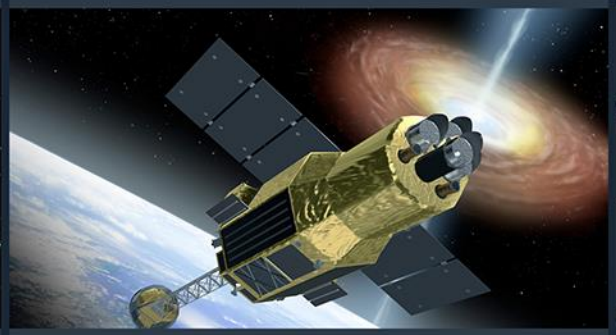
ESA-led Mission



NASA supplied the ST7/Disturbance Reduction System (DRS)

ASTRO-H
11/2015 NET

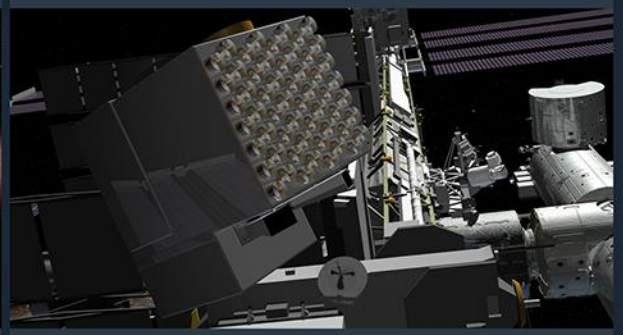
JAXA-led Mission



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

NICER
8/2016

NASA Mission



Neutron Star Interior Composition Explorer

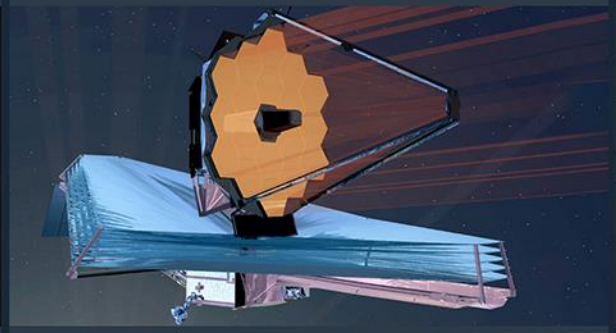
TESS
8/2017

NASA Mission

Transiting Exoplanet Survey Satellite

JWST
10/2018

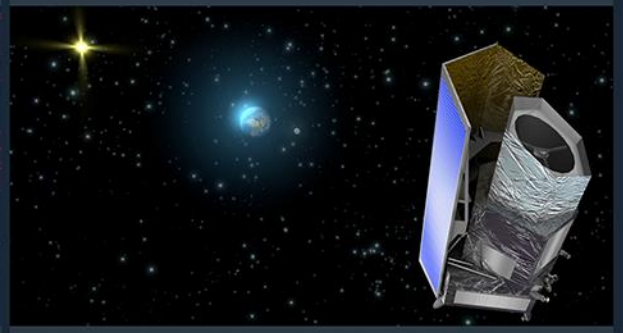
NASA Mission



James Webb Space Telescope

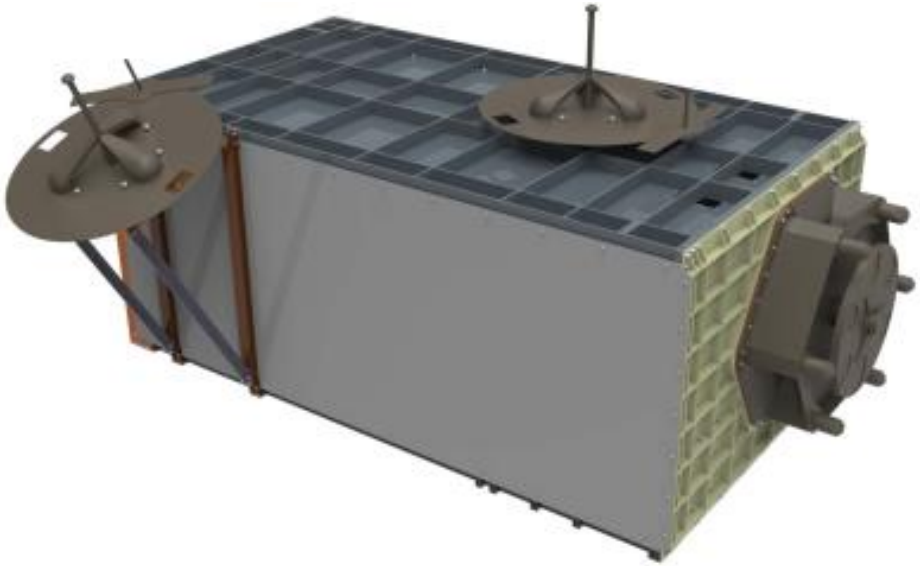
Euclid
2020

ESA-led Mission



NASA is supplying the NISP Sensor Chip System (SCS)

CREAM
Cosmic Ray Energetics and Mass



PI: Eun-Suk Seo.

Mission: Cosmic ray particle detector astrophysics.

Science goal: Measure cosmic ray particle energy spectra rom 10 exp12 to 10 exp15 eV over elemental range of protons to iron.

Instruments: Tungsten/scintillating fiber Calorimeter, Silicon charge detector, Top and Bottom counting detectors, Boronated Scintillator detector.

Operations: 2016 launch with 1 year minimum required, 3 years desired.

CURENT STATUS:

- Suborbital class research project for flight operations on the International Space Station (ISS) Japanese Exposed Facility (JEM-EF).
- Major partners:
  - PI and science lead: Univ. of MD
  - Project Management : NASA WFF
  - Other science collaborators: Sungkyunkwan National Univ. (South Korea, Kyungpock National Univ. (South Korea), Northern Kentucky Univ., Penn State Univ.
- Tentative launch date: August 2016 on SpaceX-11 to the ISS.
- KDP-C: April 2013
- KDP-D: September 2014
- Delivered to KSC: August 2015

LPF - Status

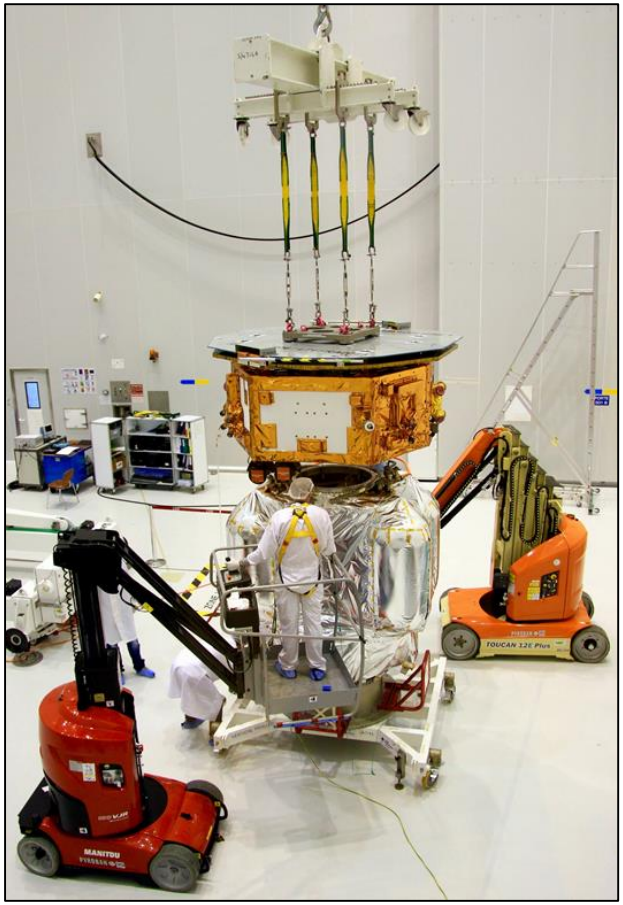
- 2012: ST7 delivered to ESA, integrated later in the year
- ESA thrusters changed to GAIA cold gas thrusters
- Final ground testing met or exceeded all requirements.
- September 3: spacecraft, propulsion module and launch I&T complete, ready for shipping
- Numerous operations exercises have been carried out.
- October 8: Flown to Kourou.
- December 1, 11:15 pm EST: scheduled launch on Vega 6
- L+74 d: LTP operations start
- L+186 d: ST7 operations start
- L+288 d: Nominal mission ends.
- Extended mission under consideration.

ST-7/LISA Pathfinder
ST-7/Disturbance Reduction System (DRS)

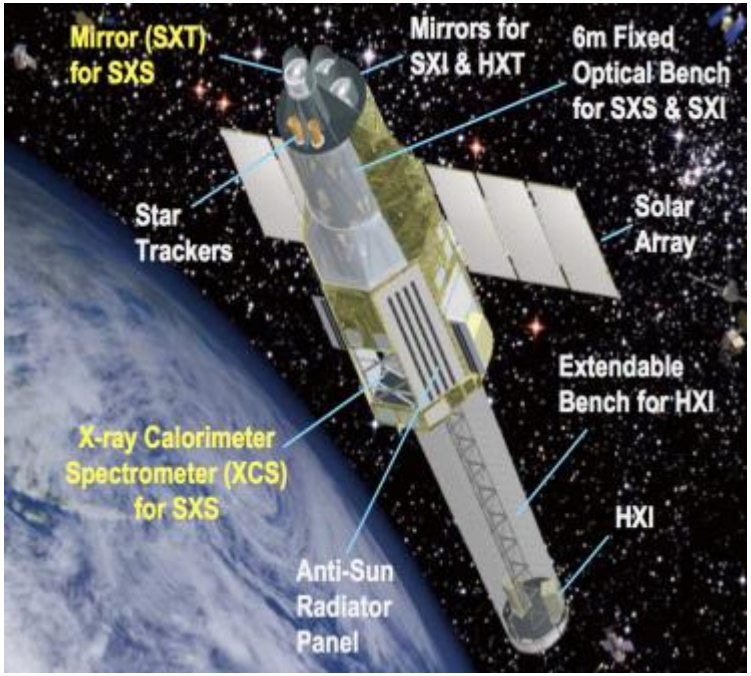
- ESA Mission with NASA Collaborating
- Project Category: 3 Risk Class: C
- DRS flies on the ESA LISA Pathfinder spacecraft
- Sun-Earth L1 halo orbit
- Drag-free satellite to offset solar pressure
- Payload delivery: July 2009 – COMPLETE
- Launch date: December 2, 2015
- LPF prime mission: 7 months
- Data Analysis: 12 months

CURRENT STATUS:

- LISA Pathfinder shipped to Guiana Space Port, Kourou, French Guiana-on October 8
- Spacecraft final closeouts are ongoing
- Launch December 2, 2015 (UT)
- Extended mission being discussed



ASTRO-H
Soft X-ray Spectrometer and Soft X-ray Telescope Mirrors



- **Explorer Mission of Opportunity**
- **PI**: R. Kelley, Goddard Space Flight Center
- **Launch Date**: NET Jan 2016 on JAXA H-IIA
- **Science Objectives**: Study the physics of cosmic sources via high-resolution X-ray spectroscopy. The SXS will enable a wide range of physical measurements of sources ranging from stellar coronae to clusters of galaxies.
- **Operations**: Prime Mission is 3 years

CURRENT STATUS

The U.S. is providing instrument contributions to the JAXA ASTRO-H mission.

- Soft X-ray telescope mirrors (SXT-S and SXT-I) – Both delivered.
- X-ray Calorimeter Spectrometer Insert (CSI), including Adiabatic De-magnitization Refrigerator (ADR) and ADR Controller
- Aperture Assembly
- X-ray Electronics Box (X-box)
- High Temperature Superconducting Leads

- All U.S. hardware has been integrated onto the spacecraft.
- Successfully completed spacecraft level environmental testing

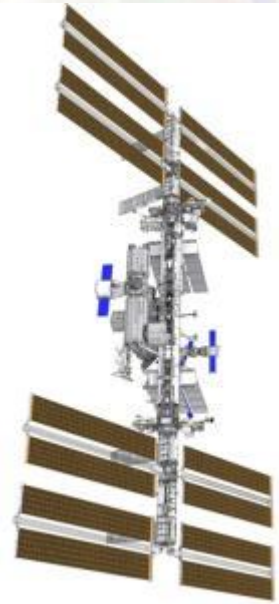
UPCOMING EVENTS:

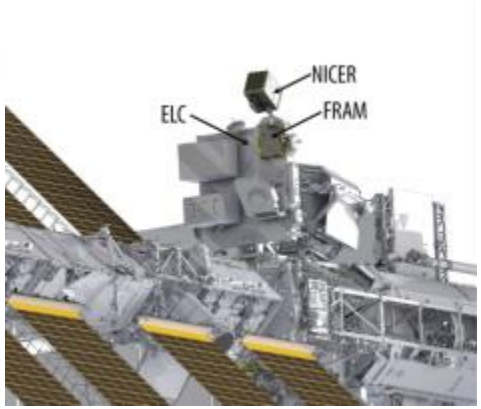
- Early November - Final spacecraft comprehensive performance test
- Late November –shipment to Tanegashima launch site
- Late NET November 2015 (TBC) – Launch
- Late Spring 2016 (TBC) – Cycle 1 GO call

NICER

Neutron Star Interior Composition Explorer

Intl Space Station (ISS)





- **Explorer Mission of Opportunity**
- **PI:** Keith Gendreau, GSFC
- **Launch:** August 2016 on Space-X Falcon 9
- **Science Objectives:** Perform high-time-resolution and spectroscopic observations of neutron stars in the .2-12 keV energy range to study the physics of ultra-dense matter in the core of neutron stars.
- **Instrument:** X-ray Timing Instrument uses X-ray concentrators and detectors to detect X-ray photons and return energy and time of arrival.
- **Platform:** Located externally on the ISS, ExPRESS Logistics Carrier 2, Starboard 3 site
- **Operations:** Operated on a non-interference basis for 18 months
- **SEXTANT** for Pulsar navigation demo funded by NASA's Space Technology Mission Directorate

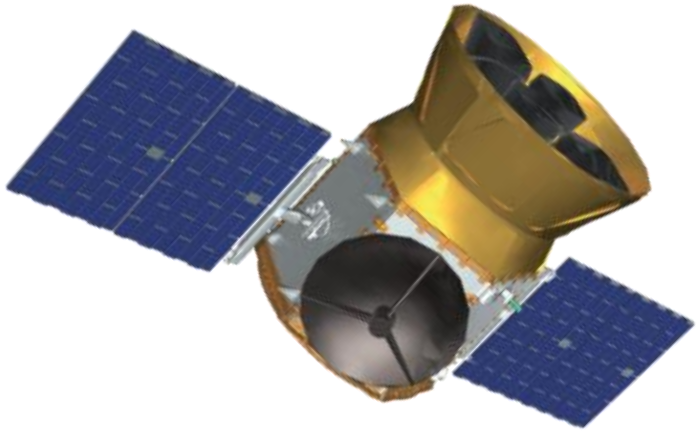
CURRENT STATUS:

- All subsystems/sub-assemblies have completed fabrication and environmental testing
- The NICER project has now started final payload integration

UPCOMING EVENTS:

- Dec 10-11: Pre-environmental Review
- Jan 21 2016: KDP-D
- February 2016: Start of payload environmental testing
- August 2016 (TBC): Launch

TESS
Transiting Exoplanet Survey Satellite



Standard Explorer (EX) Mission

PI: G. Ricker (MIT)

Mission: All-Sky photometric exoplanet mapping mission.

Science goal: Search for transiting exoplanets around the nearby, bright stars.

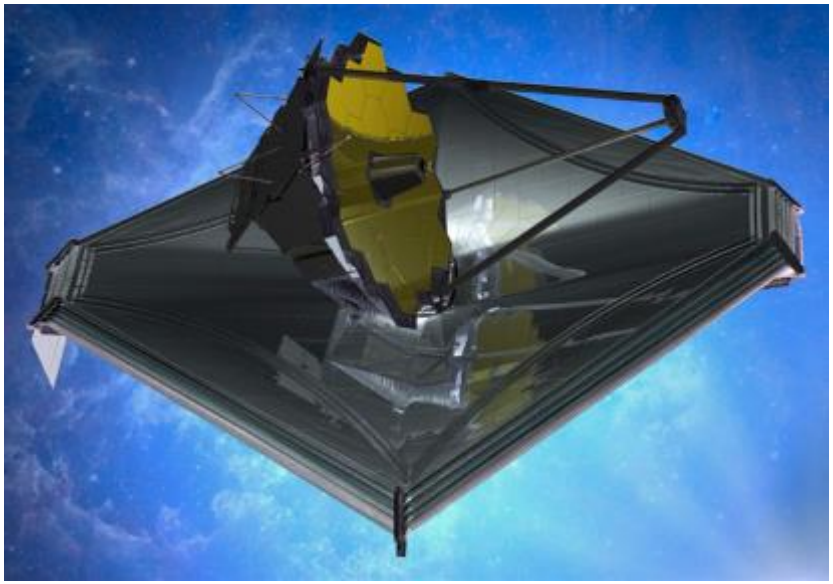
Instruments: Four wide field of view (24x24 degrees) CCD cameras with overlapping field of view–operating in the Visible-IR spectrum (0.6-1 micron).

Operations: NLT June 2018 launch with a 3-year prime mission including 2 years of spacecraft operations and an additional 1 year ground-based observations and analysis.

CURRENT STATUS:

- Downselected April 2013.
- Major partners:
  - PI and science lead: MIT
  - Project management: NASA GSFC
  - Instrument: Lincoln Laboratory
  - Spacecraft: Orbital Science Corp
- Tentative launch readiness date NLT June 2018.
- High-Earth elliptical orbit (17 x 58.7 Earth radii).
- Development progressing on plan.
  - Systems Requirement Review (SRR) successfully completed on February 12-13, 2014.
  - Preliminary Design Review (PDR) successfully completed Sept 9-12, 2014.
  - Confirmation Review, for approval to enter implementation phase, successfully completed October 31, 2014.
  - CDR held August 4-7, 2015
  - Delta CDR planned for ~December 2015

JWST
James Webb Space Telescope



Large Infrared Space Observatory

Top priority of 2000 Decadal Survey

Science themes: First Light; Assembly of Galaxies; Birth of Stars and Planetary Systems; Planetary Systems and the Origins of Life

Mission: 6.5m deployable, segmented telescope at L2, passively cooled to <50K behind a large, deployable sunshield

Instruments: Near IR Camera, Near IR Spectrograph, Mid IR Instrument, Near IR Imager and Slitless Spectrograph

Operations: 2018 launch for a 5-year prime mission

Partners: ESA, CSA

FY2015 Accomplishments

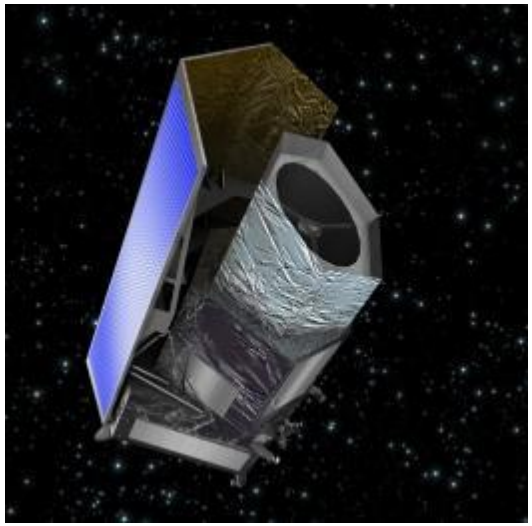
- Completed instrument hardware replacements, and prepared ISIM for its final test before integration with the telescope
- Completed MIRI cryocooler flight units
- Conducted tests at JSC in preparation for 2016 full telescope plus ISIM test
- Delivered spacecraft bus structure to I&T

FY2016 Plans

- Assemble the Telescope
- Complete ISIM testing and integrate with the telescope
- Complete sunshield membrane manufacturing
- Begin integration of spacecraft bus components (e.g. electronics, propulsion) with the spacecraft bus structure

Euclid

A visible and near-infrared telescope to explore cosmic evolution



- **ESA Cosmic Vision 2015-2025 Mission**, M-Class with NASA participation.
- 1.2-m mirror, visible & near-IR images, spectra
- **Launch Date**: December 2020
- **Science Objectives**:
  - Euclid will look back 10 billion years into cosmic history.
  - Probe the history of cosmic expansion (influenced by dark energy and dark matter) and how gravity pulls galaxies together to form the largest structures.
  - The shapes of distant galaxies appear distorted because the gravity of dark matter bends their light (gravitational lensing). Measuring this distortion tells us how the largest structures were built up over cosmic time.
  - Measuring how strongly galaxies are clumped together tells us how gravity influences their motions, and how dark energy has affected the cosmic expansion.

CURRENT STATUS:

- Currently in implementation phase.
- ~50 U.S. scientists are members of the Euclid Science Team that will analyze the data, and make maps of the sky.
- The qualification detectors from the detector vendor are currently being tested at GSFC's Detector Characterization Lab.
- NASA has all contracts in place at the detector vendor, with the last one expected to be in place in November 2015.
- End of detector engineering phase was delayed by ~23 months, delivery of NASA-provided sensor systems will slip by same amount
- The Euclid Mission PDR was held October 20, 2015.
- NASA rebaseline will be in January 2016 (TBC).

Astrophysics Missions in Pre-Formulation

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

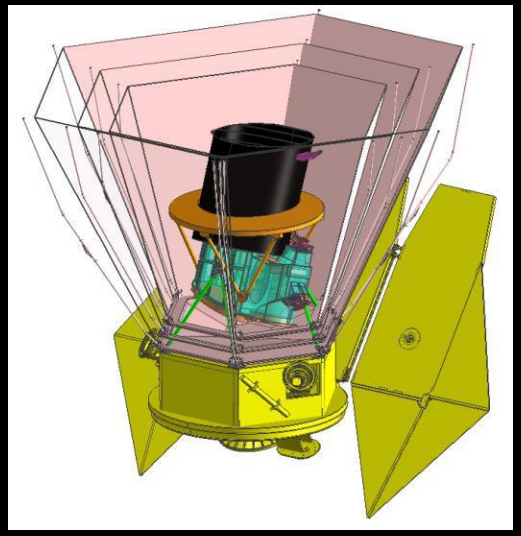
MIDEX / MO – 2022/2023

WFIRST-AFTA – NLT 2026

Athena – 2028

All launch dates notional

Astrophysics SMEX/MO Missions in Formulation



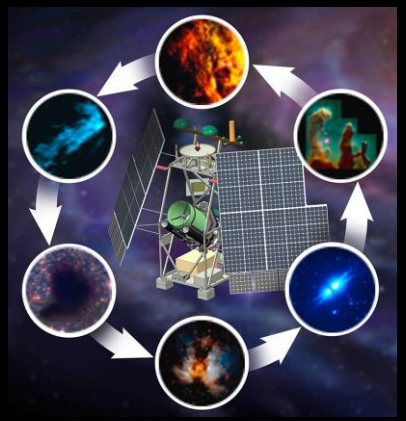
SPHEREx
PI: J. Bock, Caltech
An All-Sky Near-IR Spectral Survey

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

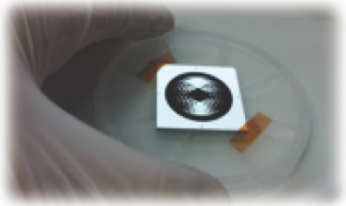
PI: C. Walker, U. Arizona
GUSTO: Gal/Xgal U/LDB Spectroscopic - Stratospheric Terahertz Observatory



Executive Summary

- Huge progress on WFIRST over the past two years
- SDT studies & NRC Harrison committee report confirm that WFIRST-AFTA exceeds NWNH requirements in all areas.
- $107M in FY14 & 15 has enabled major steps forward and NRC-Harrison committee recommendations have been addressed (H4RGs, coronagraph, mission design). Planning against $56M in FY16, exact amount depends on appropriations.
- Coronagraph on track, technology development on schedule. Wide Field detector technology development on schedule
- MCR scheduled for Dec 8-9. Prepared for start of formulation (KDP-A) as early as January 2016.
- SDT 2014 & 15 studies completed
- Preparatory Science teams selected
- Pasadena conferences held
- Special session at AAS's & IAU
- Science team NRA released
- Industry study RFIs received
- Significant international interest (Canada, ESA, Japan, Korea)

WFIRST H4RG-10

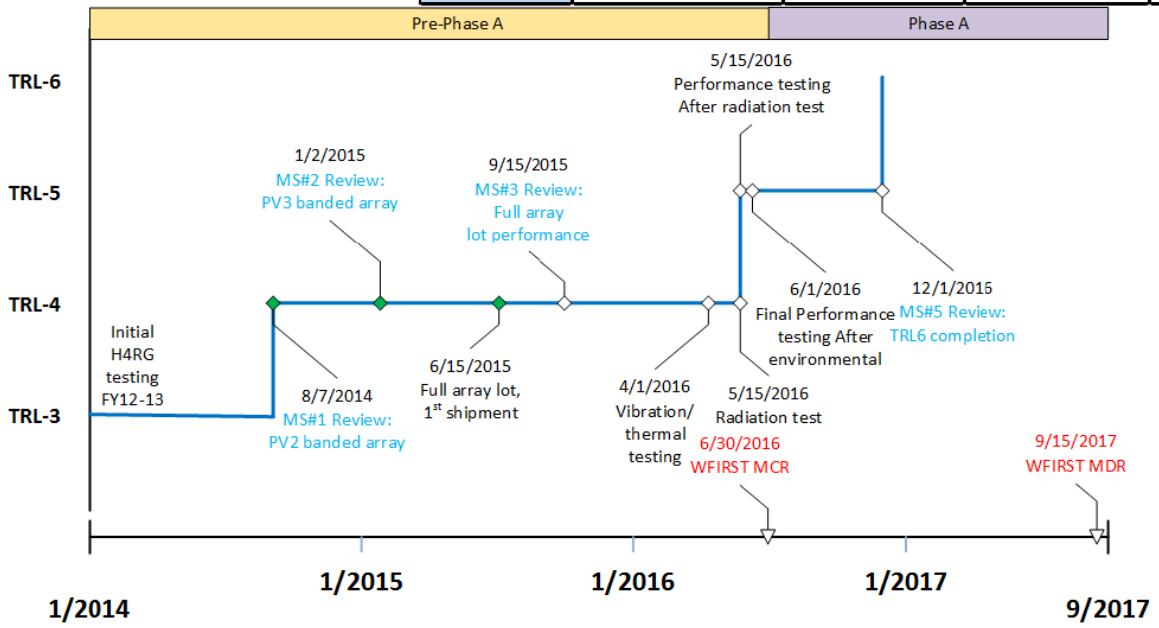


Shaped-Pupil Coronagraph Mask

WFIRST Detector Technology Milestone Progress

Table below shows range of results for the first 4 full arrays; all are within MS#3 specifications.

Detector	Median Dark Current (e/s)	CDS Noise (electrons)	QE (%) (av. 800-2350nm)	Crosstalk (%) (nearest neighbor)	Pixels with Nominal Photo Response
MS3 req't	<0.1	<20	>60	<3.0	>95
Range	0.001-0.007	14.5-16.6	89-94	1.8%-2%	96-99%



Test timeline uses full arrays to allow early environmental testing for TRL-6 over 2 years before mission PDR.

Coronagraph Technology Milestones

WFIRST
WIDE-FIELD INFRARED SURVEY TELESCOPE
DARK ENERGY • EXOPLANETS • ASTROPHYSICS

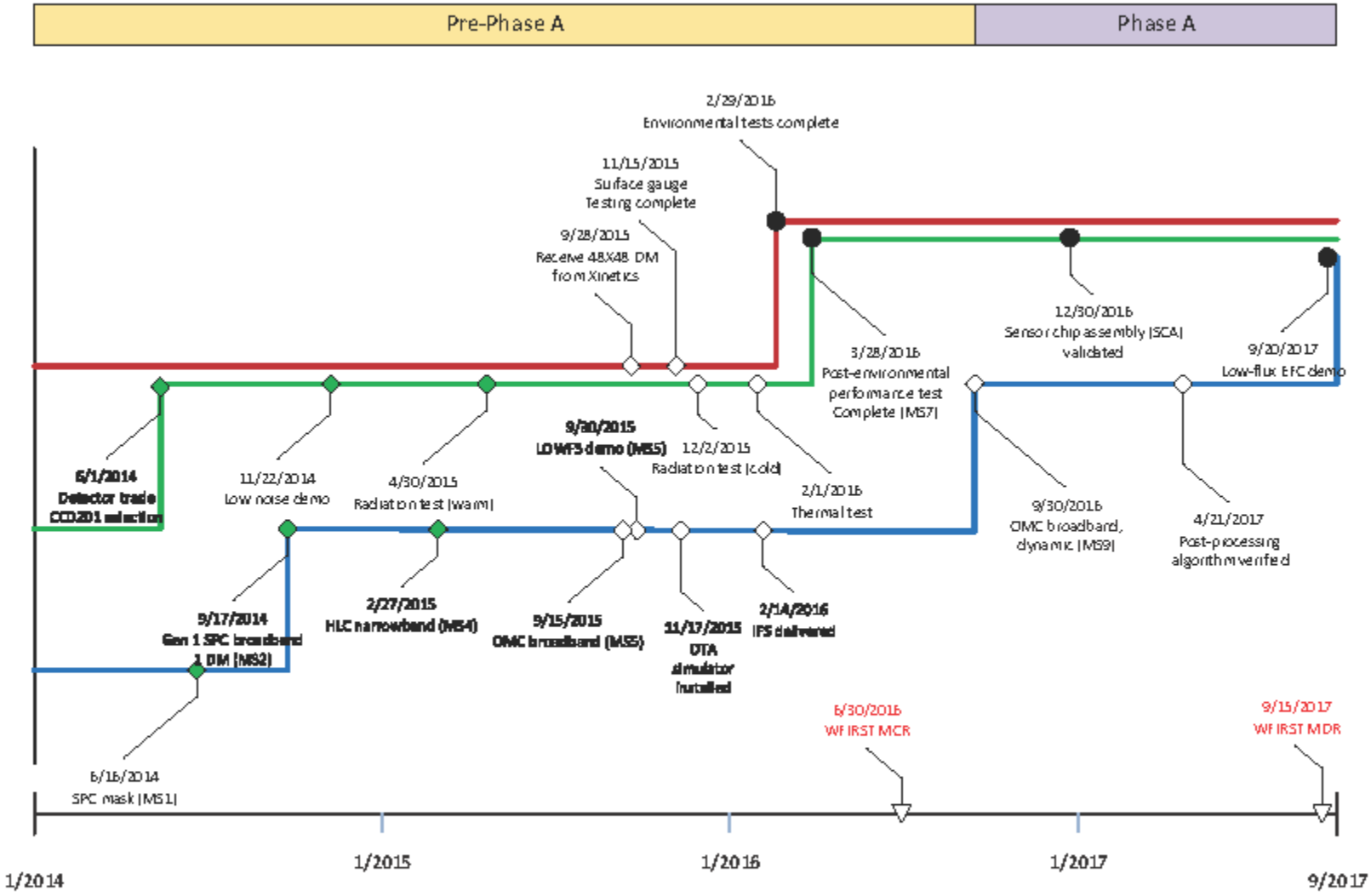
MS #	Milestone	Date
1 ✓	First-generation reflective Shaped-Pupil apodizing mask has been fabricated with black silicon specular reflectivity of less than 10^{-4} and 20 µm pixel size.	7/21/14
2 ✓	Shaped Pupil Coronagraph in the High Contrast Imaging Testbed demonstrates 10^{-8} raw contrast with narrowband light at 550 nm in a static environment.	9/30/14
3 ✓	First-generation PIAACMC focal plane phase mask with at least 12 concentric rings has been fabricated and characterized; results are consistent with model predictions of 10^{-8} raw contrast with 10% broadband light centered at 550 nm.	12/15/14
4 ✓	Hybrid-Lyot Coronagraph in the High Contrast Imaging Testbed demonstrates 10^{-8} raw contrast with narrowband light at 550 nm in a static environment.	2/28/15
5 ✓	Occulting Mask Coronagraph in the High Contrast Imaging Testbed demonstrates 10^{-8} raw contrast with 10% broadband light centered at 550 nm in a static environment.	9/15/15
6 ✓	Low Order Wavefront Sensing and Control subsystem provides pointing jitter sensing better than 0.4 mas and meets pointing and low order wavefront drift control requirements.	9/30/15
7	Spectrograph detector and read-out electronics are demonstrated to have dark current less than 0.001 e/pix/s and read noise less than 1 e/pix/frame.	8/25/16
8	PIAACMC coronagraph in the High Contrast Imaging Testbed demonstrates 10^{-8} raw contrast with 10% broadband light centered at 550 nm in a static environment; contrast sensitivity to pointing and focus is characterized.	9/30/16
9	Occulting Mask Coronagraph in the High Contrast Imaging Testbed demonstrates 10^{-8} raw contrast with 10% broadband light centered at 550 nm in a simulated dynamic environment.	9/30/16

Excellent progress on technology development

WIDE-FIELD INFRARED SURVEY TELESCOPE

WFIRST • ASTROPHYSICS • EXOPLANETS • DARK ENERGY

Coronagraph Technology Path to TRL-6



Occulting Mask Coronagraph (OMC) system

Deformable Mirror (DM)

Low noise detector (EMCCD)

WIDE-FIELD INFRARED SURVEY TELESCOPE

WFIRST • ASTROPHYSICS • EXOPLANETS • DARK ENERGY

#2

Recent Activities

- Completed design report with SDT – March '15.
- Developed life cycle mission cost (combination of parametric, grassroots, and analogy)
- Validated by independent cost assessment (Aerospace CATE).
- MCR design cycle progressing to completion in December.
- Milestones for Coronagraph and IR detectors continue to make excellent progress.
  - Technology Assessment Committee provides for external review of technology milestones.
- Risk management process being actively utilized.
- Industry RFI for potential participation in WFIRST development recently conducted; study solicitation this fall.
- Solicitation for WFIRST science team released July 17th.

NASA Cost Estimate	FY10$B	FY15$B	RY$B
Mission Cost w/coronagraph	1.8-2.1	2.0-2.3	2.5-2.8
Cost of adding coronagraph	0.32	0.35	-
NWNH Mission Estimate*	1.6	1.8	-

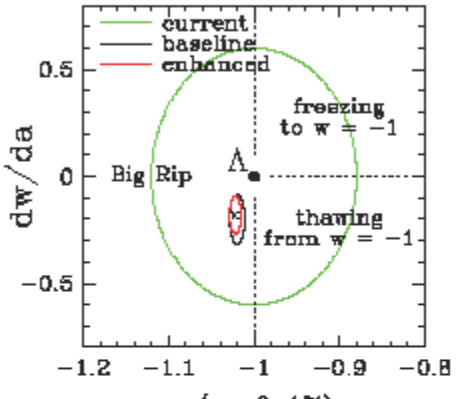
* NWNH cost estimate did not include the GI/GO program

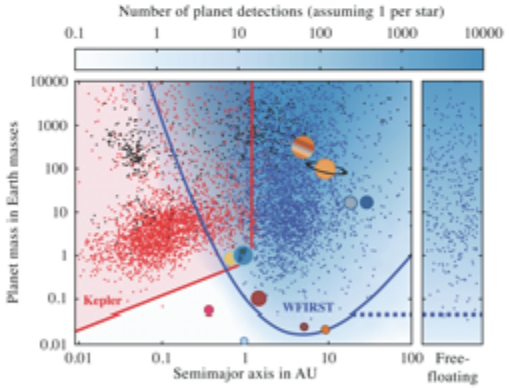
Path Forward

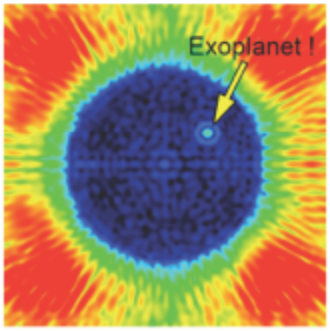
- Mission Concept Review schedule for Dec 8-9.
- Industry study solicitation to be released.
- Developing KDP-A documentation and products per NPR 7120.5E (control plans, descope plan, design reference, Formulation Agreement, etc.)
- Proposals for WFIRST Science Team due October 15; selection around Dec 1.
- Science Investigation Team kick-off planned for the first week of February.
- Award of industry studies in early 2016.
- Prepared for the start of formulation (KDP-A) as early as January 2016.
- Acquisition Strategy Meeting (ASM) in spring; finalizes acquisition approach.
- Systems Requirements Review/Mission Design Review (SRR/MDR) to be held prior to end of Formulation Phase.
- At the conclusion of the Formulation Phase, KDP-B and transition to development.

Summary

- Over the past two years, increased funding has enabled significant progress in technology maturation as well as additional fidelity in the design reference mission.
- WFIRST with the 2.4-m telescope and coronagraph provides an exciting science program, superior to that recommended by NWNH and also advances exoplanet imaging technology (the highest ranked medium-class NWNH recommendation).
- Great opportunity for astronomy and astrophysics discoveries. Broad community support for WFIRST.
- Key development areas are anchored in a decade of investments in JPL's HCIT and GSFC's DCL.
- Great progress made in pre-formulation, ready for KDP-A and launch in mid-2020s.

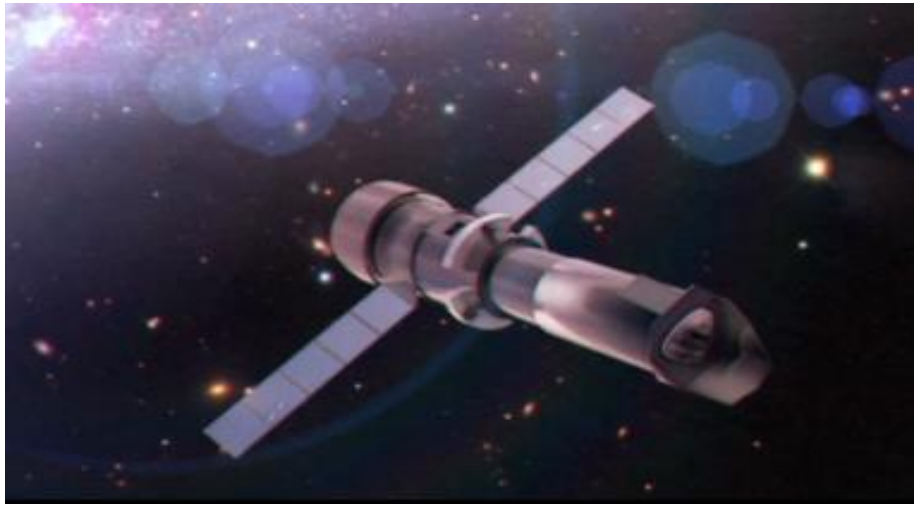






Athena

Advanced **T**elescope for **H**igh **En**ergy **A**strophysics

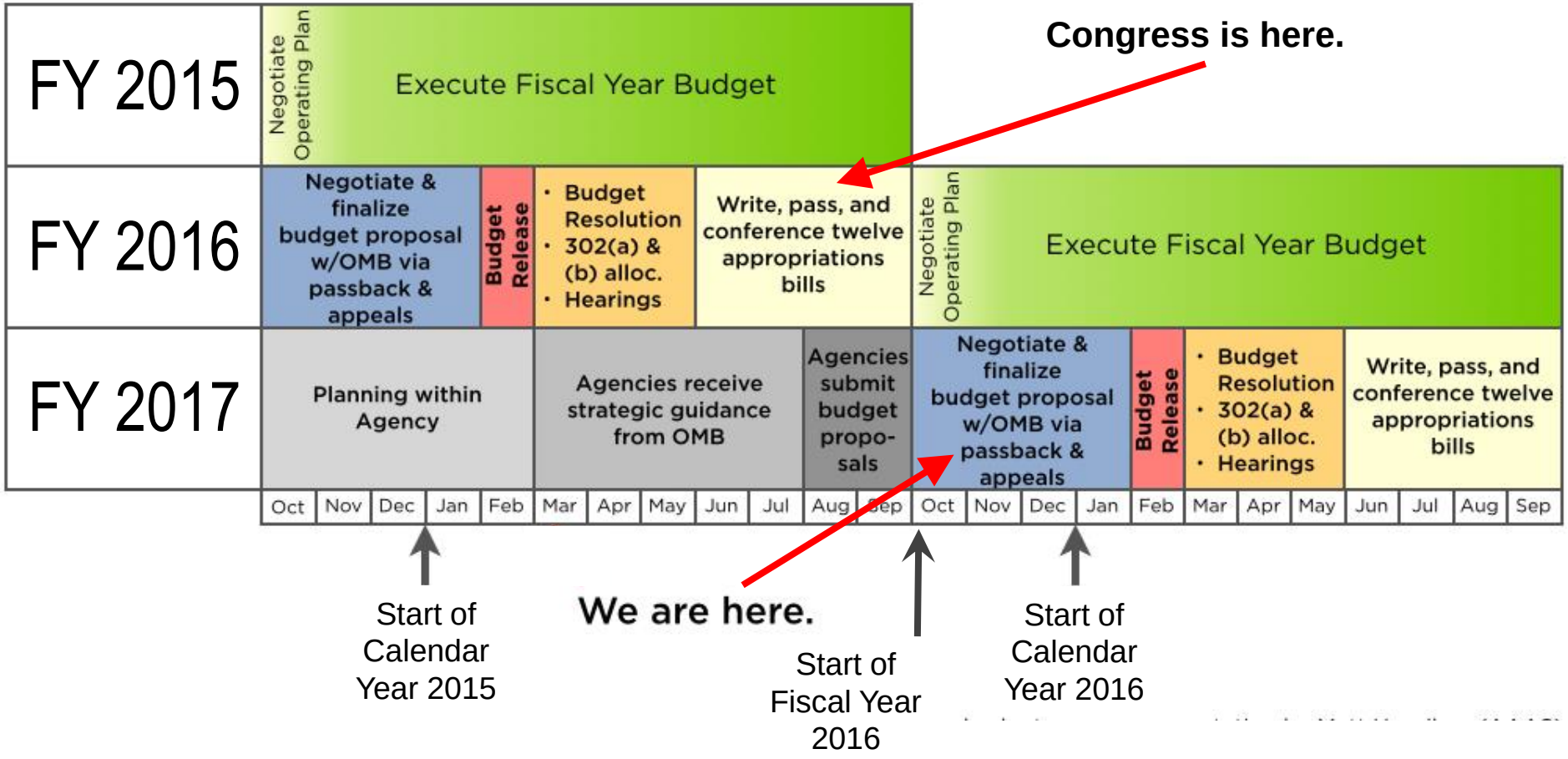


- **Second ESA Cosmic Vision Large mission**
  - L-class with NASA/JAXA participation
  - Decadal Survey recommendation
  - Large X-ray mirror, X-IFU and WFI instruments
- **Launch Date:** 2028
- **Breakthrough Technologies**:
  - High Throughput, Wide FOV, High spectral resolution X-ray Astronomy
  - 10x Chandra area, 100x improved non-dispersive spectral resolution, 5x FOV.
- **Science Objectives**: The Hot and Energetic Universe: How does ordinary matter assemble into the large scale structures that we see today? How do black holes grow and shape the Universe?

CURRENT STATUS:

- Selected as 2nd Large mission in ESA Cosmic Visions Program
- Currently in 2 year Study Phase
- NASA and US community involved in Study Phase via membership on ESA-chartered Athena Science Study Team and Science Working Groups
- NASA budgeting for a $100M-$150M hardware contribution, plus a US GO program and a U.S. data center
- NASA will provide the sensor array for the X-ray Integral Field Unit (calorimeter)
- NASA and ESA are discussing other possible NASA contributions, such as:
  - A contribution to the Wide Field Imager
  - Use of the NASA XRCF for Calibration
  - Contribution to science data center (U.S. node)
- NASA continues to invest in Athena technologies via SAT and directed investigations.

Nominal Federal Budget Cycle



Adapted by Kevin Marvel (AAS)
https://aas.org/files/budgetprocess_adaptedfromaaas.jpg
from budget presentation by Matt Hourihan (AAAS)
http://www.aaas.org/page/presentations

FY16 President's Budget Request

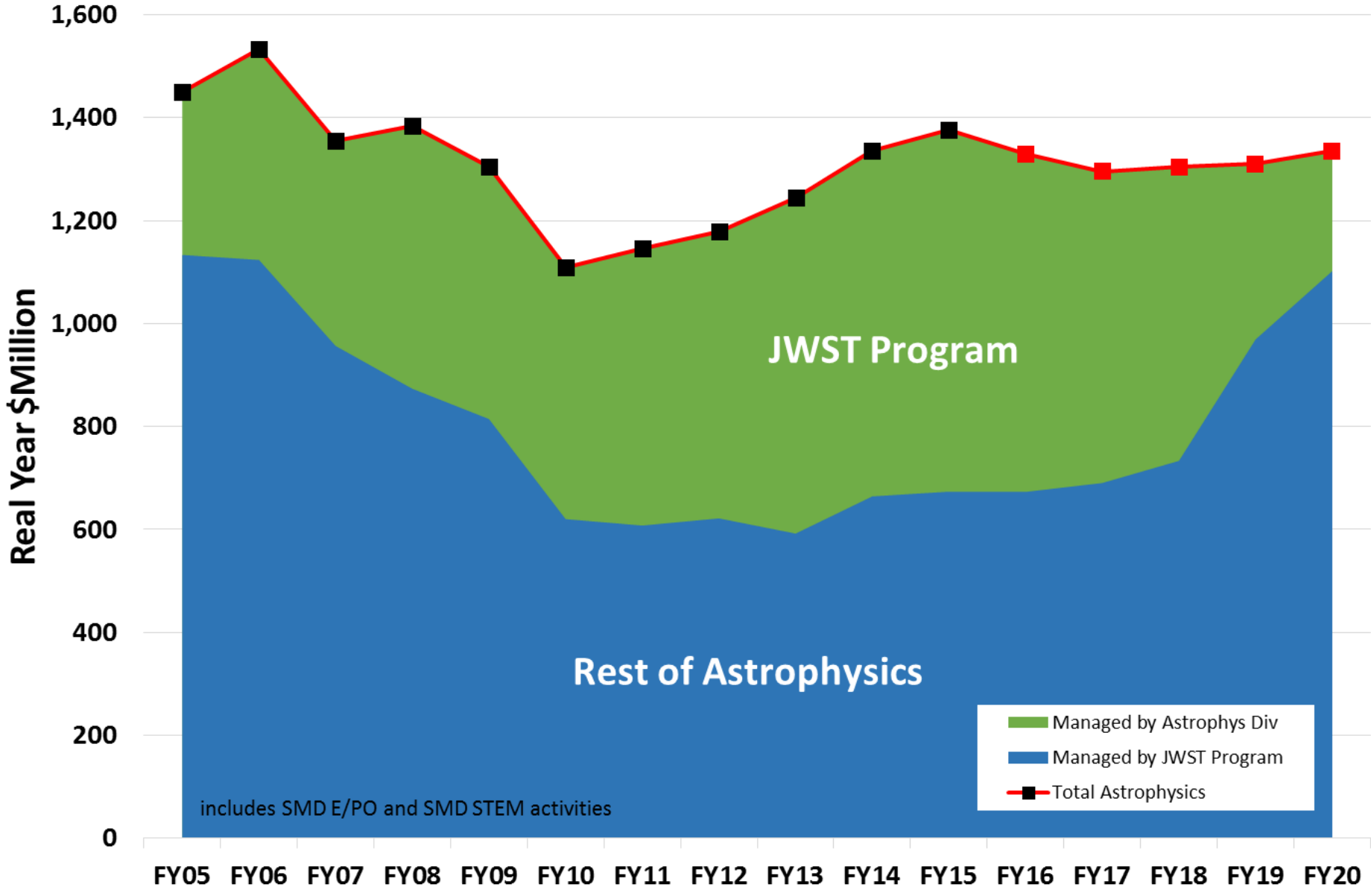
Outyears are notional planning from FY16 President's budget request

($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

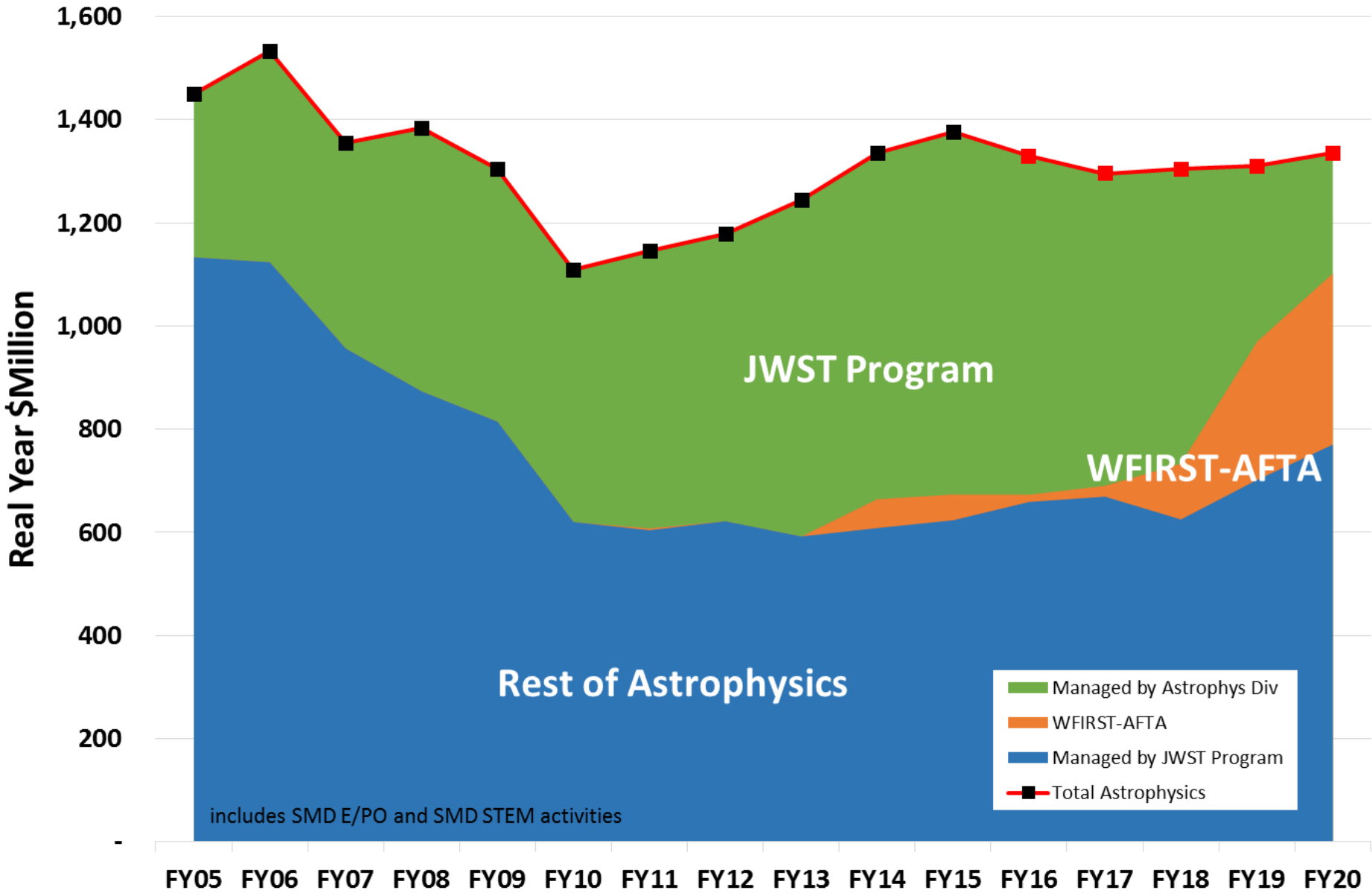
- Continues preformulation of WFIRST-AFTA as the "Astrophysics Decadal Strategic Mission."
- Grows Astrophysics Research and Analysis (including Astrophysics Data Analysis Program) from ~$80M/yr to ~$90M/yr in FY16.
- Supports completion of missions under development, including LPF/ST7, ASTRO-H, NICER, 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.

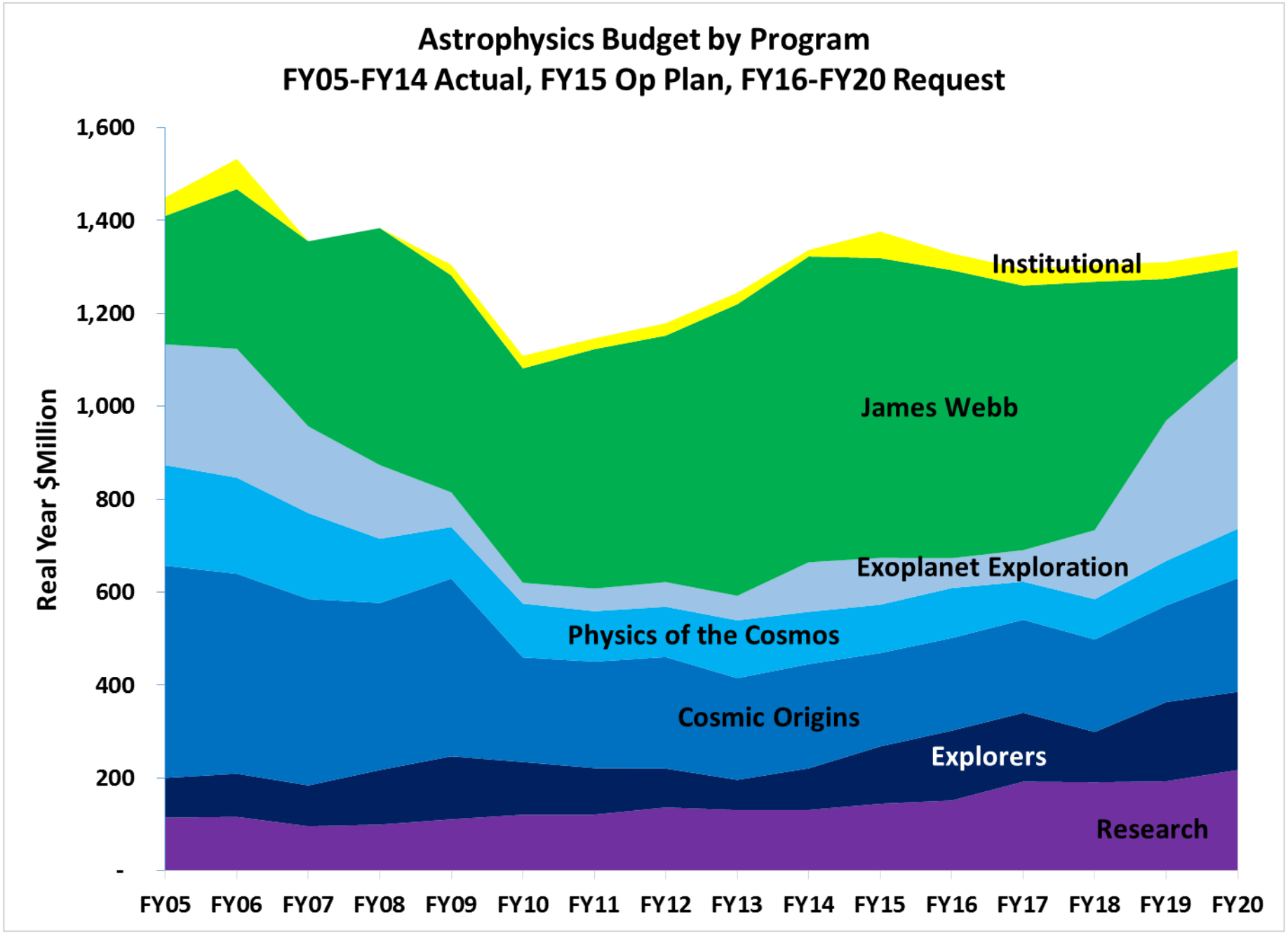
* Excludes "SMD STEM Activities" in all years.

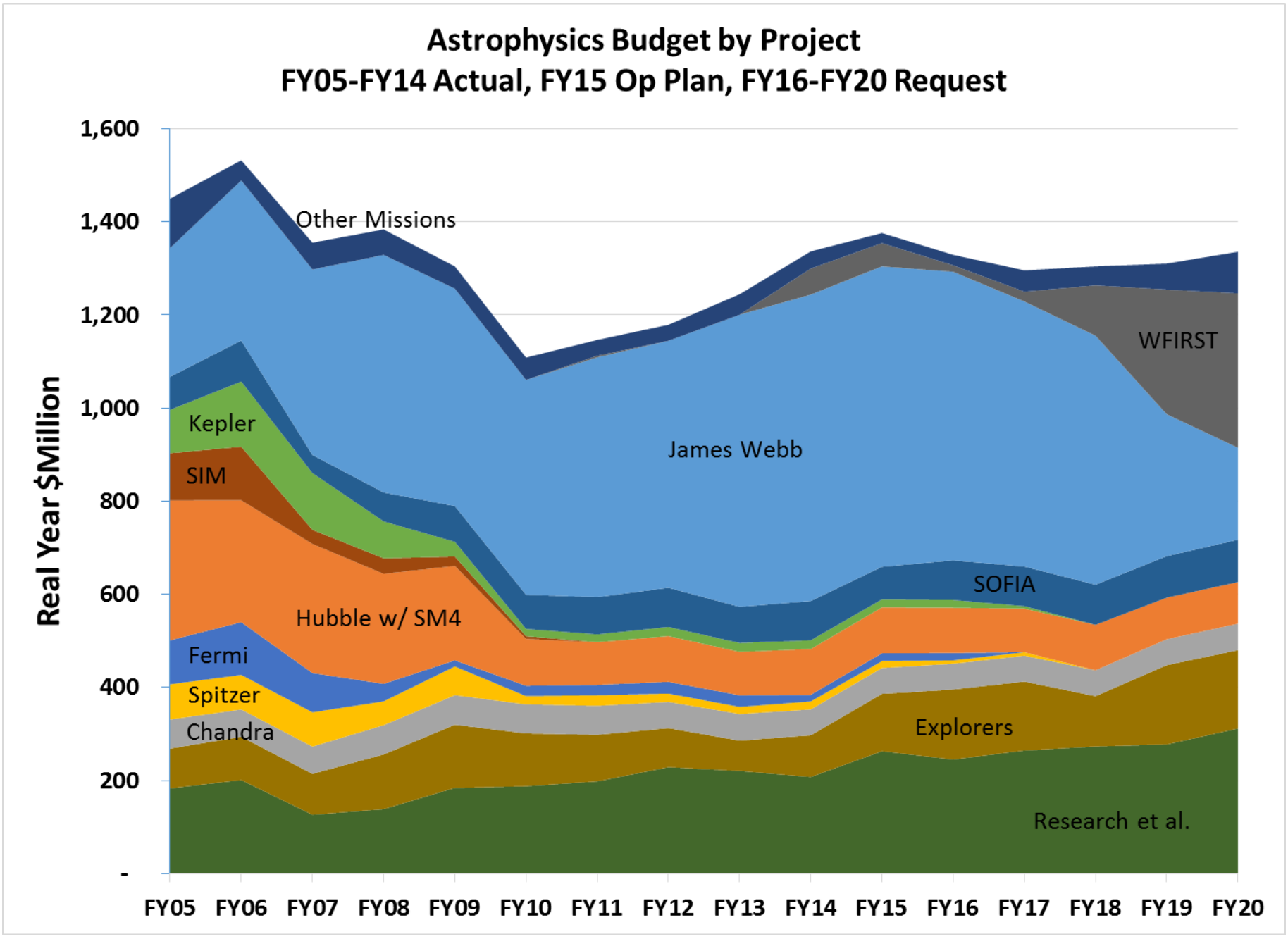
Astrophysics Budget by Project
FY05-FY14 Actual, FY15 Op Plan, FY16-FY20 Request

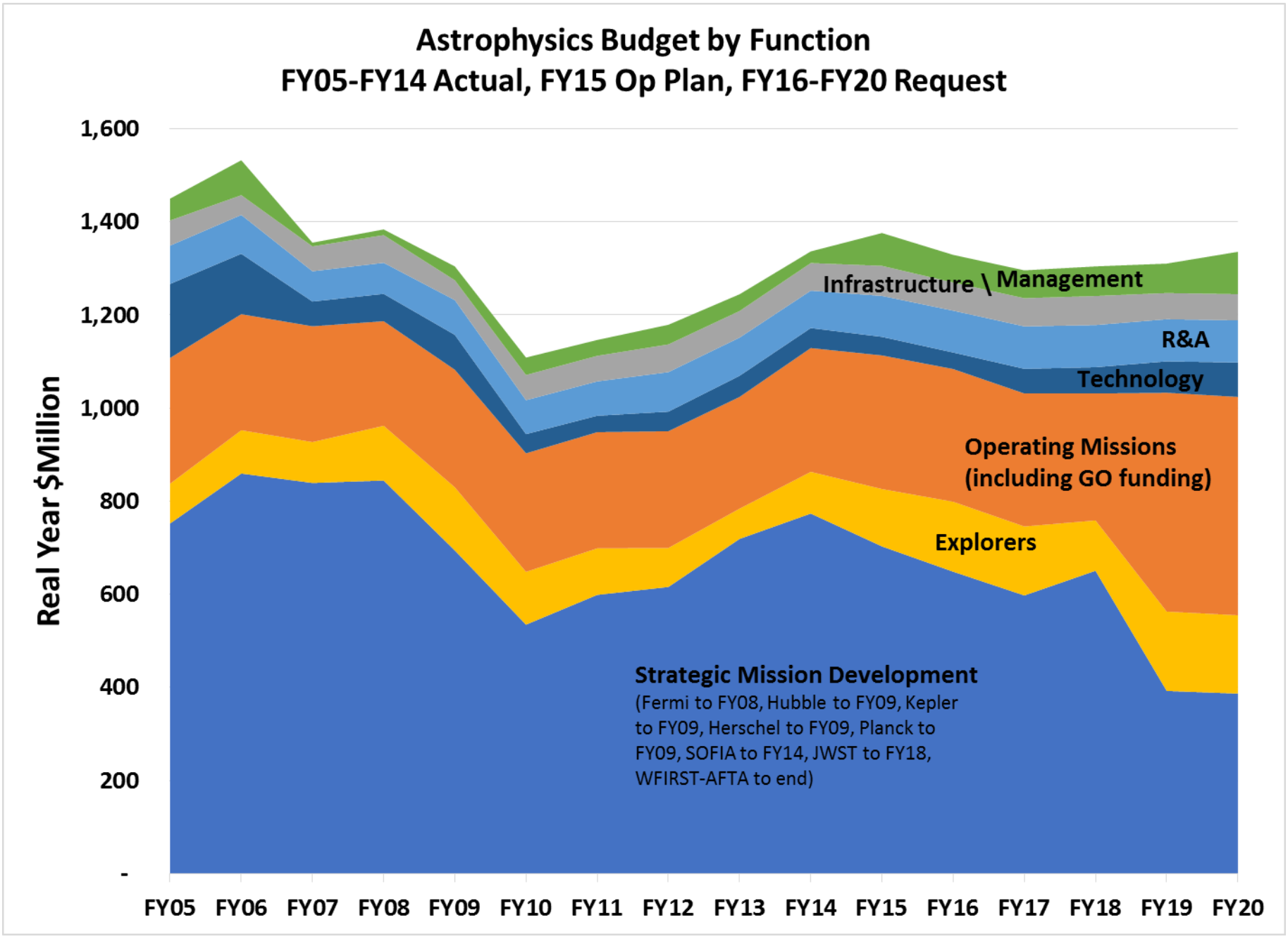


Astrophysics Budget by Project
FY05-FY14 Actual, FY15 Op Plan, FY16-FY20 Request




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
Real Year $Million
1,600
1,400
1,200
1,000
800
600
400
200
-
FY05
FY06
FY07
FY08
FY09
FY10
FY11
FY12
FY13
FY14
FY15
FY16
FY17
FY18
FY19
FY20
Infrastructure \ Management
R&A
Technology
Operating Missions
(including GO funding)
Explorers
Strategic Mission Development
(Fermi to FY08, Hubble to FY09, Kepler
to FY09, Herschel to FY09, Planck to
FY09, SOFIA to FY14, JWST to FY18,
WFIRST-AFTA to end)

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

Implementing the 2010 Decadal Survey

- 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 2010 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 and community groups.
- NASA Astrophysics is addressing all of the recommendations in the 2010 Decadal Survey and substantial progress is being made.
  - 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.
- The Mid-Term Review is underway.
  - http://sites.nationalacademies.org/SSB/CurrentProjects/SSB_161177

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.

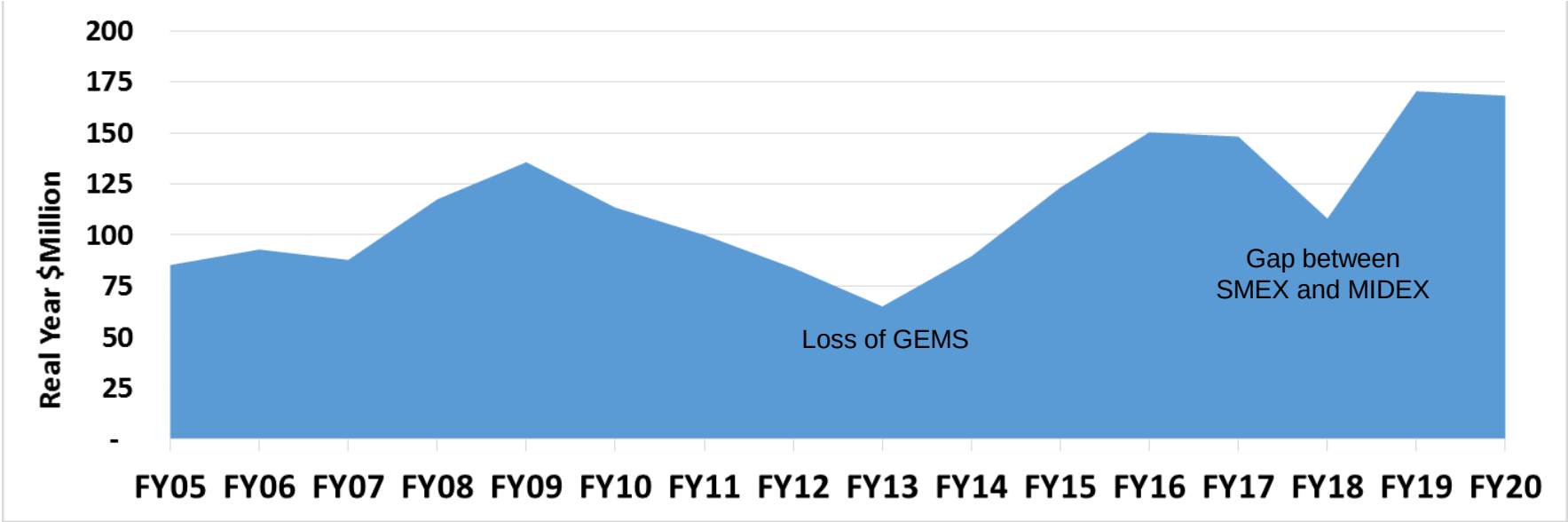
Response to Recommendations: Explorers

- 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: New Worlds Tech

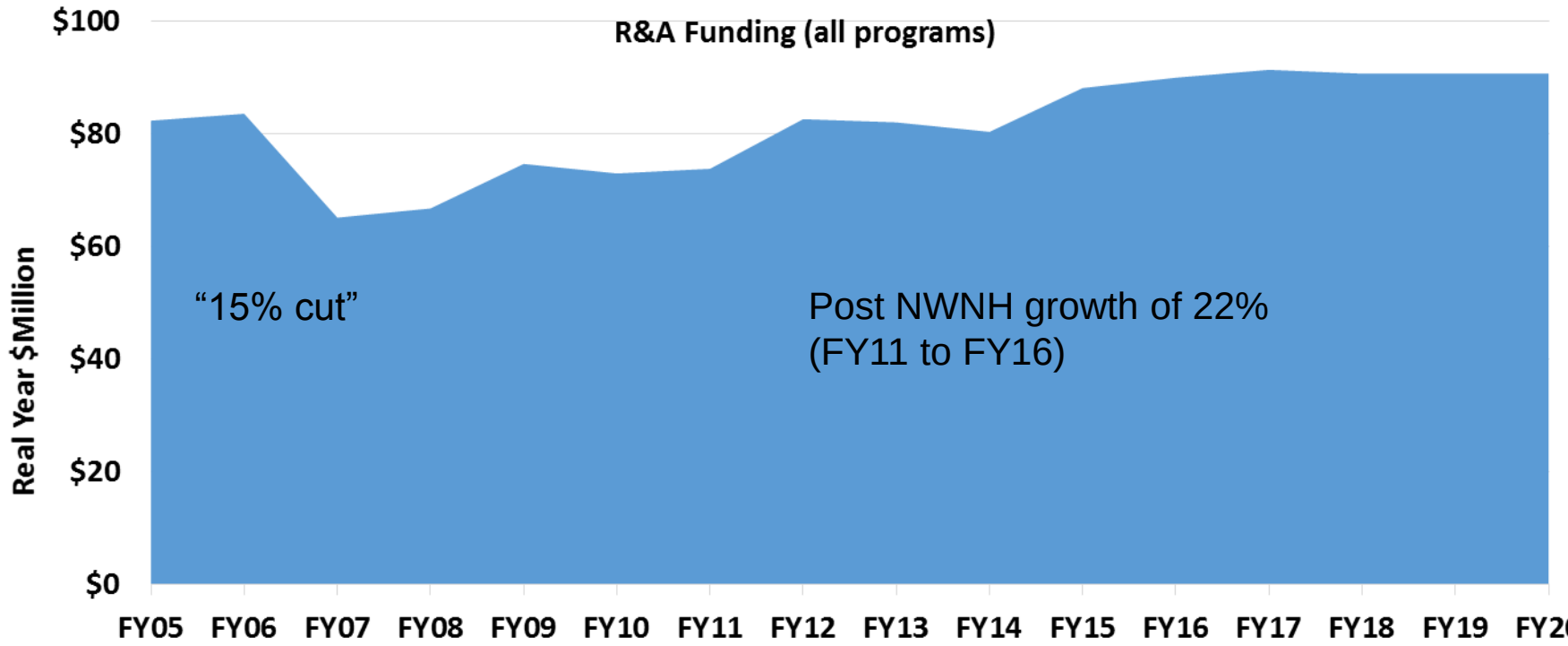
- Estimated spending on New Worlds technology including precursor science, FY11-FY20
  - WFIRST-AFTA coronagraph, technology development and formulation/design ~$100M
  - Technology Demonstration for Exoplanet Missions (TDEM) element of Strategic Astrophysics Technology (SAT) ~$52M
  - NN-EXPLORE initiative 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

- 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: 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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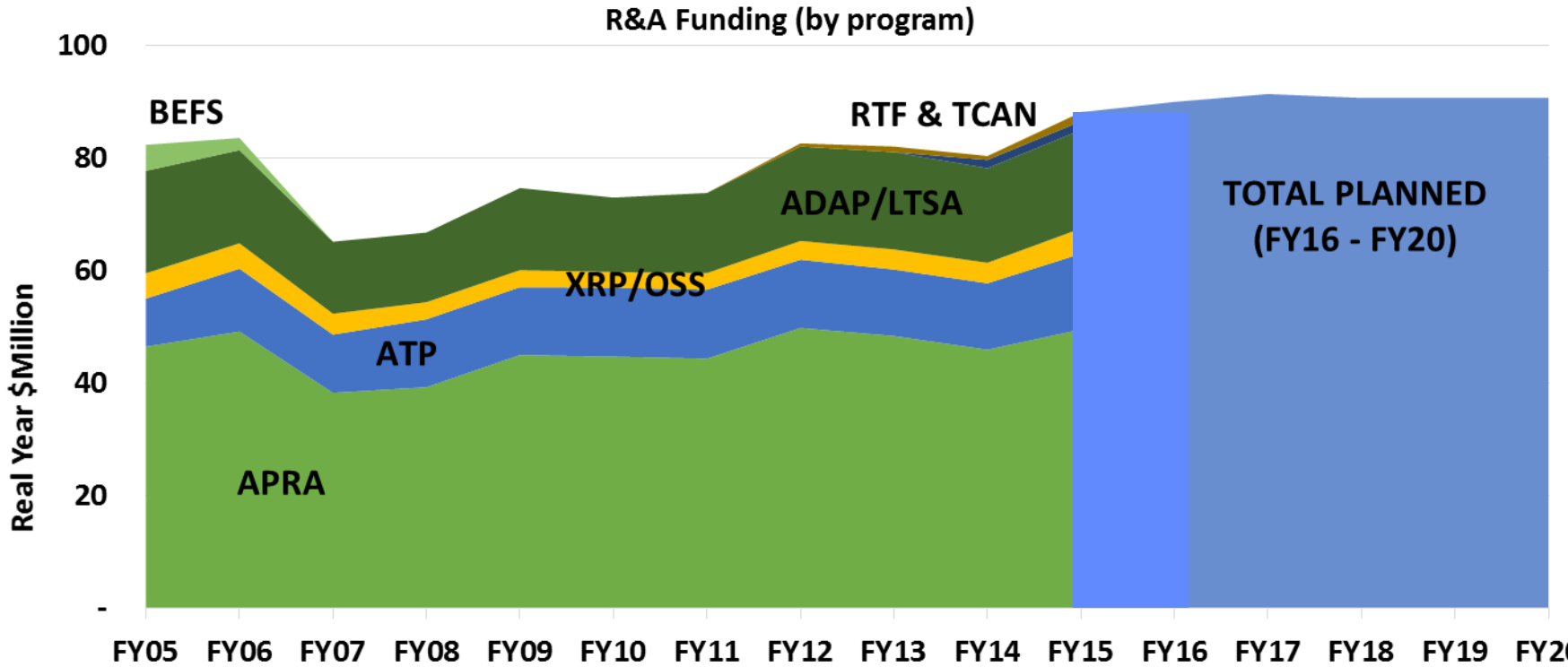
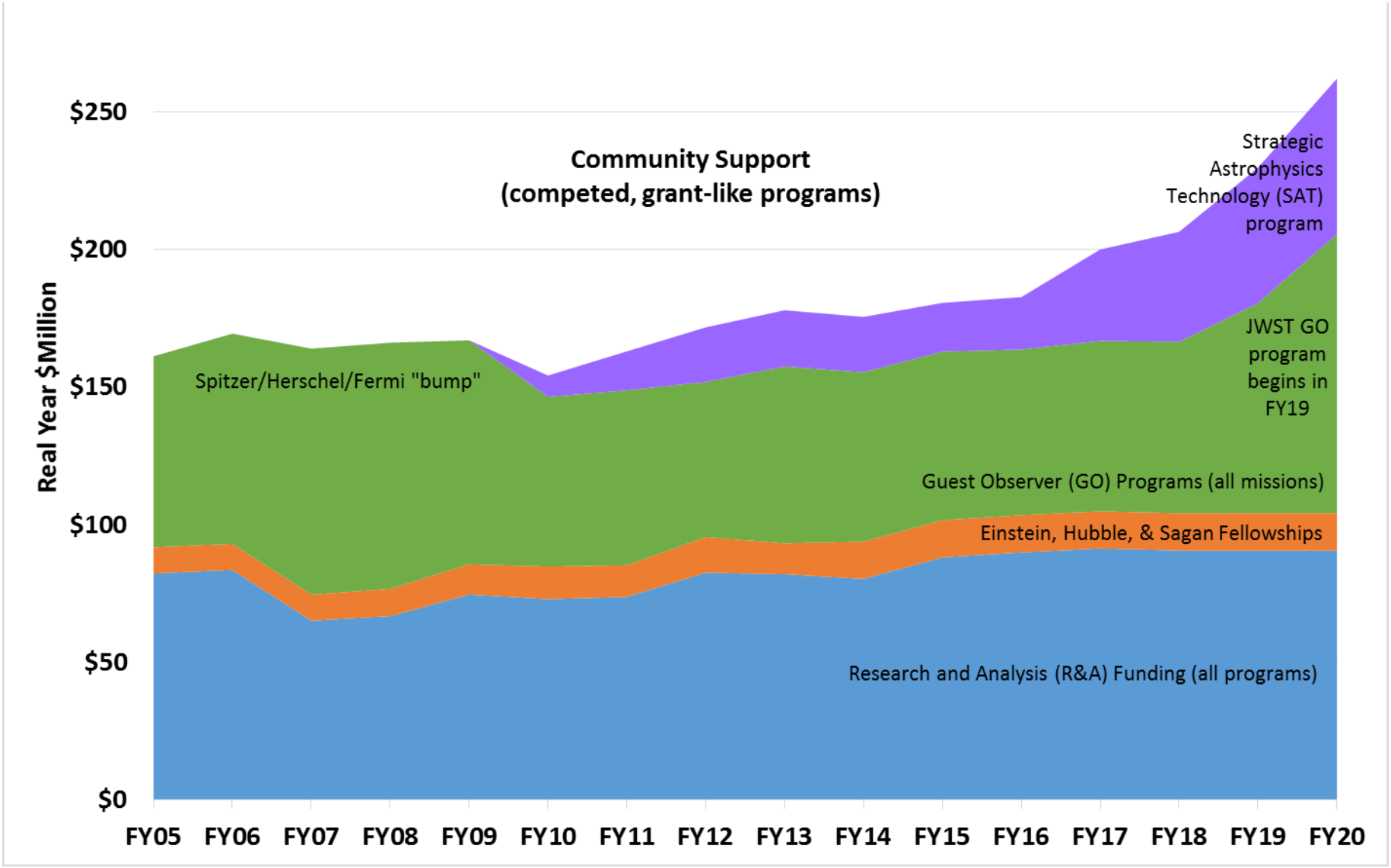


Response to Recommendations: Core Research



Proposal Selections Since January 2015

Status: October 22, 2015

	Proposal Due Date	Notify Date	Days past received	Number received	Number selected	% selected
Swift GI – Cycle 11	Sep 25, 2014	Jan 6, 2015	123	165	39	24%
Kepler K2 GO – Cycle 1	Sep 23, 2014	Jan 16, 2015	115	92	36	39%
Spitzer GO – Cycle 11	Oct 29, 2014	Dec 15, 2014	45	157	45	29%
Roman Tech Stage 1	Nov 6, 2014	Feb 3, 2015	89	8	3	38%
NuSTAR GO – Cycle ++	Nov 25, 2014	Apr 17, 2015	143	193	35	18%
Fermi GO – Cycle 8	Jan 22, 2015	June 26, 2015	155	190	36	19%
NESSF-15	Feb 1, 2015	June 2, 2015	121	134	10	7%
Kepler K2 GO – Cycle 2	Feb 27, 2015	June 12, 2015	105	76	35	46%
Chandra GO – Cycle 17	Mar 17, 2015	July 17, 2015	122	582	175	30%
APRA	Mar 20, 2015	Aug 12, 2015	145	149	40	27%
SAT	Mar 20, 2015	Aug 12, 2015	145	28	9	32%
Hubble GO – Cycle 23	Apr 23, 2015	June 24, 2015	62	1114	261	23%
EPDS (Doppler Spectr)	Apr 24, 2015	July 2, 2015	69	6	2	33%
ADAP (Data Analysis)	May 15, 2015	Sep 29, 2015	137	250	51	20%
Exoplanet Research	May 22, 2015	Oct 15, 2015	146	43	7	16%
Kepler K2 GO – Cycle 3	Jul 1, 2015		113	72		
Spitzer GO – Cycle 12	Sep 11, 2015		41	104		
SOFIA 3rd Gen Instrum	Oct 7, 2015					
WFIRST Sci. Inv. Teams	Oct 15, 2015					

100% of 2015 selections announced within 155 days

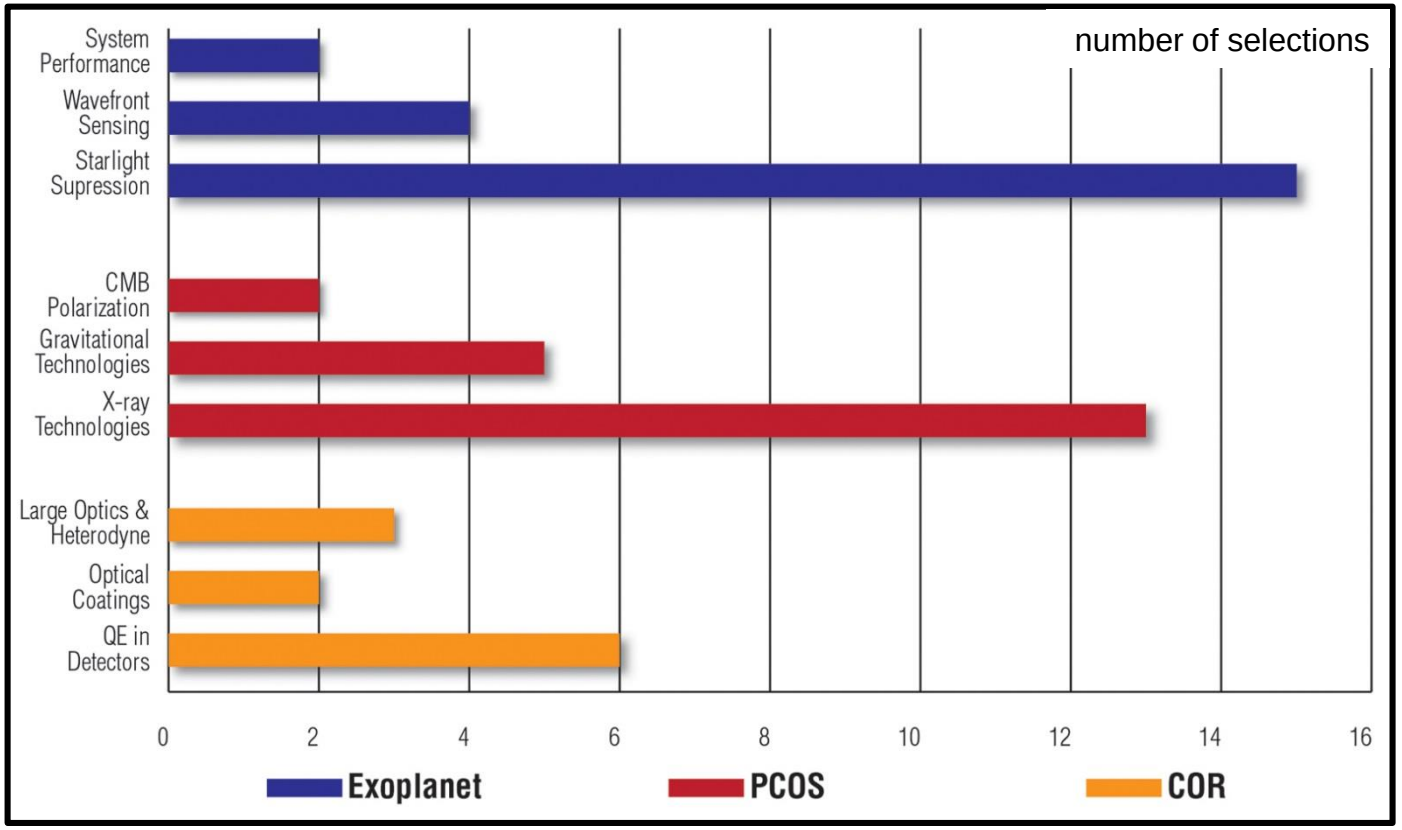
Response to Recommendations: Intermediate Tech

- 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

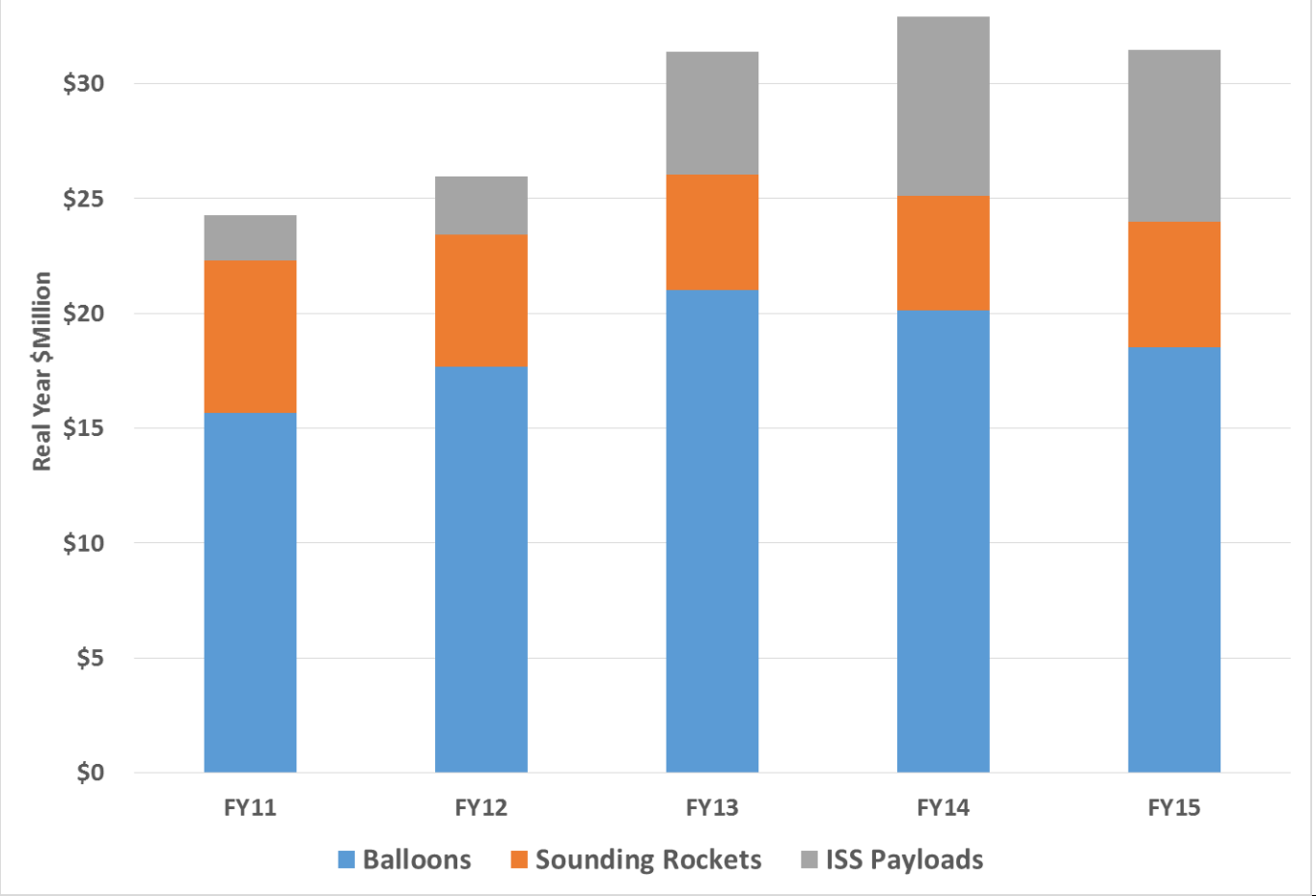


$17 M	$29M	$18M

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

Response to Recommendations: 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



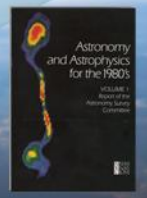
Response to Recommendations: Suborbital

- 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)

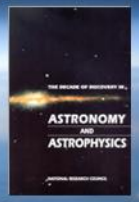
ASTROPHYSICS

Decadal Survey Missions

1972
Decadal Survey
Hubble



1982
Decadal Survey
Chandra

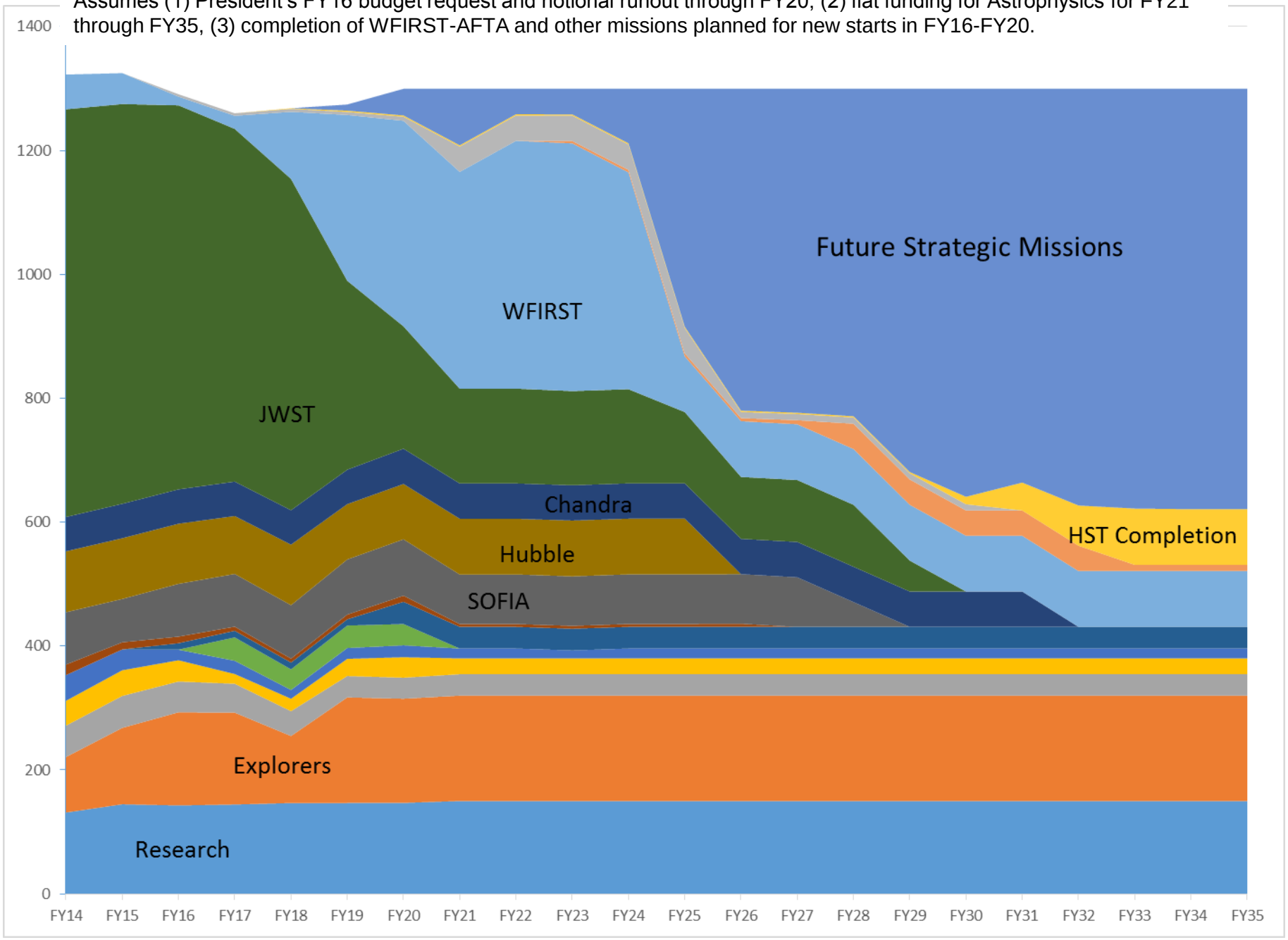


1991
Decadal Survey
Spitzer, SOFIA

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.



The Space Science Decadal Surveys: Lessons Learned and Best Practices (NRC, 2015)

- "Moreover, the period between decadal surveys is an ideal time to work on mission concepts and to bring them up to a minimal standard of development. … The Astrophysics Division of SMD recently proposed just such an activity to prepare for Astro2020. The opportunity of using the time between surveys to update the science and formulate possible missions is arguably the best way to achieve the goals of a two-phase process, without prolonging the decadal survey process."
- "Some pre-work with the scientific community and its representative groups prior to the official start of a survey could help ensure the survey completion in the minimum possible time. Such pre-work could reduce the pressure on a survey to define and refine concepts for study very early in its discussions. A recent policy announcement by the director of NASA's Astrophysics Division aims to do just this."
- "Best Practice: Agencies, committees of the Academies', community workshops and meetings, and white papers can contribute to pre-survey science priority identification as preparation for, and a valuable contribution to, the next survey. These activities can also spur early development, evaluation, and maturation of concepts for new missions for potential priorities well in advance of the survey itself."

The Space Science Decadal Surveys: Lessons Learned and Best Practices (NRC, 2015) Chapter 2, pp. 18-19

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.”

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

Other Missions called out in 2010 Decadal Survey and 30-year Visionary Roadmap

- Gravitational Wave Surveyor
  - Current plan: Partner with ESA on L3 Gravitational Wave Observatory
  - NASA will not sponsor a mission concept study for a NASA-led GW mission as long as (a) we are planning to partner with ESA on L3 and (b) ESA is planning on executing the L3 GW mission; to do so would be tantamount to leaving the L3 partnership
  - “LISA” will need to be re-prioritized for the 2020 Decadal Survey. NASA is considering a GW science team to study NASA’s role in L3 and to prepare a report to present to the 2020 Decadal Survey.
- Inflation Probe
  - Current plan: (a) Developing technology per 2010 Decadal Survey, (b) studying partnership on JAXA LiteBIRD mission, (c) awaiting guidance from Mid Term Review Committee per 2010 Decadal Survey
  - Decision later on whether NASA wants to sponsor a mission concept study for an Inflation Probe, either as one of several Probe studies or as a special case

Preparing for the 2020 Decadal Survey
Large Mission Concepts

Comments on Science and Technology Definition Teams

- STDTs will be selected by HQ
  - Community call for self nominations, nominally on day after AAS Town Hall at Jan 2016 AAS Meeting in Kissimmee
  - Candidates vetted by NASA HQ and Program Office plus consult with Center Study Office
  - Astrophysics Division Director will appoint STDT Chairs and members
- STDTs will be chartered
  - Charter available at time of STDT call
- STDTs will have significant role and responsibility
  - Develop science case
  - Flow science case into mission requirements
  - Vet technology gap list
  - Make decisions in cost/capability vs science trades

Preparing for the 2020 Decadal Survey
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

Preparing for the 2020 Decadal Survey
Thinking about Probes

- What was done 10 years ago?
  - Origins Probes Mission Concepts (2004)
    - ROSES call for quick (~9 month) paper concept studies
    - ~9 concepts selected in 2004; total ~$1M ($100K average)
  - Astrophysics Strategic Mission Concepts Study (ASMC; 2007)
    - ROSES call for ~1 year concept studies with mission design lab run
    - ~19 ASMC concepts selected in 2008; total $13M ($700K average)

- Possibilities this time
  - Real mission concept studies
    - Just like AMCS ($700K each in FY08)
    - Exoplanet Probe studies cost $3M each
    - Where does funding come from?
  - Paper mission concept studies, with or without mission design lab run
    - Just like Origins Probes ($100K each)
  - Self selected, self funded
    - Anybody can submit a white paper to the 2020 Decadal Survey

Preparing for the 2020 Decadal Survey
Thinking about Probes

- Suggestion for the Decadal Survey: Recommend a Probe AO
  - Similar to Planetary Science Division's New Frontiers AO
  - Recent Probe-class missions include
    - Spitzer, Fermi, Kepler
    - New Horizons, JUNO, OSIRIS-Rex (New Frontiers missions)
  - Community identifies to the Decadal Survey mission concepts that could plausibly be done as Probes
  - Decadal Survey prioritizes a short list of mission concepts that should be accomplished on a Probe budget for the Probe AO
  - NASA issues a Probe AO and selects a Probe proposal that is responsive in a compelling manner to Decadal Survey identified science objectives for one of the mission concepts (determined by peer review) and can be accomplished as a Probe (determined by TMC review)

- Funding allotted to Probes "slows down" the large mission(s) that follow WFIRST

Preparing for the 2020 Decadal Survey
Thinking about Probes

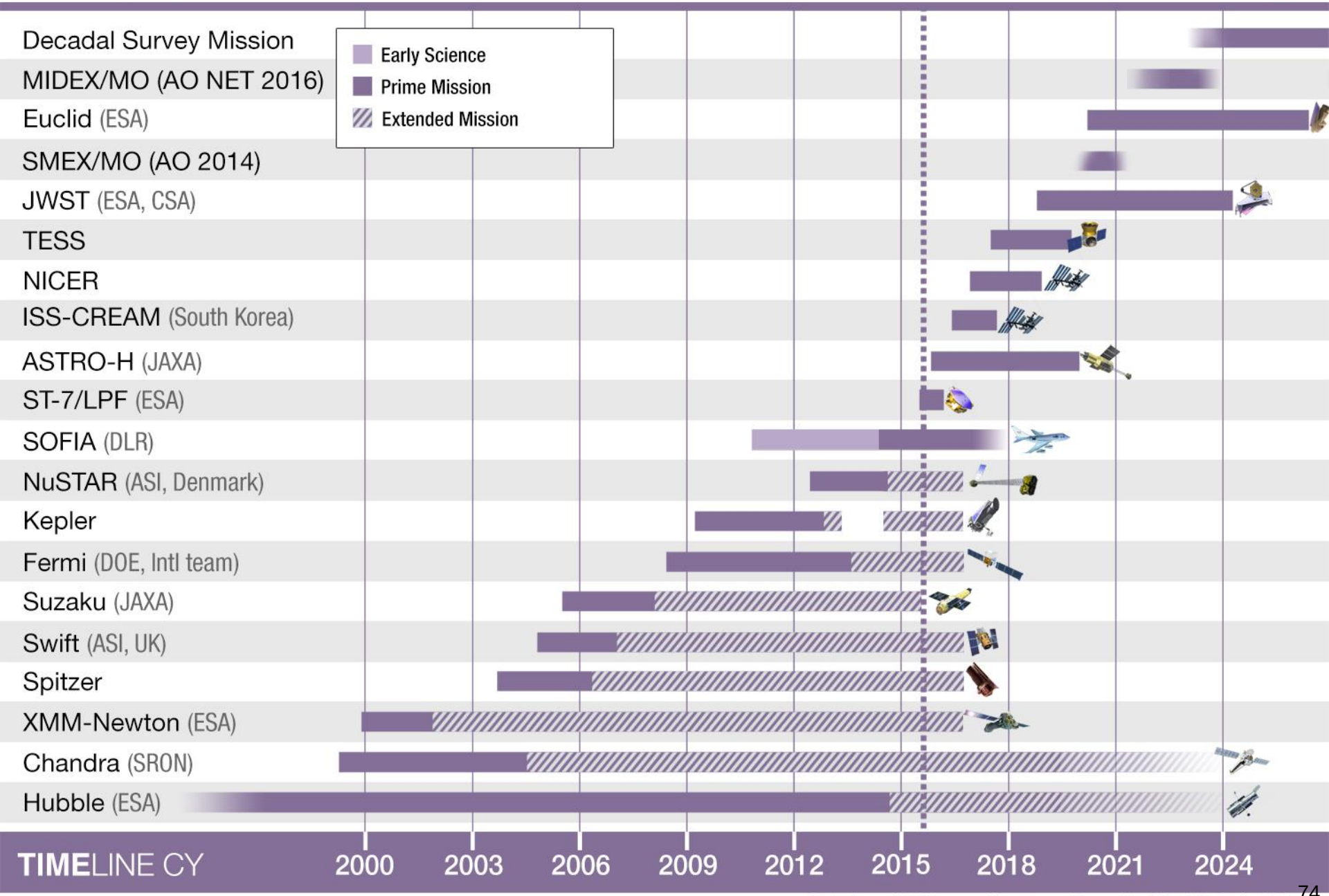
- The concept of “Exemplar Probes”
  - Some probe concepts could be studied and serve as examples through analogy that other probe missions are possible; such a list would not be intended to be complete list of possible and compelling probe concepts.
  - For instance, Exo-C probe study shows that a 1.4m telescope with a single capable instrument and stringent spacecraft performance (e.g., pointing) can be realized as a Probe-class mission for $1B or less.
  - Other probe-class exemplars already exist, including Exo-S, Rendezvous, WFIRST DRM-2, and the three X-ray probes studied by the X-ray CST.

- Role of exemplars for 2020 Decadal Survey
  - Whether the 2020 Decadal Survey recommends one or more specific Probes as priorities, or recommends a New Frontiers-like Astrophysics Probe Program, exemplars provide the science phase space that can be accomplished with probe-class missions

Preparing for the 2020 Decadal Survey
Thinking about Probes

- Concept A
  - Fund ~10 paper mission concept studies
  - Select them through peer reviewed proposals submitted in response to a ROSES solicitation
  - NASA conducts a non-advocate, parametric cost assessment of final concepts
  - NASA cost assessment plus existing exemplars provides rationale for believing these missions can be realized as Probes
- Concept B
  - Concept A plus
  - Conduct detailed study and better cost assessment of a few probes as additional exemplars
- Concept C
  - Fund ~3 full mission concepts
  - Selection process TBD

Astrophysics Timeline



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

Backup

SOFIA
Stratospheric Observatory for Infrared Astronomy

- **World's Largest Airborne Observatory**
- 2.5-meter telescope
- 80/20 Partnership between NASA and the German Aerospace Center (DLR)
- Science Center and Program Management at NASA-Ames Research Center
- Science Flight Operations at NASA-Armstrong Flight Research Center
- Four US and Two German science instruments commissioned
  - Provide imaging, spectroscopy and photometry ranging from visible to far infrared
  - Advanced science instruments under development for future operation

CURRENT STATUS:

- Observatory entered full operations in May 2014
- Program Management transition to NASA-Ames Research Center completed on October 1, 2015
- Observing status:
  - Cycle 3 in progress since February 2015
  - Cycle 4 to begin in February 2016
  - Completed Southern Hemisphere deployment with 4 science instruments
- Second generation instruments:
  - Commissioned upGREAT, multi-pixel heterodyne spectrometer (German instrument)
  - Testing/integrating HAWC+, far infrared imager & polarimeter; 2016 commissioning (U.S. instrument)
- Third-generation instrument to be selected in 2016
- Implemented science community feedback and IG recommendations for improved science productivity
  - Increased support for guest investigators
  - Increased capacity to deploy multiple instruments
  - Streamlined maintenance processes to increase observatory availability
  - Increased support for future science instrumentation
- 722 hours of science data from completed Cycles (Early Science through Cycle 2) has led, so far, to:
  - 52 peer-reviewed science papers
  - On average, one paper per 1.5 flights (so far)
  - Publications in 2 high-impact journals (*Nature* and *Science*)
  - Occultation data (Cycle 3) synergetic with New Horizons

Kepler
Kepler Space Telescope

- **NASA's first space mission dedicated to the search for extrasolar planets, or exoplanets**
- **PI:** W. Borucki, NASA Ames Research Center
- **Launch Date:** March 6, 2009
- **Payload:** 0.95-meter diameter telescope designed to measure the tiny dimming that occurs when an orbiting planet passes in front of ('transits') a star
- **Scientific objectives:**
  - conduct census of exoplanet systems
  - explore the structure and diversity of extrasolar planetary systems
  - determine the frequency of habitable, Earth-sized planets in our galaxy

CURRENT STATUS:

- Kepler "K2" observation method was approved for operations through FY2016 after completion of the 2014 Senior Review.
  - Kepler is conducting observations along the ecliptic, changing its orientation four times per year.
  - The seventh 75-day Campaign started October 3.
  - December 18, 2014: First confirmed planet discovery using K2 observation method
- From 2009-13, Kepler continuously monitored 100 sq. deg. field in constellations of Cygnus and Lyra for 4+ years.
  - These observations ended after failure of 2nd reaction wheel.
- Analysis of first 4 years of Kepler data has revealed:
  - Approximately 4696 exoplanet candidates
  - Approximately 1033 candidates confirmed as planets to date
  - Almost 300 exoplanets (confirmed and candidates) discovered in their star's "habitable zone".
- Analysis of the full (4+ year) Kepler data set ongoing.