National Aeronautics and Space Administration

EXPLORE SCIENCE

NASA Astrophysics

The Decadal Survey on Astronomy and Astrophysics (Astro2020)
National Academies Keck Center, Washington DC
July 15, 2019

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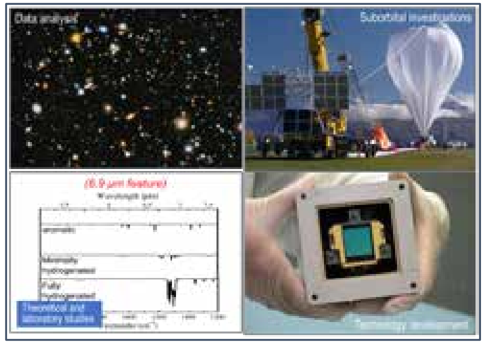
Decadal Survey Goal

- NASA’s highest aspiration for the 2020 Decadal Survey is that it be ambitious
  - The important science questions require new and ambitious capabilities
  - Ambitious missions prioritized by previous Decadal Surveys have always led to paradigm shifting discoveries about the universe
- If you plan to a diminishing budget, you get a diminishing program.
  - Great visions inspire great budgets.

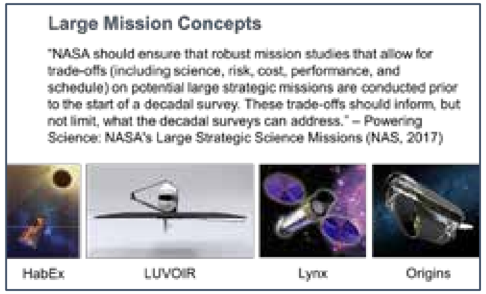
Outline

Setting the Stage

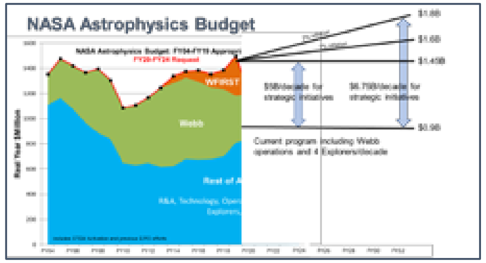
Program of Record



Program of the Future



Planning Guidelines



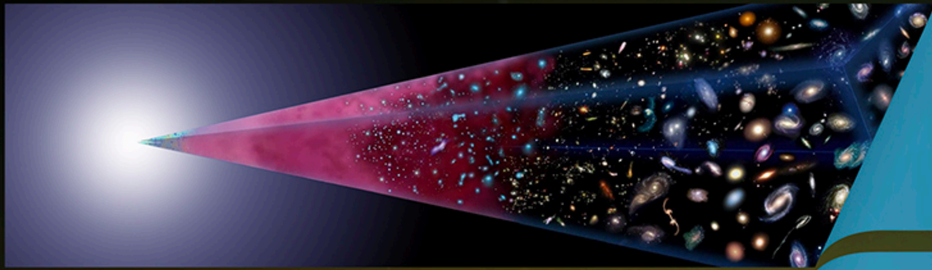
The following charts have been corrected from the version presented on July 15:

Charts 34-35 – In FY24, Webb is in Operations

Chart 49 – FUSE and GALEX had partners

Setting the Stage

Why Astrophysics?



How did our universe begin and evolve?

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

Are we alone?

Enduring National Strategic Drivers

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

Why Astrophysics?

How did our universe

"Success criteria are progress in answering fundamental science questions, implementing the decadal survey priorities, and responding to direction from the Executive Branch and Congress."

NASA Strategic Plan (2018)

Enduring National Strategic Drivers

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

NASA is “Not a Science Agency”

The National Science Foundation Act of 1950 (Public Law 81-507) creates the National Science Foundation. NSF’s mission is

> To promote the progress of science.
>
> For the purpose of advancing the national health, prosperity, and welfare; securing the national defense.

The National Aeronautics and Space Act of 1958 (Public Law 85–568) creates the National Aeronautics and Space Administration. NASA’s mission is

> To conduct aeronautical and space activities.
>
> For the purpose of expansion of human knowledge; improvement of aeronautical and space vehicles; development of vehicles capable of carrying instruments and humans through space; preservation of the role of the United States as a leader in space science and technology.

NASA is a mission-oriented agency, and science is the purpose and consequence of our space missions.

Enduring Value of Decadal Surveys

"Decadal surveys are the most prominent and influential activity of the Space Studies Board (SSB) of the National Academies of Sciences, Engineering, and Medicine." – The Space Science Decadal Surveys: Lessons Learned and Best Practices (NAS, 2015)

NASA Authorization Act(s) include language that the NASA Administrator should set science priorities by following the guidance provided by the scientific community through the Decadal Surveys.

NASA Science Plan(s) include language that scientific priorities for future NASA science missions are guided by Decadal Surveys produced by the National Academies of Sciences, Engineering, and Medicine.

The Decadal Survey report is representative of consensus vision of science goals and a program to accomplish them.

NASA implements Decadal Survey priorities.

Decadal Survey Goal

"Identify the most compelling science challenges and frontiers in astronomy and astrophysics, which shall motivate the committee's strategy for the future." – Astro2020 Statement of Task

- The important science questions require new and ambitious capabilities

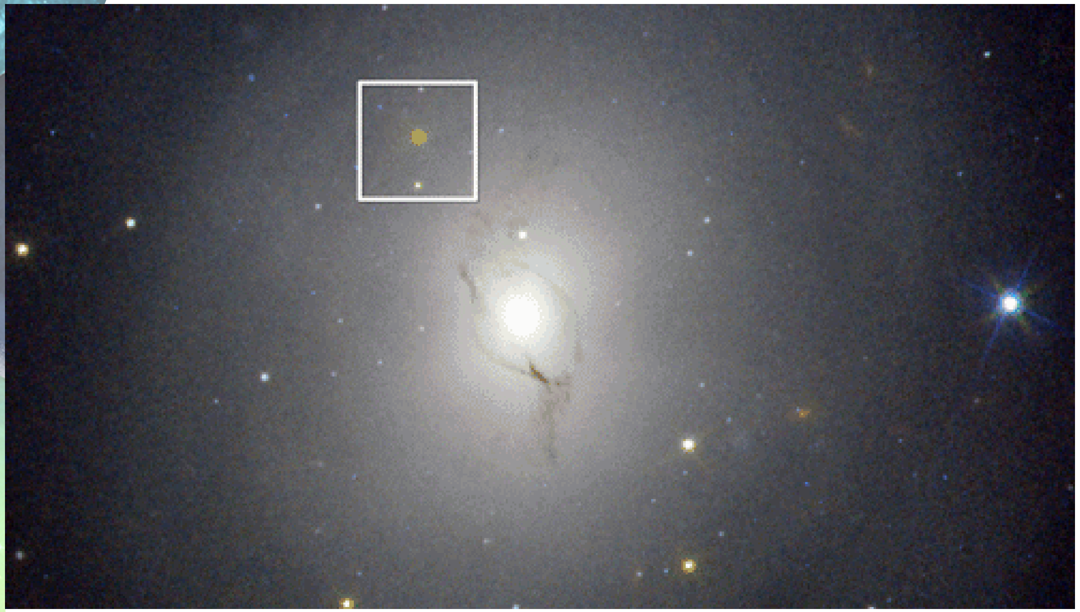
"Develop a comprehensive research strategy to advance the frontiers of astronomy and astrophysics for the period 2022-2032 that will include identifying, recommending, and ranking the highest priority research activities." – Astro2020 Statement of Task

- Ambitious missions prioritized by previous Decadal Surveys have always led to paradigm shifting discoveries about the universe

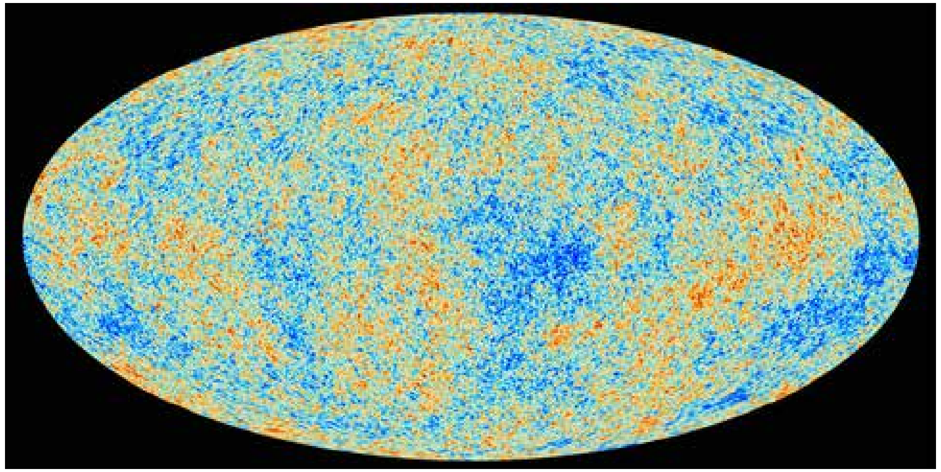
NASA's highest aspiration for the 2020 Decadal Survey is that it be ambitious

Physics of the Cosmos

Probe the origin and destiny of our universe, including the nature of black holes, dark energy, dark matter and gravity

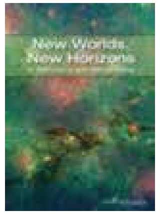


Fermi detected the EM radiation from the LIGO event GW170817 - later followed up by Chandra, Hubble, Swift and other ground-based and space-based telescopes.



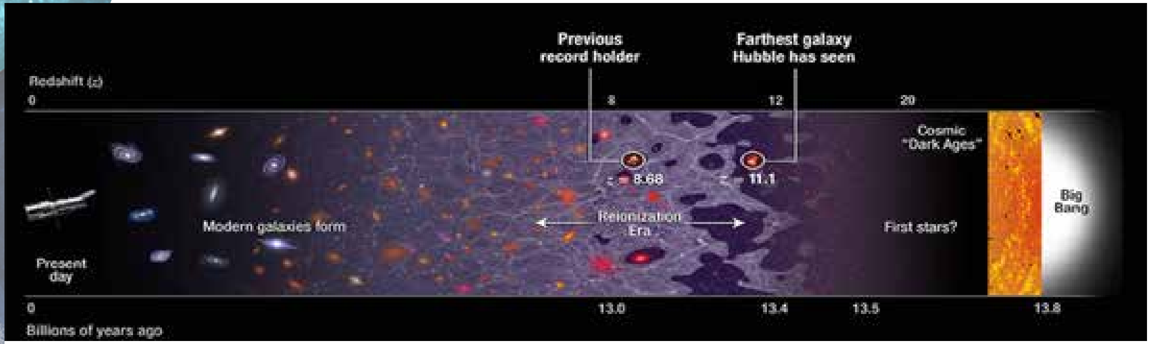
Planck team (winner of Gruber prize) made the most accurate measurements of the age of the universe, rate of expansion, and other cosmological properties

Physics of the Universe

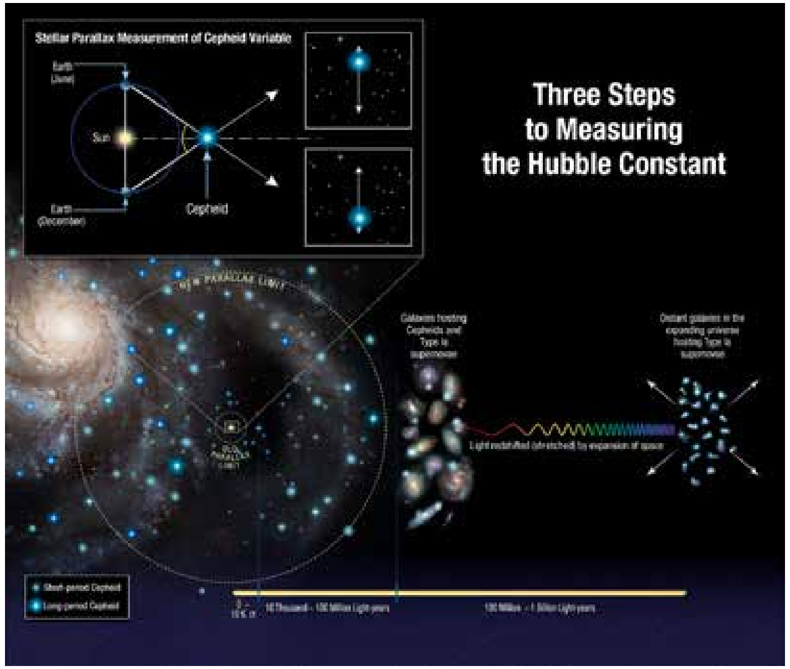


Cosmic Origins

Explore the origin and evolution of the galaxies, stars and planets that make up our universe

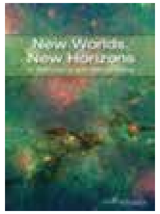


Spitzer and Hubble observations allowed confirmation of a z~11.1 galaxy, only 400 million years after the Big Bang.



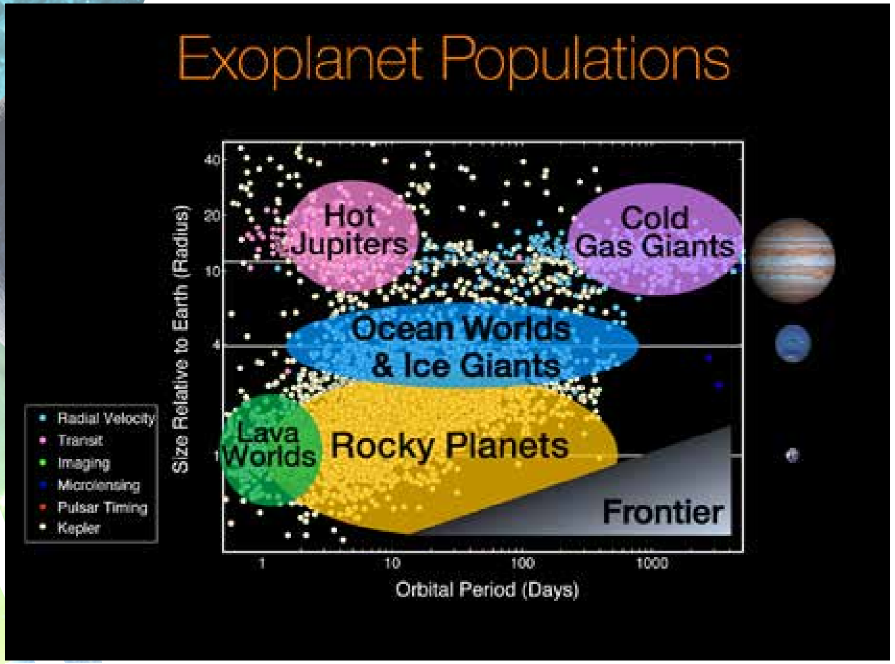
Astronomers measured the Hubble constant to an unprecedented accuracy, reducing the total uncertainty to 2.3 percent. But there is now a statistically significant discrepancy with the Planck results which have a lower H_0 -- this result may point to new, undiscovered physics.

Cosmic Dawn

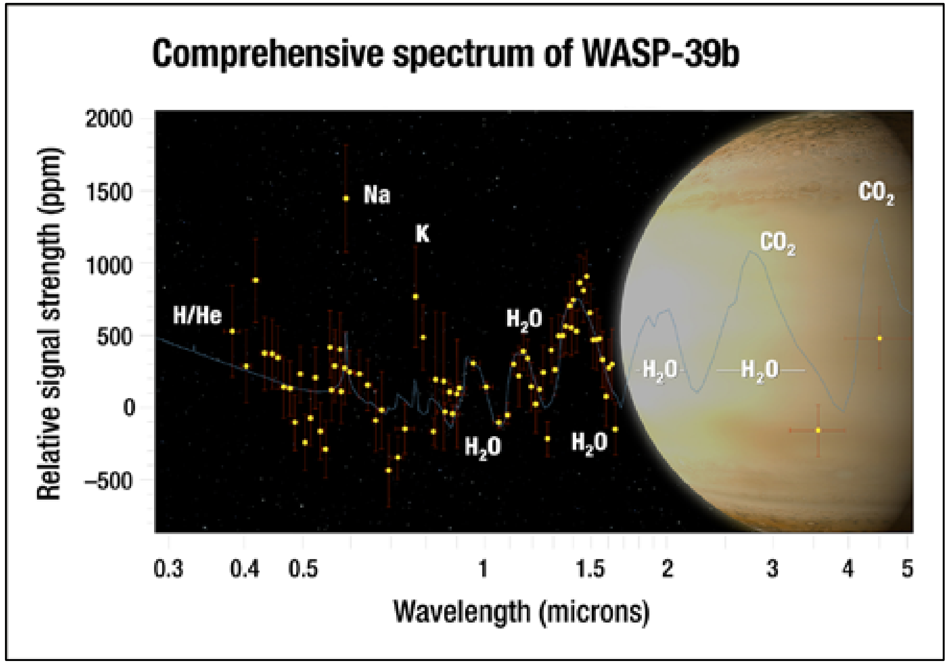


Exoplanet Exploration

Discover and study planets around other stars, and explore whether they could harbor life

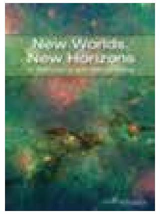


Kepler discovered that exoplanets are ubiquitous, and that rocky planets in the habitable zone are common. TESS will identify the best transiting exoplanets for spectroscopic characterization.



Using Hubble and Spitzer space telescopes, astronomers clear evidence for a large amount (3x amount on Saturn) of water vapor in WASP-39b. In the next decade, telescopes like Webb will continue to characterize exoplanet atmospheres

New Worlds



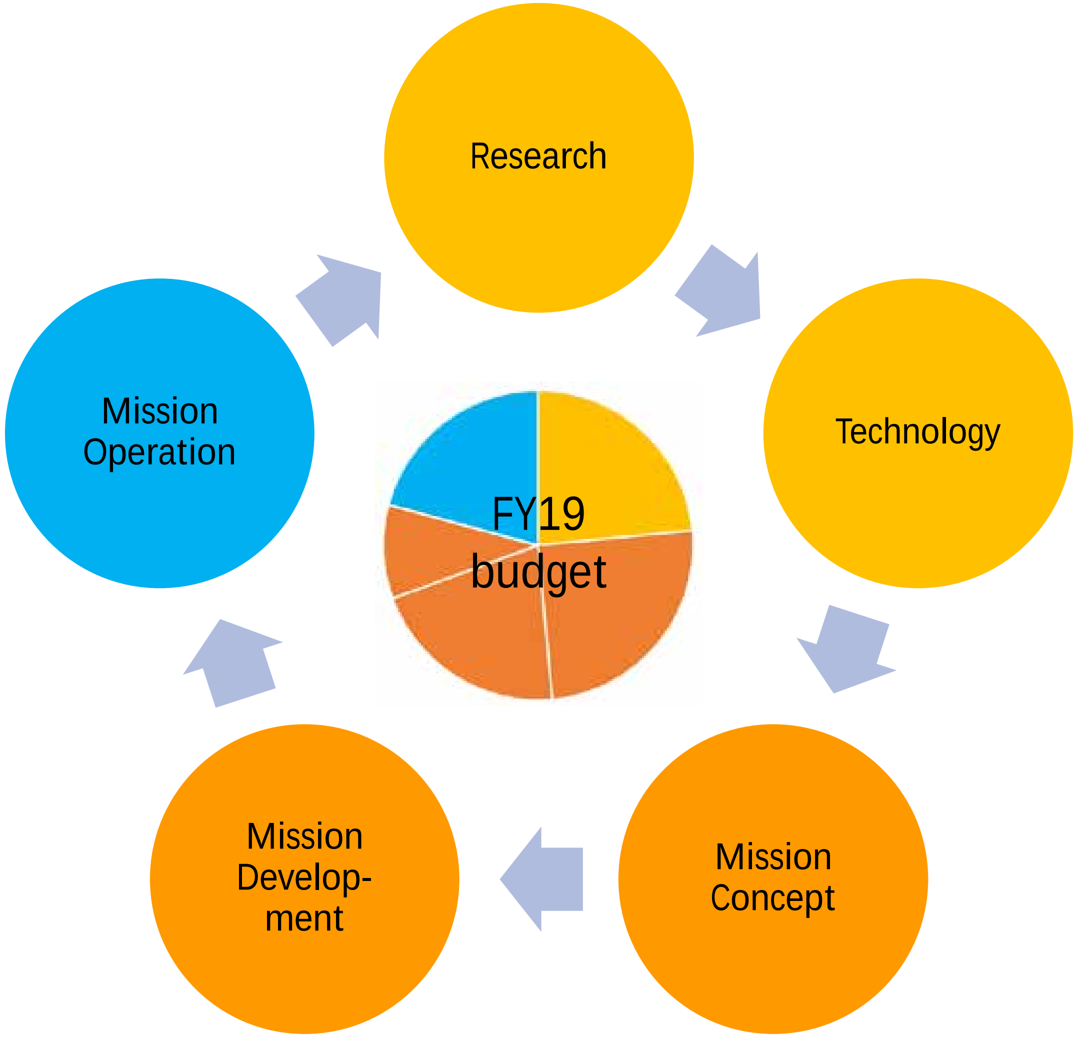
Implementing the 2010 Decadal Survey

Prioritized Recommendation	NASA plans
LARGE ACTIVITIES	
WFIRST	Element & mission PDR in CY2019, KDP-C in early CY2020
Explorers	4 AOs per decade (SMEX 2014, MIDEX 2016, SMEX 2019, MIDEX 2021 (planned), SMEX 2024 (planned))
LISA	Partnering on ESA's LISA gravitational wave observatory
IXO	Partnering on ESA's Athena x-ray observatory
MEDIUM ACTIVITIES	
Exoplanet technology & precursor science	WFIRST coronagraph, starshade and coronagraph technology development, NN-EXPLORE (PRV instrument, EPRV WG), LBTI
Inflation Probe technology	Balloon-borne technology experiments, detector technology investments
SMALL ACTIVITIES	
R&A augmentations	R&A up 60% from FY10 to FY24; added RTF, TCAN, evolved XRP
Mid-TRL technology	Initiated SAT program, includes competed and directed technologies
Suborbital (class) missions	Added New Zealand, offering super-pressure balloon, added CubeSats

Implementing the 2016 Midterm Assessment

Recommendation	NASA plans
4-1 Commission the WIETR; if cost growth threatens decadal priorities and program balance, then descope WFIRST	Done. WIETR completed; descopes taken before KDP-B, further descopes being taken during Phase B as part of PDR process.
4-2 Treat Euclid beyond commitments to ESA as lower priority than Decadal Survey priorities	Done. Euclid commitments to ESA met, unused UFE returned to the Astrophysics budget, no growth in non-hardware elements of Euclid.
4-3 Execute at least four Explorer AOs during the 2012-2021 decade, each with a MO call and a mission selection	Done. AOs in 2014, 2016, 2019, and 2021 (planned), selected missions (IXPE, SPHEREx), and selected MOs (GUSTO, CASE [TBD]) all in-guide budget.
4-4 Restore support for GW research to enable a partnership on LISA that restores the full LISA capability.	Done. LISA Preparatory Science program initiated. NASA contribution to LISA enables 3-arm architecture.
4-5 Participate in Athena, with contributions enhancing mission scientific capabilities.	Done. NASA contributions enhance both instrument scientific capabilities and make use of unique XRCF capabilities.

Program of Record



NASA's Astrophysics Program

Large (Flagship) Missions

- Conduct compelling science that only the U.S. has the capability to lead

Medium (Probe) and Small (Explorer) Missions

- Enable more focused or specialized capabilities and science objectives

International Partnerships

- Use scientific synergies between NASA and its international partners for a win-win outcome

Supporting Research and Technology

- Lay the foundation of the NASA science program
- Invest in the US scientific community and National capabilities
- Maximize scientific output of missions
- Develop innovative ideas and next generation technology for future missions
- Develop the next generation of scientists, engineers, and innovators

Principles of NASA Science

Investment choices are based on scientific merit via peer review and open competition

Active participation by the research community beyond NASA is critical to success

Effective international and inter/intra-agency partnerships leverage NASA resources and extend the reach of our science results

A balanced portfolio of space missions and mission enabling programs sustains progress toward NASA’s science goals

The pace of scientific progress is enhanced by rapid, open access to data from science missions

Accountability, transparent processes, accessible results, and capture of lessons learned are essential features of this Federal science enterprise

The NASA mandate includes broad public communication

Source: NASA Science Plan (2014)

Active participation by the research community beyond NASA is critical to success

- Decadal Survey and other National Academies studies
- Senior Review
- Federal Advisory Committees and Program Analysis Groups
- Peer review of proposals for spaceflight investigations
- Peer review of research and supporting technology investigations
- Peer review of observing proposals for NASA space telescopes
- User Groups for missions in operation
- Science Working Groups for missions under development
- Science and Technology Development Teams for missions under study

Building An Excellent Workforce

NASA achieves excellence by relying on diverse teams, both within and external to NASA, to most effectively perform NASA's work

"Assess the state of the profession. Identify areas of concern and importance [regarding] the future vitality and capability of the astronomy and astrophysics work force. Where possible, provide specific, actionable and practical recommendations to the agencies." – Astro2020 Statement of Task

NASA Science Mission Directorate

- Developed a PI resources webpage at https://science.nasa.gov/researchers/new-pi-resources
- Introduced pre-reviews of mission peer review panels to ensure diversity
- Added a code of conduct requirement for SMD-funded conferences to ROSES 2019
- Included career development positions and associated evaluation criteria as part of Discovery and New Frontiers AOs
- Implemented a Code of Conduct and implicit bias training for all ROSES peer reviews
- Adopting dual anonymous reviews for all GO programs, and piloting them for other R&A programs, following successful demonstration by STScI for Hubble GO program
- Presented a national symposium by SMD AA Thomas Zurbuchen on lessons learned regarding mission proposal success
- Is developing award terms and conditions mandating reporting harassment, similar to NSF's
- Is presenting information sessions at major conferences to support people developing first proposal

NASA is looking forward to specific, actionable, and practical recommendations

Reviewing the Program of Record

"Consider the status and evolution of ongoing programs ("programs of record") of the agencies, including the balance of activities and investments of all relevant and appropriate sizes and types, research programs (including individual investigator programs), ongoing support of operational missions and facilities, and the balance that would best address the committee's recommended science priorities and comprehensive strategy." – Astro2020 Statement of Task

NASA is defining its Program of Record as those activities which will continue as planned through the next decade in the absence of recommendations from the Decadal Survey to make changes.

Changes to the Program of Record will change the projected budget available for new initiatives in the coming decade.

Recommending a less expensive Program of Record will create a larger "Decadal Survey wedge" under all budget scenarios

Astrophysics Management Structure

- **Astrophysics Division**
  - **Flight Programs**
    - Astrophysics Strategic Missions @ HQ
      - WFIRST
      - Webb*
      - SOFIA**
    - Astrophysics Explorers @ GSFC
      - IXPE GUSTO
      - XRISM Euclid
      - SPHEREx
  - **Supporting Research and Technology Programs**
    - PCOS/COR @ GSFC
      - LISA Study
      - Athena Study
    - EXEP @ JPL
      - Ground-based Partnerships (Keck, NN-EXPLORE)
    - Research @ HQ
      - Operating Missions
      - Balloons
      - Archives

* after commissioning (CY2021)

** after restructuring (CY2019)

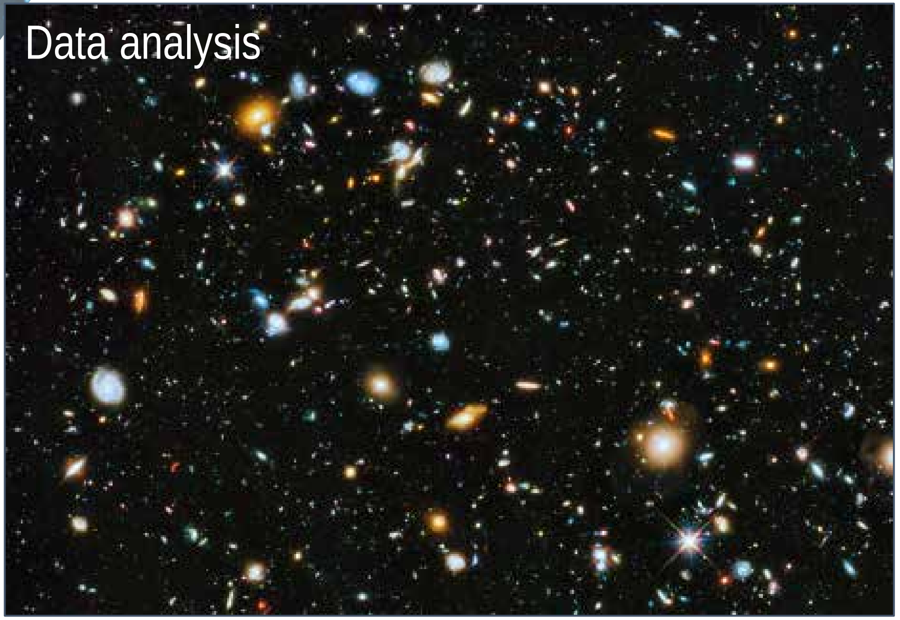
Program of Record

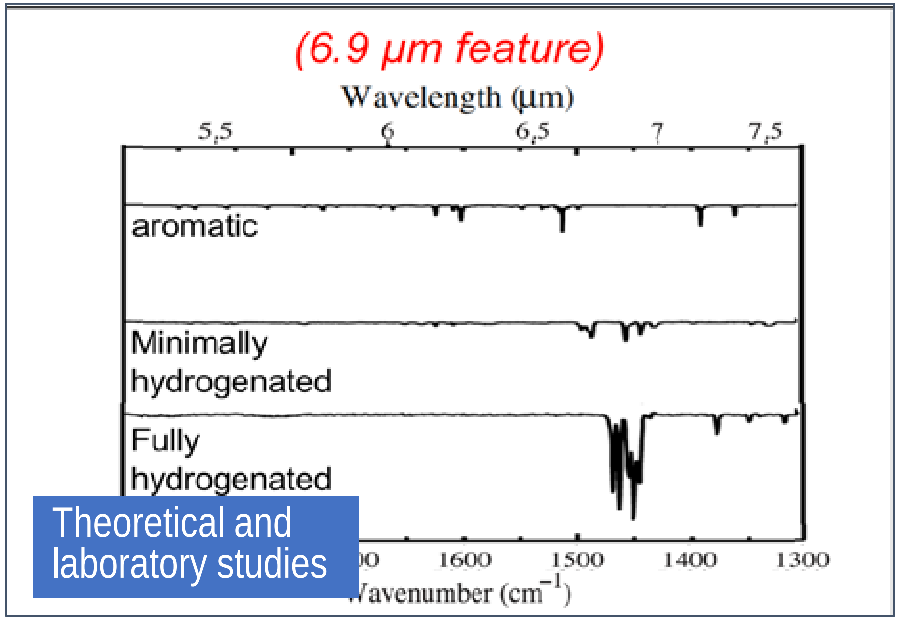
Supporting Research & Technology

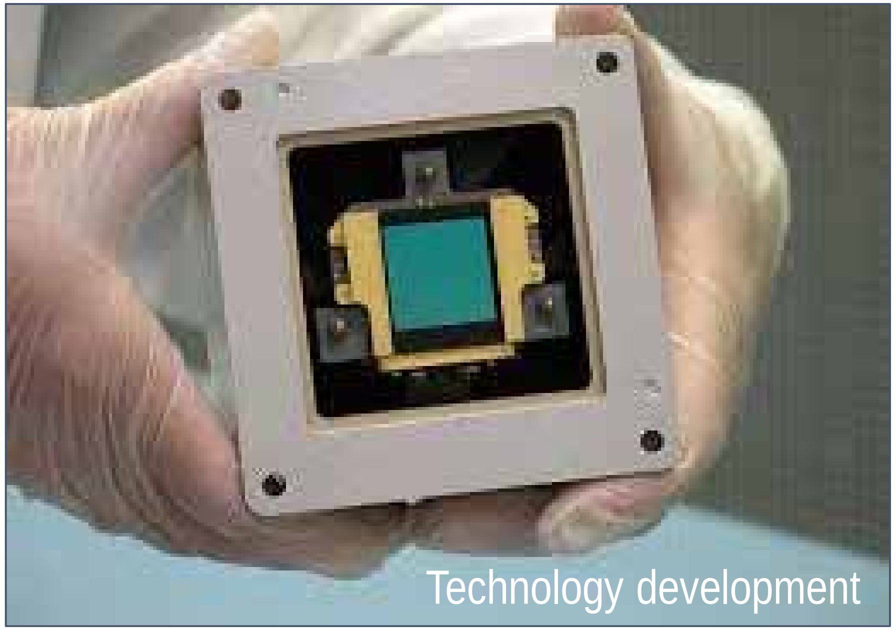
Operating Missions

Missions in Development or Under Study

Supporting Research and Technology





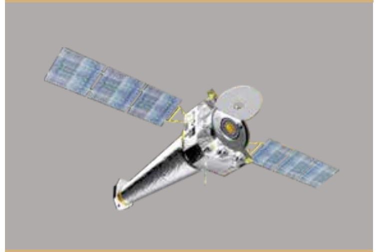


Operating Missions

Hubble 4/90
NASA Strategic Mission

Hubble Space Telescope

Chandra 7/99
NASA Strategic Mission



Chandra X-ray Observatory

XMM-Newton 12/99
ESA-led Mission

X-ray Multi Mirror - Newton

Spitzer 8/03
NASA Strategic Mission

Spitzer Space Telescope

Gehrels Swift 11/04
NASA MIDEX Mission

Neil Gehrels Swift Gamma-ray Burst Explorer

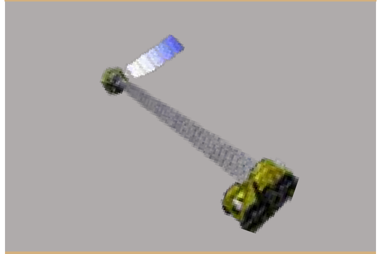
Fermi 6/08
NASA Strategic Mission

Fermi Gamma-ray Space Telescope

Kepler 3/09
NASA Discovery Mission

Mission Complete!

NuSTAR 6/12
NASA SMEX Mission



Nuclear Spectroscopic Telescope Array

SOFIA 5/14
NASA Strategic Mission

Stratospheric Observatory for Infrared Astronomy

ISS-NICER 6/17
NASA Explorers Miss. of Oppty

Neutron Star Interior Composition Explorer

TESS 4/18
NASA MIDEX Mission

Transiting Exoplanet Survey Satellite

Operating Missions (including GO programs)

Hubble 4/90
NASA Strategic Mission

GO Program

Hubble Space Telescope

Chandra 7/99
NASA Strategic Mission

GO Program

Chandra X-ray Observatory

XMM-Newton 12/99
ESA-led Mission

GO Program

X-ray Multi Mirror - Newton

Spitzer 8/03
NASA Strategic Mission

Mission ending Jan 31, 2020

Spitzer Space Telescope

Gehrels Swift 11/04
NASA MIDEX Mission

GO Program

Neil Gehrels Swift Gamma-ray Burst Explorer

Fermi 6/08
NASA Strategic Mission

GO Program

Fermi Gamma-ray Space Telescope

Kepler 3/09
NASA Discovery Mission

Mission Complete!

NuSTAR 6/12
NASA SMEX Mission

GO Program

Nuclear Spectroscopic Telescope Array

SOFIA 5/14
NASA Strategic Mission

GO Program

Stratospheric Observatory for Infrared Astronomy

ISS-NICER 6/17
NASA Explorers Miss. of Oppty

GO Program

Neutron Star Interior Composition Explorer

TESS 4/18
NASA MIDEX Mission

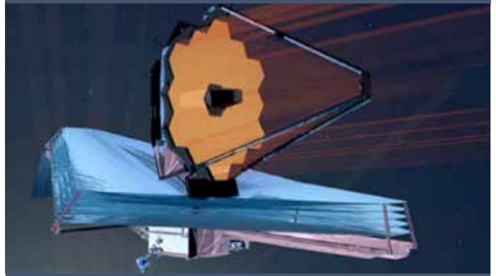
GO Program

Transiting Exoplanet Survey Satellite

Missions in Development or Under Study

Webb
2021

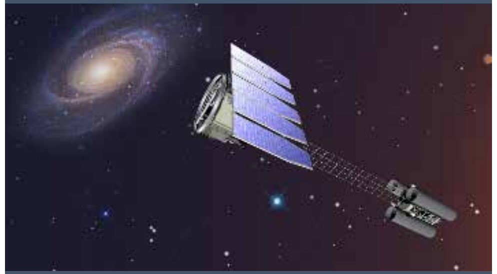
NASA Strategic Mission



James Webb
Space Telescope

IXPE
2021

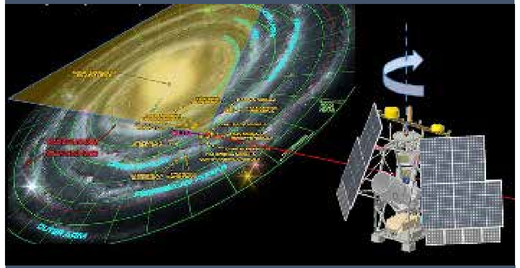
NASA Explorers Mission



Imaging X-ray
Polarimetry Explorer

GUSTO
2021

NASA Explorers Mission



Galactic/ Extragalactic ULDB
Spectroscopic Terahertz Observatory

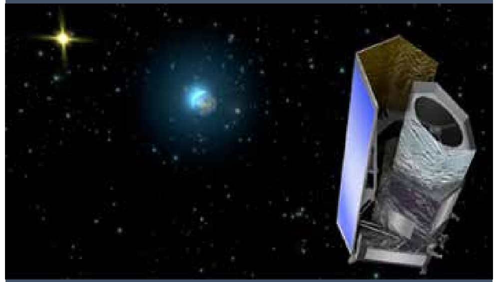
XRISM
2022

JAXA-led Mission

NASA is supplying the Resolve
detector and X-ray mirrors

Euclid
2022

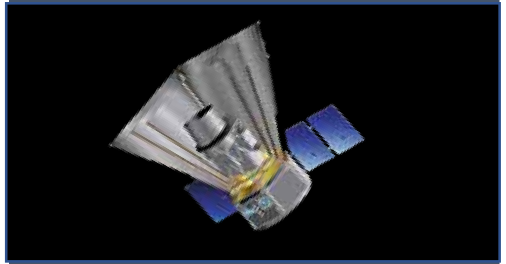
ESA-led Mission



NASA is supplying the NISP
sensor chip system

SPHEREx
2023

NASA Explorers Mission



Spectro-Photometer for the History of
the Universe, Epoch of Reionization,
and Ices Explorer

WFIRST
Mid 2020s

NASA Strategic Mission

Wide Field Infrared
Survey Telescope

Athena / LISA
2030s

ESA-led Missions

NASA is supplying instrument
and mission systems

Missions in Development or Under Study

Webb 2021
NASA Strategic Mission

GO Program

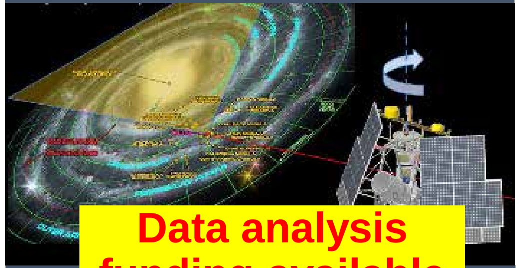
James Webb
Space Telescope

IXPE 2021
NASA Explorers Mission

GO Program in extended phase per Senior Review

Polarimetry Explorer

GUSTO 2021
NASA Explorers Mission



Data analysis funding available via ADAP

Sp... y

XRISM 2022
JAXA-led Mission

GO Program

NASA is supplying the Resolve
detector and X-ray mirrors

Euclid 2022
ESA-led Mission

Archival Research Program

sensor chip system

SPHEREx 2023
NASA Explorers Mission

Archival Research Program

Spec... ry of
the U... tion,
and Ices Explorer

WFIRST Mid 2020s
NASA Strategic Mission

GO Program

Wide Field Infrared
Survey Telescope

Athena / LISA 2030s
ESA-led Missions

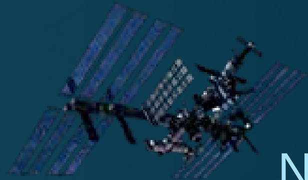
ESA data policies not yet set

NASA is supplying instrument
and mission systems

Astrophysics Explorers Program

Gehrels Swift

NuSTAR



NICER

TESS

4 AOs per decade

Announcement of Opportunity
Explorer 2011

MIDEX 2011

Announcement of Opportunity
Astrophysics Explorers Program
2014 Small Explorer (SMEX)

SMEX 2014

Announcement of Opportunity
Astrophysics Explorers Program
2016 Medium Explorer (MIDEX)

MIDEX 2016

Announcement of Opportunity
Astrophysics Explorers Program
2019 Small Explorer (SMEX)

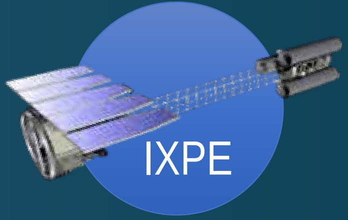
SMEX 2019

Announcement of Opportunity
Astrophysics Explorers Program
2016 Medium Explorer (MIDEX)

MIDEX 2021

Small and Mid-Size Missions

TESS



IXPE

SPHEREx

Directed 2017

Missions of Opportunity

NICER

GUSTO

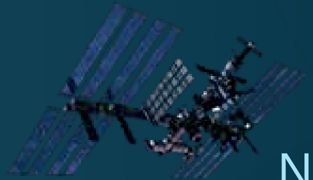
MO TBD

XRISM

Astrophysics Explorers Program

Gehrels Swift

NuSTAR



NICER

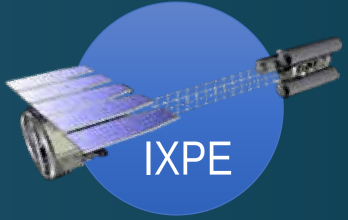
TESS

4 AOs per decade

MIDEX 2011	SMEX 2014	MIDEX 2016	SMEX 2019	MIDEX 2021
Announcement of Opportunity Explorer 2011	Announcement of Opportunity Astrophysics Explorers Program 2014 Small Explorer (SMEX)	Announcement of Opportunity Astrophysics Explorers Program 2016 Medium Explorer (MIDEX)	Released!	Announcement of Opportunity Astrophysics Explorers Program 2016 Medium Explorer (MIDEX)

Small and Mid-Size Missions

TESS



IXPE

SPHEREx

Missions of Opportunity

NICER

GUSTO

MO TBD

XRISM

Explorers Mission of Opportunity AO includes new opportunities:

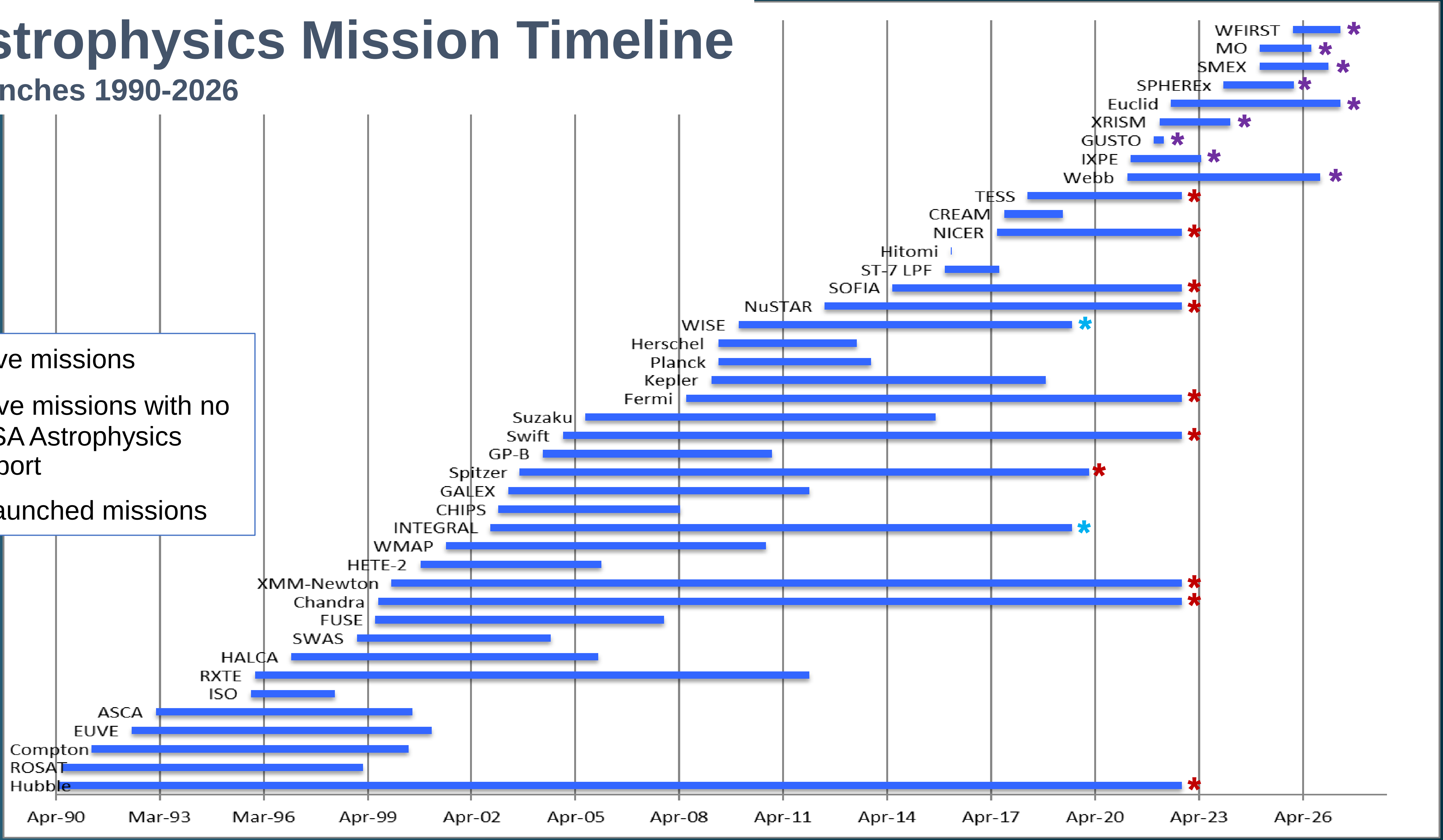
- NASA-provided RideShare
- SmallSat Secondary Payloads
- Opportunities enabled by the Artemis Program

Program of Record

Supporting Research & Technology	**R&A**: ADAP, ATP, TCAN, XRP, Hubble Fellows, GO programs	**Technology**: APRA, SAT, Roman Fellows, Future flagship technologies	**Research support**: Keck, Balloon project, Astrophysics archives
Operating Missions	**Explorers**: Gehrels Swift, NuSTAR, NICER, TESS	**International Partnerships**: XMM-Newton	**Strategic Missions**: Hubble, Chandra, Spitzer, Fermi, SOFIA
Missions in Development or Under Study	**Explorers**: IXPE, GUSTO, SPHEREx, AO2019, AO2021, etc.	**International Partnerships**: Euclid, XRISM, Athena, LISA	**Strategic Missions**: Webb, WFIRST

Astrophysics Mission Timeline

Launches 1990-2026



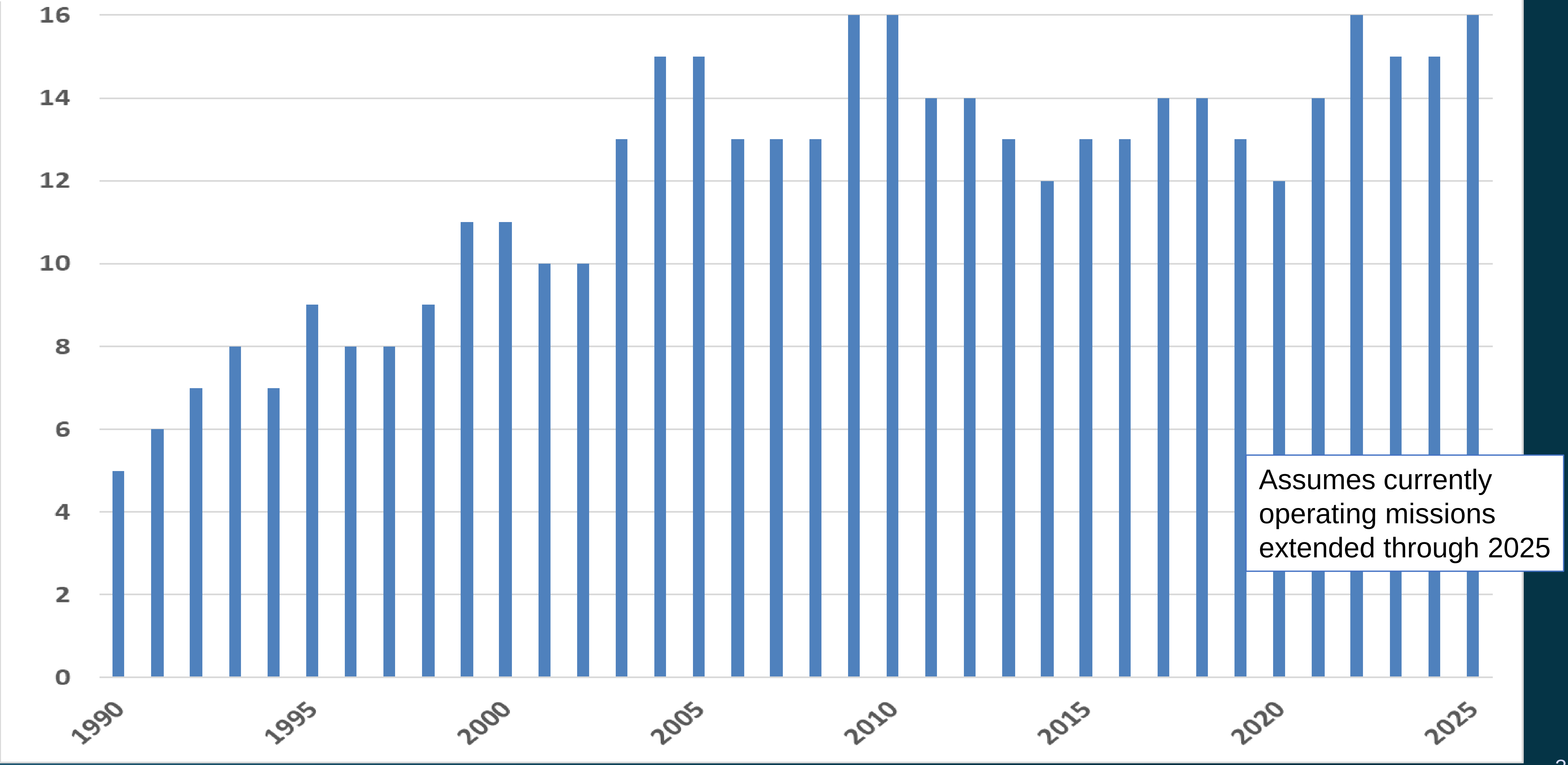
* Active missions

* Active missions with no NASA Astrophysics support

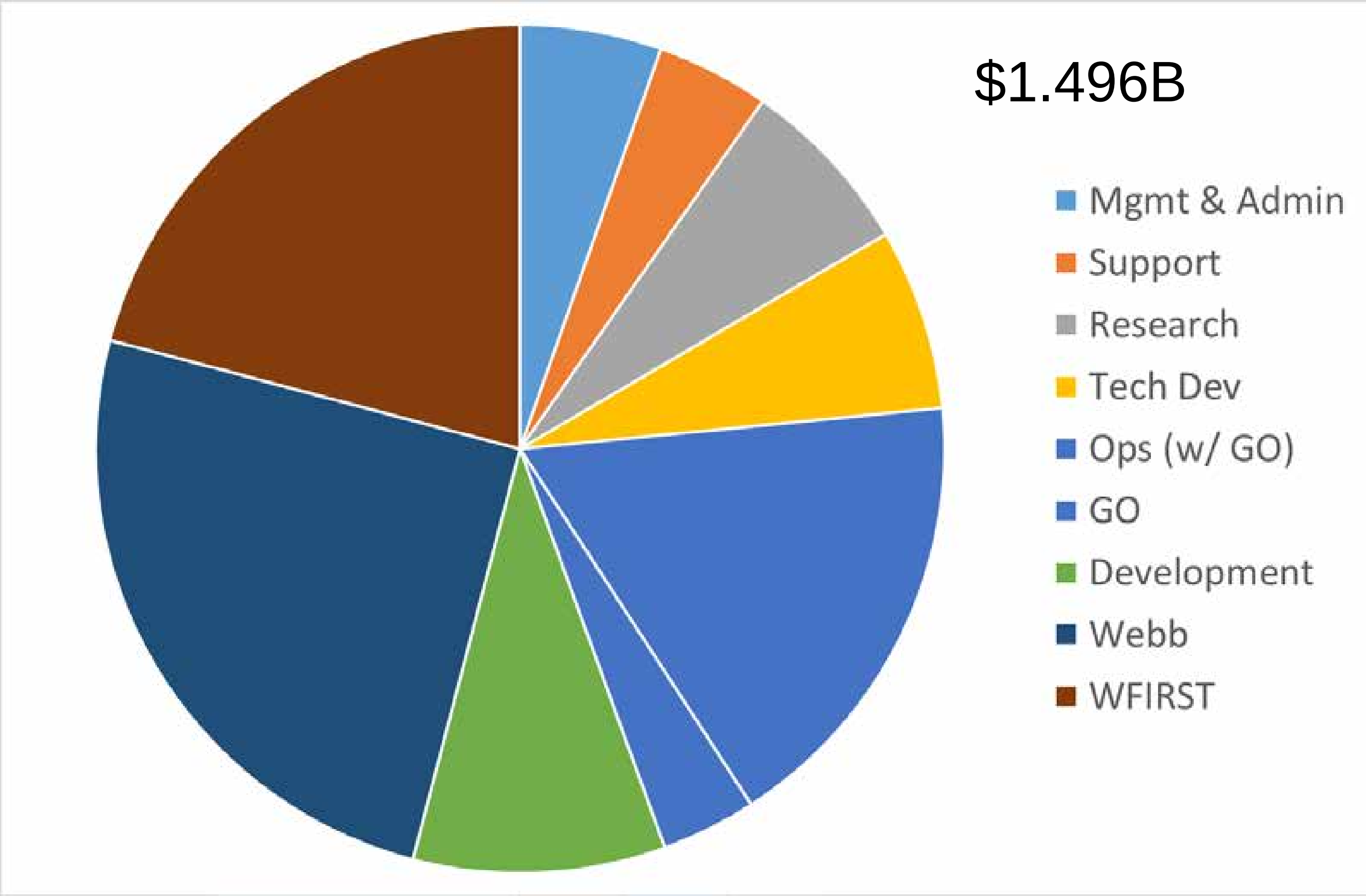
* Unlaunched missions

Astrophysics Mission Timeline

Missions operating each year

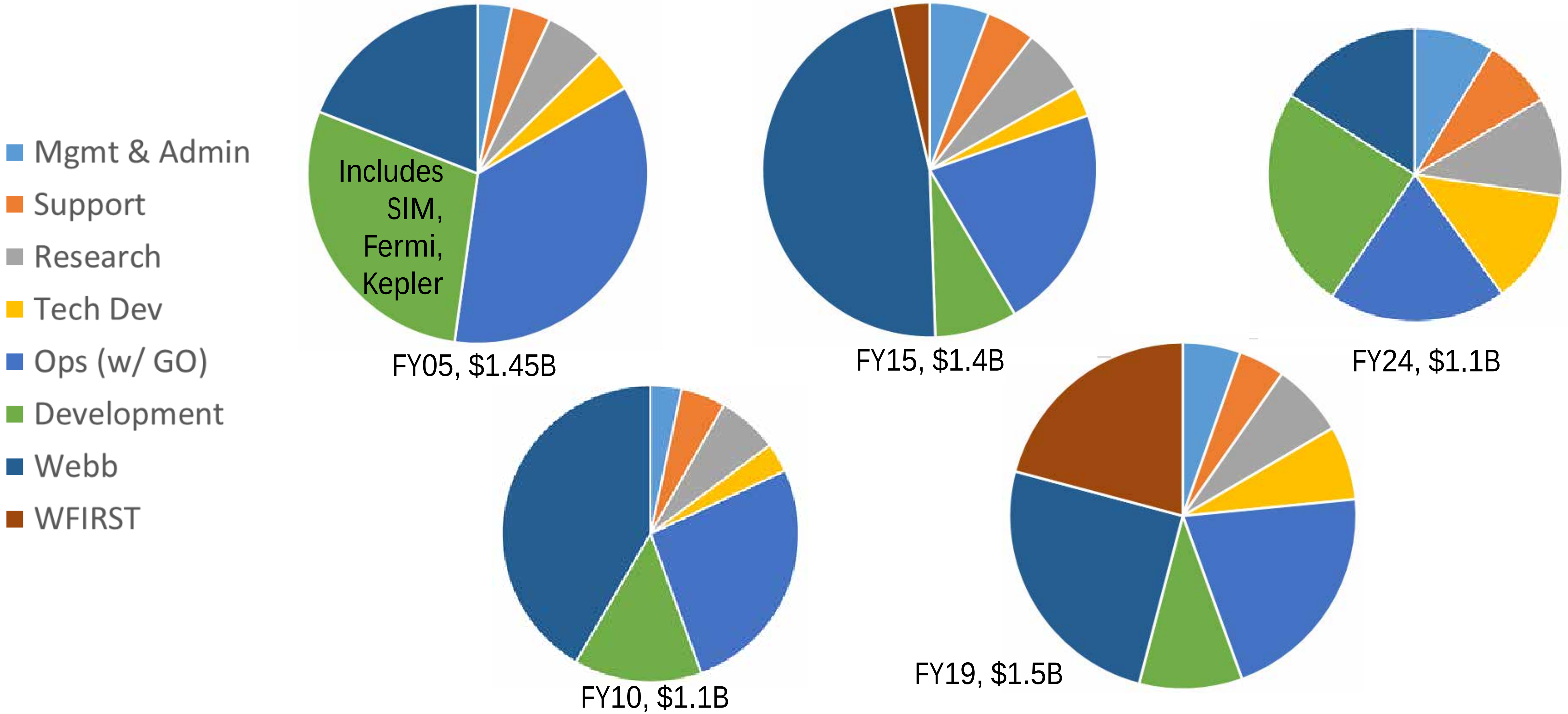


FY19 Budget Snapshot



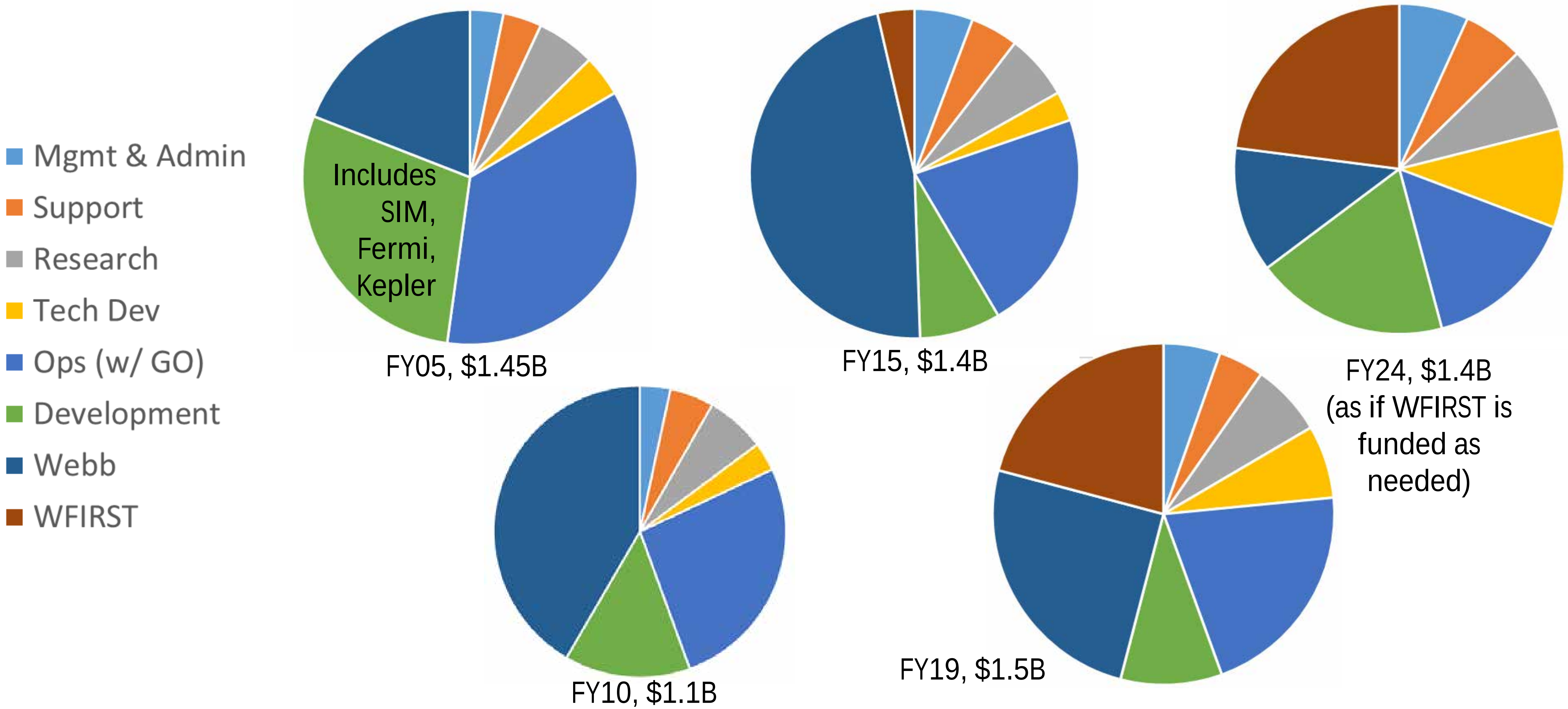
FY05, FY10, FY15, FY19, FY24 Budget Snapshots

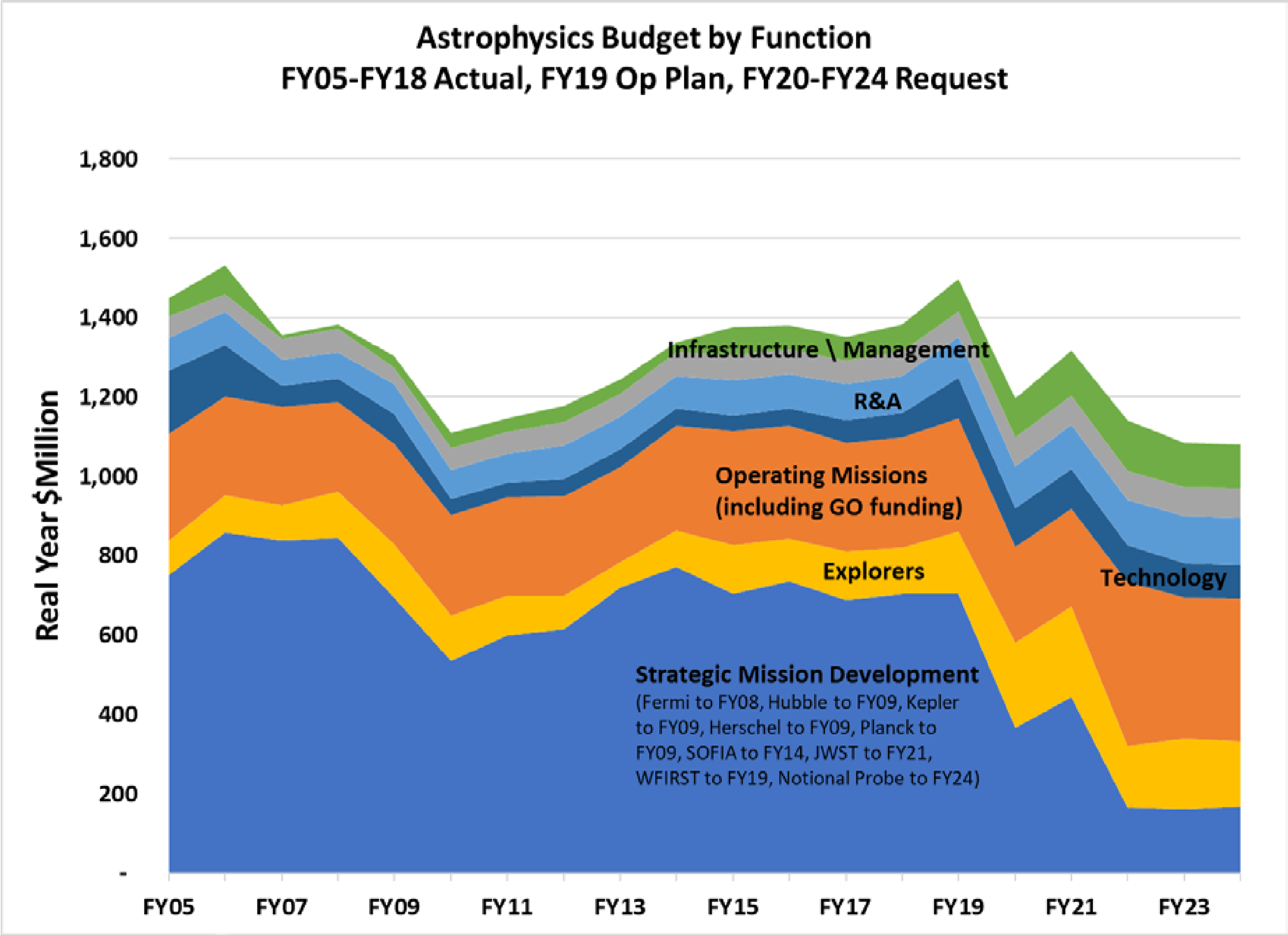
In FY24, Webb is in Operation



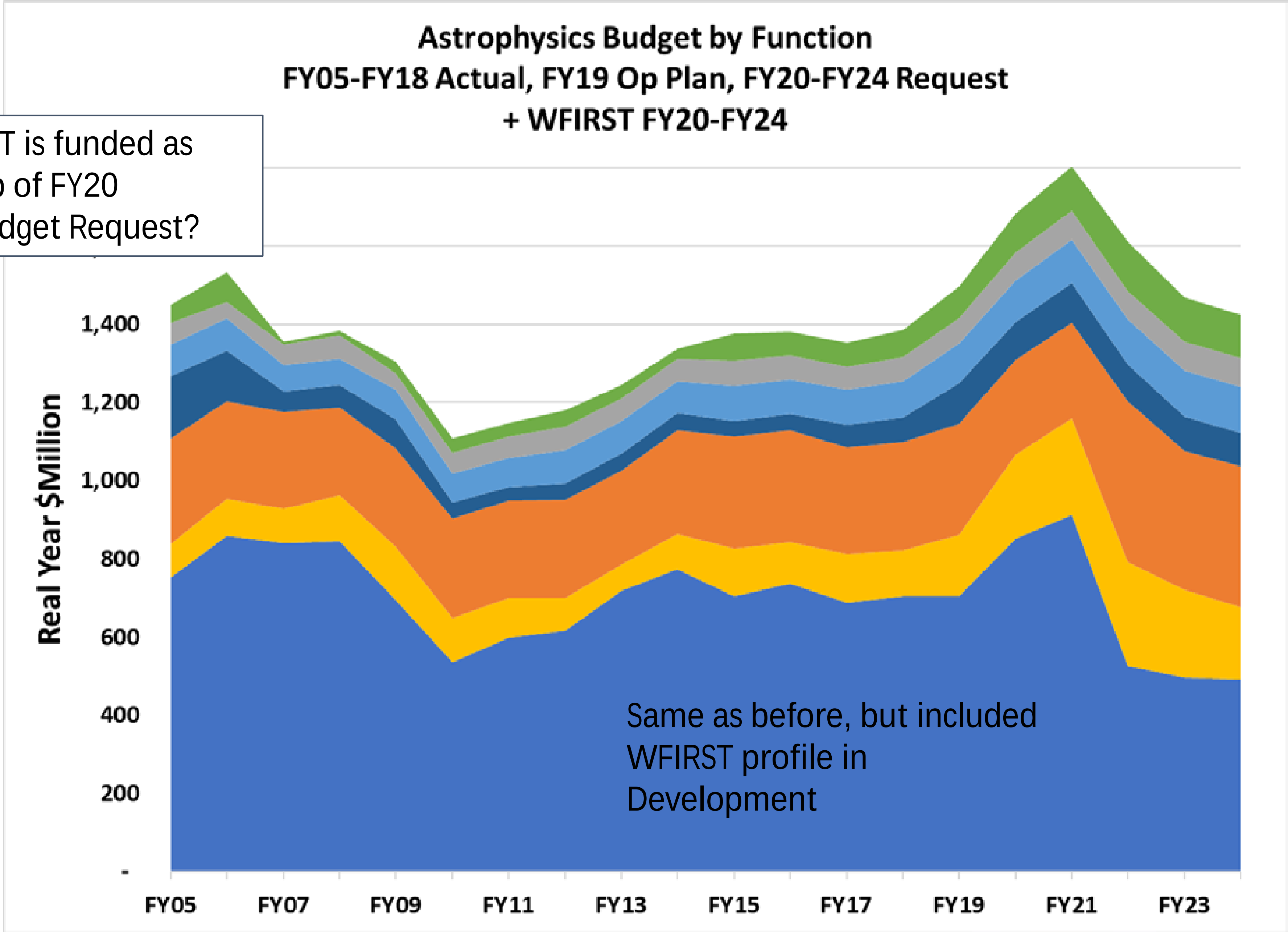
FY05, FY10, FY15, FY19, FY24 Budget Snapshots

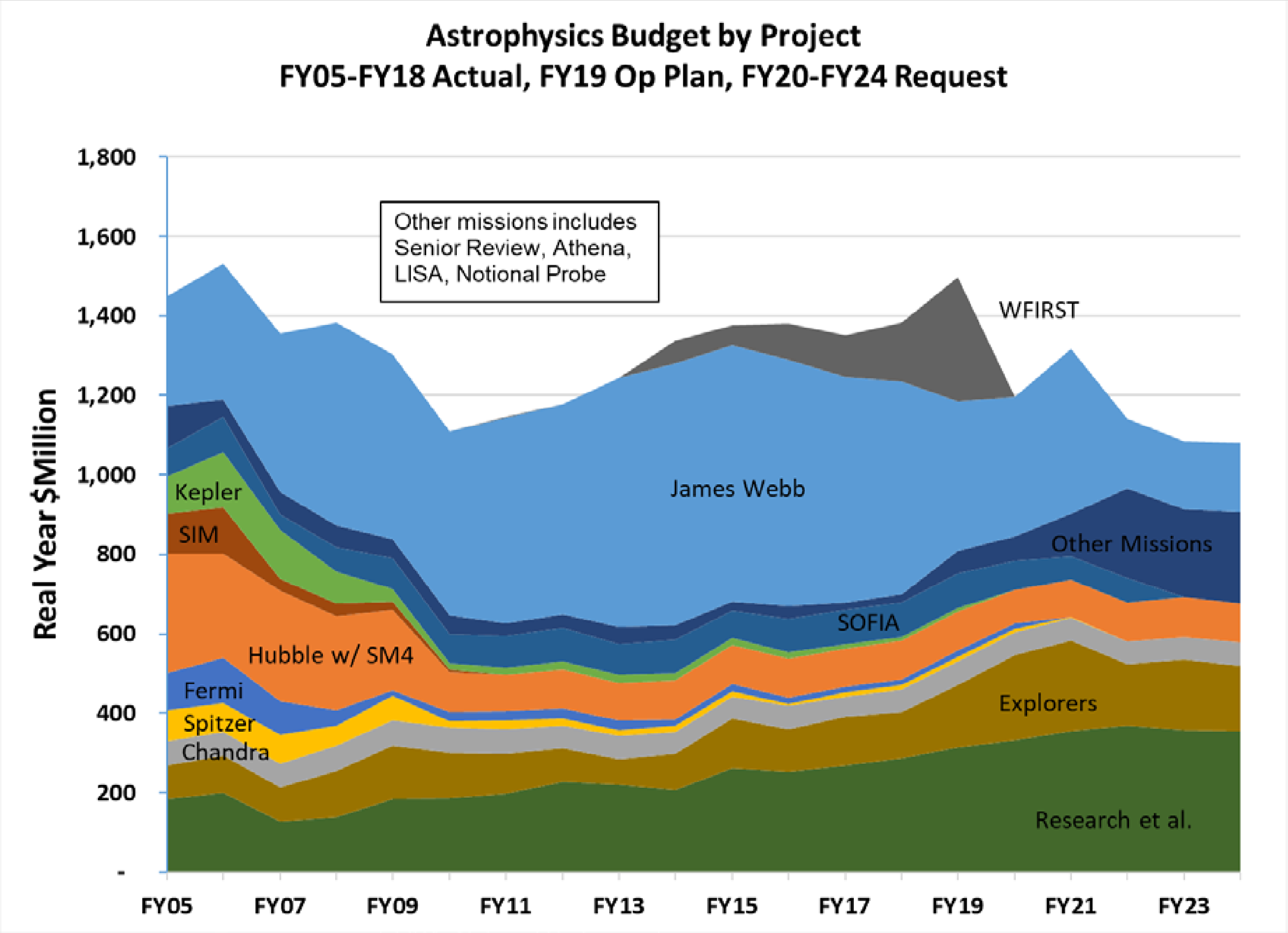
In FY24, Webb is in Operation




Astrophysics Budget by Function
FY05-FY18 Actual, FY19 Op Plan, FY20-FY24 Request
Real Year $Million
1,800
1,600
1,400
1,200
1,000
800
600
400
200
-
FY05
FY07
FY09
FY11
FY13
FY15
FY17
FY19
FY21
FY23
Infrastructure \ Management
R&A
Operating Missions
(including GO funding)
Explorers
Technology
Strategic Mission Development
(Fermi to FY08, Hubble to FY09, Kepler
to FY09, Herschel to FY09, Planck to
FY09, SOFIA to FY14, JWST to FY21,
WFIRST to FY19, Notional Probe to FY24)

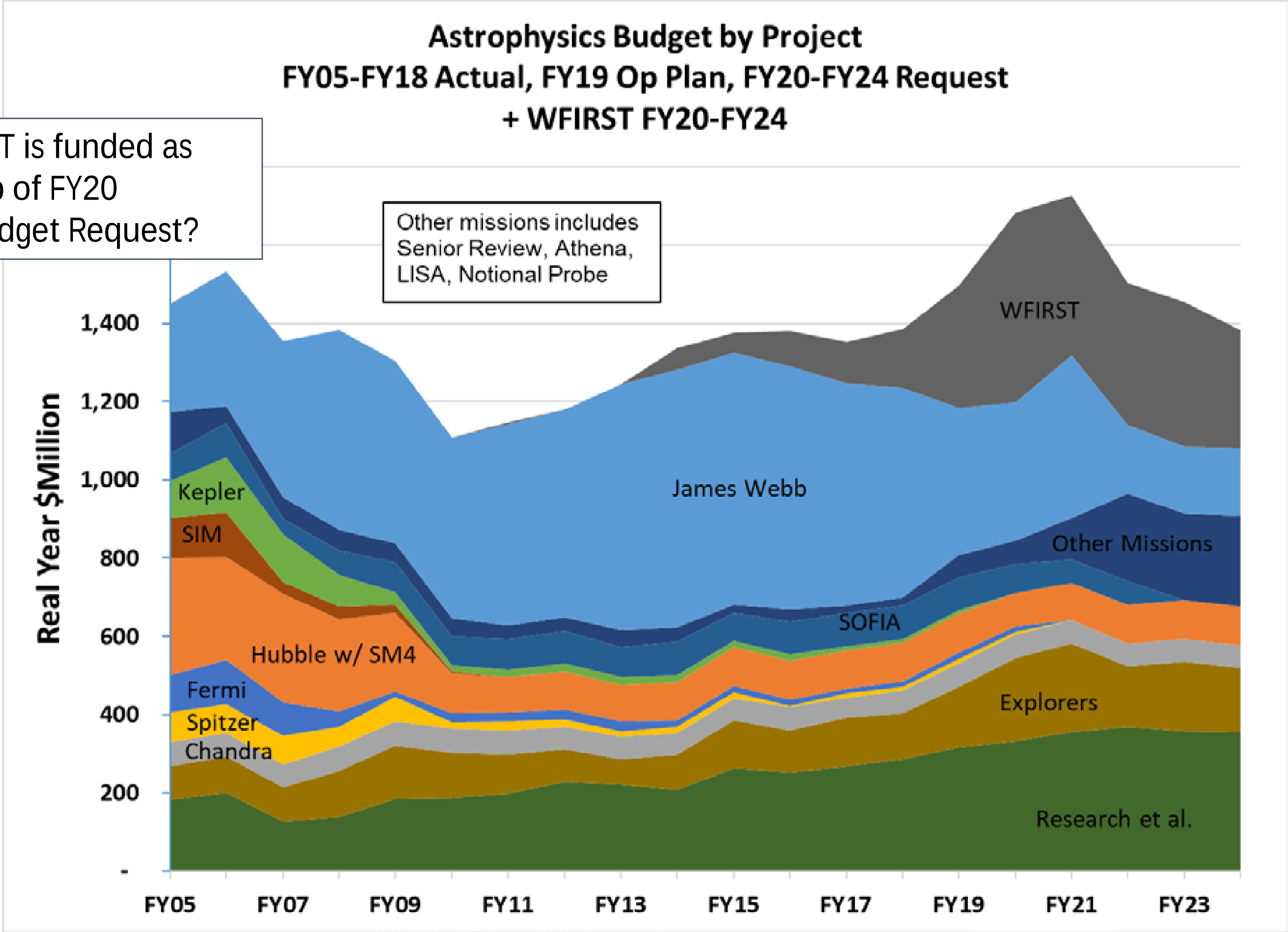
What if WFIRST is funded as needed on top of FY20 President's Budget Request?

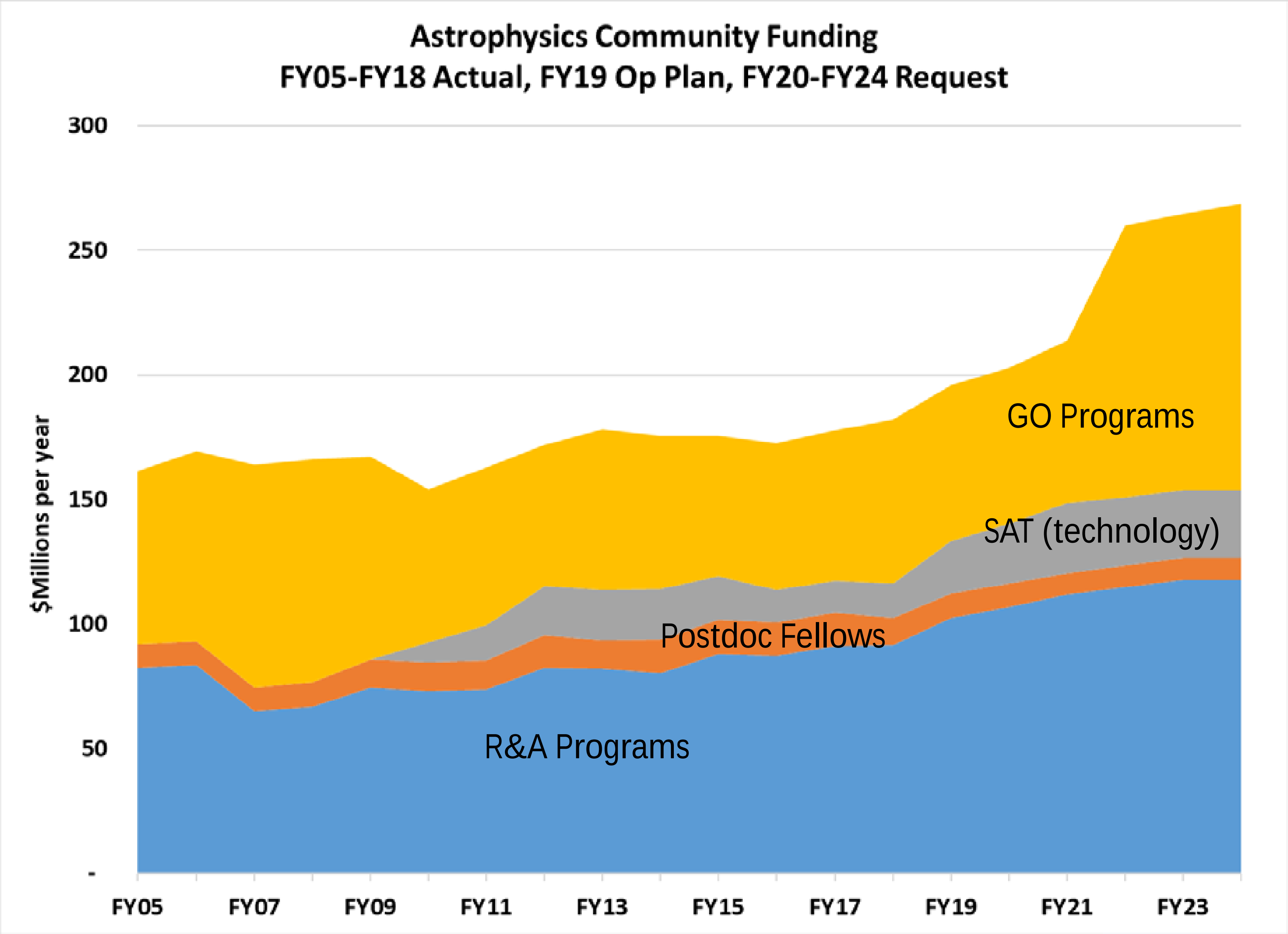




Astrophysics Budget by Project
FY05-FY18 Actual, FY19 Op Plan, FY20-FY24 Request
Real Year $Million
1,800
1,600
1,400
1,200
1,000
800
600
400
200
-
FY05
FY07
FY09
FY11
FY13
FY15
FY17
FY19
FY21
FY23
Other missions includes Senior Review, Athena, LISA, Notional Probe
WFIRST
James Webb
Kepler
SIM
Hubble w/ SM4
Fermi
Spitzer
Chandra
SOFIA
Other Missions
Explorers
Research et al.

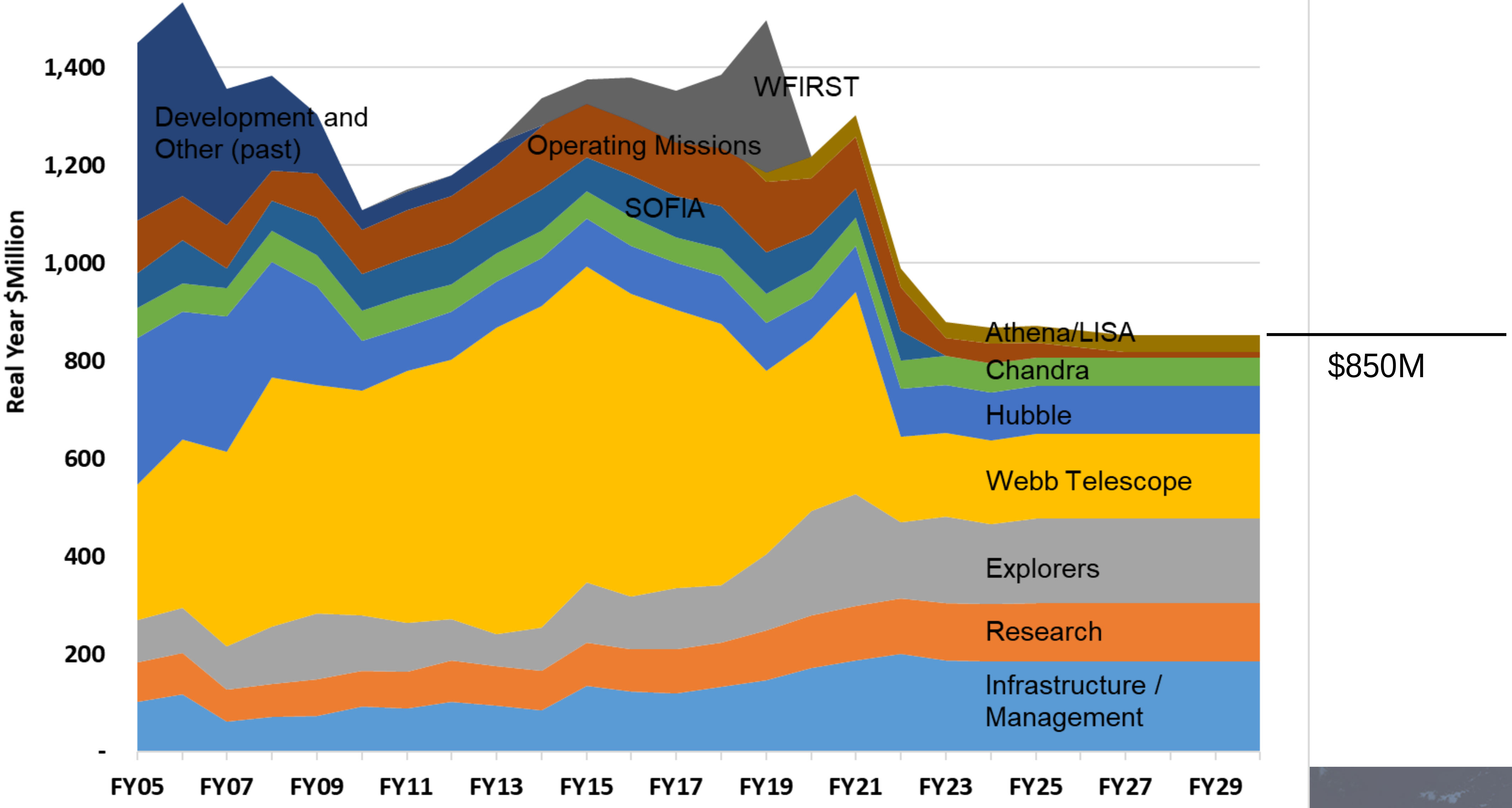
What if WFIRST is funded as needed on top of FY20 President's Budget Request?



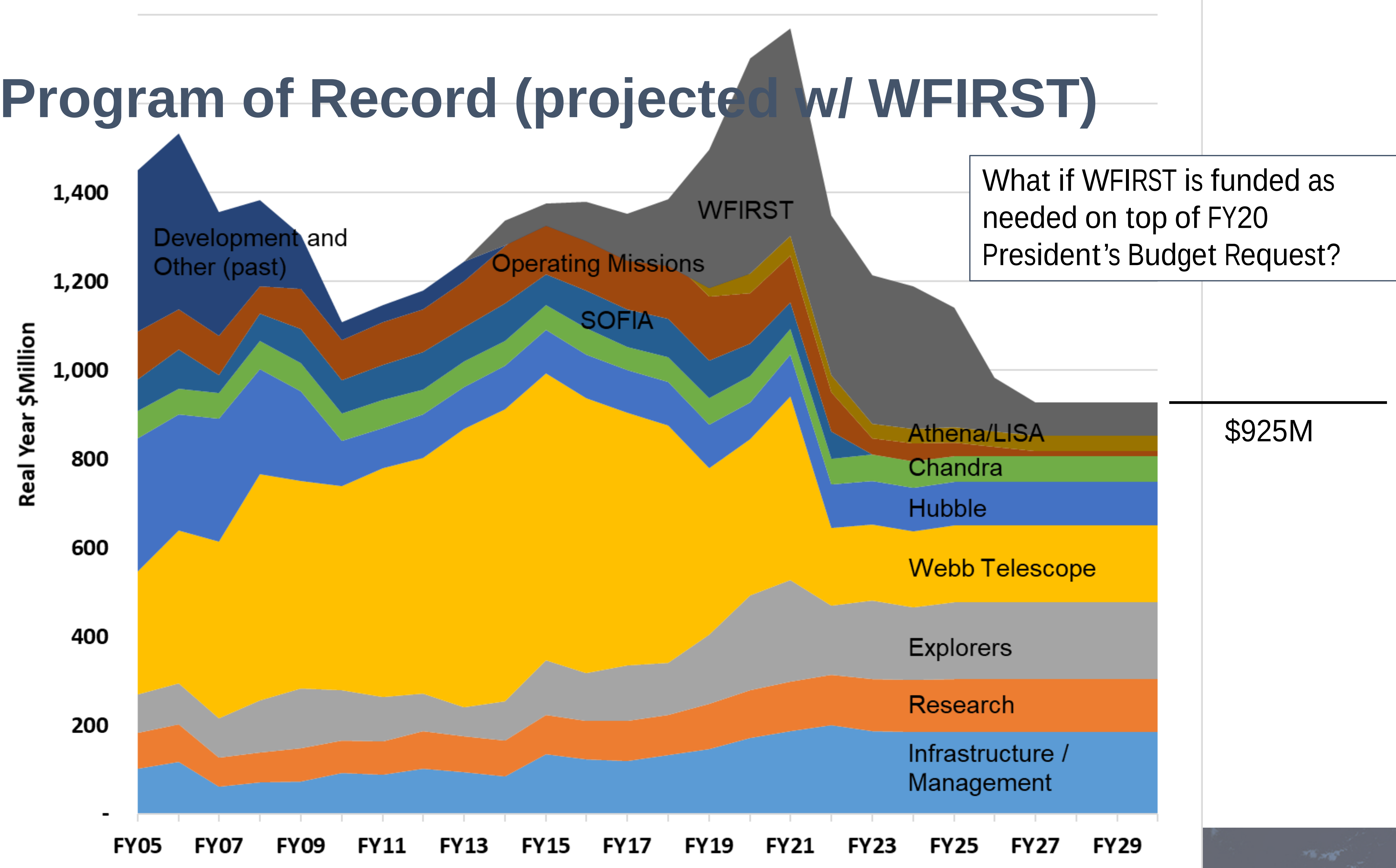


Astrophysics Community Funding
FY05-FY18 Actual, FY19 Op Plan, FY20-FY24 Request
$Millions per year
300
250
200
150
100
50
-
FY05
FY07
FY09
FY11
FY13
FY15
FY17
FY19
FY21
FY23
GO Programs
SAT (technology)
Postdoc Fellows
R&A Programs

Program of Record (projected)



Program of Record (projected w/ WFIRST)



What if WFIRST is funded as needed on top of FY20 President's Budget Request?

Program of the Future

What is a Balanced Program?

Balanced among multiple goals and priorities

- Addresses science (Decadal Survey) goals and priorities
- Addresses National goals and priorities
- Addresses NASA goals and priorities

Balanced through time

- Yields science discoveries today
- Enables science discoveries tomorrow
- Is sustainable: maintains necessary National capabilities

The needs for different mission sizes and/or wavelength diversity are necessary tools for success

- A balanced astrophysics portfolio reduces overall risk with different mission sizes that have different risk/reward postures
- A balanced astrophysics portfolio is capable of addressing multiple science goals and priorities and increases overall productivity with wavelength diversity

Strategic Missions and Competed Missions

NASA science missions are generally initiated in two different ways

Strategic missions are initiated to respond to specific science objectives

- Mission architecture and acquisition strategy is tailored to the science objectives
- Project management is generally directed to a NASA Center
- Aspects of the mission may be competed through an AO (instruments), ROSES (science team, key science projects), or an RFP (spacecraft, integration and test)
- Can be any mission size: Flagship, Medium/Probe, International Contribution, or Small
- Astro2020 should recommend strategic missions

Competed missions are initiated through an AO

- AO solicits both the science objectives and the implementation plan (architecture, team)
- NASA selection of PI-led proposal is generally “take it or leave it”
- Can be any size except flagship, though only small (MIDEX, SMEX, MOs) are in the current astrophysics program
- Astro2020 should recommend competed programs, but not specific competed missions

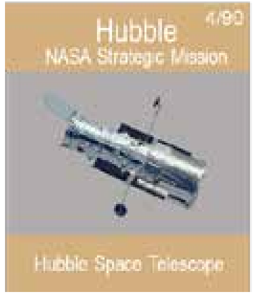
International Partnerships

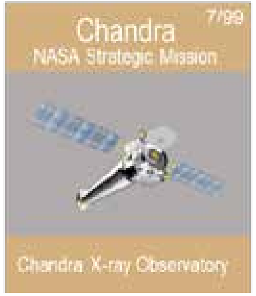
“Complex and high-cost facilities are essential to major progress in astronomy and astrophysics and typically involve collaboration of multiple nations and/or collaboration of federal and non-federal institutions. These partnerships bring great opportunities for pooling resources and expertise to fulfill scientific goals that are beyond the reach of any single country.” – New Worlds, New Horizons in Astronomy and Astrophysics (NAS, 2010)

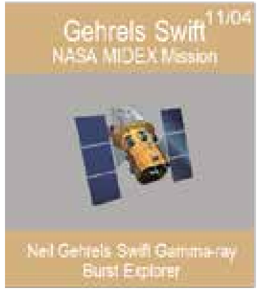
“Since its establishment in 1958, international cooperation has been a significant component of NASA's missions, playing a unique role in U.S. global engagement and diplomacy. This role extends from data sharing agreements to joint science and technology payloads, all the way up to major diplomatic initiatives. Over two-thirds of NASA’s science missions have foreign partners who enhance missions in ways NASA could not achieve on its own.” – NASA FY2020 Budget Estimates

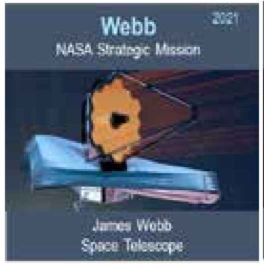
- Scientific synergies between NASA and its international partners yields a win-win outcome
- Continued NASA international collaborations and leadership in unique areas maintains US status as preferred partner
- Good partners must be good leaders and good followers

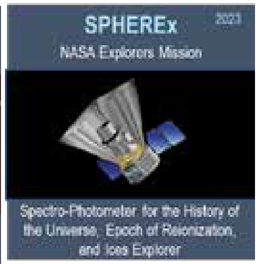
International Partnerships (Program of Record)







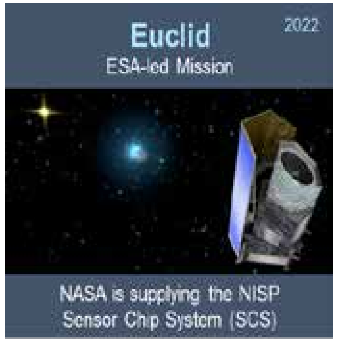




US Lead

Instrument elements

X-ray microcalorimeter,
X-ray mirrors



NIR sensor chip systems

X-ray microcalorimeter,
X-ray calibration facility

Instrument and
mission systems

Partner Lead / US Contribute

International Partnerships (Program of Record)

US Lead

Instrument elements

X-ray microcalorimeter,
X-ray mirrors

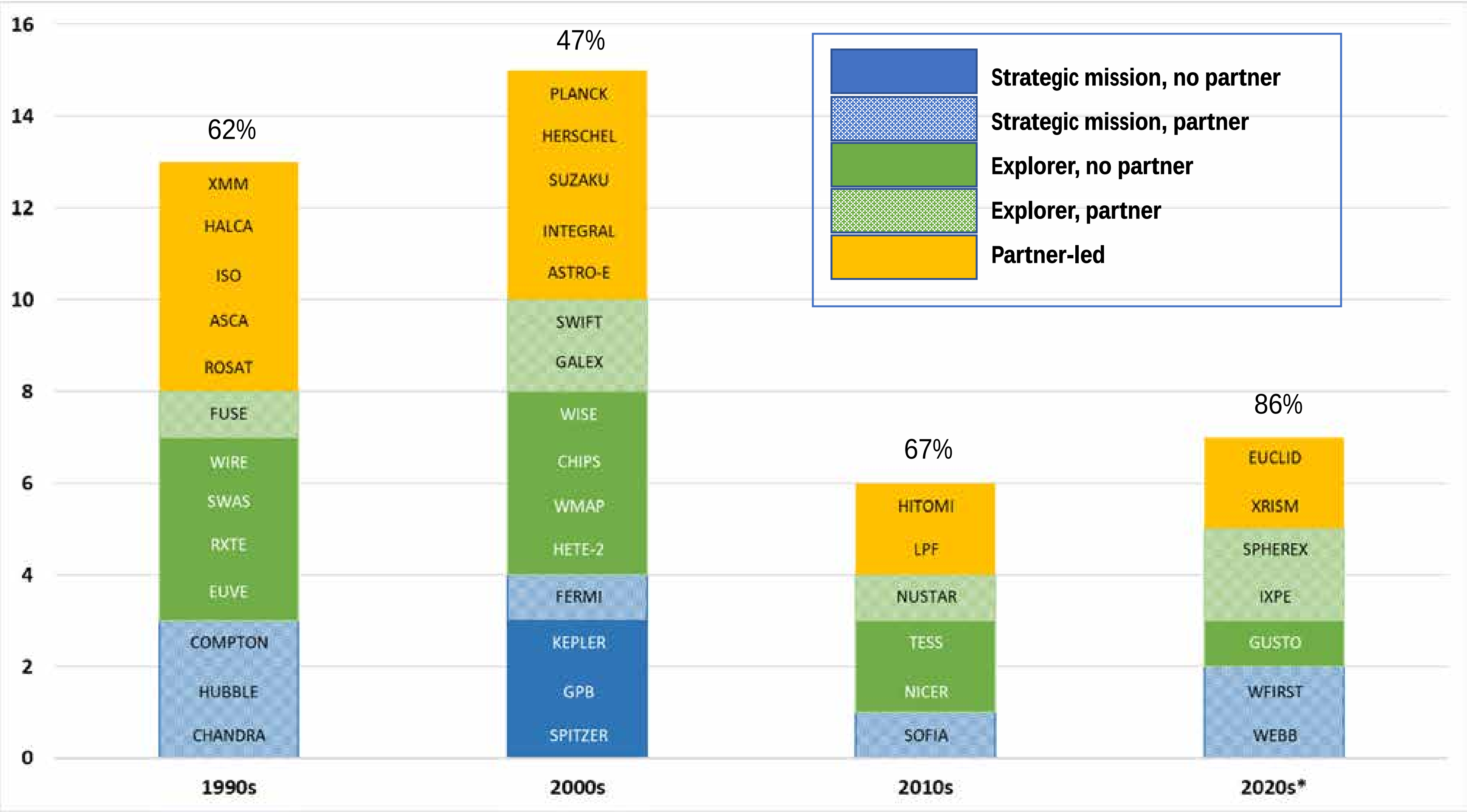
NIR sensor chip systems

X-ray microcalorimeter,
X-ray calibration facility

Instrument and
mission systems

Partner Lead / US Contribute

History of International Partnerships



Launch Date

* through WFIRST (2025)

* does not include unselected SMEX and MO missions

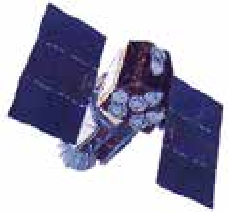
Medium Mission Concepts (Probes)

Probes are strategic missions that have had a strong impact on astrophysics, either through a focused investigation or as a broadly-capable observatory

COBE 11/89
NASA Strategic Explorer

Cosmic Background Explorer

EUVE 06/92
NASA Strategic Explorer



Extreme Ultraviolet Explorer

Rossi XTE 12/95
NASA Strategic Explorer

Rossi X-ray Timing Explorer

GP-B 04/04
NASA Strategic Mission

Gravity Probe B
The Relativity Mission

Fermi 6/08
NASA Strategic Mission

Fermi Gamma-ray Space Telescope

Kepler 3/09
NASA Discovery Mission

Kepler Space Telescope

2016 Oct	Endorsement by Astrophysics Subcommittee of plan for Probe Concept Studies
2017 Mar	Selection of 10 proposals for NASA-funded probe concept studies
2018 Jan	Presentation to community at AAS special session
2019 Mar	Submission of final reports to NASA
2019 Apr-Aug	Independent review of reports by NASA
2019 Sep	Submission of final reports with NASA findings to Astro2020

Medium Mission Concepts (Probes)

Probes are strategic missions that have had a strong impact on astrophysics, either through a focused investigation or as a broadly-capable observatory

COBE 11/89
NASA Strategic Explorer

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NASA Strategic Mission

Gravity Probe B
The Relativity Mission

Fermi 6/08
NASA Strategic Mission

Fermi Gamma-ray Space Telescope

Kepler 3/09
NASA Discovery Mission

Kepler Space Telescope

Options for 2020 Decadal Survey

- Do not recommend a medium mission in Astro2020
- Recommend specific probe(s) as medium-size strategic missions
- Recommend several specific science concepts for an AO (New Frontiers)
- Recommend an unconstrained AO (Super-Explorer)

Why Flagships

Flagships drive science

Flagships drive US capabilities and contribute to US leadership

Flagships drive NASA budget and create stakeholder support

Why Flagships

Flagships drive science

Flagships drive US capabilities and contribute to US leadership

Flagships drive NASA budget and create stakeholder support

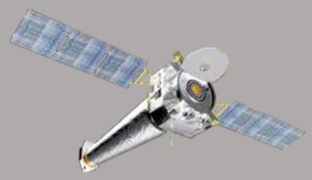
Hubble 04/90
NASA Great Observatory

Hubble Space Telescope

Compton 05/91
NASA Great Observatory

Compton Gamma Ray Observatory

Chandra 09/99
NASA Great Observatory

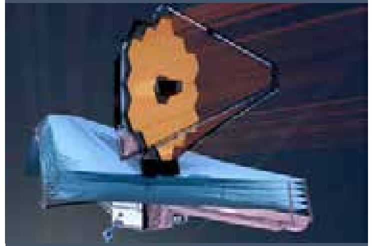


Chandra X-ray Observatory

Spitzer 8/03
NASA Great Observatory

Spitzer Space Telescope

Webb 2021
NASA Mission



James Webb Space Telescope

WFIRST Mid 2020s
NASA Mission

Wide Field Infrared Survey Telescope

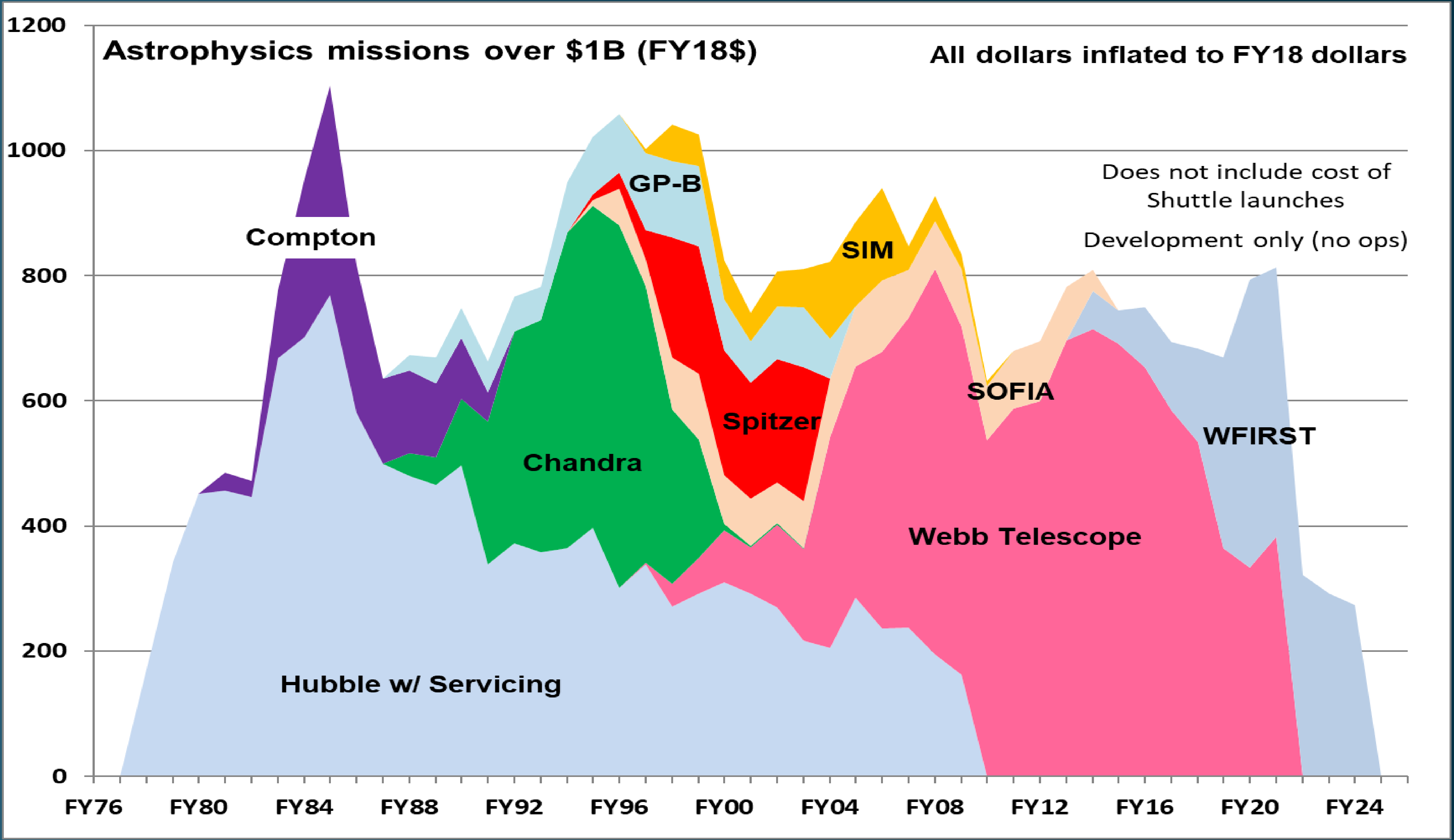
Why Flagships

Large strategic missions have multiple benefits.

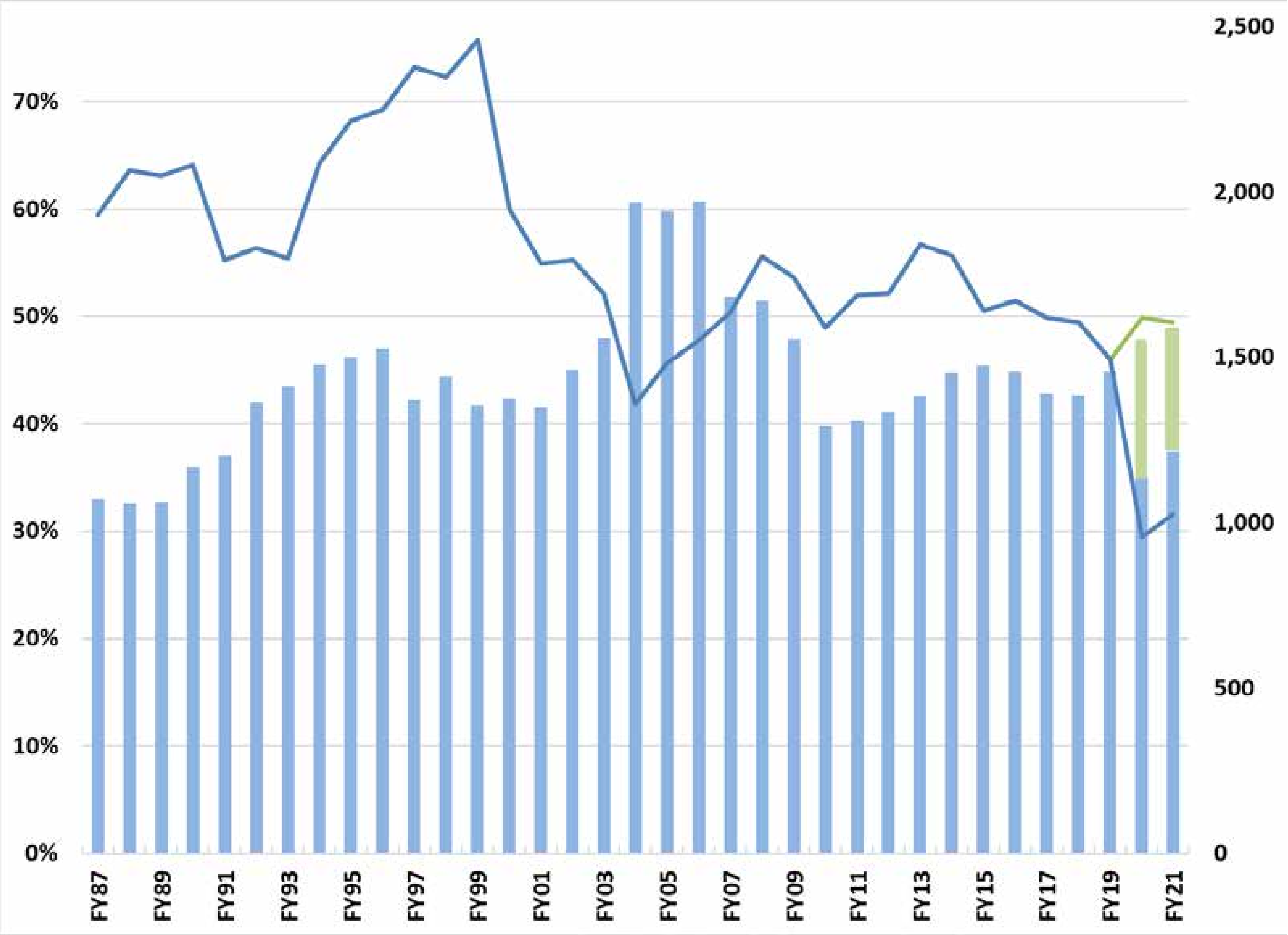
- Open new windows of scientific inquiry and answer many of the most compelling scientific questions
- Develop and deepen humanity’s understanding of the universe
- Capture science data that cannot be obtained in any other way
- Provide new technology that can benefit future small, medium, and large missions
- Support the workforce, the industrial base, and technology development
- Maintain U.S. leadership in space
- Maintain U.S. scientific leadership
- Produce discoveries that capture the public’s imagination and encourage science and technical careers
- Receive a high degree of external visibility, often representing NASA’s science program as a whole
- Provide greater opportunities for international participation, cooperation, and collaboration

“NASA should continue to plan for large strategic missions as a primary component for all science disciplines as part of a balanced program.” – Powering Science: NASA's Large Strategic Science Missions (NAS, 2017)

Astrophysics
Decadal Survey
Missions
and Astrophysics
for the 1970's
Reports of the Panels
1972
Decadal
Survey
Hubble
Astronomy
and Astrophysics
for the 1980's
1982
Decadal
Survey
Chandra
ASTRONOMY
AND
ASTROPHYSICS
1991
Decadal
Survey
Spitzer
Astronomy and Astrophysics
in the New Millennium
2001
Decadal
Survey
JWST
New Worlds,
New Horizons
2010
Decadal
Survey
WFIRST


Astrophysics missions over $1B (FY18$)
All dollars inflated to FY18 dollars
Does not include cost of Shuttle launches
Development only (no ops)
Compton
GP-B
SIM
SOFIA
Spitzer
Chandra
WFIRST
Webb Telescope
Hubble w/ Servicing
1200
1000
800
600
400
200
0
FY76
FY80
FY84
FY88
FY92
FY96
FY00
FY04
FY08
FY12
FY16
FY20
FY24

Flagship Fraction of Astrophysics Budget



All dollars inflated to FY18$.
Development only, no ops.

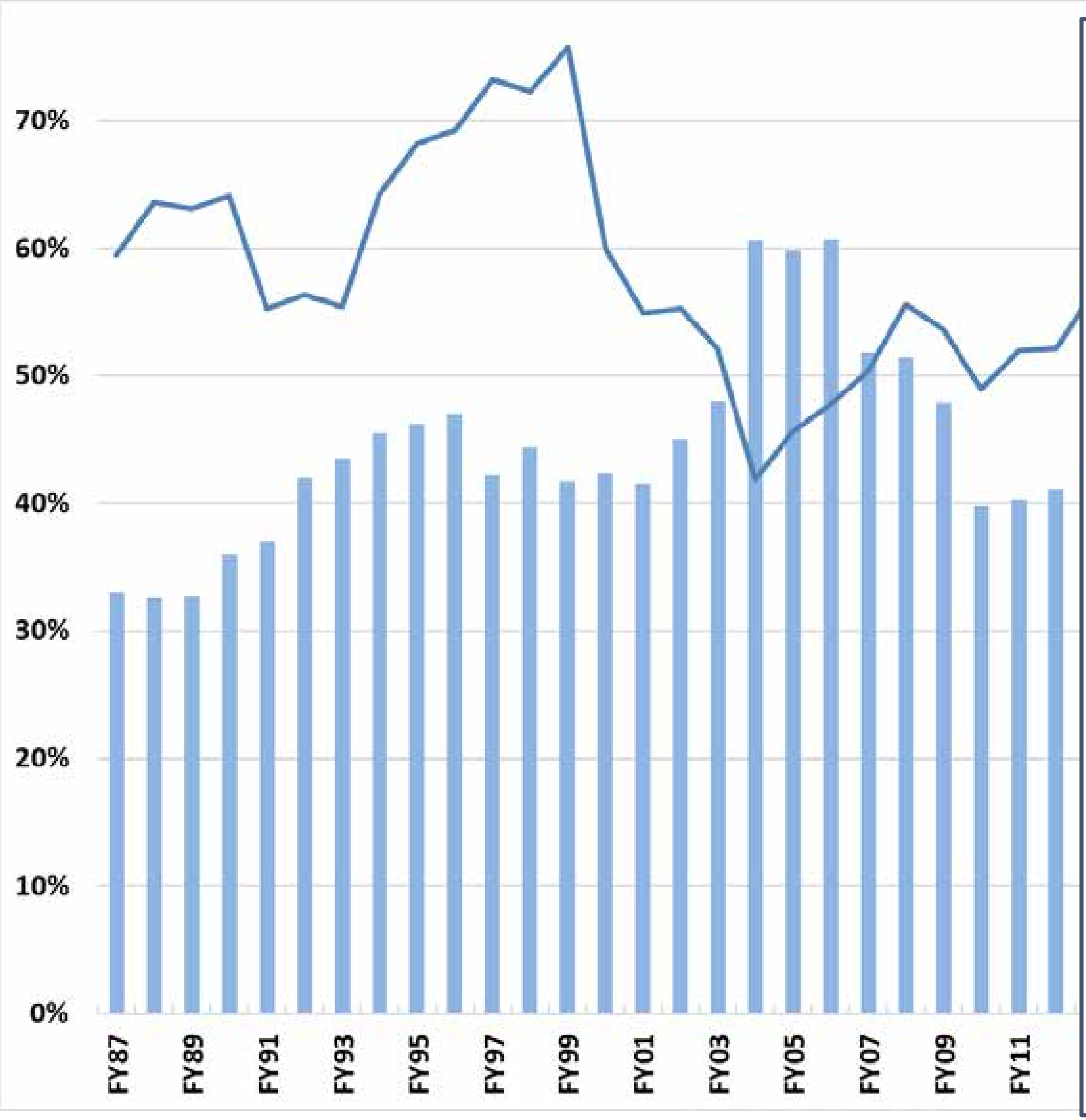
Large mission fraction (left scale)

Inflation adjusted Astrophysics budget (right scale)

Current planning budget (without WFIRST beyond FY19)

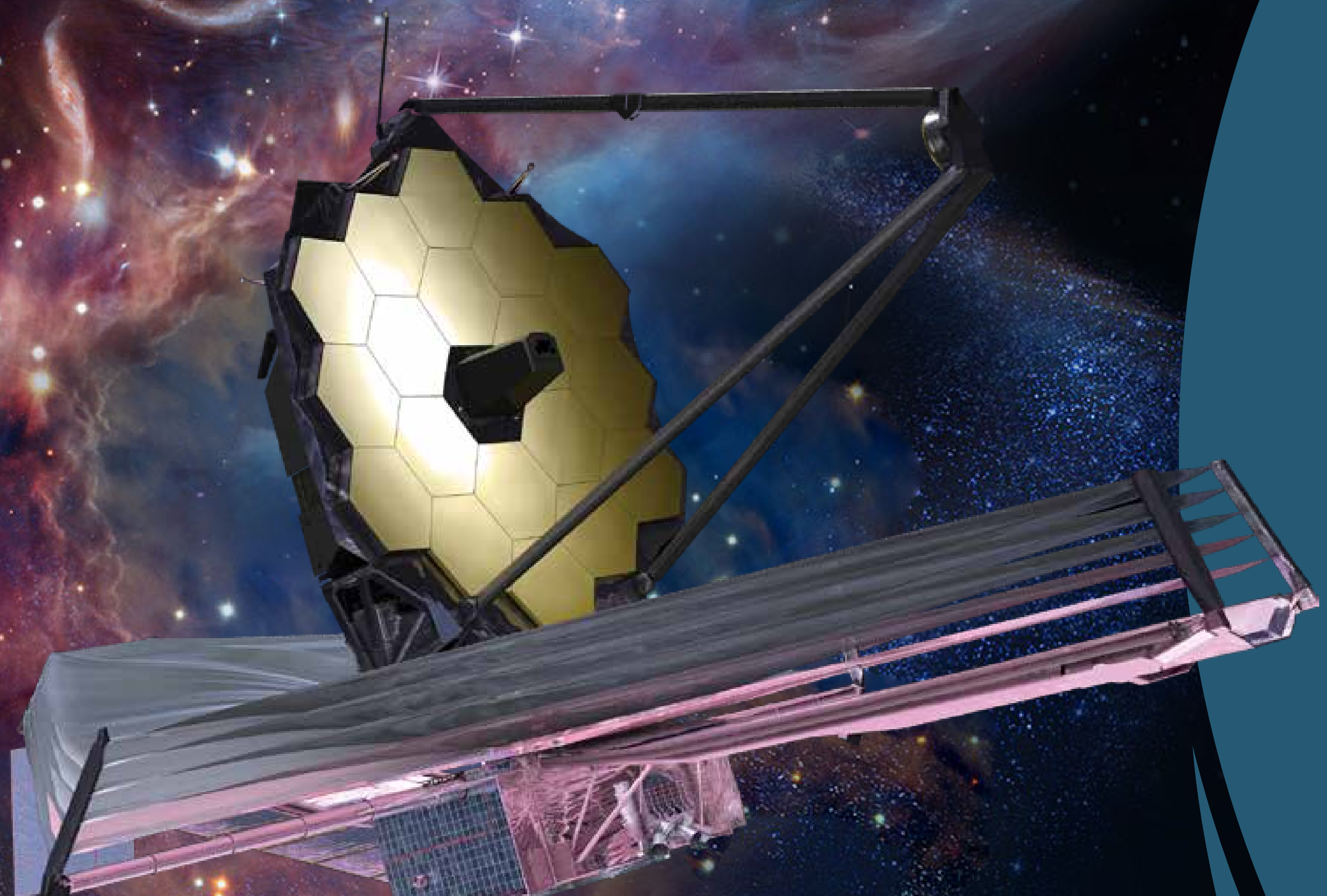
What if WFIRST is funded as needed on top of FY20 President's Budget Request?

Flagship Fraction of Astrophysics Budget



Correcting community myths:

- Myth – Webb is taking up an oversized fraction of the Astrophysics budget.
  Fact – NASA has always spent 55%-70% of the annual budget on developing large missions.
- Myth – When a flagship development overruns, it eats into the rest of the program (R&A, Explorers, etc.).
  Fact – When a flagship overruns, it delays the next flagship. NASA protects R&A and the Explorers from flagship overruns to maintain a balanced program.
- Myth – The reduction in Explorer launch rate around 2010 was due to Webb.
  Fact – The reduction in Explorer launch rate around 2010 was due to a reduction in the overall Astrophysics budget.



Webb

The James Webb Space Telescope

An international mission to seek first light of stars and galaxies in the early universe and explore distant planets

Seeking Light from the First Stars and Galaxies

Exploring Distant Worlds—Exoplanets & the Outer Solar System

Led by NASA, in partnership with ESA and CSA

Science program defined through peer-review, including future key projects

Observations spanning a wide variety of Astrophysics are already in the works through the Guaranteed Time Observers programs and the Early Release Science program

The Webb payload (telescope + instruments, left) and spacecraft element (spacecraft + sunshield, right) in the clean room in Redondo Beach, CA before spacecraft element environmental testing and observatory integration

Webb

The James Webb Space Telescope

- Science payload completed three months cryogenic testing at end of 2017
- Spacecraft and sunshield integration complete January 2018
- Spacecraft element including sunshield completed environmental testing May 2019
- Science payload and spacecraft integration planned for Fall 2019, followed by test deployment of sunshield
- Testing of full observatory begins in 2019 and continues in 2020
- Webb overrun covered using offsets from Astrophysics Probes

James Webb Space Telescope

- Webb is in its final phases of integration and testing, recently successfully completing the final thermal vacuum test of the spacecraft element. All of Webb's components have now been exposed to the varied conditions encountered during launch and while in orbit a million miles away from Earth.

- Webb is the most complex and largest international space science project in U.S. history, and the highest priority science mission within NASA. Unprecedented extensive and rigorous testing is necessary to ensure Webb will have a launch and deployment checkout that succeeds with high confidence – there are no second chances after launch.

- The project is approximately 90 percent complete at the project's contractor, Northrop Grumman Aerospace Systems in Redondo Beach, California. While significant milestones have been successfully completed, issues including minor anomalies and necessary component replacements were revealed during testing, significantly reducing the schedule margin leading to launch. NASA and the contractor have a plan to mitigate schedule and cost impacts, and preserve a March 2021 launch.

- With the excellent performance of Webb during testing thus far, NASA is confident of the observatory's success. Late this Summer, the optical telescope and instruments will be integrated onto the spacecraft, followed by observatory environmental testing this Winter and Spring. After final deployments, alignments, and functional testing, Webb will be shipped to French Guiana for launch.

Wide Field Infrared Survey Telescope

Work continues with FY19 funding

2016 – Completed Mission Concept review and began Phase A

2018 – Completed Mission Design review / System requirements Review and began Phase B

2019 – Completing Preliminary Design Reviews

2020 – Complete Confirmation Review and begin Phase C

2021 – Call for Core Surveys

Mid-2020s – Launch

WFIRST is 100 to 1500 times faster than Hubble for large surveys at equivalent area and depth

Science Program includes

- Dark energy and the fate of the universe through surveys measuring the expansion history of the universe and the growth of structure
- The full distribution of planets around stars through a microlensing survey
- Wide-field infrared surveys of the universe through General Observer and Archival Research programs
- Technology development for the characterization of exoplanets through a Coronagraph Technology Demonstration Instrument

Large Mission Concepts

“NASA should ensure that robust mission studies that allow for trade-offs (including science, risk, cost, performance, and schedule) on potential large strategic missions are conducted prior to the start of a decadal survey. These trade-offs should inform, but not limit, what the decadal surveys can address.” – Powering Science: NASA's Large Strategic Science Missions (NAS, 2017)

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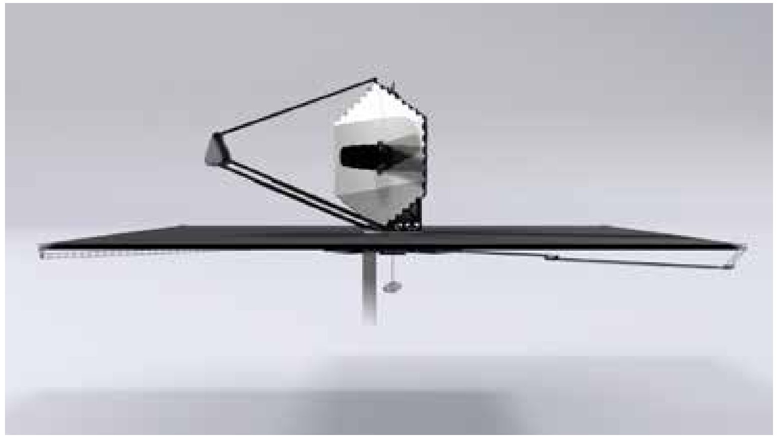
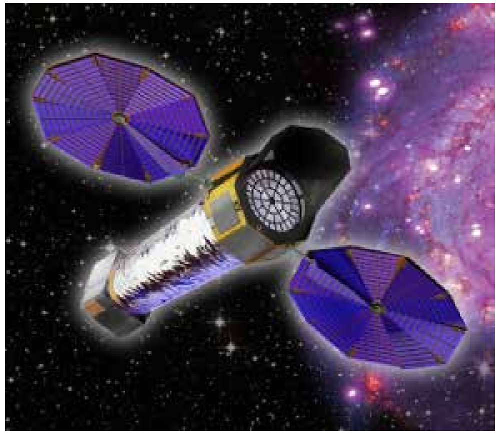
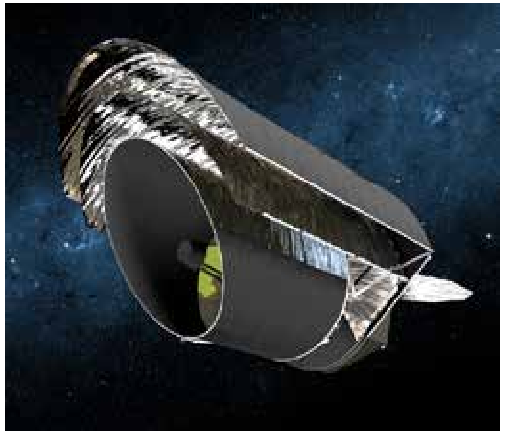
HabEx



LUVOIR



Lynx



Origins

Large Mission Concepts

2013	30-year Visionary Roadmap: *Enduring Quests, Daring Visions*
2015 Jan-Oct	Community-based process to identify large mission concepts
2015 Oct	Endorsement by Astrophysics Subcommittee of four large mission concepts
2015 Nov-Dec	Initiation of Community-based STDTs; members appointed in 2016 Apr after an open call for nominations
2016 – 2020	Technology investments to support four large mission concepts, in addition to supporting Astro2010 priorities
2018 Jan	Presentation to community at AAS special session
2018 Aug	Committee on Astronomy and Astrophysics report on NASA's preparations for Astro2020
2018 Aug	Interim reports (https://science.nasa.gov/astrophysics/2020-decadal-survey-planning)
2019 Jan	Presentation to community at AAS special session
2019 Aug 23	Submission of final reports to NASA by Astrophysics Advisory Committee
2019 Sep	Independent assessment of reports by NASA's Large Mission Concepts Independent Assessment Team
2019 Oct	Submission of final reports to Astro2020

Technology Development

- Space-based observational astrophysics suffers from uniqueness and exceptionalism.
  - NASA Astrophysics addresses the most difficult and profound questions about the nature and origin of the Universe and is seeking life outside our Solar System.
  - Astrophysics is a photon-starved discipline, demanding exquisite performance from all systems and subsystems utilized in on-sky observation and detection.
- Groundbreaking discoveries in astrophysics are directly related to advancements in technology.
  - Lack of investments on technologies will impact science achievements.
  - To lower the cost of space missions, innovation is not an option; it is required to break the current paradigm of practices and status-quo.
- Within the last five years, we have learned and understood about the technology gaps that are an obstacle to implement, build, test and launch future large missions. This knowledge and awareness have been gained through:
  - The Strategic Astrophysics Technology Program (SAT, started in 2009),
  - Technology management by PCOS/COR and EXEP (since 2009) including the tracking of milestones and TRL advancements for technology grants,
  - The Large Mission Concept Studies (STDTs – since 2016), and
  - Investment over the decade in strategic technologies including ultrastable telescopes, coronagraphs, starshades, X-ray optics, cryocoolers, and detectors.

Large Mission Concepts

HabEx

Starshade Petal Deployment Position Accuracy, Starshade Petal Shape and Stability, Large Mirror Fabrication, Large Mirror Coating Uniformity, Coronagraph Architecture, Low-order wavefront Sense/Control, Deformable Mirrors, Starshade Edge Scattering, Starshade Starlight Suppression and Modeling, Starshade Lateral Formation Sensing, Microthrusters, Laser Metrology, electron multiplication CCDs, near-IR avalanche photodiodes

LUVOIR

Coronagraph Architecture, Deformable Mirrors, LOWFS/OBWFS, UV & Red-enhanced EMCCDs, Mirror Segment Substrate, Mirror Segment Metrology, Picometer Rigid Body Actuators, Far-UV Broadband Coating, Active Dynamic Isolation, Thermal Sensing & Control, Ultra-stable System Architecture, Large-format CMOS Arrays, GaN Microchannel Plates, Next-generation Microshutter Arrays

Lynx X-ray Surveyor

High-resolution, lightweight X-ray optics, low-stress X-ray reflecting coatings, megapixel X-ray imaging detectors, large-format, high resolution X-ray detectors, X-ray grating arrays

Origins Space Telescope

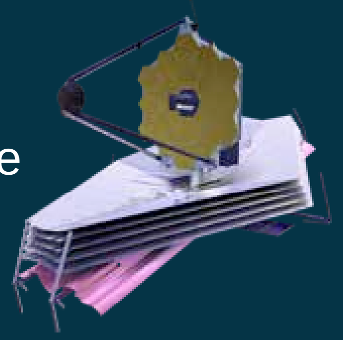
Far IR Detectors, Cryogenic Readouts for Far IR Detectors, Warm readout electronics for large format Far IR detectors, Mid IR detectors, Sub-Kelvin Coolers, 4.5 K cryocoolers

- A well-planned technology roadmap and aggressive technology development reduces the risk for the next mission
- Each study identified technology gaps and developed a technology maturation roadmap
- Most technology gaps are being addressed through NASA astrophysics technology development programs (SAT, APRA)

Why do today's flagships cost so much?

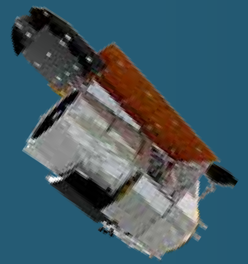
The tyranny of inflation

Hubble cost ~$3B (not including servicing missions)



If we started Hubble in 2007, it would have cost $8.3B in inflated dollars

We started Webb in 2007, it will cost $8.8B, and it has ~10x the collecting area of Hubble



If we started Hubble in 2016, it would have cost $9.7B in inflated dollars

We started WFIRST in 2016, it will cost $3.2-3.9B, and it has the same collecting area and 100x the field-of-view of Hubble

Today's flagships benefit from decades of investment in technology and capabilities across NASA and the aerospace industry

Cost Estimation of Flagships

Why is it hard?

- Flagship missions, due to the unprecedented nature of their science and their significant complexity, are inherently difficult to estimate.
- NASA mission costs are typically estimated given cost model or analogy cost based on historical cost and technical data. Given that Flagship missions are first of a kind, there are no comparable costs to use as an estimate.
- Design trades and options are numerous through the formulation phase. Establishing a robust, stable technical baseline prior to the start of development, and therefore developing a robust, stable cost estimate, is extremely challenging.

What are best practices?

- Conduct a science assessment and concept feasibility study to determine the value of the science and define technology challenges.
- Fund technology development with defined pass/fail gates for each technology and each technology readiness level.
- Provide a funding profile that allows work to be done at the most efficient time. Include adequate reserves and use them to solve problems at the optimal time.
- Establish stable science and measurement requirements early. Avoid mission creep.

Managing Flagship Development

NASA has learned lessons in the development of flagships, including Webb, that it is applying to WFIRST

- Enabling technologies, including system-level technologies, must be matured early
- Mature technologies and mission concepts in parallel
- Pay attention to technology maturation of systems and to manufacturability
- Adequate funding, including project reserves, must be budgeted for each year of formulation
- Requirements must be established before standing up the full design team; stability of requirements is important

Managing Flagship Development

"Utilize and recommend decision rules, where appropriate, for the comprehensive research strategy that can accommodate significant but reasonable deviations in the projected budget or changes in urgency precipitated by new discoveries or unanticipated competitive activities."
– Astro2020 Statement of Task

Recognizing that future budgets are unknowable, and also that the cost and schedule to develop an ambitious flagship mission cannot be accurately known until the mission design approaches Preliminary Design Review (PDR) maturity, decision rules are useful for guiding NASA's decisions in the face of sub-optimal budgetary circumstances.

- Descope mission capabilities but preserve schedule and total cost
- Protect core program and maintain balanced program by extending development schedule, and delaying next strategic mission, even though total cost increases
- Fund mission to ensure schedule and minimize total cost even if program is temporarily unbalanced


Astrophysics
Decadal Survey
Missions
and Astrophysics
for the 1970s
Reports of the Panels
1972
Decadal
Survey
Hubble
Astronomy
and Astrophysics
for the 1980's
1982
Decadal
Survey
Chandra
ASTRONOMY
AND
ASTROPHYSICS
1991
Decadal
Survey
Spitzer
Astronomy and Astrophysics
in the New Millennium
2001
Decadal
Survey
JWST
New Worlds,
New Horizons
2010
Decadal
Survey
WFIRST

Planning Guidelines

Decadal Survey Planning

NASA is:

- ü Sponsoring 4 community-based Science and Technology Definition Teams (STDTs) to partner with a NASA Center-based engineering team and study large (strategic) mission concept studies selected from the NASA Astrophysics 30-year Visionary Roadmap, a community-based report, and the 2010 Decadal Survey
- ü Supporting 10 PI-led Study Teams for Probe-size mission concept studies, selected competitively
- ü Supporting several other planning activities / studies / white papers including:
  - Balloon Program Roadmap
  - Evolution of NASA Data Centers
  - In-Space Servicing/In-Space Assembly
- ü Investing in next-generation technologies, including ultrastable telescope technology, starshades, coronagraphs, x-ray mirrors, cryocoolers, detectors, etc.

https://science.nasa.gov/astrophysics/2020-decadal-survey-planning

Decadal Survey Planning

The objective of NASA's Decadal Survey Planning is a well informed Decadal Survey Steering Committee

Large mission concept studies provide notional architecture(s) and preliminary cost ranges for missions that address compelling science objectives

- Accurate cost estimates are not possible for pre-Phase A mission concepts

Medium (probe) mission concept studies provide notional mission concepts for more focused and less costly missions

- Probe studies are less mature than large mission studies
- There are probe concept studies not funded through this program

For any assumed future budget, the Decadal Survey Steering Committee can recommend a combination of large and medium missions

Recommending "cost vs cadence" balance for the next NASA astrophysics missions is one of the the primary outcomes of Astro2020

Guidance on Future Budgets

"Consider agency expectations of future budget allocations in the field, including interface areas, as well as expectations for the completion of projects already under development, and design recommendations based on budget scenarios relative to those expectations; the study may also consider scenarios that account for higher or lower than anticipated allocations." – Astro2020 Statement of Task

"Decadal surveys are concerned with budgets over the next 10 years, so updates on the next one or two budgets are not central to the task. Rather, it is the projected out-year budgets that are important, and they are, by nature, even more uncertain. A different approach to setting anticipated funding levels, one separated from year-to-year expectations and fulfillment, would be to use the previous budgets of the particular NASA or NSF division, averaged over some number of years preceding the survey, as a basis for the "baseline" budget for the survey program. A flat budget, perhaps with a yearly adjustment for inflation, could be the starting point for planning a program, with a possible "up" and "down" adjustment assumed to provide a budget that would envelope future fluctuations in the division budgets." – The Space Science Decadal Surveys: Lessons Learned and Best Practices (NAS, 2015)

Guidance on Future Budgets

All guidance is for Astrophysics including Webb Telescope

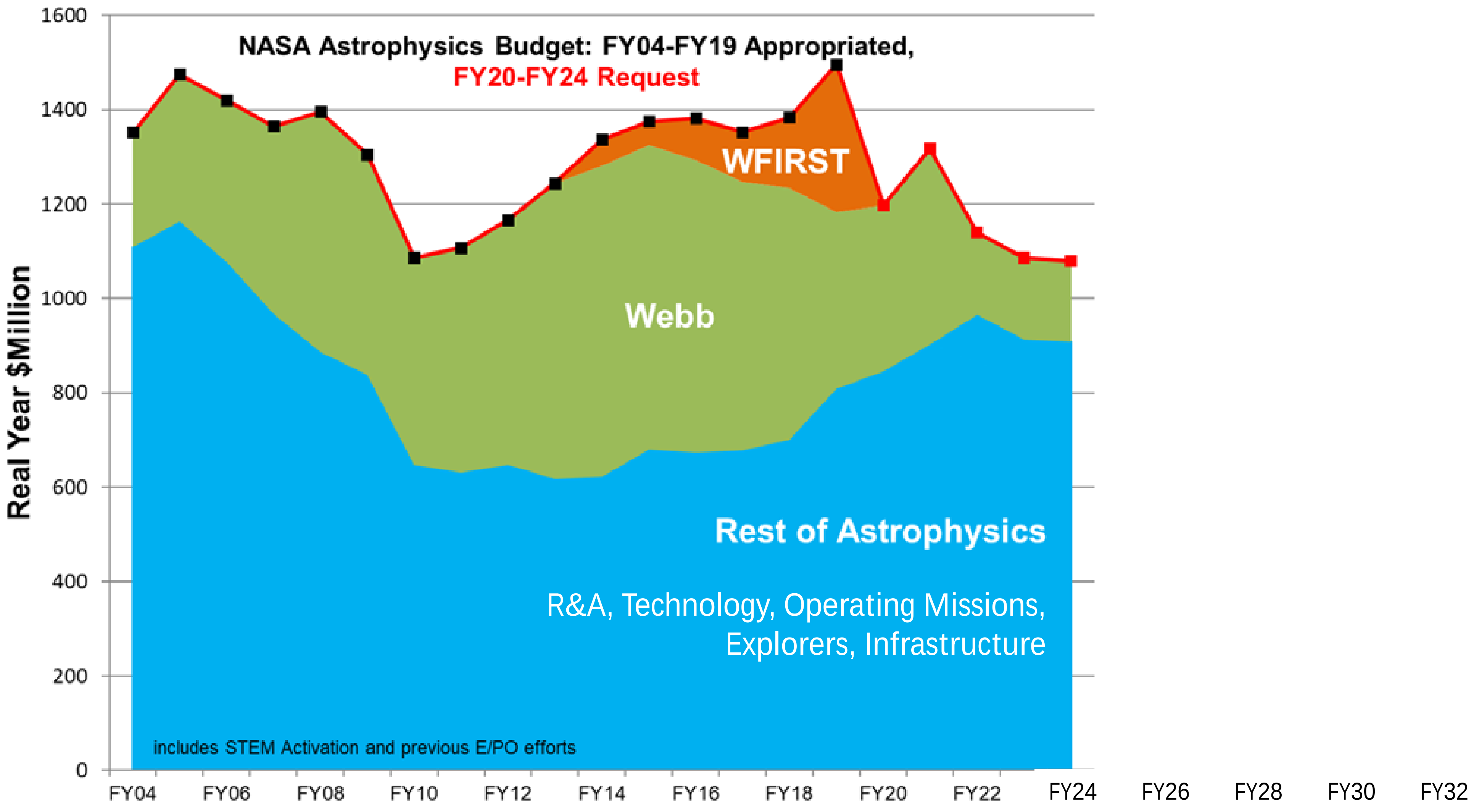
Lower bound budget projection – Extrapolation of out year planning numbers for President's FY20 budget request. Average of FY22-FY24 planning numbers is $1.1B/yr

Empirical budget projection – Extrapolation of recent NASA Astrophysics appropriations. Average of FY17-FY19 appropriations is $1.4B/yr

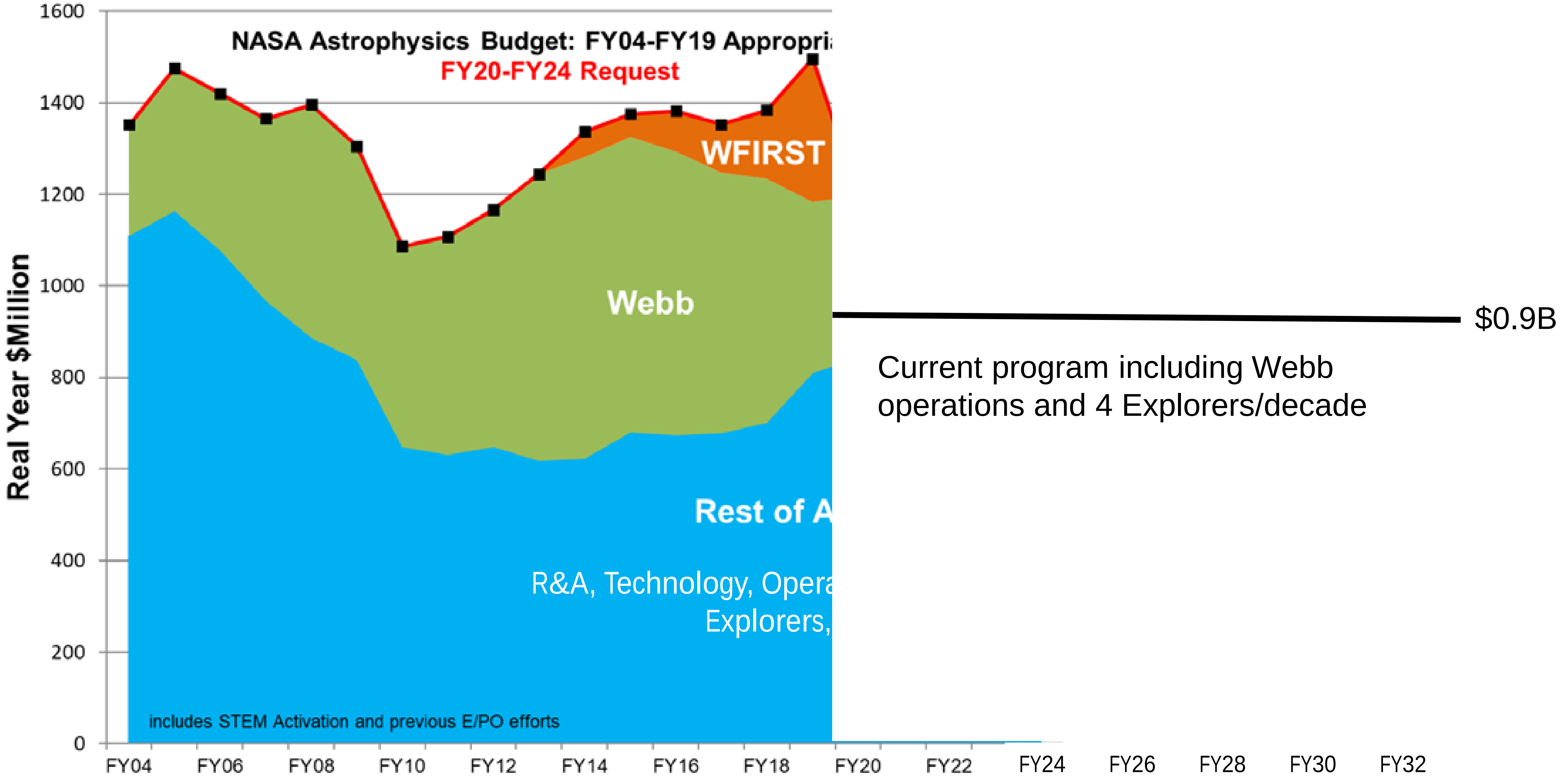
Optimistic budget projection – Empirical budget projection plus 1% inflationary growth in the out years. Budget grows from $1.5B (FY19) to $1.6B (FY25) to $1.7B (FY30)

Upper bound budget projection – Empirical budget projection plus 2% inflationary growth in the out years. Budget grows from $1.5B (FY19) to $1.7B (FY25) to $1.9B (FY30)

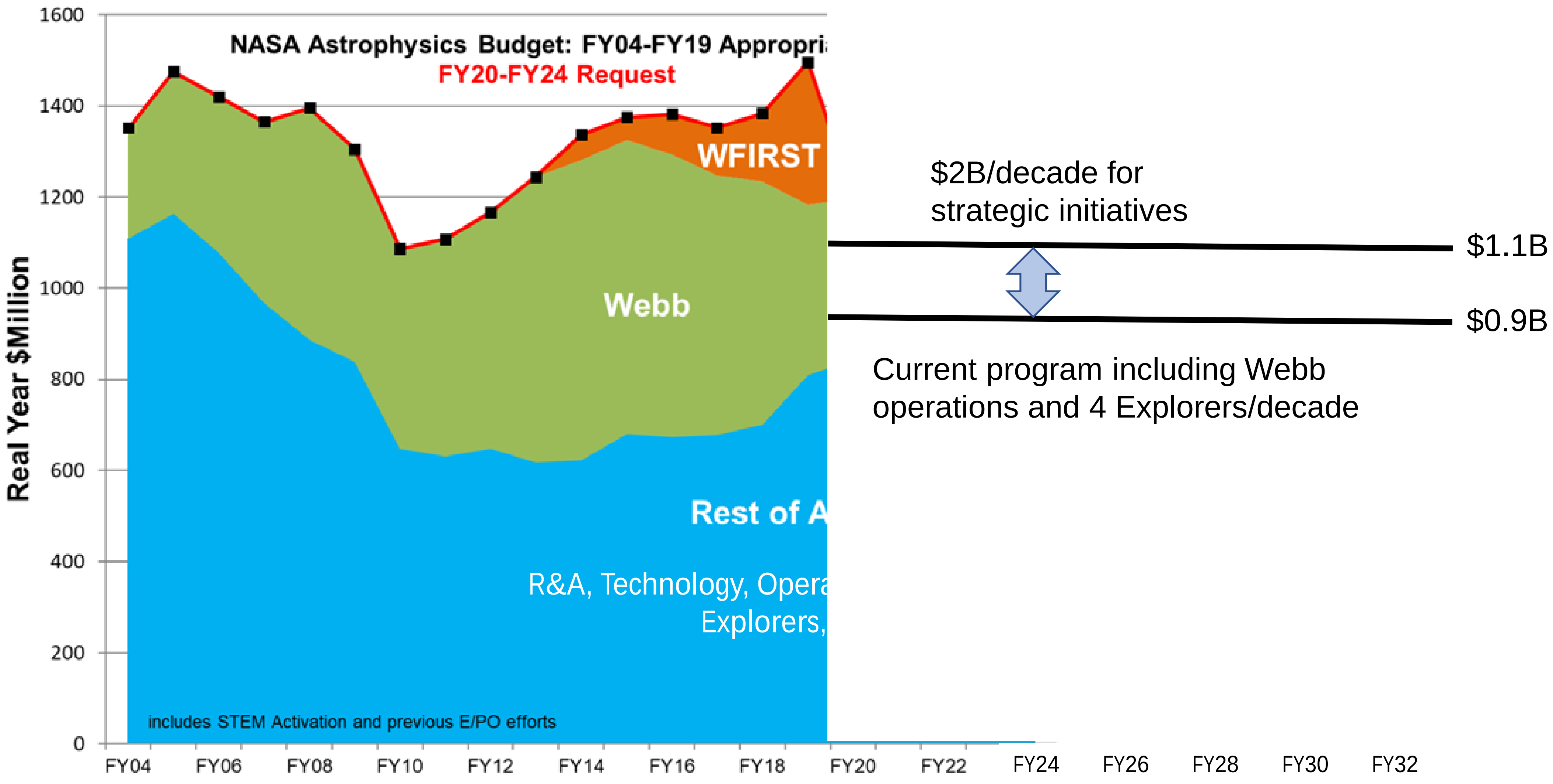
NASA Astrophysics Budget



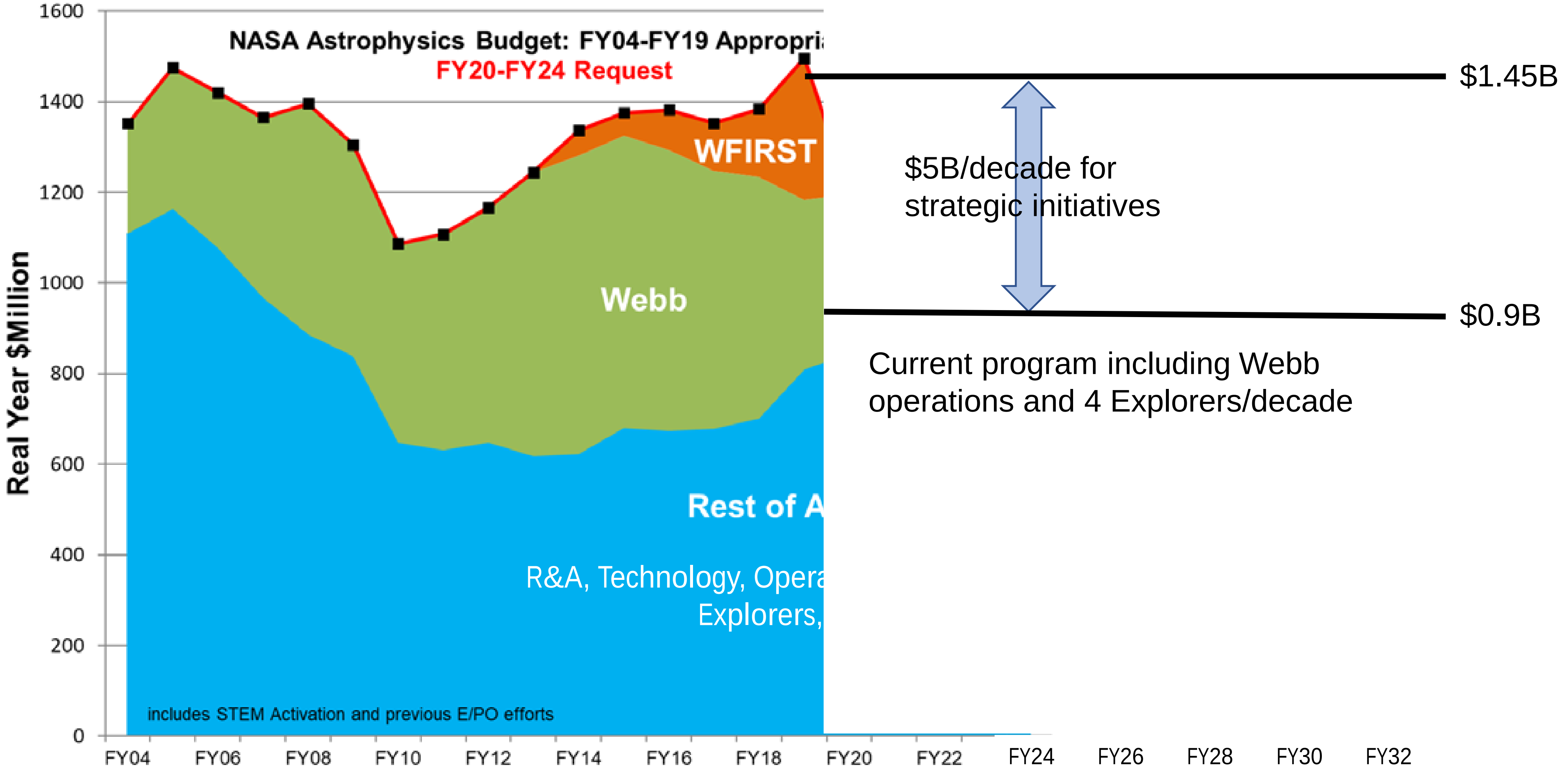
NASA Astrophysics Budget



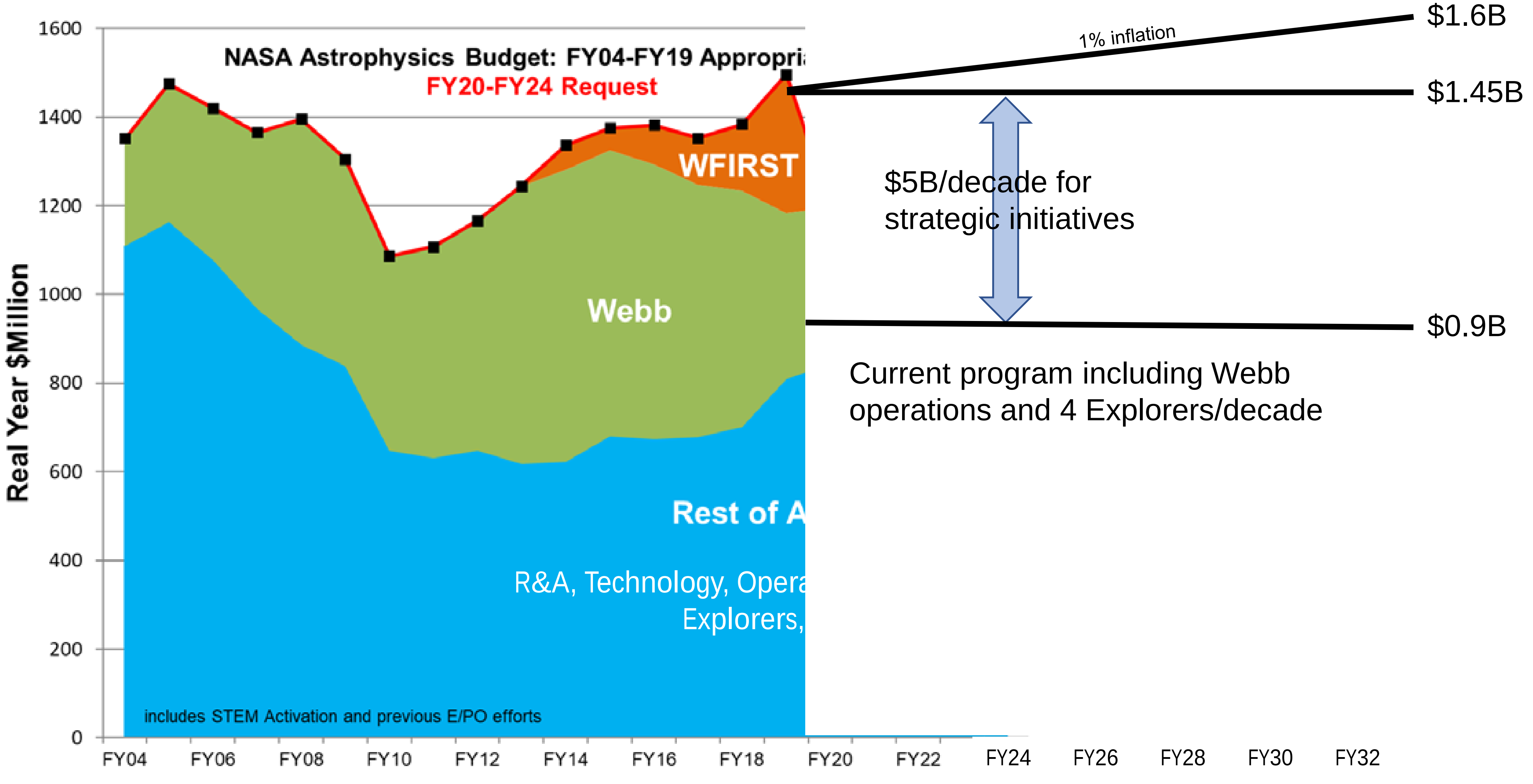
NASA Astrophysics Budget



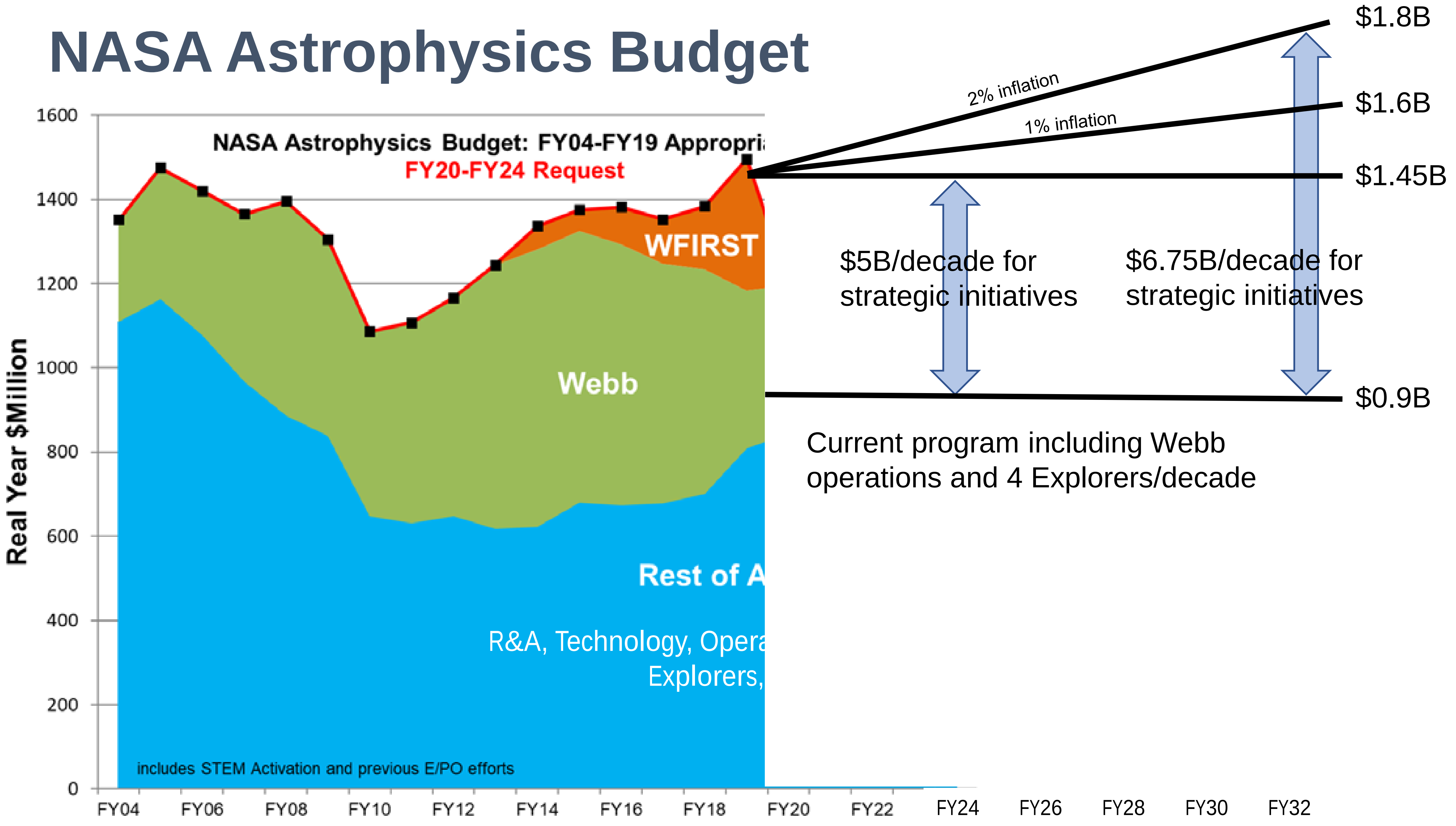
NASA Astrophysics Budget



NASA Astrophysics Budget



NASA Astrophysics Budget



Decadal Survey Goal

- NASA's highest aspiration for the 2020 Decadal Survey is that it be ambitious
  - The important science questions require new and ambitious capabilities
  - Ambitious missions prioritized by previous Decadal Surveys have always led to paradigm shifting discoveries about the universe
- If you plan to a diminishing budget, you get a diminishing program.
  - Great visions inspire great budgets.

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Carpe Posterum