EXPLORE SCIENCE

National Aeronautics and Space Administration

NASA Astrophysics and Astro2020

Astro2020 Panel on Electromagnetic Observations from Space 1
October 30, 2019
Astro2020 Panel on Electromagnetic Observations from Space 2
November 5, 2019

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Science Mission Directorate
@PHertzNASA

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 justify great budgets.

Setting the Stage

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.

Does NASA stand for “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.

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

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

Reviewing the Program of Record

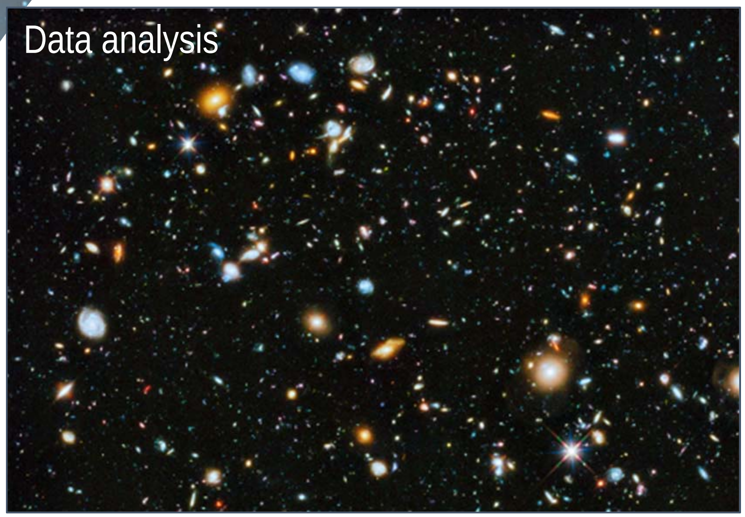
“Consider the status and evolution of ongoing programs (“programs of record”) of the agencies, including the balance of activities and investments of all relevant and appropriate sizes and types, research programs (including individual investigator programs), ongoing support of operational missions and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

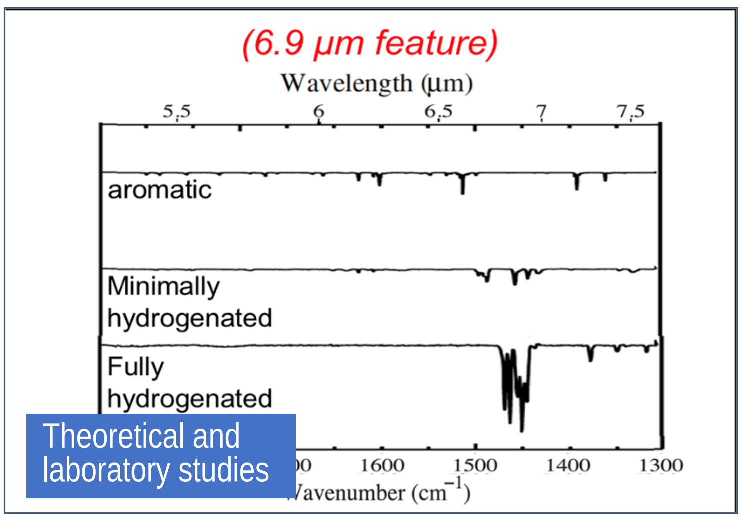
NASA is defining its Program of Record as those activities which will continue as planned through the next decade in the absence of recommendations from the Decadal Survey to make changes.

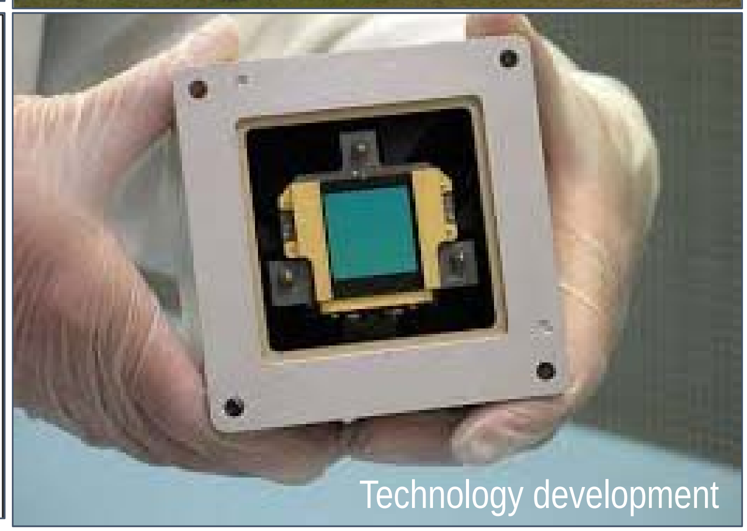
Changes to the Program of Record will change the projected budget available for new initiatives in the coming decade.

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

Supporting Research and Technology







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

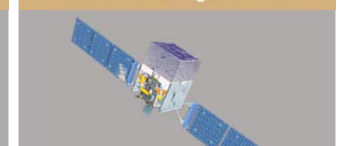
GO Program
X-ray Multi Mirror - Newton

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

GO Program

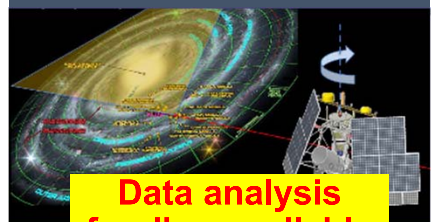
James Webb
Space Telescope

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

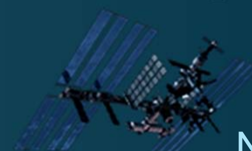
ESA data policies not yet set

NASA is supplying instrument
and mission systems

Astrophysics Explorers Program

Gehrels Swift

NuSTAR



NICER

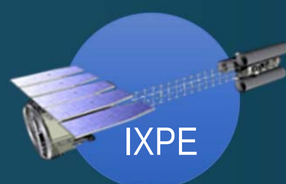
TESS

4 AOs per decade

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

Small and Mid-Size Missions

TESS



IXPE

SPHEREx

Missions of Opportunity

NICER

GUSTO

MO TBD

XRISM

Explorers Mission of Opportunity AO includes new opportunities:

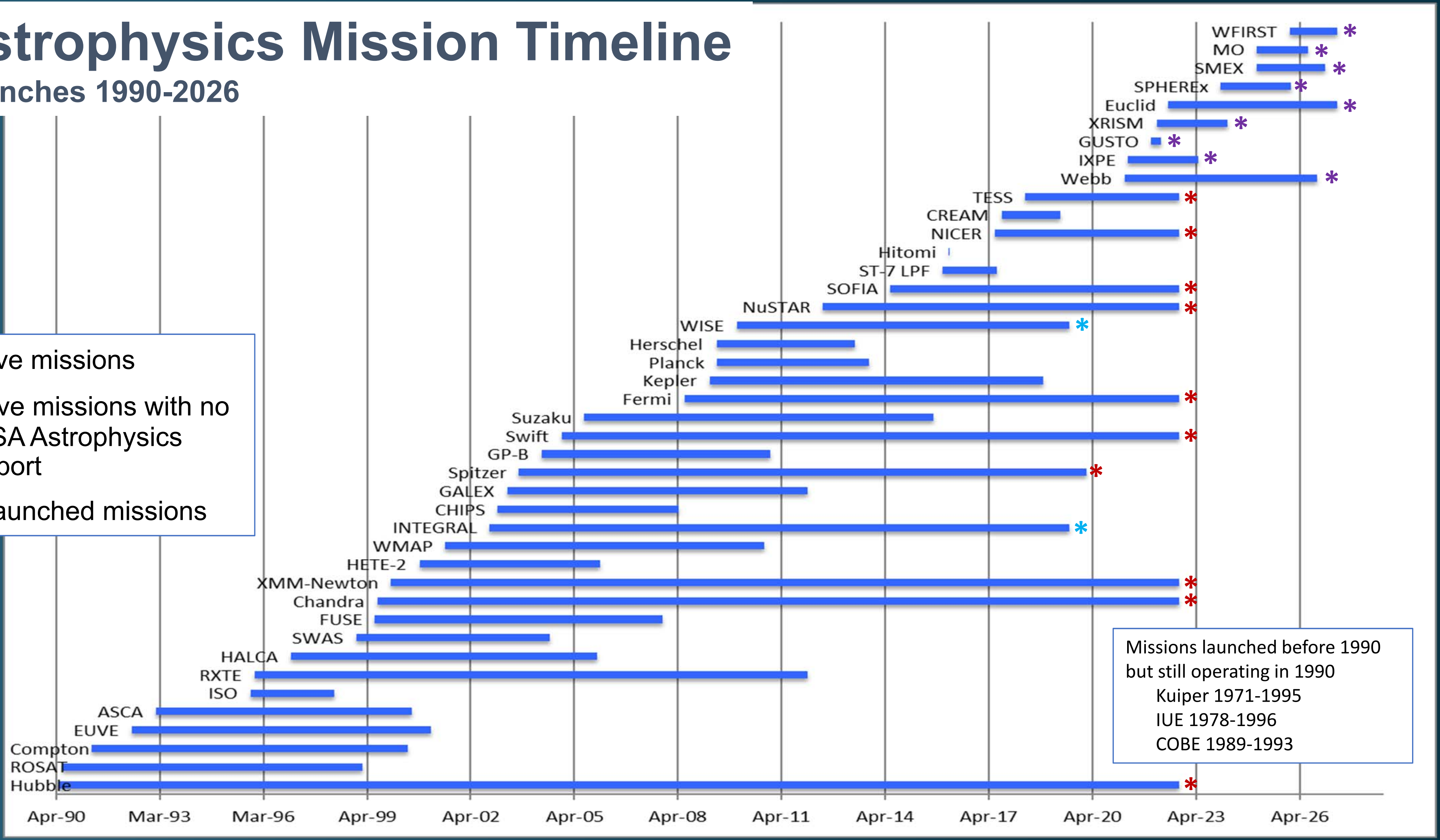
- NASA-provided RideShare
- SmallSat Secondary Payloads
- Opportunities enabled by the Artemis Program

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

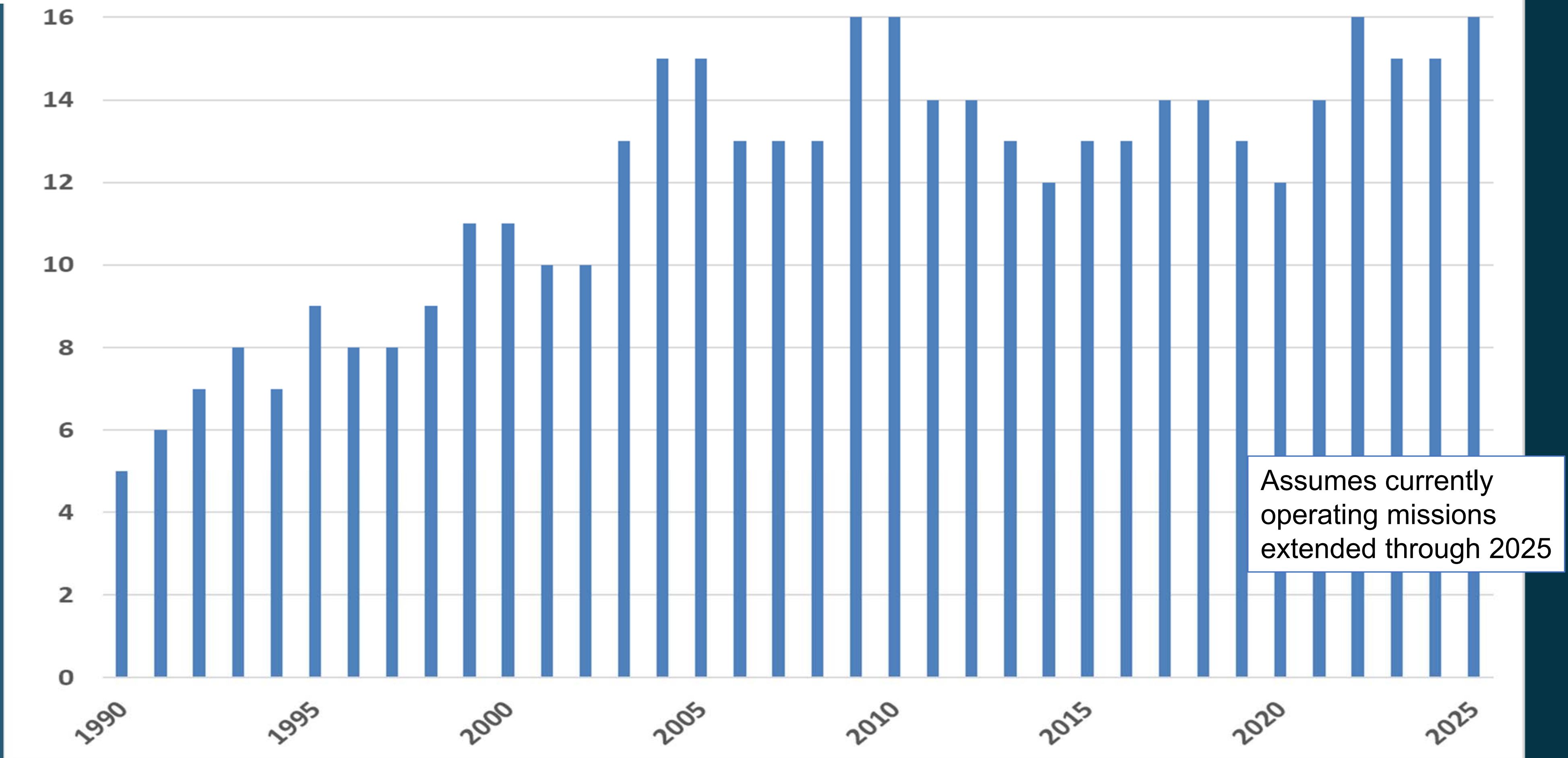
* Active missions with no NASA Astrophysics support

* Unlaunched missions

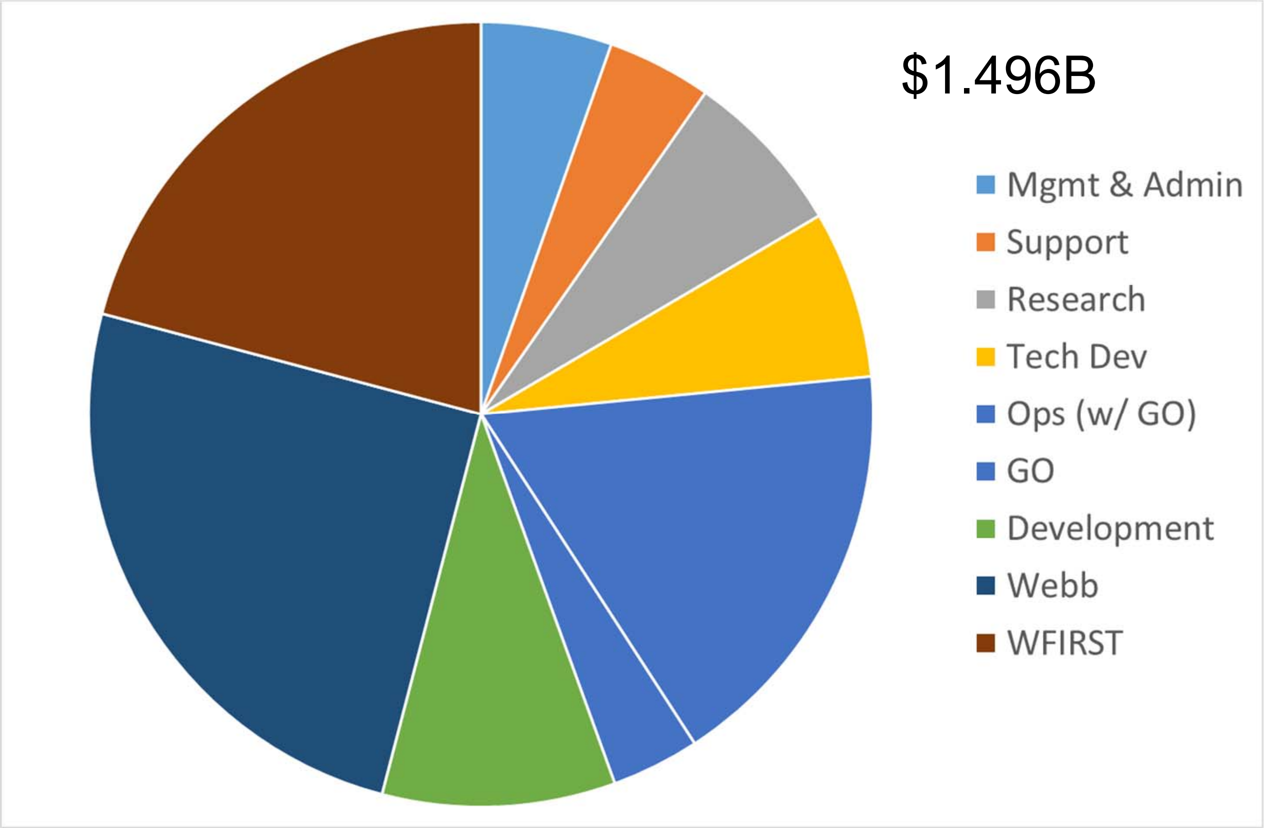
Missions launched before 1990 but still operating in 1990
Kuiper 1971-1995
IUE 1978-1996
COBE 1989-1993

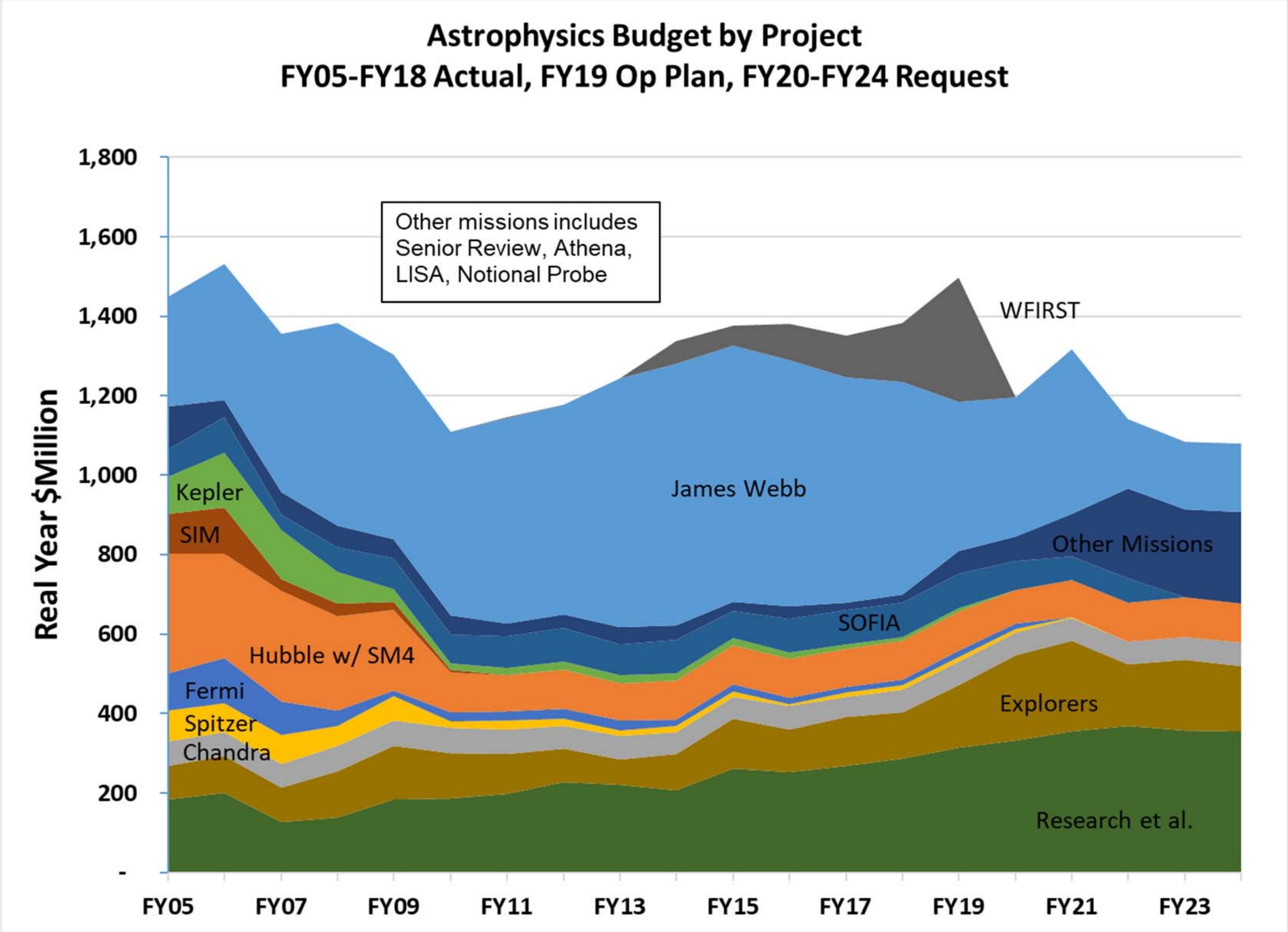
Astrophysics Mission Timeline

Missions operating each year



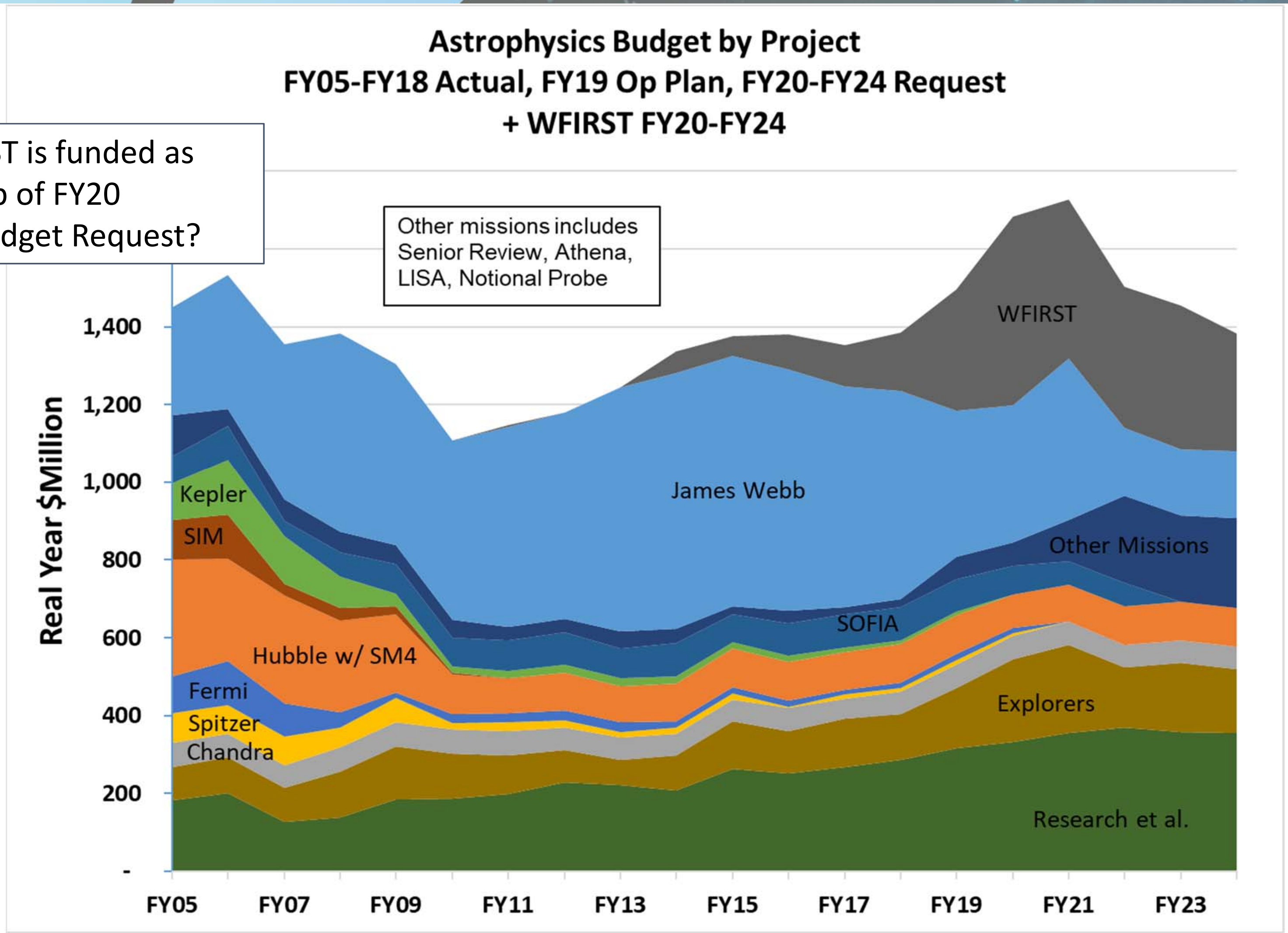
FY19 Budget Snapshot



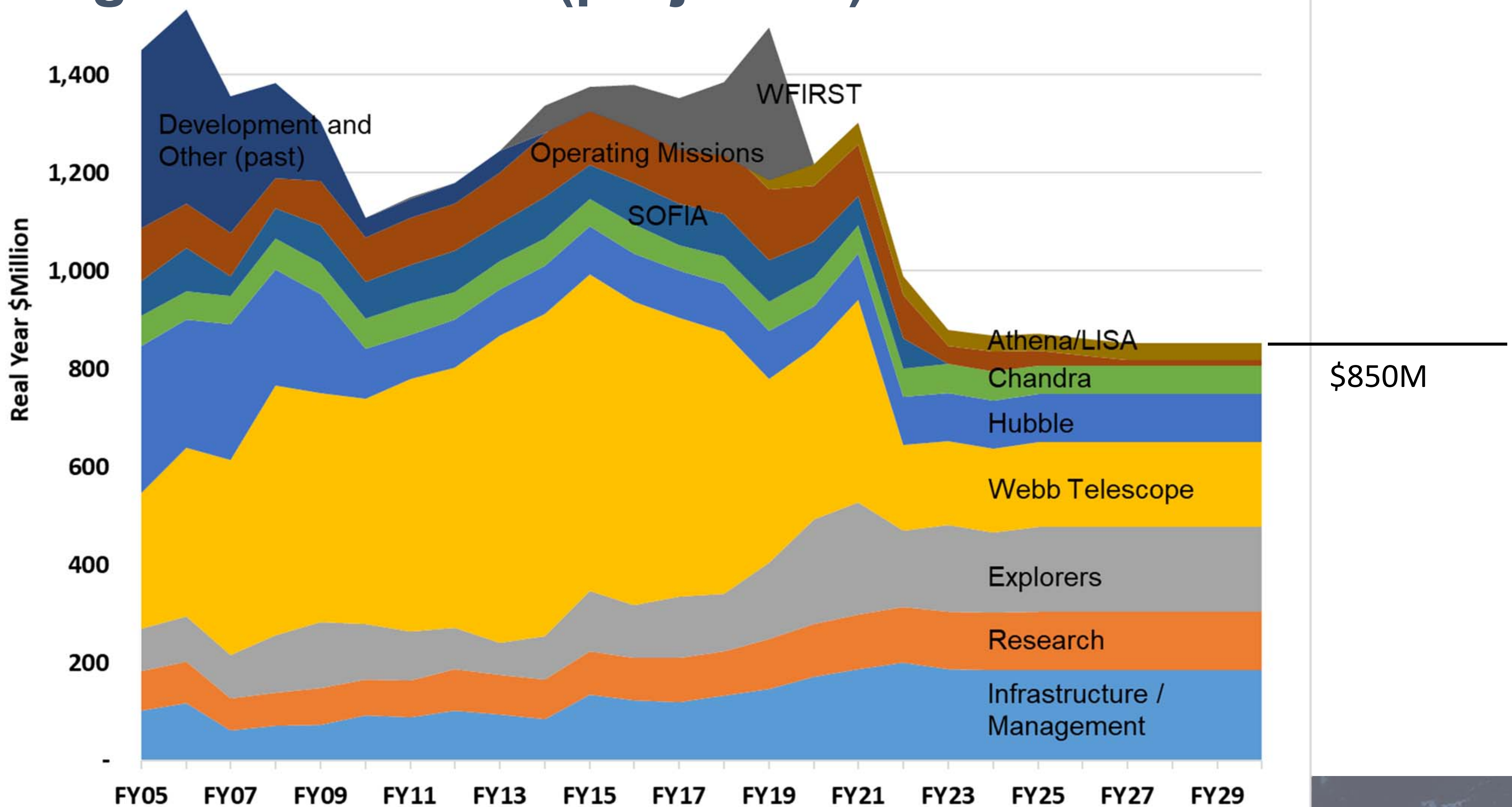


Astrophysics Budget by Project
FY05-FY18 Actual, FY19 Op Plan, FY20-FY24 Request
Other missions includes Senior Review, Athena, LISA, Notional Probe
WFIRST
James Webb
Other Missions
SOFIA
Kepler
SIM
Hubble w/ SM4
Fermi
Spitzer
Chandra
Explorers
Research et al.
Real Year $Million
1,800
1,600
1,400
1,200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

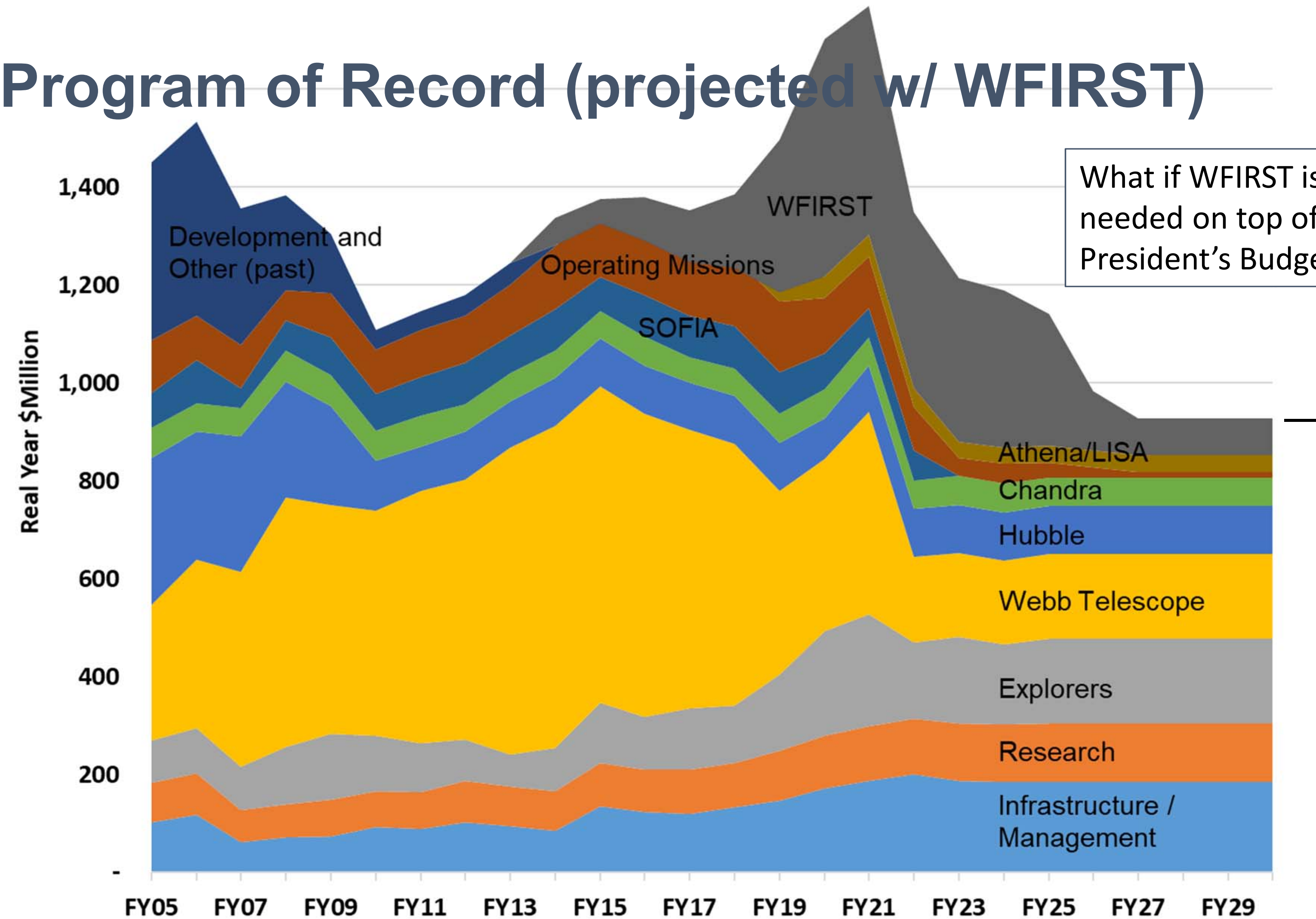
What if WFIRST is funded as needed on top of FY20 President's Budget Request?



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

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

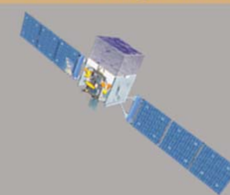
Rossi XTE 12/95
NASA Strategic Explorer

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
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NASA Strategic Mission

Gravity Probe B
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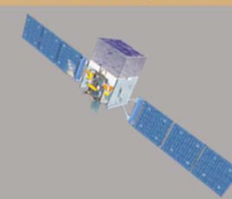
NASA Strategic Mission



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

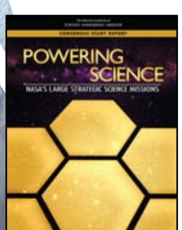
Flagships drive US capabilities and contribute to US leadership

Flagships drive NASA budget and create stakeholder support

Why Flagships

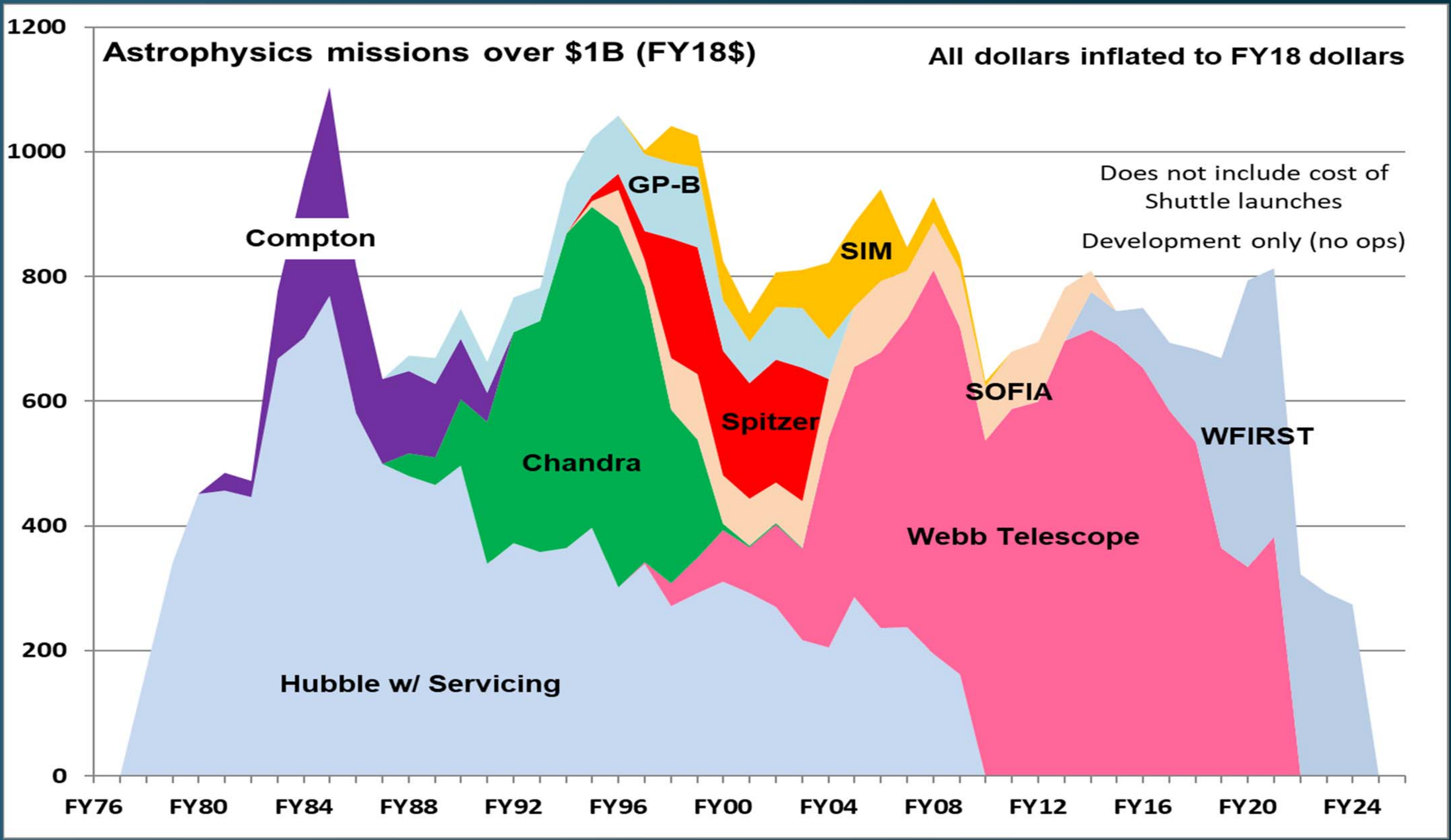
Large strategic missions have multiple benefits.

- 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



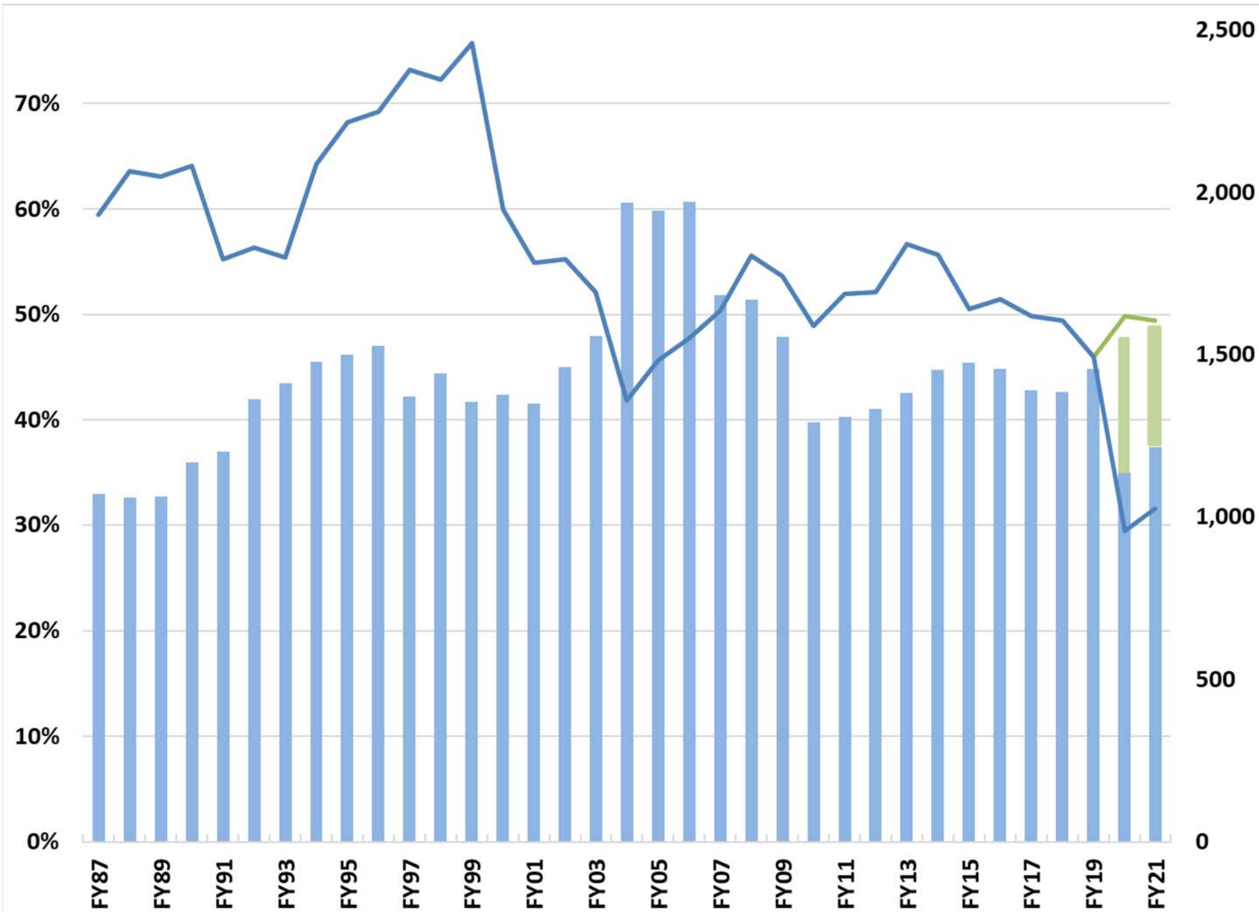
"NASA should continue to plan for large strategic missions as a primary component for all science disciplines as part of a balanced program." – Powering Science: NASA's Large Strategic Science Missions (NAS, 2017)


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



Astrophysics missions over $1B (FY18$)
All dollars inflated to FY18 dollars
Does not include cost of Shuttle launches
Development only (no ops)
1200
1000
800
600
400
200
0
Compton
GP-B
SIM
SOFIA
Spitzer
Chandra
WFIRST
Webb Telescope
Hubble w/ Servicing
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.

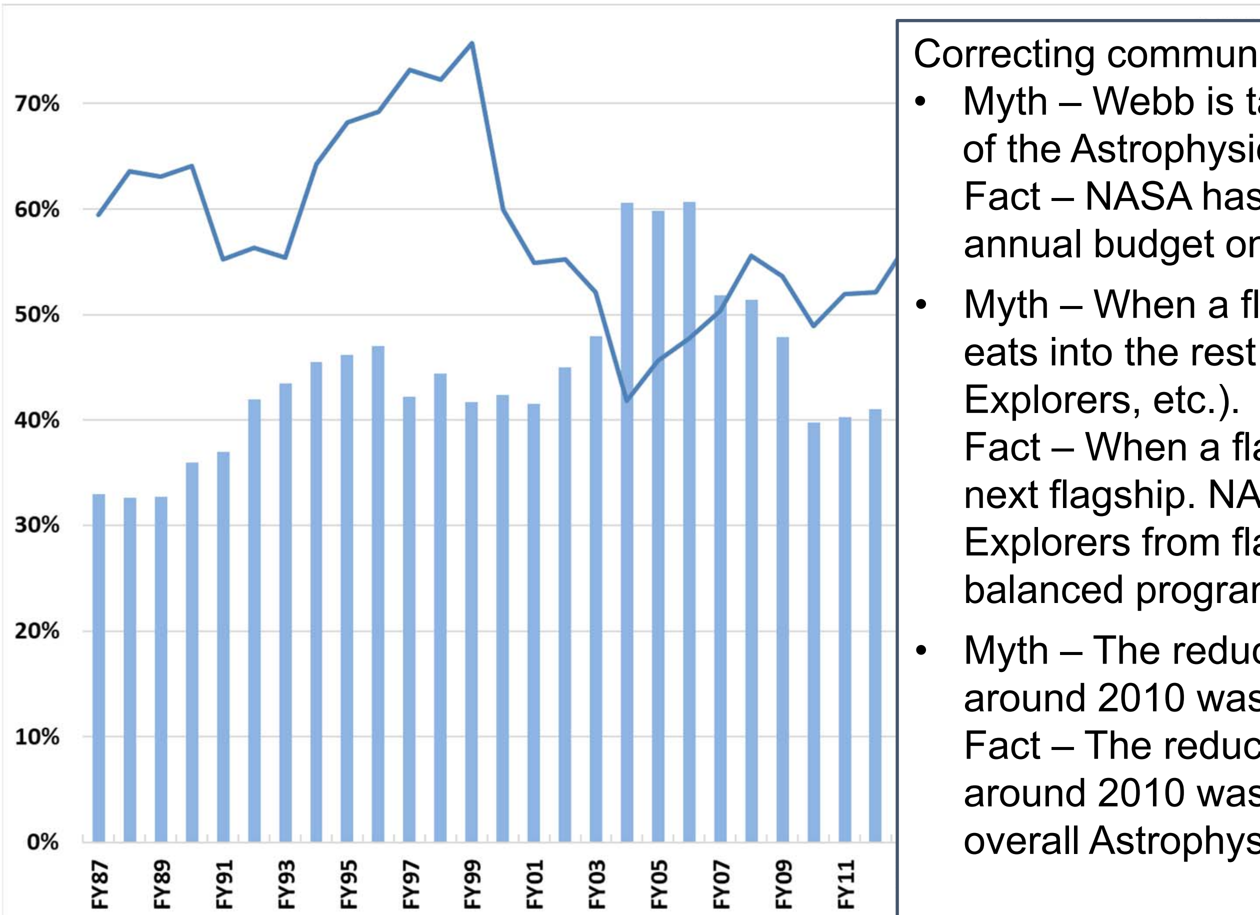
Large mission fraction (left scale)

Inflation adjusted Astrophysics budget (right scale)

Current planning budget (without WFIRST beyond FY19)

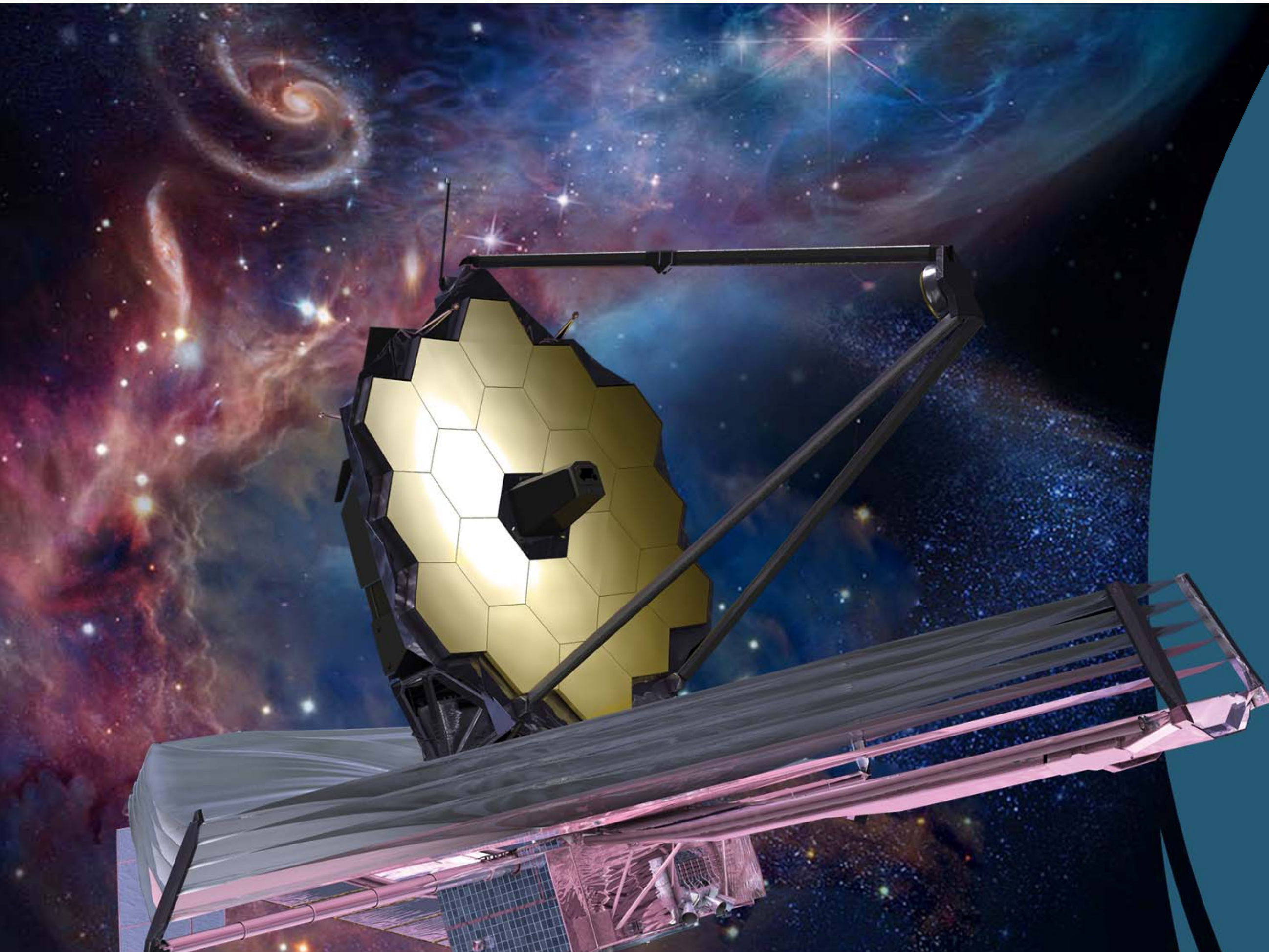
What if WFIRST is funded as needed on top of FY20 President's Budget Request?

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 completed September 2019
- Test deployment of sunshield completed October 2019
- Testing of full observatory begins in 2019 and continues in 2020
- Webb overrun covered using offsets from Astrophysics Probes

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

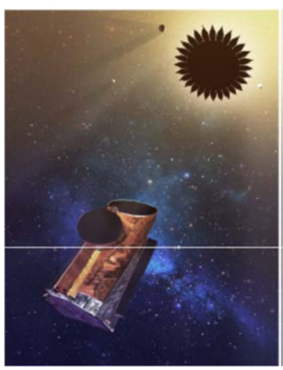
WFIRST is 100 to 1500 times faster than Hubble for large surveys at equivalent area and depth

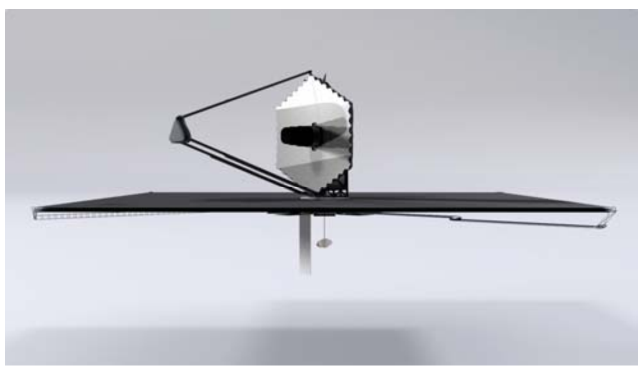
Science Program includes

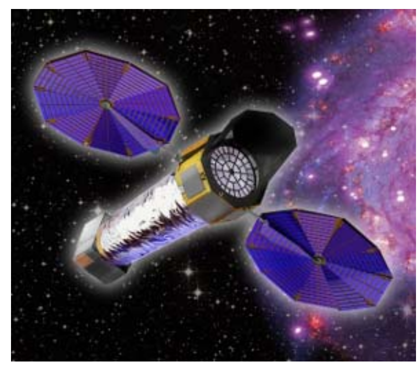
- Dark energy and the fate of the universe through surveys measuring the expansion history of the universe and the growth of structure
- The full distribution of planets around stars through a microlensing survey
- Wide-field infrared surveys of the universe through General Observer and Archival Research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

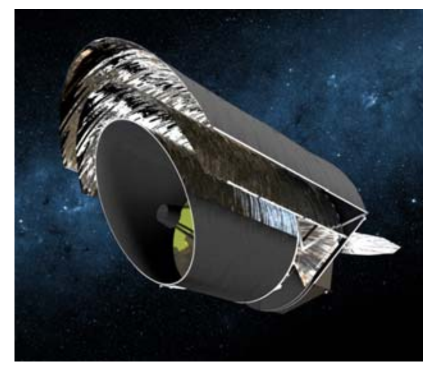
Large Mission Concepts

“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)


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
2019 Jan	Presentation to community at AAS special session
2019 Aug	Submission of final reports to NASA and public release
2019 Sep	Independent assessment of reports by NASA's Large Mission Concepts Independent Assessment Team
2019 Oct	Submission of NASA assessment to Astro2020

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

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)

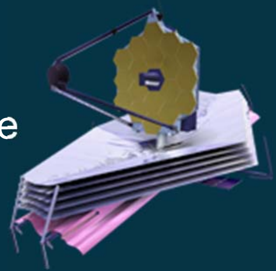
Why do today's flagships cost so much?

Inflation matters

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

Planning Guidelines

Guidance on Future Budgets

All guidance is for Astrophysics including Webb Telescope

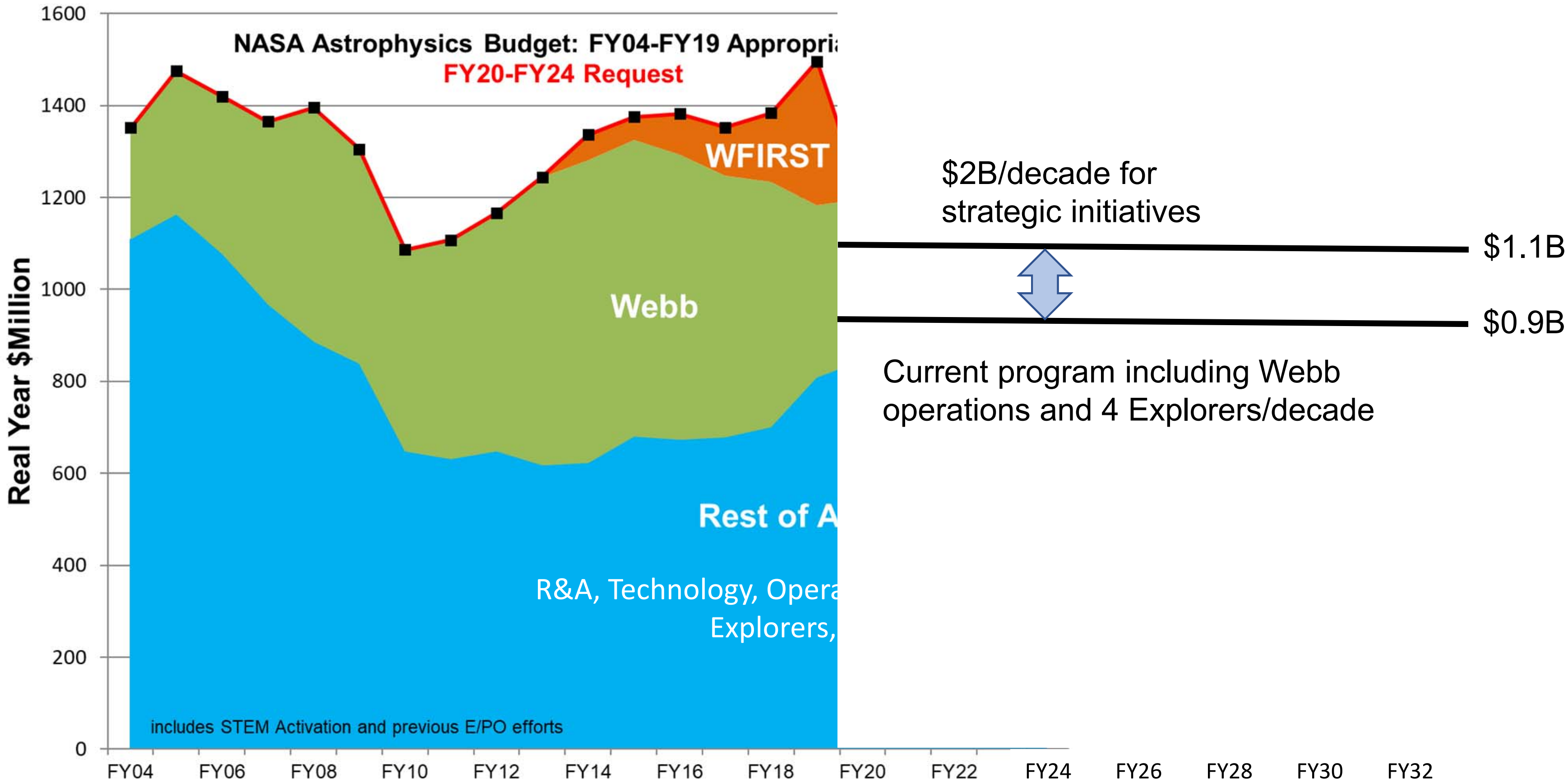
Lower bound budget projection – Extrapolation of out year planning numbers for President's FY20 budget request. Average of FY22-FY24 planning numbers is $1.1B/yr

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

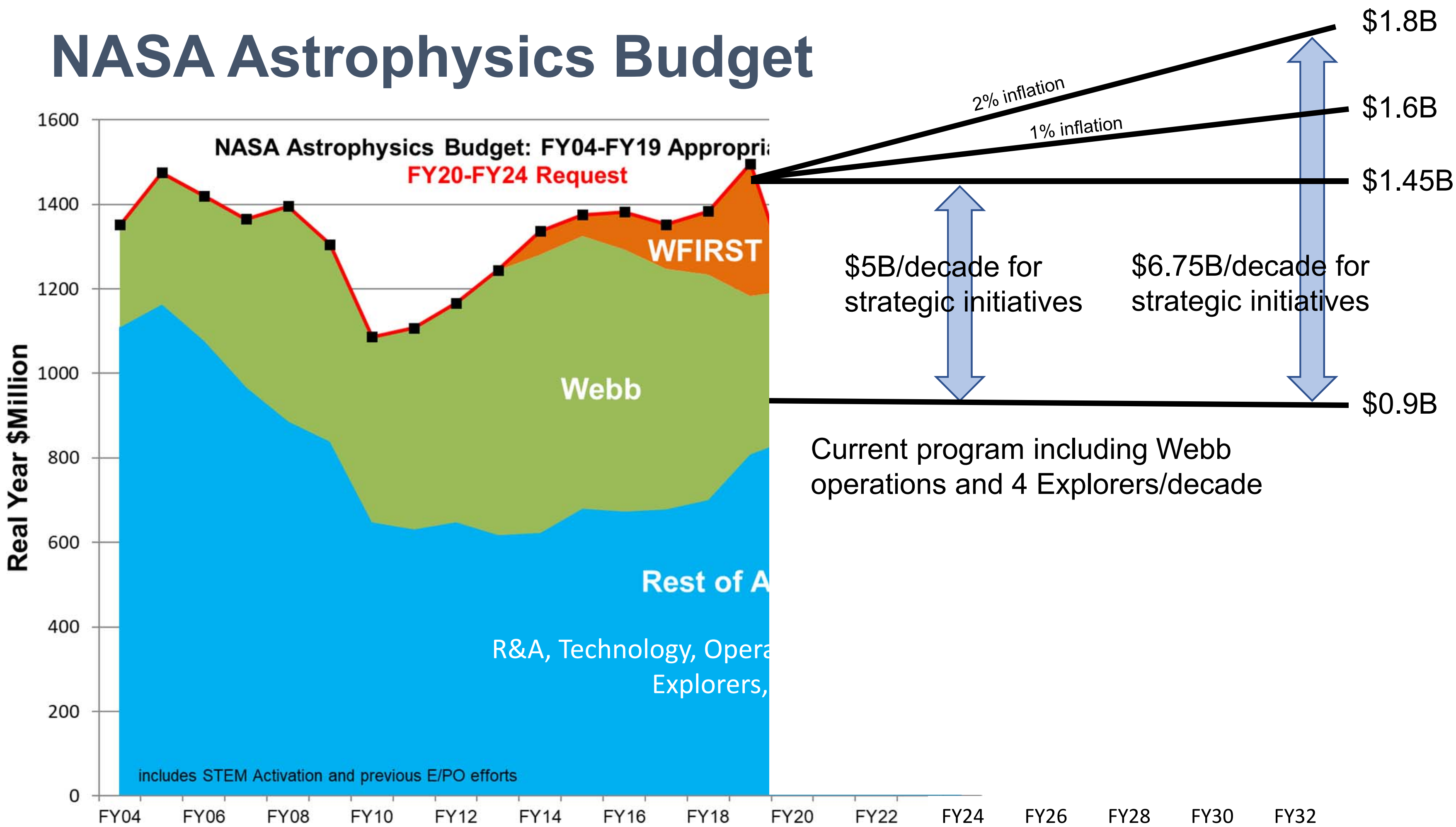
Optimistic budget projection – Empirical budget projection plus 1% inflationary growth in the out years. Budget grows from $1.5B (FY19) to $1.6B (FY25) to $1.7B (FY30)

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



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 justify great budgets.

Carpe Posterum