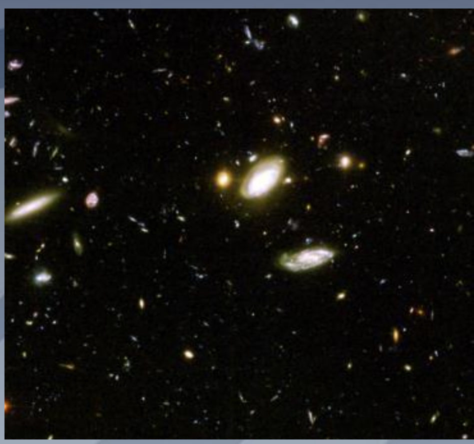
National Aeronautics and Space Administration

Astrophysics

Large Strategic Missions



Committee on Strategic Science Missions

National Academies' Keck Center

Washington, DC

Paul Hertz

Director, Astrophysics Division

Science Mission Directorate

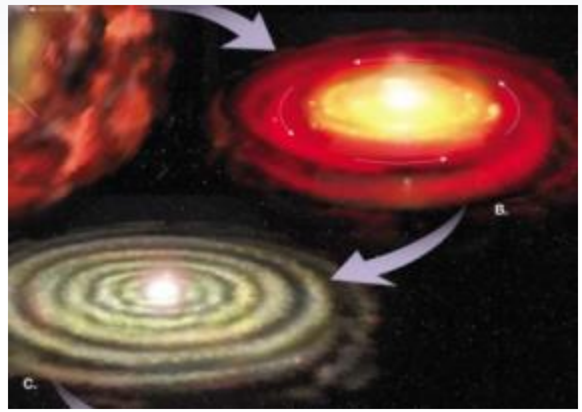
@PHertzNASA

October 5, 2016

Why Astrophysics?

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

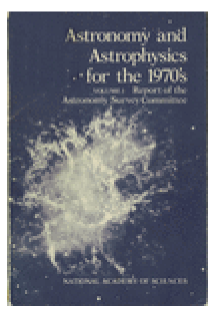
1. How did our universe begin and evolve?



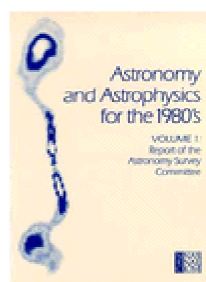
2. How did galaxies, stars, and planets come to be?

3. Are We Alone?

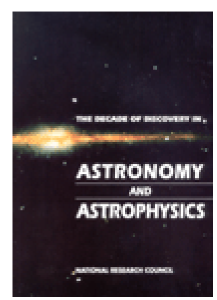
These national strategic drivers are enduring



1972

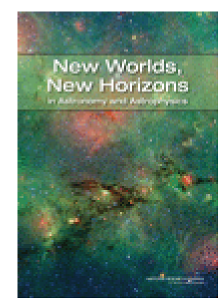


1982



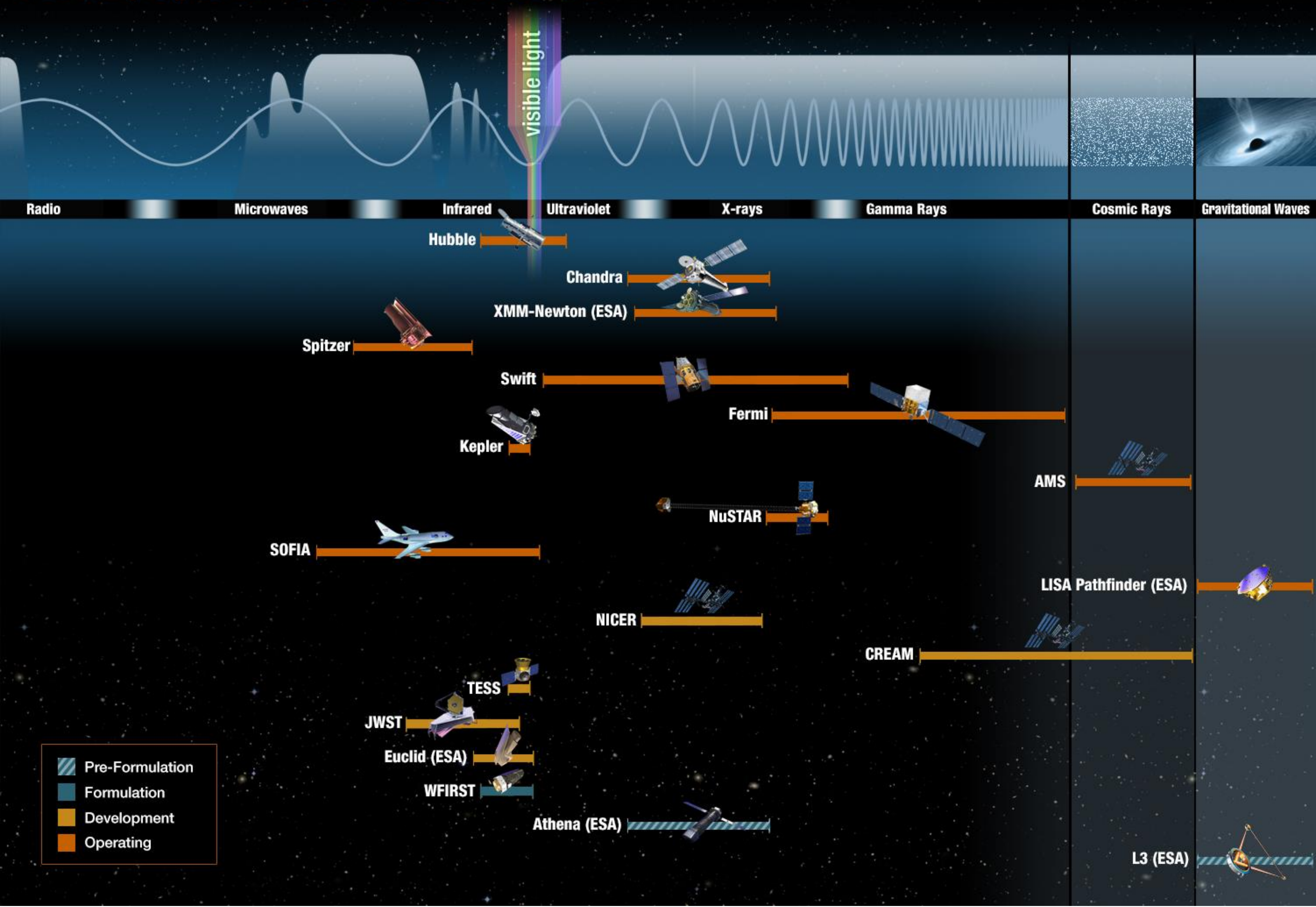
1991

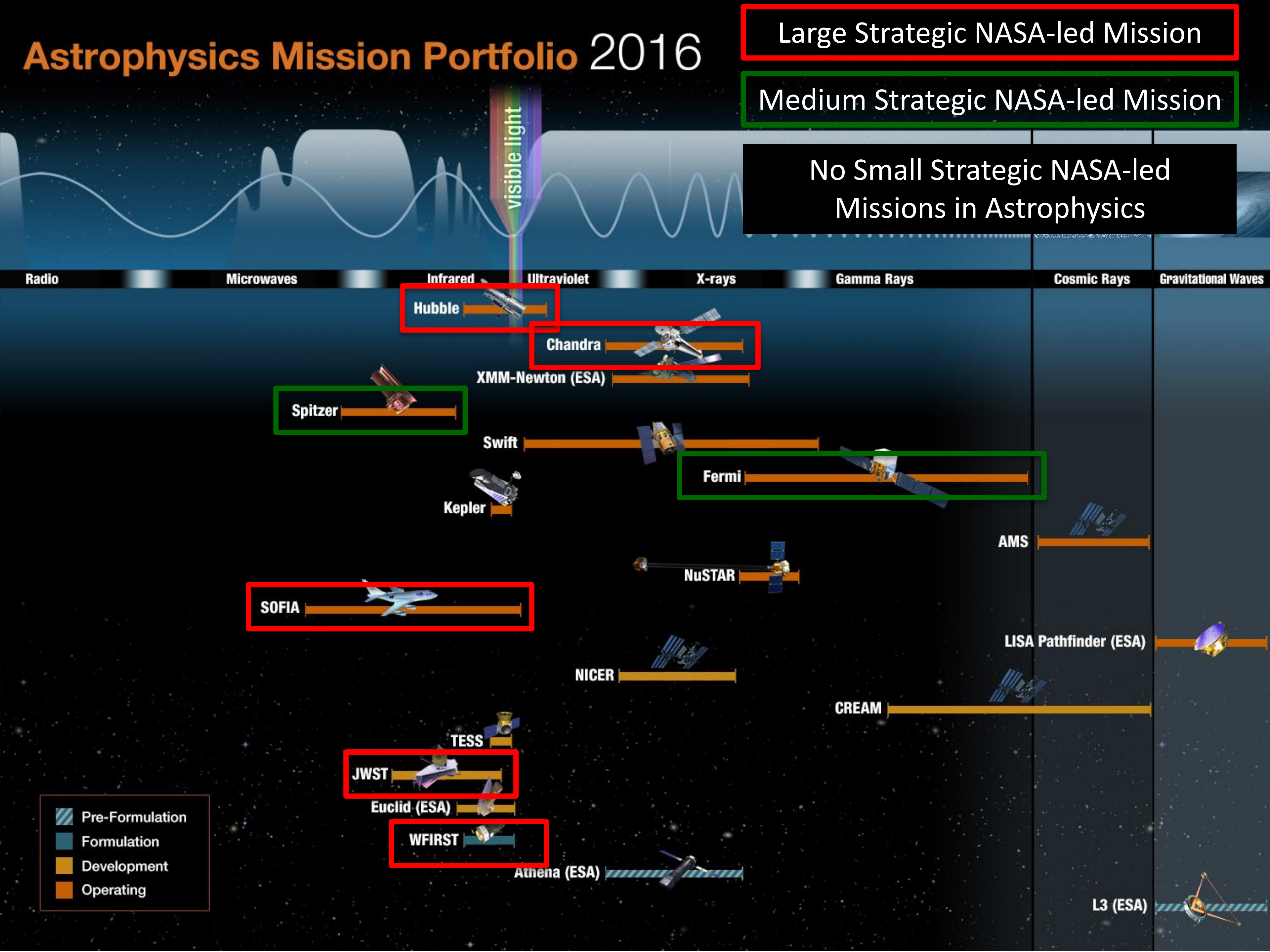
2001



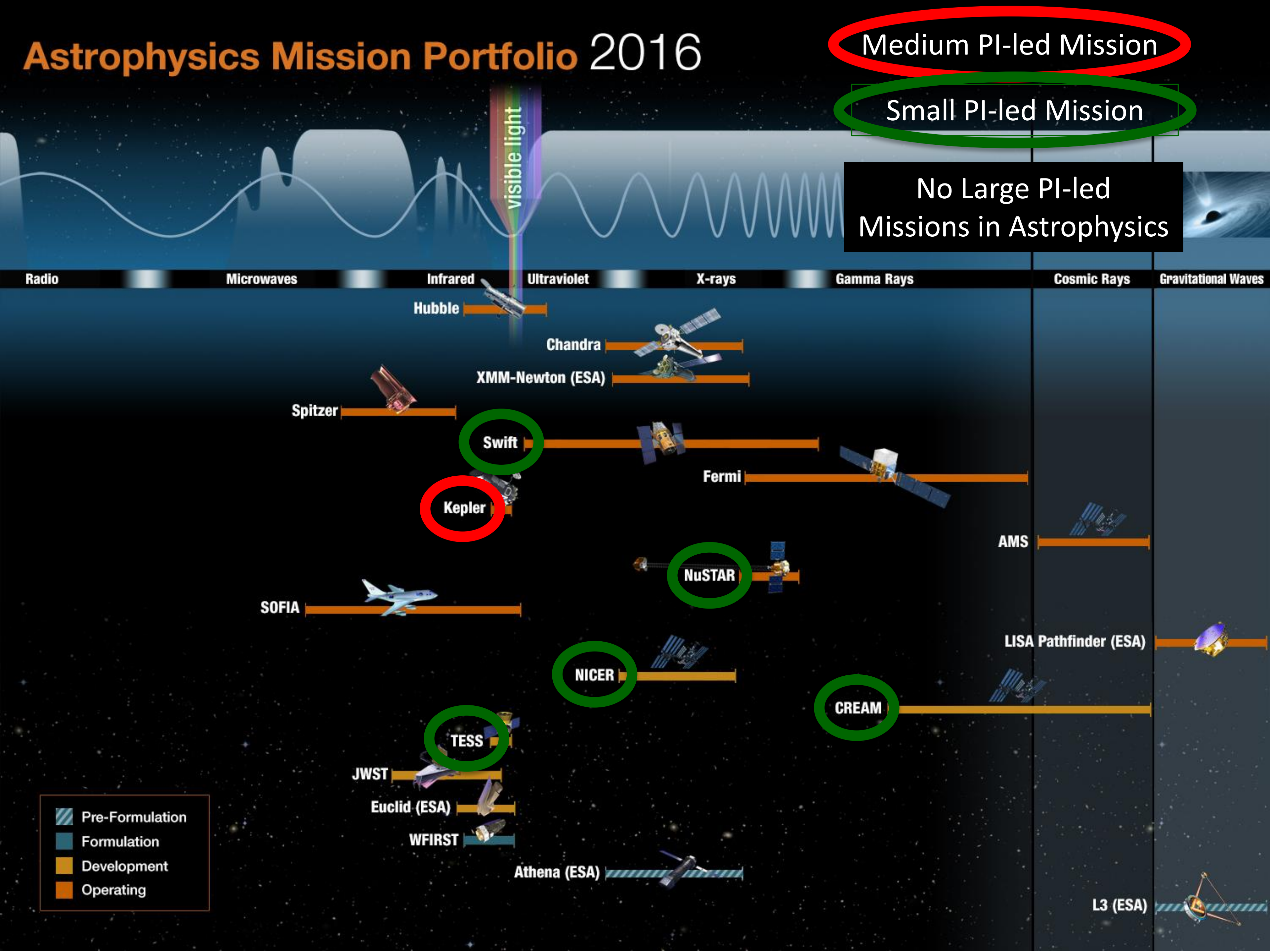
2010

Astrophysics Mission Portfolio 2016

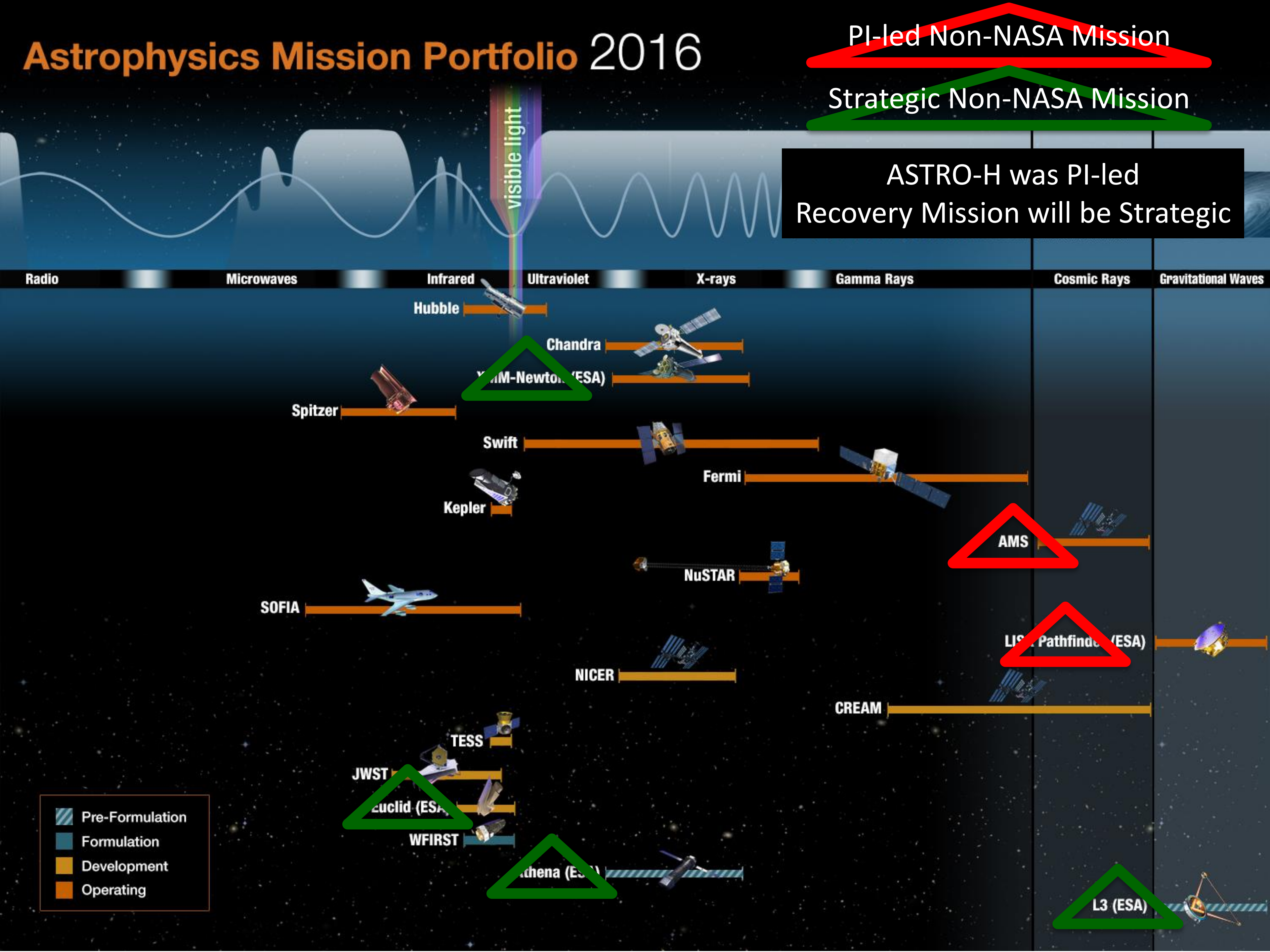




Astrophysics Mission Portfolio 2016
Large Strategic NASA-led Mission
Medium Strategic NASA-led Mission
No Small Strategic NASA-led Missions in Astrophysics
visible light
Radio
Microwaves
Infrared
Ultraviolet
X-rays
Gamma Rays
Cosmic Rays
Gravitational Waves
Hubble
Chandra
XMM-Newton (ESA)
Spitzer
Swift
Fermi
Kepler
AMS
NuSTAR
SOFIA
LISA Pathfinder (ESA)
NICER
CREAM
TESS
JWST
Euclid (ESA)
WFIRST
Athena (ESA)
L3 (ESA)
Pre-Formulation
Formulation
Development
Operating

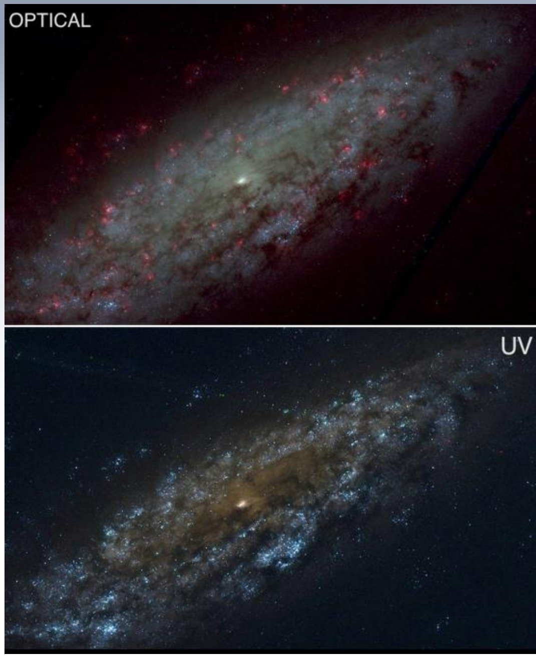


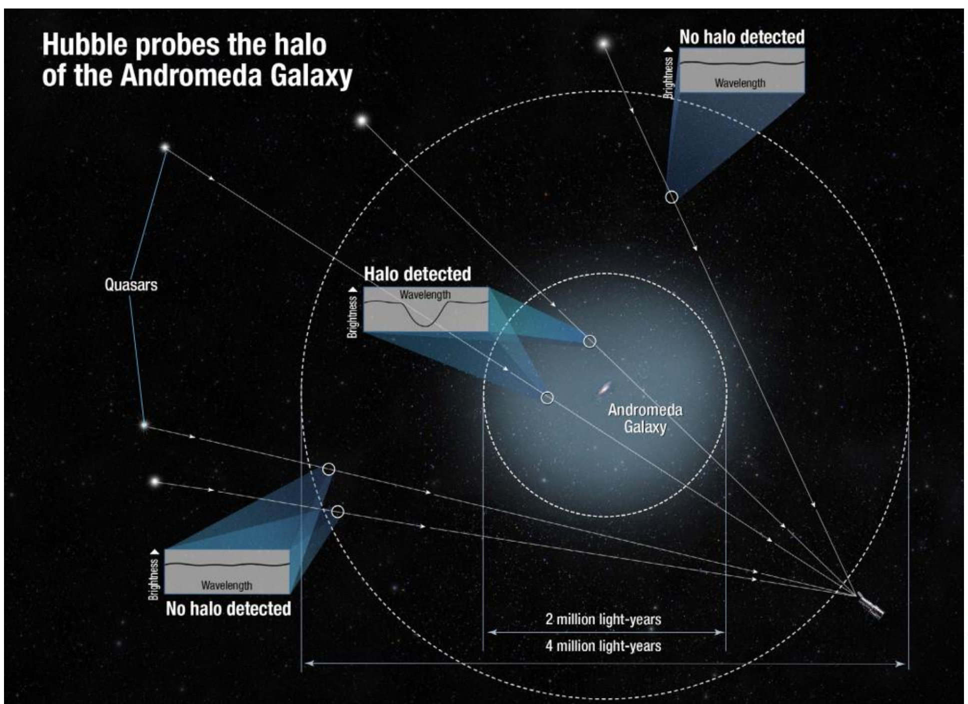
Astrophysics Mission Portfolio 2016
Medium PI-led Mission
Small PI-led Mission
No Large PI-led Missions in Astrophysics
visible light
Radio
Microwaves
Infrared
Ultraviolet
X-rays
Gamma Rays
Cosmic Rays
Gravitational Waves
Hubble
Chandra
XMM-Newton (ESA)
Spitzer
Swift
Fermi
Kepler
AMS
NuSTAR
SOFIA
LISA Pathfinder (ESA)
NICER
CREAM
TESS
JWST
Euclid (ESA)
WFIRST
Athena (ESA)
L3 (ESA)
Pre-Formulation
Formulation
Development
Operating

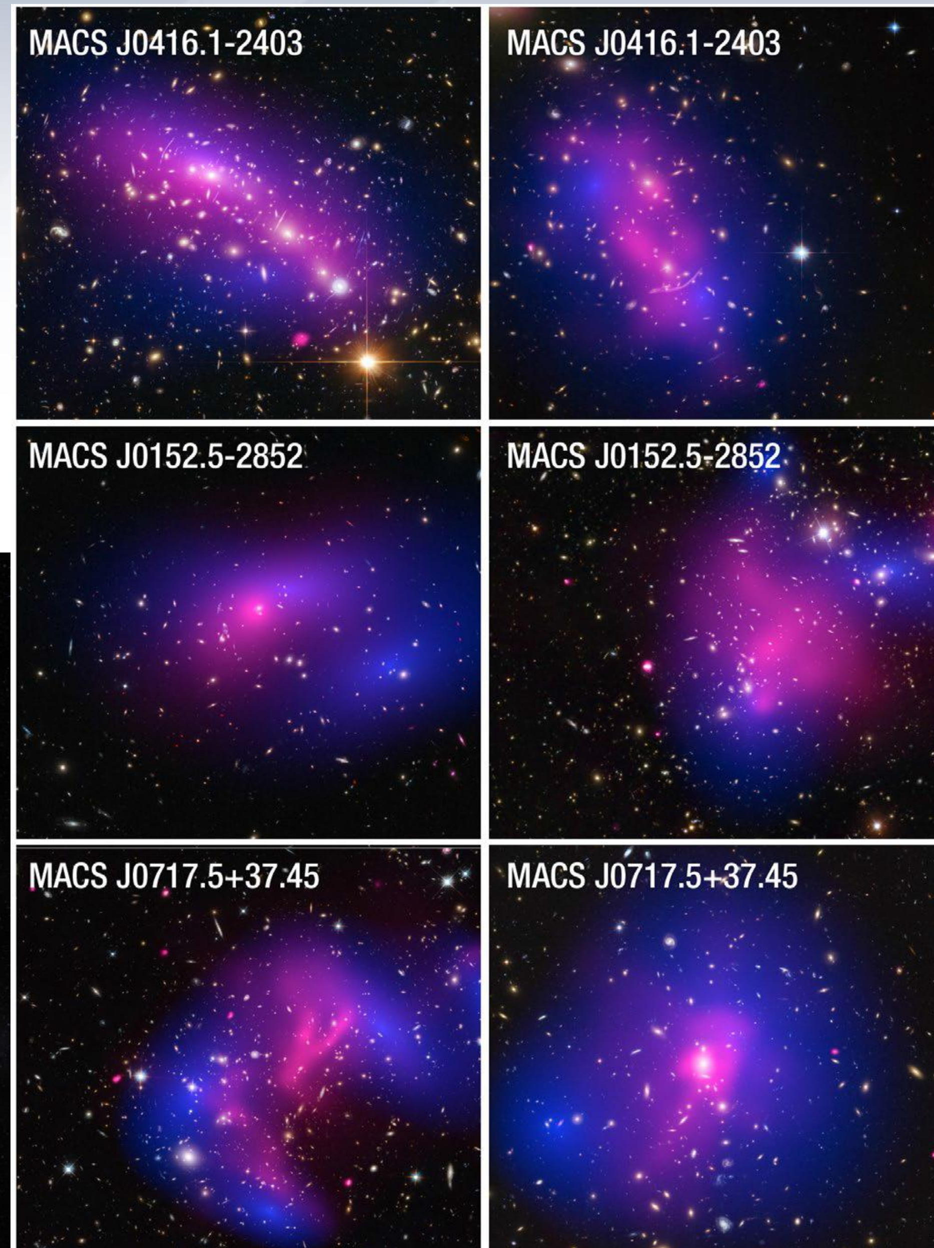


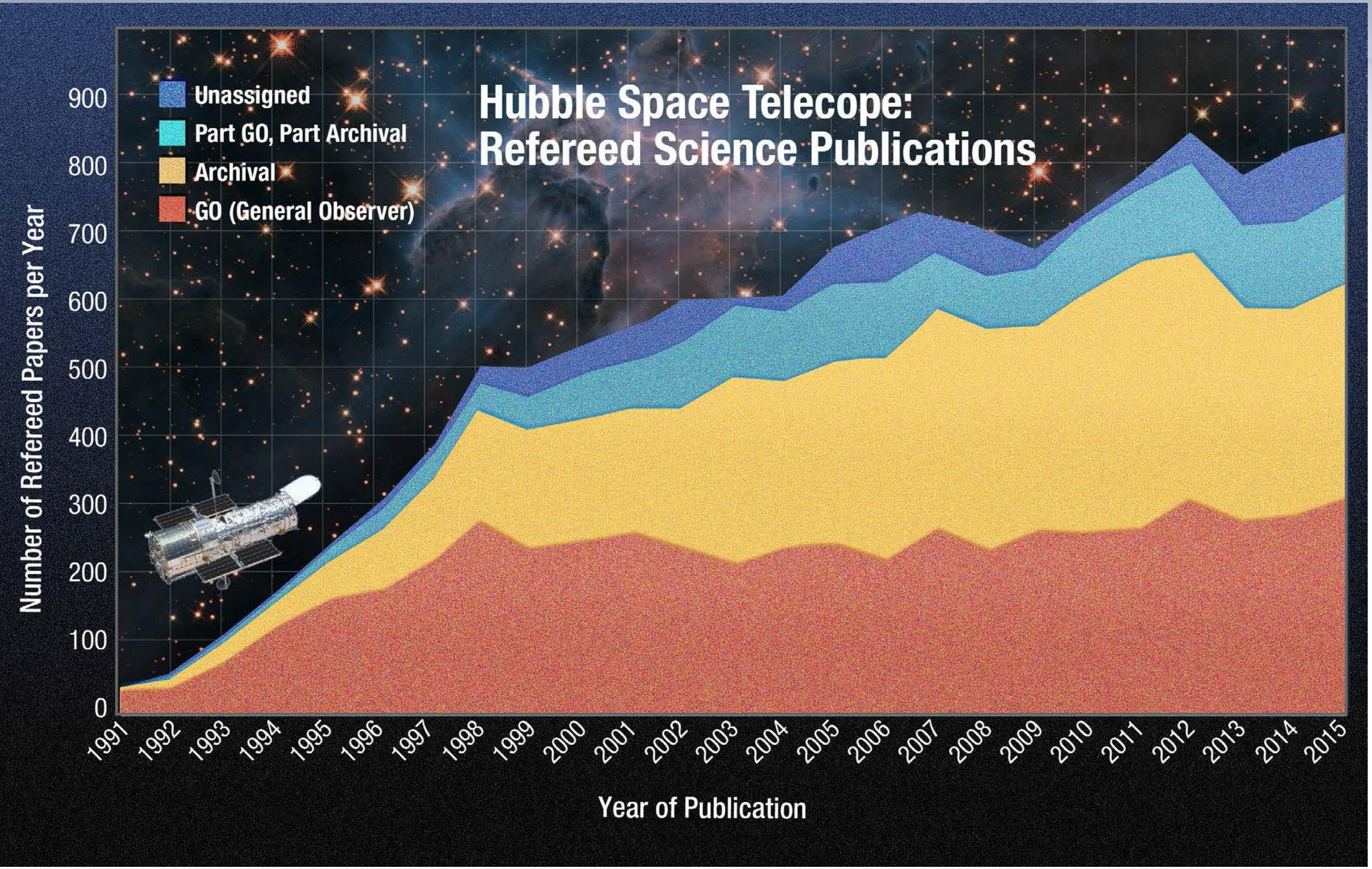
Astrophysics Mission Portfolio 2016
PI-led Non-NASA Mission
Strategic Non-NASA Mission
ASTRO-H was PI-led
Recovery Mission will be Strategic
visible light
Radio
Microwaves
Infrared
Ultraviolet
X-rays
Gamma Rays
Cosmic Rays
Gravitational Waves
Hubble
Chandra
XMM-Newton (ESA)
Spitzer
Swift
Fermi
Kepler
AMS
NuSTAR
SOFIA
LISA Pathfinder (ESA)
NICER
CREAM
TESS
JWST
Euclid (ESA)
WFIRST
Athena (ESA)
L3 (ESA)
Pre-Formulation
Formulation
Development
Operating

Hubble Space Telescope

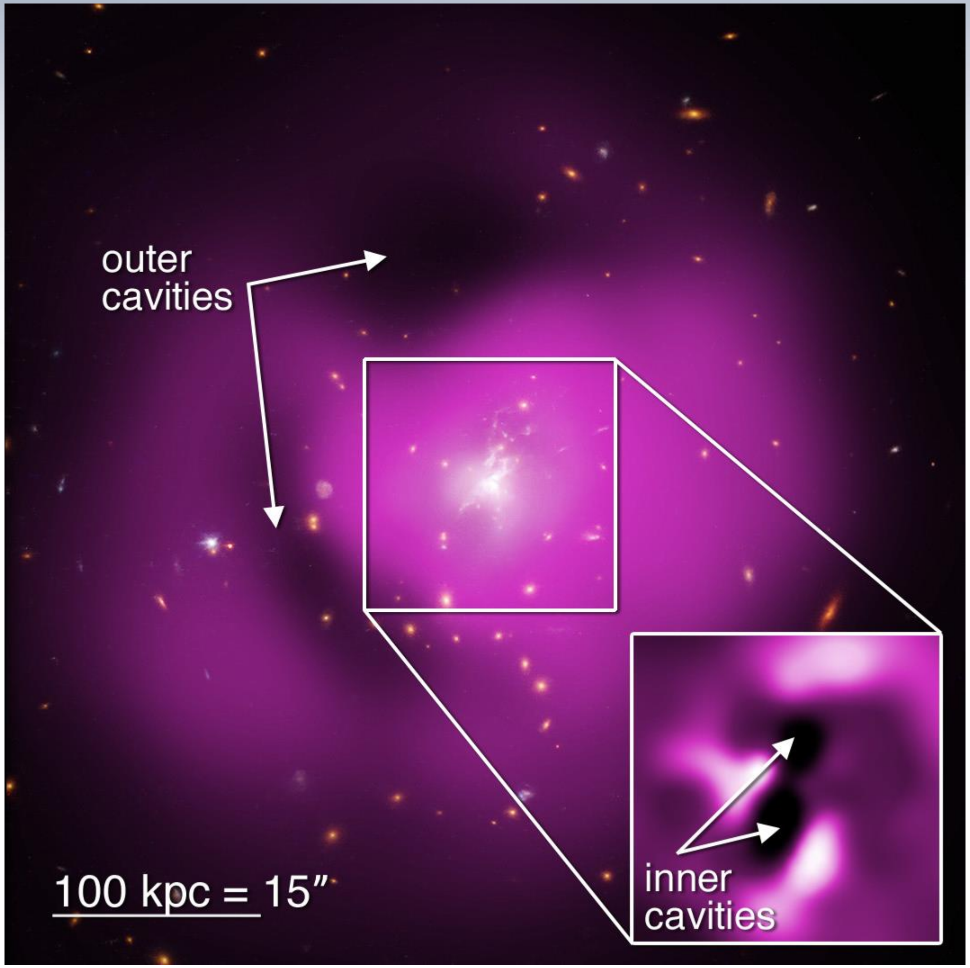


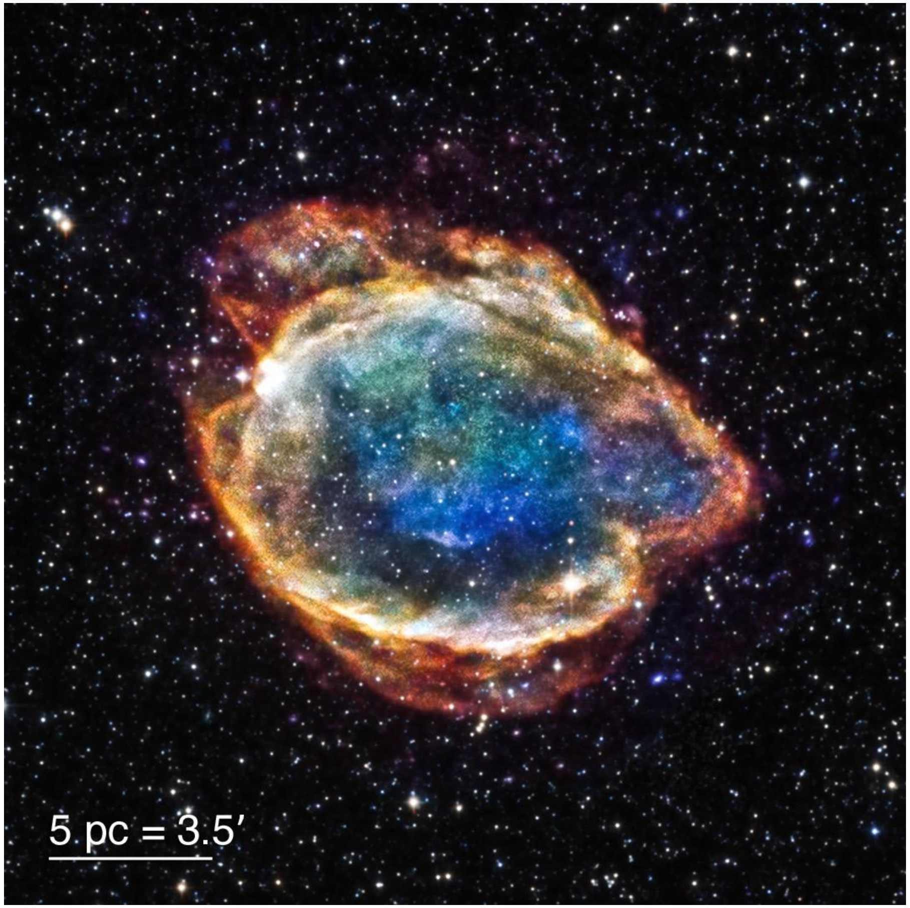




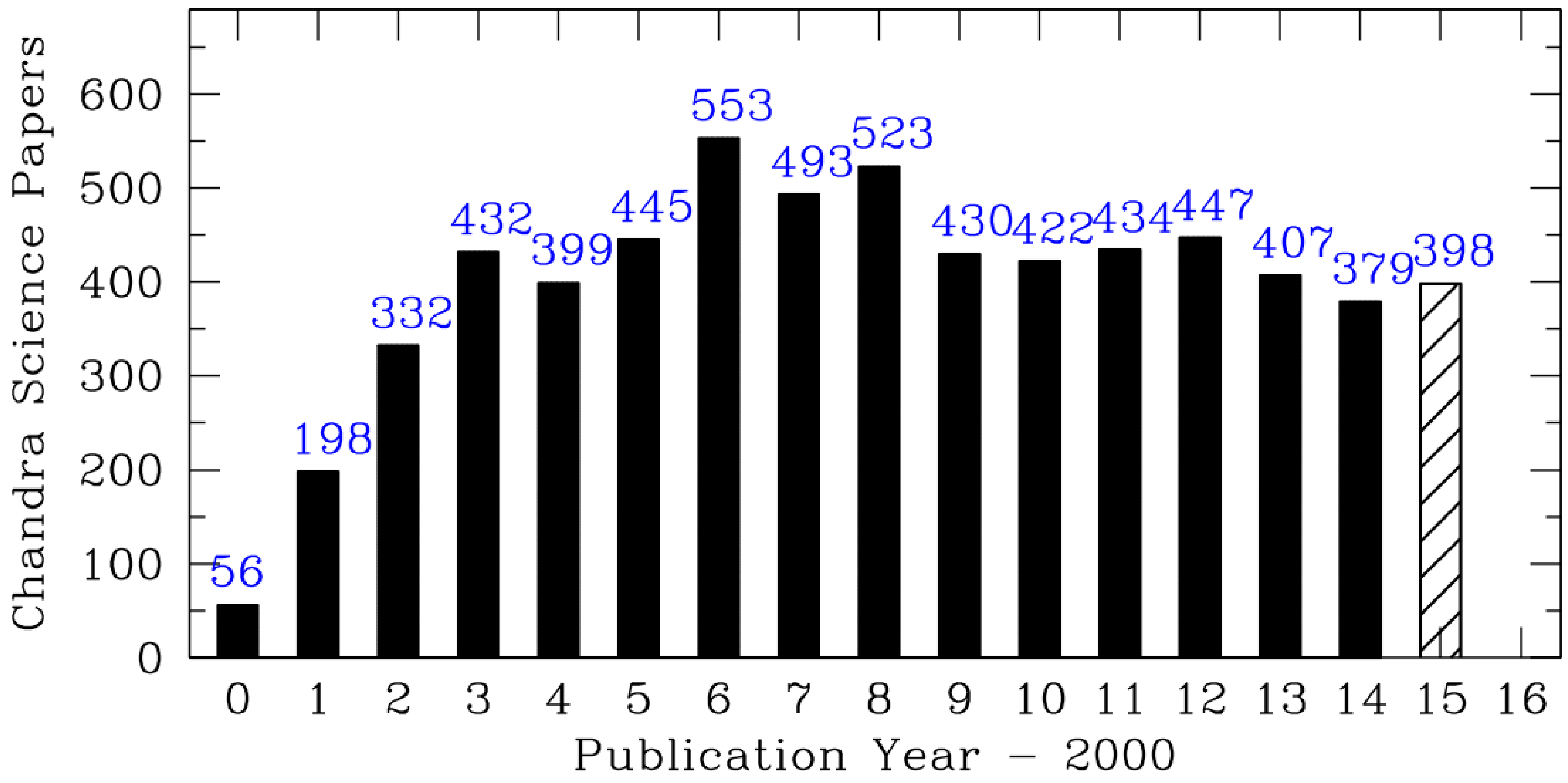

Hubble Space Telecope:
Refereed Science Publications
Unassigned
Part GO, Part Archival
Archival
GO (General Observer)
Number of Refereed Papers per Year
0
100
200
300
400
500
600
700
800
900
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
Year of Publication

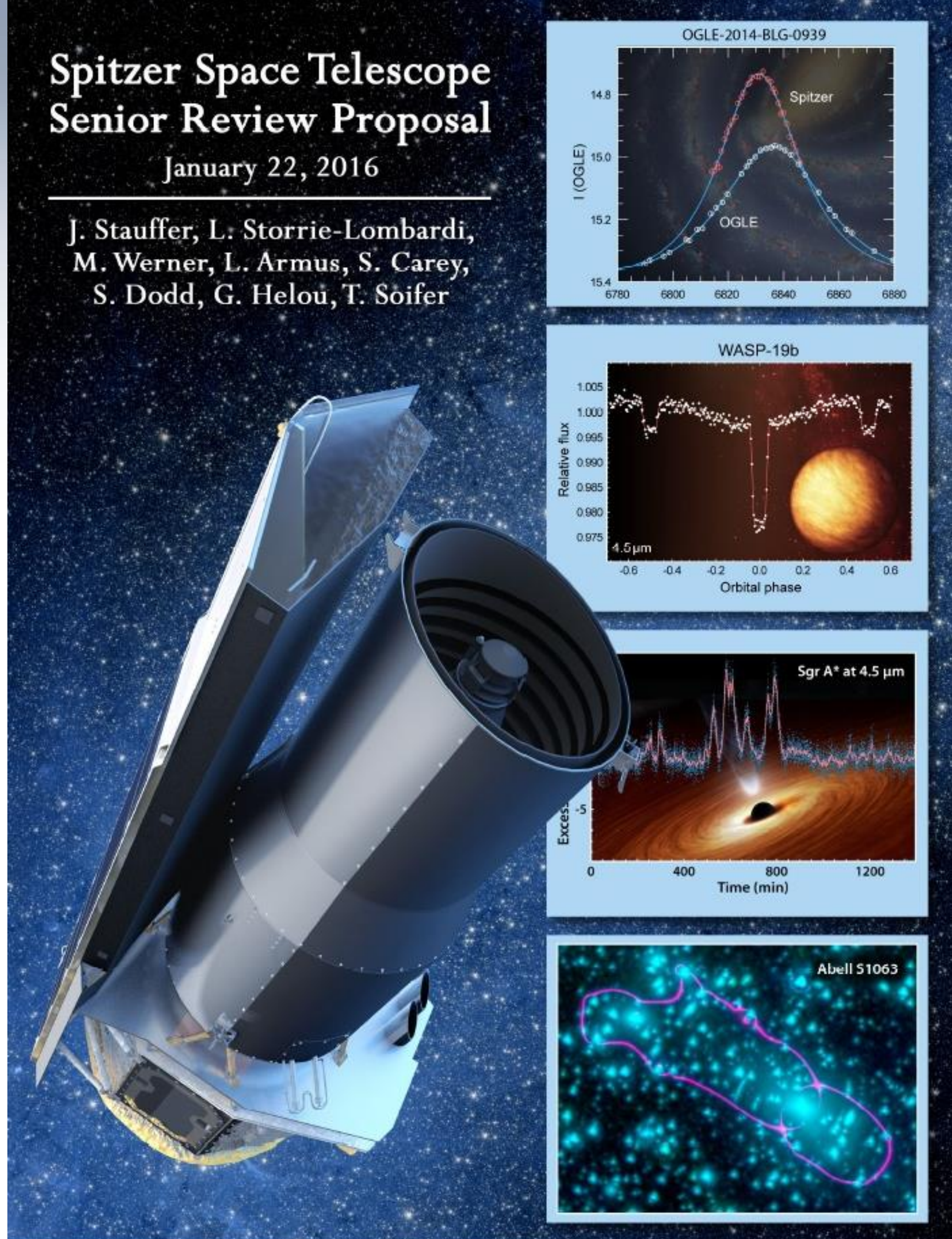
Chandra X-ray Observatory



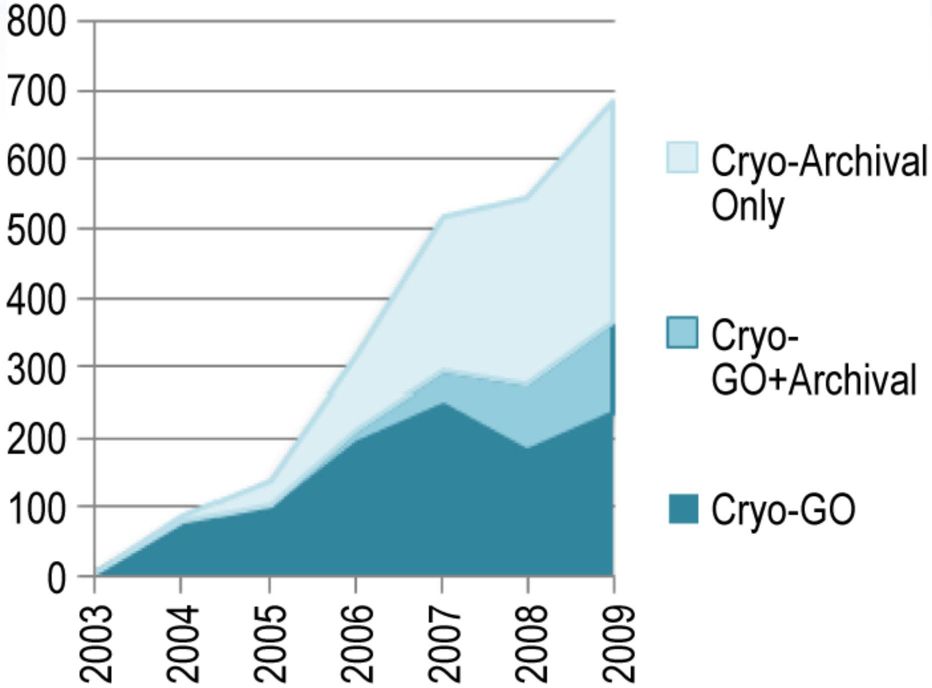


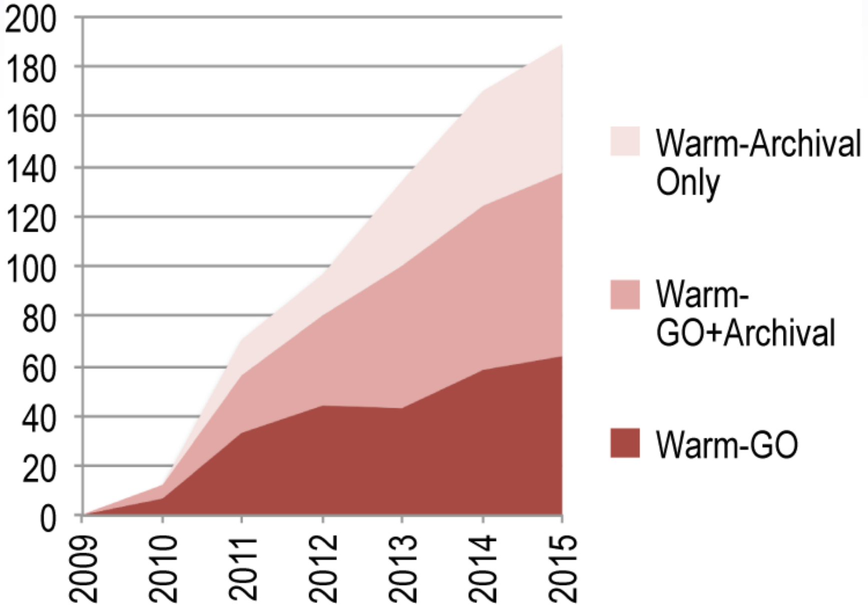
Chandra X-ray Observatory



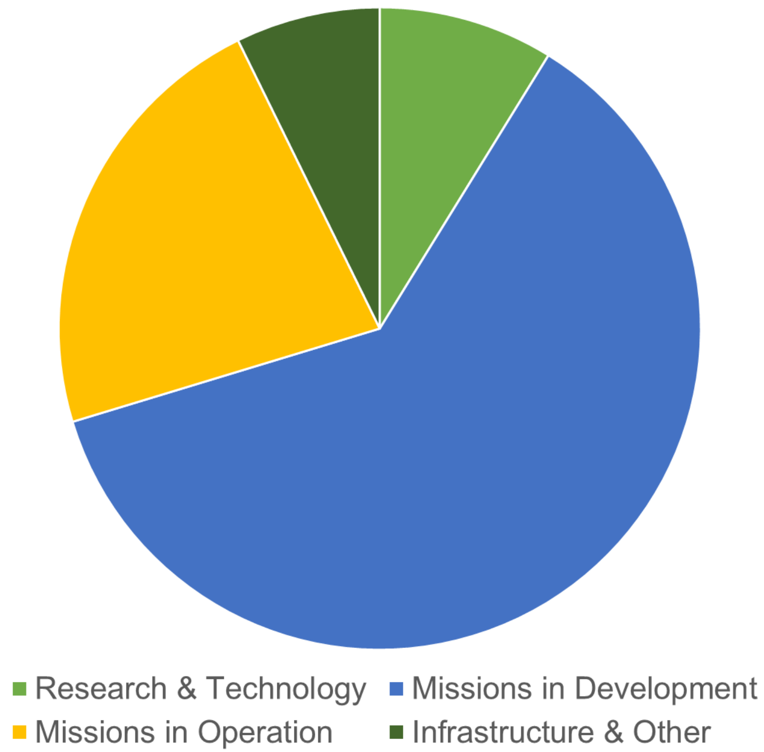

Spitzer Space Telescope
Senior Review Proposal
January 22, 2016
J. Stauffer, L. Storrie-Lombardi,
M. Werner, L. Armus, S. Carey,
S. Dodd, G. Helou, T. Soifer
OGLE-2014-BLG-0939
Spitzer
OGLE
I (OGLE)
WASP-19b
Relative flux
4.5 μm
Orbital phase
Sgr A* at 4.5 μm
Time (min)
Abell S1063

Spitzer Space Telescope





NASA Astrophysics



FY 2016
Total US$ 1,333 M

Missions in Development includes Webb, ISS-NICER, ISS-CREAM, TESS, Euclid, WFIRST

Missions in Operation includes Hubble, Chandra, XMM-Newton, Spitzer, Swift, Fermi, Kepler, NuSTAR, SOFIA, LISA Pathfinder

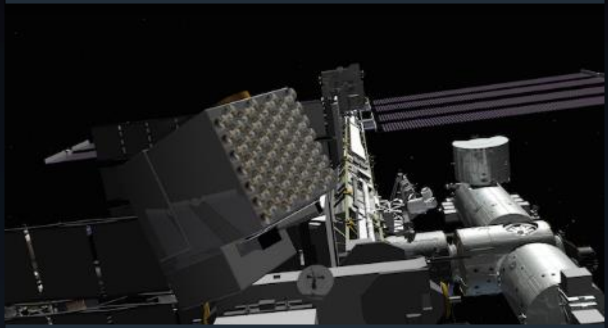
Infrastructure & Other includes data archives, suborbital balloons, ground-based telescopes, management

Research & Technology includes basic technology, strategic technology, suborbital payloads, theory, data analysis, fellowships

Astrophysics Missions in Development

ISS-NICER
2/2017

NASA Mission



Neutron Star Interior
Composition Explorer

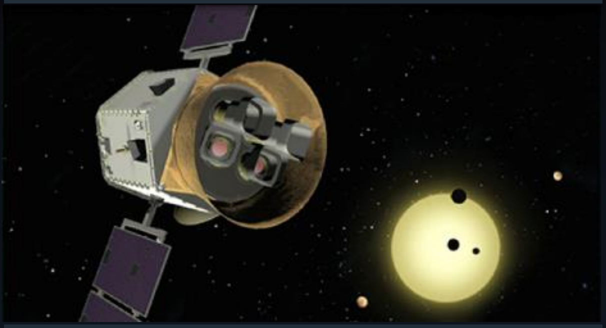
ISS-CREAM
6/2017

NASA Mission

Cosmic Ray Energetics
And Mass

TESS
12/ 2017

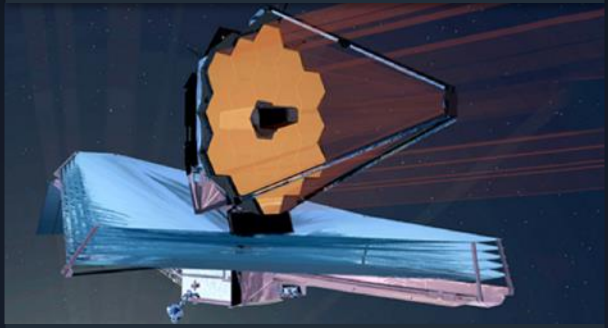
NASA Mission



Transiting Exoplanet
Survey Satellite

Webb
10/2018

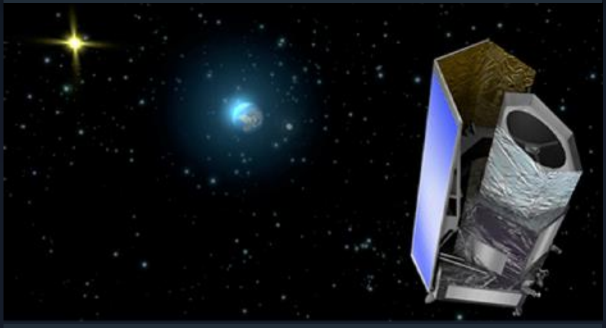
NASA Mission



James Webb
Space Telescope

Euclid
2020

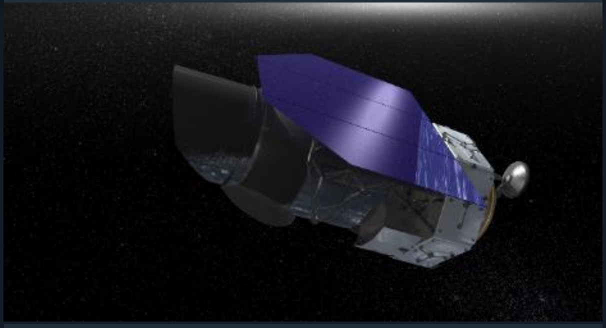
ESA-led Mission



NASA is supplying the NISP
Sensor Chip System (SCS)

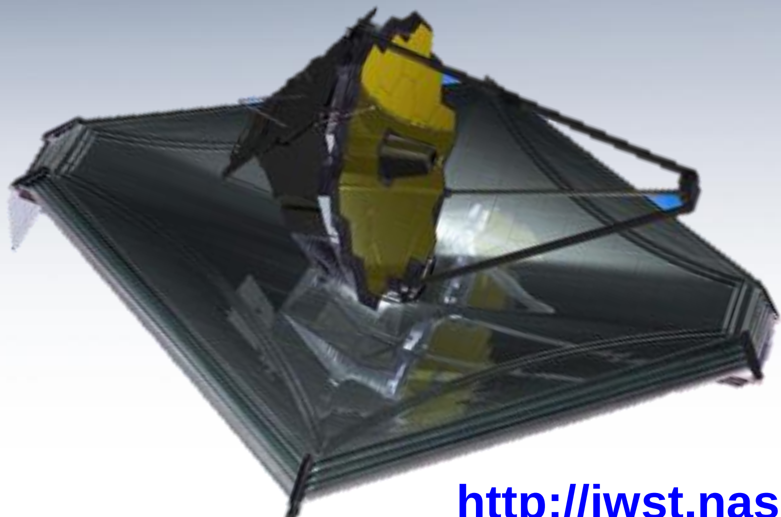
WFIRST
Mid 2020s

NASA Mission



Wide-Field Infrared
Survey Telescope

James Webb Space Telescope



http://jwst.nasa.gov/

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

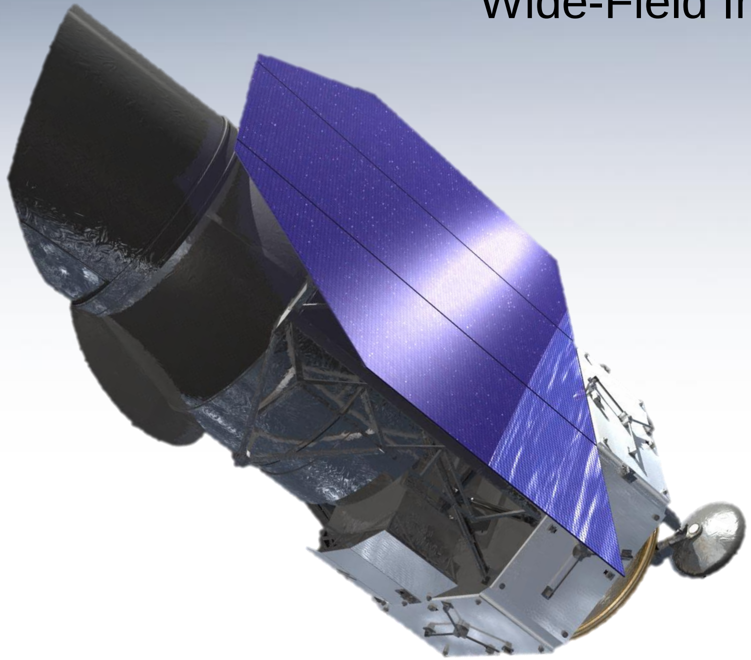
Operations: 2018 launch for a 5-year prime mission

Partners: ESA, CSA

JWST remains on track for an October 2018 launch

WFIRST

Wide-Field Infrared Survey Telescope



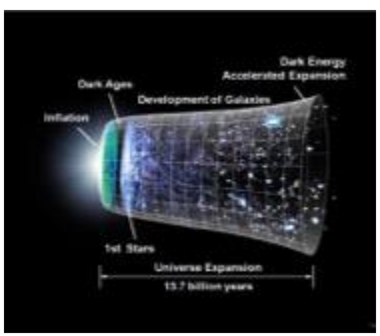
WFIRST highest ranked large space mission in 2010 Decadal Survey

- Study Dark Energy, Exoplanet Census, NIR Sky Survey

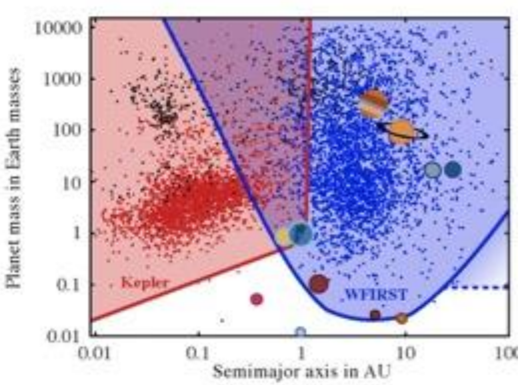
Use of 2.4m telescope enables

- Hubble quality imaging over 100x more sky
- Imaging of exoplanets with 10^{-9} contrast with a coronagraph

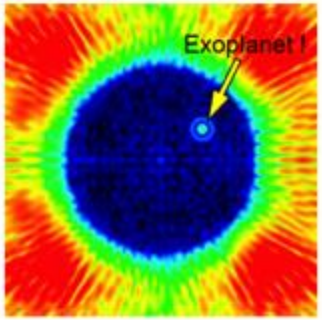
Dark Energy



Exoplanets

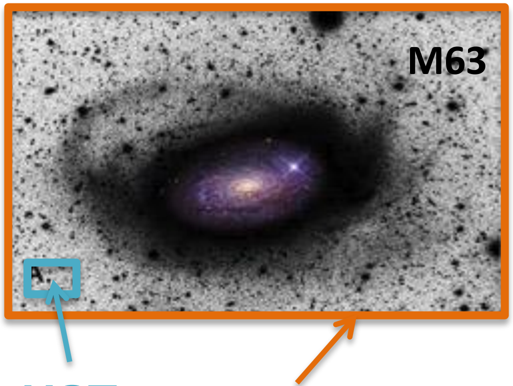


Microlensing



Coronagraph

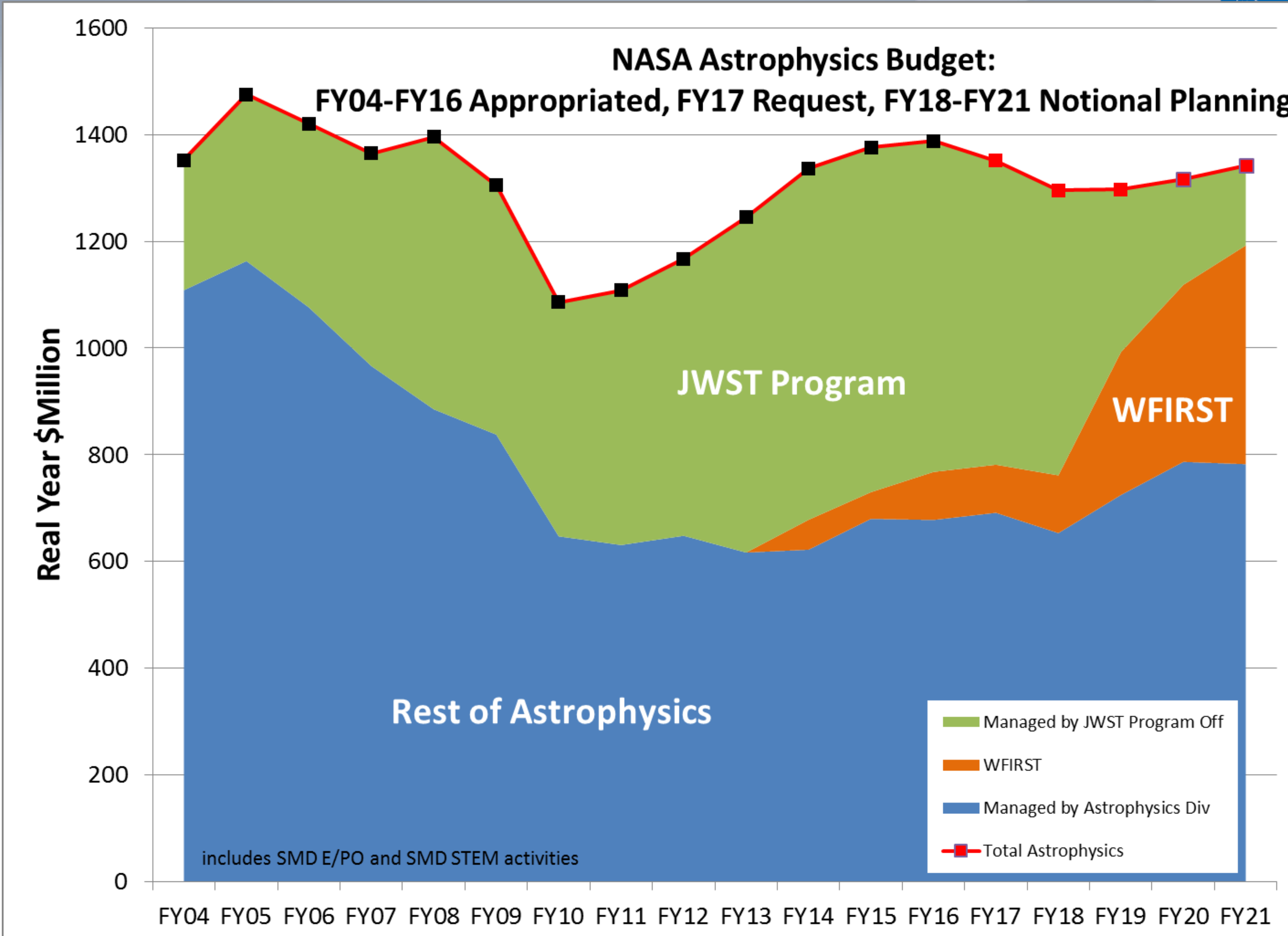
Astrophysics



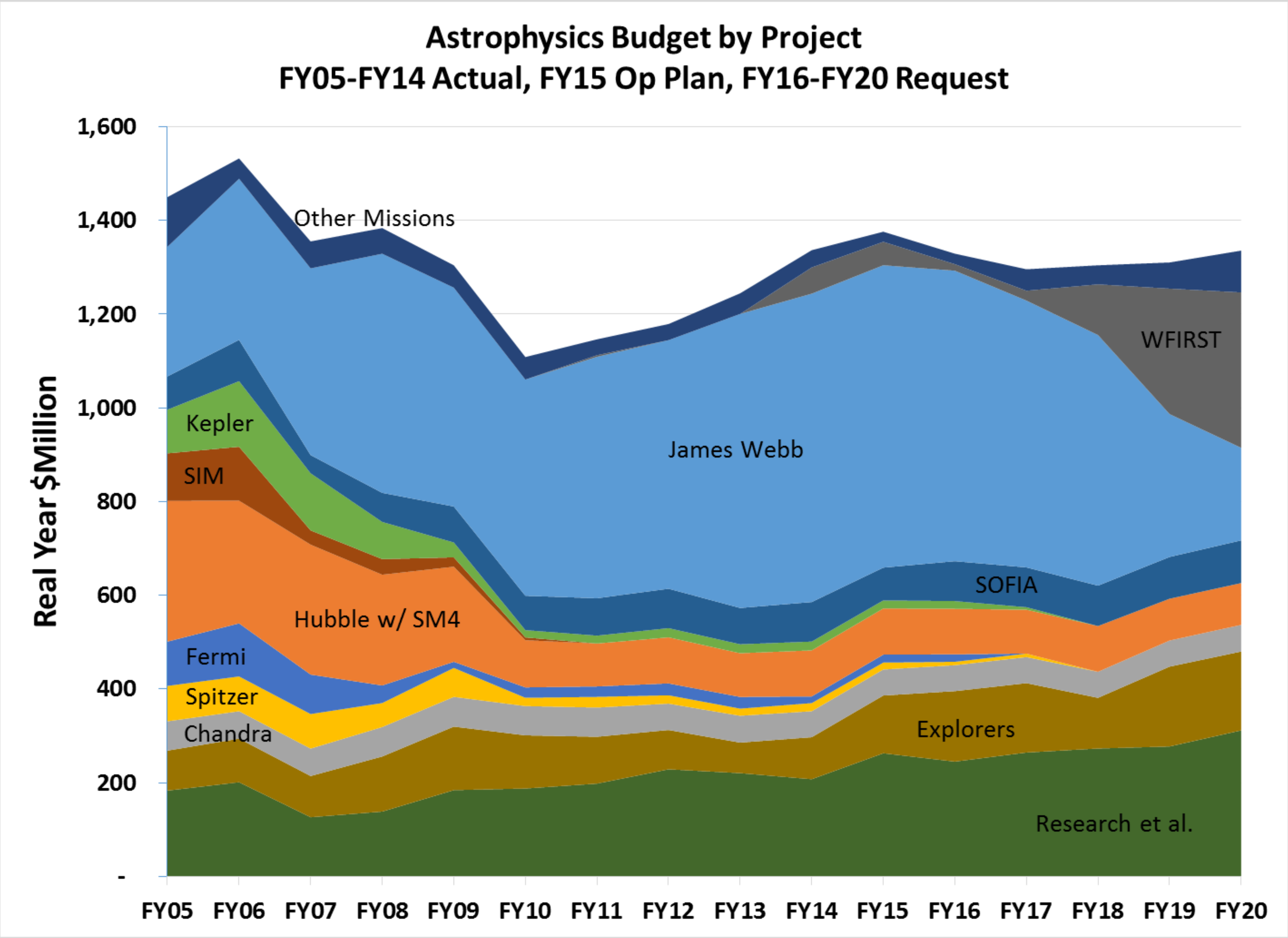
HST

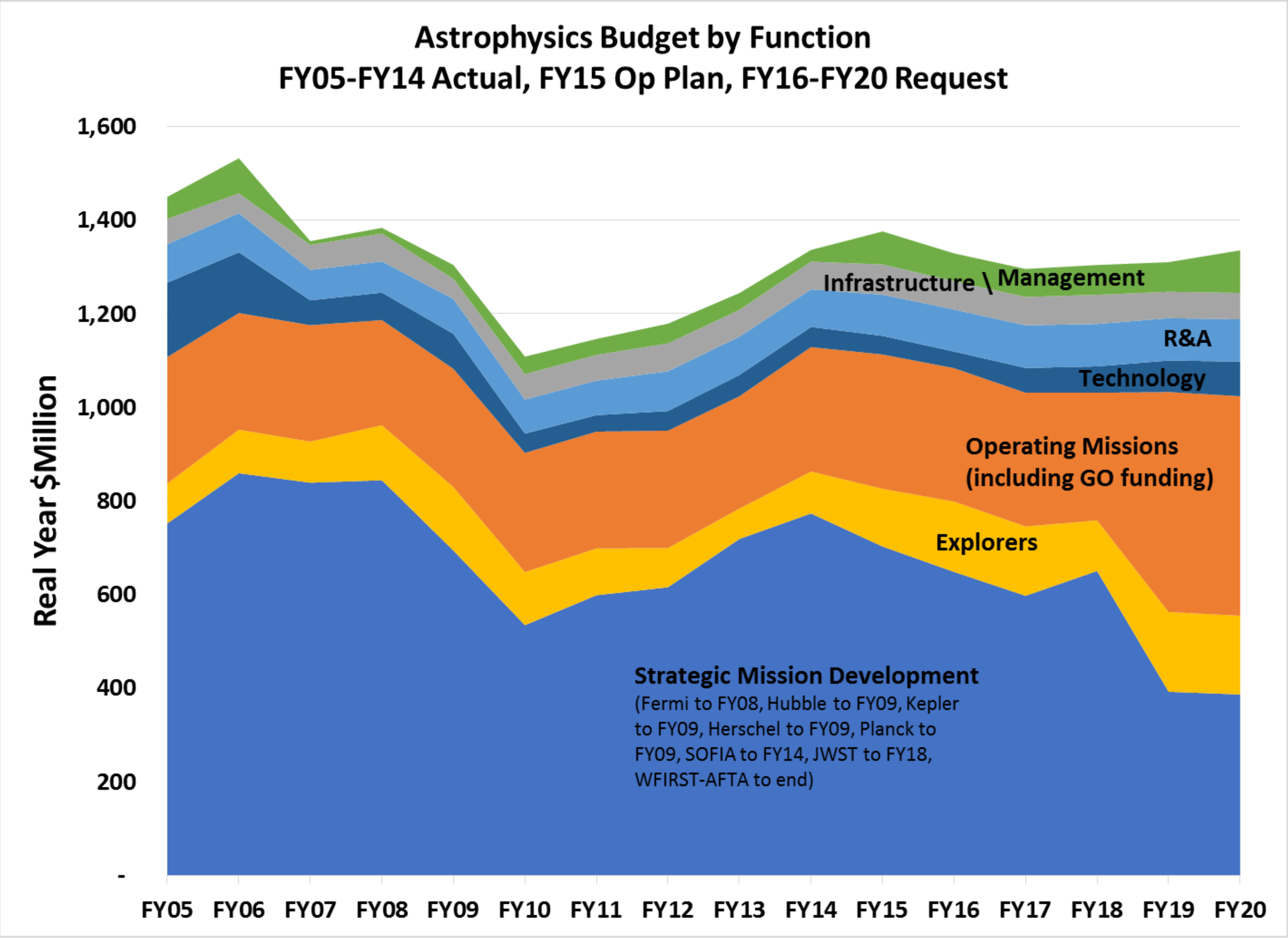
WFIRST

http://wfirst.gsfc.nasa.gov/



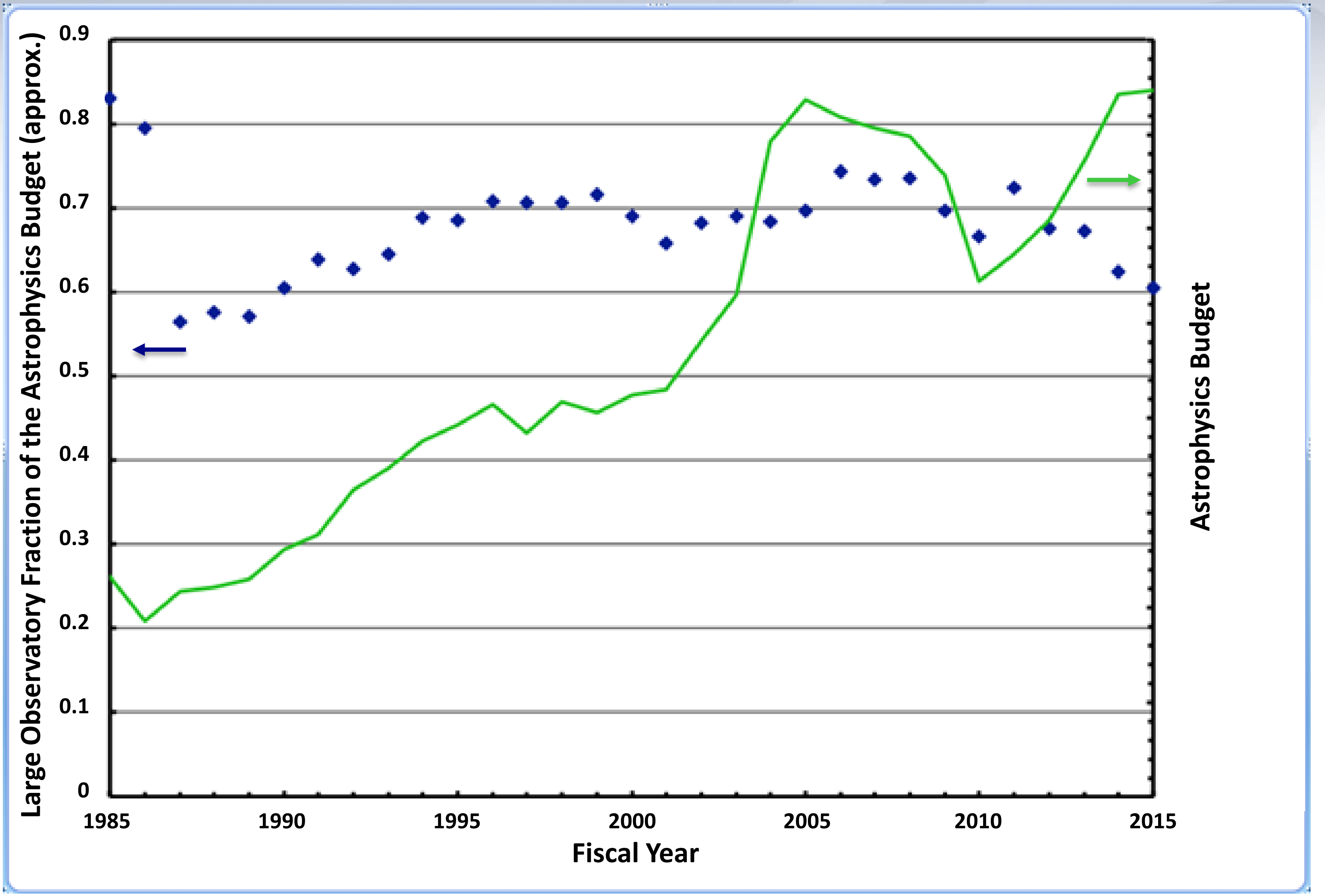
NASA Astrophysics Budget:
FY04-FY16 Appropriated, FY17 Request, FY18-FY21 Notional Planning
Real Year $Million
1600
1400
1200
1000
800
600
400
200
0
JWST Program
WFIRST
Rest of Astrophysics
includes SMD E/PO and SMD STEM activities
Managed by JWST Program Off
WFIRST
Managed by Astrophysics Div
Total Astrophysics
FY04 FY05 FY06 FY07 FY08 FY09 FY10 FY11 FY12 FY13 FY14 FY15 FY16 FY17 FY18 FY19 FY20 FY21


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
-
FY05
FY06
FY07
FY08
FY09
FY10
FY11
FY12
FY13
FY14
FY15
FY16
FY17
FY18
FY19
FY20
Other Missions
Kepler
SIM
Hubble w/ SM4
Fermi
Spitzer
Chandra
James Webb
WFIRST
SOFIA
Explorers
Research et al.



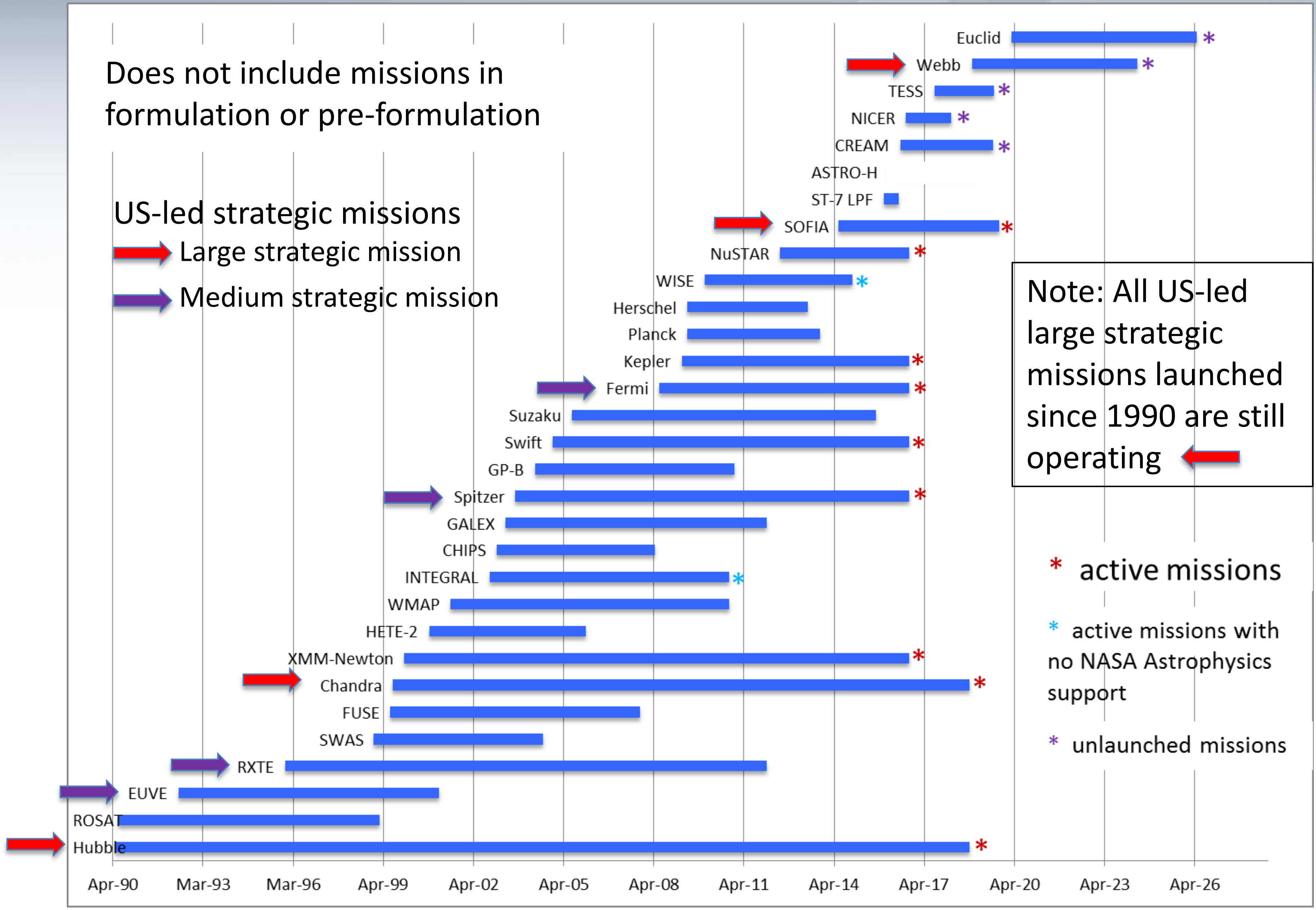
Astrophysics Budget by Function
FY05-FY14 Actual, FY15 Op Plan, FY16-FY20 Request
1,600
1,400
1,200
1,000
800
600
400
200
-
Real Year $Million
Infrastructure \ Management
R&A
Technology
Operating Missions
(including GO funding)
Explorers
Strategic Mission Development
(Fermi to FY08, Hubble to FY09, Kepler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

Fraction of budget on Large Observatories



Astrophysics Mission Timeline

Updated October 2015



Current Strategic Missions

NASA-led (launch year)	Development Cost Phases C-D ($M)	FY16 Operating Cost ($M)
Hubble Space Telescope (1990)	$1,526.2 M	$ 98.3 M
Chandra X-ray Observatory (1999)	$1,514.0 M	$ 59.8 M
Spitzer Space Telescope	$707.0 M	$ 15.2 M
Fermi Gamma-ray Space Telescope	$418.8 M	$ 15.9 M
SOFIA (2014)	$1,048.9 M	$ 83.6 M
James Webb Space Telescope (2018)	$6,188.8 M	N/A
WFIRST (mid-2020s)	$2,363.9 M	N/A
Not NASA-led (lead agency) (launch year)		
XMM-Newton (ESA) (1999)	$28.3 M	$ 2.9 M
LISA Pathfinder (ESA) (2016)	$82.8 M	$1.2 M
Euclid (ESA) (2020)	$117.7 M	N/A
X-ray Recovery Mission (JAXA)	Under discussion	N/A
Athena (ESA)	Under discussion	N/A
L3 Gravitational Wave Observatory (ESA)	Under discussion	N/A

Current Mission Sizes

- Small missions are PI-led, AO selected through the Astrophysics Explorers Program
  - Small Complete Missions of Opportunity (SCM MO): AO cost cap $75M
  - Small Explorers (SMEX): PI-managed cost cap $125M; LCC $250M
  - Medium Explorers (MIDEX): PI-managed cost cap $250M; LCC $400M

- Medium missions (also called Astrophysics Probes) are strategic missions recommended by the Decadal Survey
  - Total LCC between $400M and $1B

- Large missions are strategic missions recommended by the Decadal Survey
  - Total LCC in excess of $1B

- Contributions to non-NASA missions may either by PI-led, AO selected (Partner Missions of Opportunity) or may be strategic in origin.
  - Partner Missions of Opportunity (PMO): AO cost cap $75M
  - Strategic Contribution: Typically $100-300M

Committee Questions: Strategic Science

- Decadal survey science priorities require large missions. The following examples are from the 2010 Decadal Survey:
  - Dark energy
  - Exo-Earth characterization
  - Gravitational wave detection
  - Large area, high resolution X-ray spectroscopy

- Large missions have pros and cons
  - \+ Large missions accomplish science that cannot otherwise be done
  - \+ Large, general purpose observatories can be used by the general observer community in ways that were not envisioned by the designers nor captured in the science requirements
  - \+ Large missions drive development of new capabilities that can be infused later into smaller missions without further technical development
  - – Large mission costs must be carefully managed to preserve programmatic balance
  - – Large missions are too big to fail

Committee Questions: Capability and Leadership

- What concerns do you have about how long flagship missions take for development and the difficulty for young researchers or even potential future PIs to gain experience?
  - Flagship mission instruments are for the most experienced PIs
  - A balanced program provides opportunities for PI development through suborbital investigations, instruments, small missions
- What is the value of flagship missions for science base concerns? Talent pools, corporate knowledge, continuity of capabilities etc., and the impact on the future health of this support base?
  - It is conceivable that the science base could be maintained with a large fleet of small observatories, but it would not be paradigm shifting science
  - The US has unique capabilities for large mirror systems, low noise detectors, high contrast imaging, etc.
  - Many of these capabilities are unique to astrophysics; some have dual use
  - Without an ongoing program of missions that use these capabilities, the capabilities will be lost
- What is the role of international partnerships in strategic and flagship missions? How is this different for other classes of missions?
  - It is anticipated that all future large missions will be international in nature
  - That is not true for medium and small missions

Committee Questions: Technology Development

- Do you have a separate technology development line?
  - Astrophysics develops technology primarily through three mechanisms:
  - Astrophysics Research and Analysis (APRA) is a 100% technology R&A program. Approximately 50% of the funding goes toward low TRL work (TRL 1-3) in detectors and other technology areas, and the other 50% goes toward suborbital payloads that use balloons, sounding rockets, cubesats, and the ISS to take technologies to TRL 7/8/9.
  - Strategic Astrophysics Technology (SAT) is a combination of competed and directed technology efforts directed at developing the technologies needed for future strategic missions, usually identified in the Decadal Survey or Astrophysics Roadmap, through TRL 3-5/6.
  - Preformulation of large strategic missions includes focused technology development of any outstanding technology needs. For instance, WFIRST has been developing detector and coronagraph technology.
  - Relevant technology is also developed by NASA STMD and other Federal agencies.

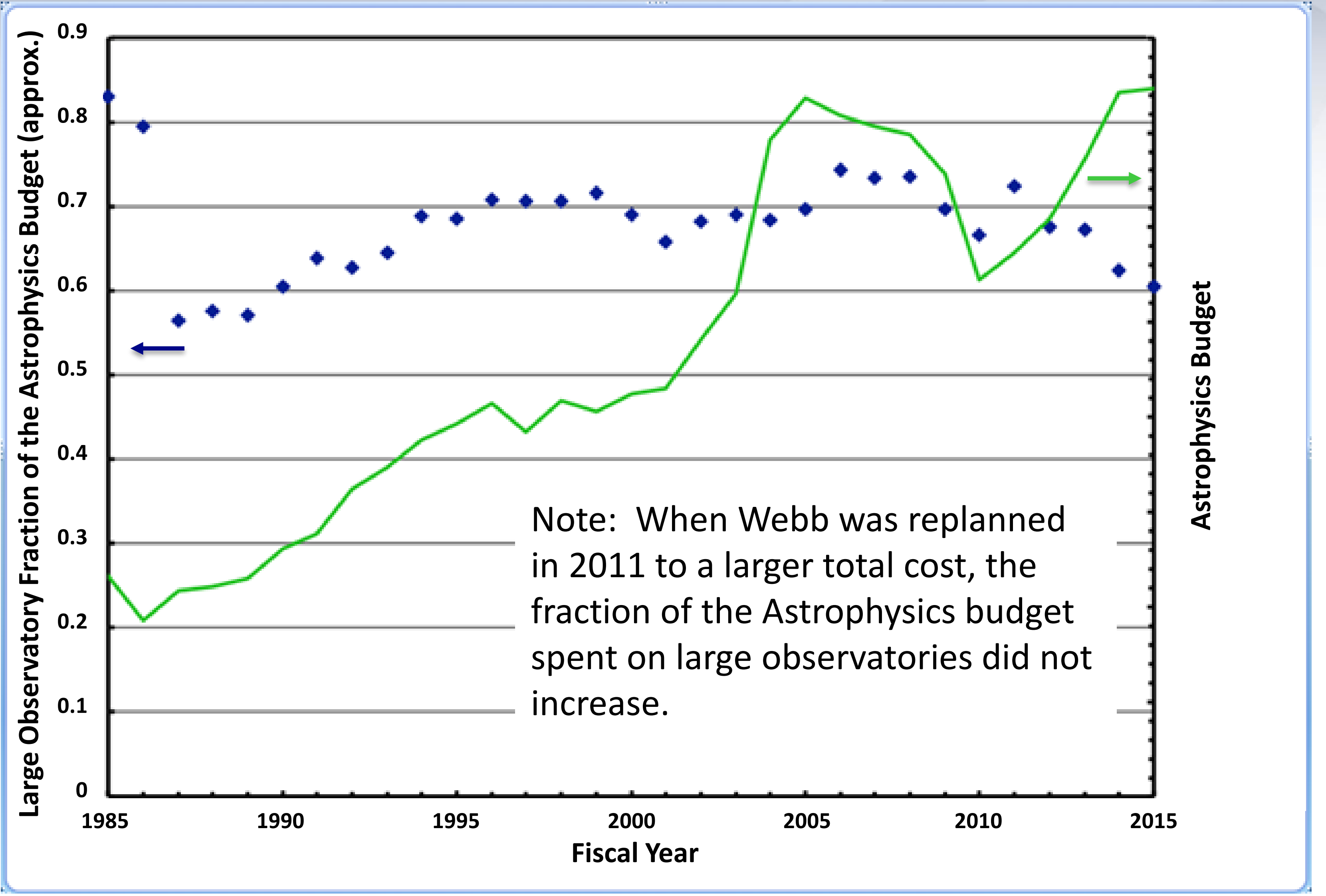
Committee Questions: Technology Development

- Do you primarily use flagship missions for technology development?
  - Not primarily. However mid-TRL technology development is always a part of preformulation for large strategic missions.
  - Large strategic missions that do not require technology development are generally less compelling.
- Can you afford the risk of including new technologies on flagship missions?
  - Yes but it must be appropriately funded, appropriately managed, and begun during preformulation.
- Can you do technology development with smaller size missions?
  - Yes but Explorers are by definition expected to be low risk and to apply already developed technology.
  - The technology for Explorers, as well as strategic missions, is developed in the APRA and SAT programs and generally tested on suborbital missions.
- Do you treat new technology at all differently on flagship missions vs. small missions (by, for example, incentivizing missions to use new technologies)?
  - Astrophysics has not yet chosen to incentivize PI-led Explorers to use new technologies. All the relevant technologies can be tested in the suborbital program before being infused into an Explorer.
  - Flagships are generally enabled through the application of new technology. Technology development is a necessary part of preformulation and is the objective of the SAT program.

Committee Questions: Cost Control for Large Missions

- How do cost overruns on flagship class missions affect the other mission classes in your portfolio?
  - Lessons learned from JWST:
    - Mature technology early
    - Properly scope the effort (descope early, assess requirements)
    - Budget adequate reserves year-by-year
    - Understand the budget impact of carrying risks and delays into the future
  - Program balance can be maintained (no impact to other mission classes) by extending development period without increasing annual budget. Impact is delay to start of next large strategic mission.
  - Lowest cost impact is to solve overruns when they happen, but this necessarily has a current impact on other mission classes, so not always chosen.
- How do you address cost overruns on flagship missions vs. how you address cost overruns on smaller class missions?
  - Large strategic missions are probably too important scientifically to cancel when they overrun. Overruns must be handled through descopes and replanning.
  - PI-led Explorers are cost capped, and they should be terminated if they overrun significantly before confirmation. The ability to stay within the cost cap is a feature of the mission class and also a factor in the selection.

Fraction of budget on Large Observatories




Formulation
Implementation
Primary Ops
Extended Ops
Spitzer
8/25/2003
Kepler
3/7/2009
LISA Pathfinder (ESA)
12/3/2015
Webb
2018
WFIRST
Mid 2020s
Euclid (ESA)
2020
Chandra
7/23/1999
XMM-Newton (ESA)
12/10/1999
TESS
2017
Swift
11/20/2004
NuSTAR
6/13/2012
Fermi
6/11/2008
Hubble
4/24/1990
ISS-CREAM
2017
ISS-NICER
2017
SOFIA
Full Ops 5/2014