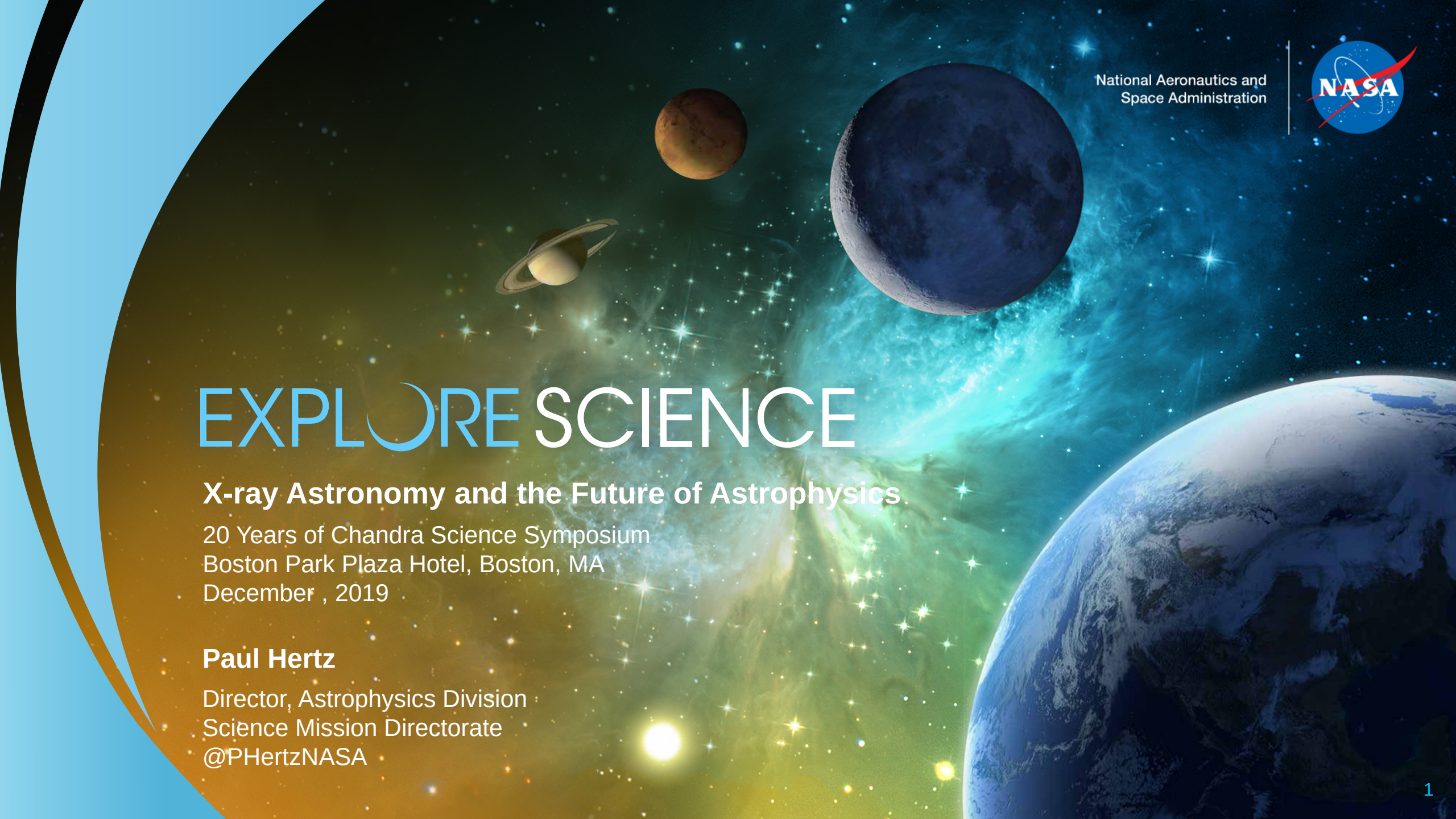


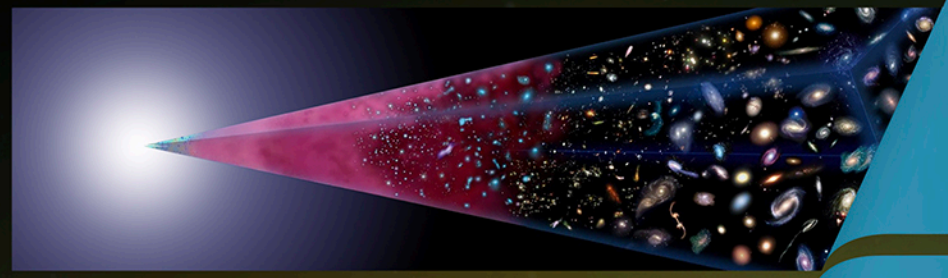
X-ray Astronomy and the Future of Astrophysics

20 Years of Chandra Science Symposium
Boston Park Plaza Hotel, Boston, MA
December , 2019

Paul Hertz

Director, Astrophysics Division
Science Mission Directorate
@PHertzNASA

Why Astrophysics?

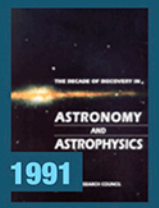


How did our universe begin and evolve?

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

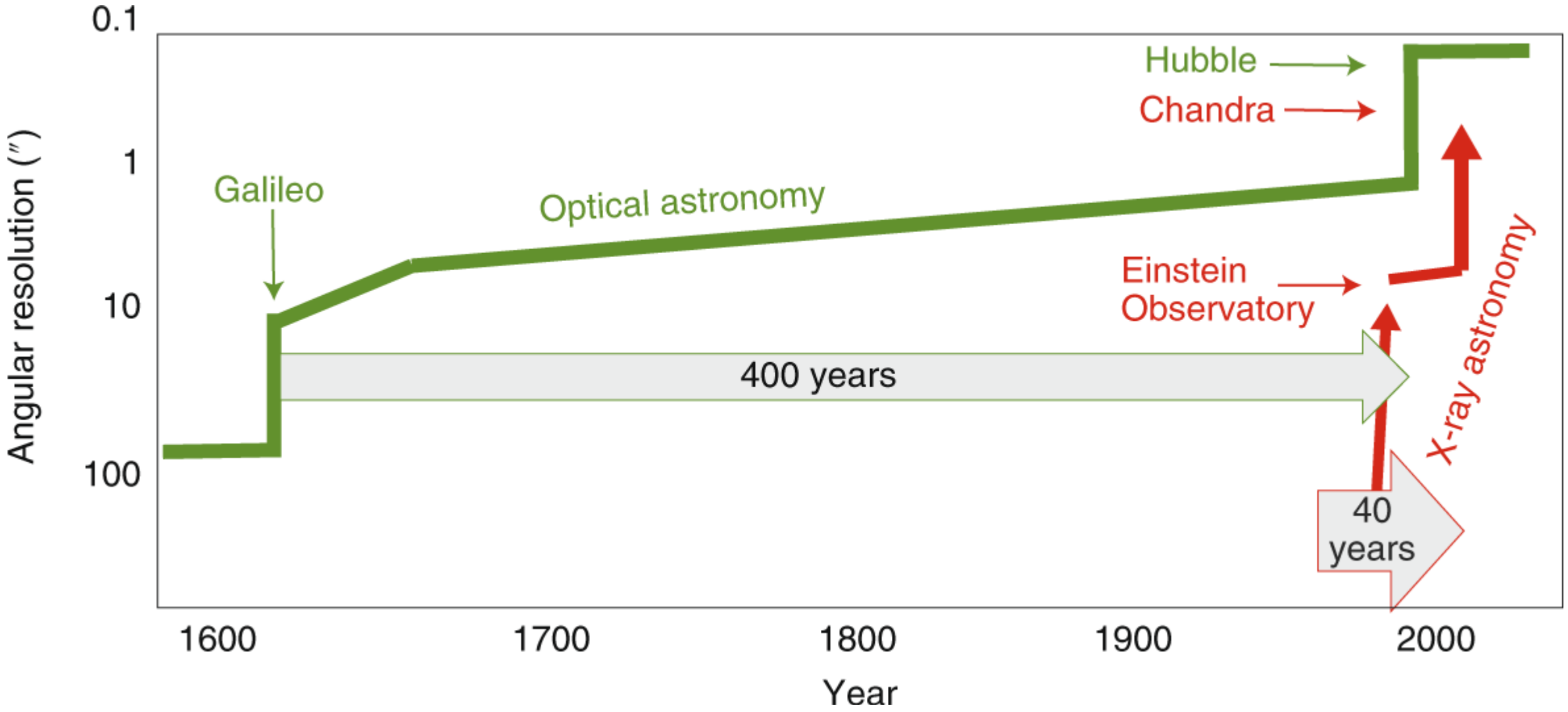
Are we alone?

Enduring National Strategic Drivers

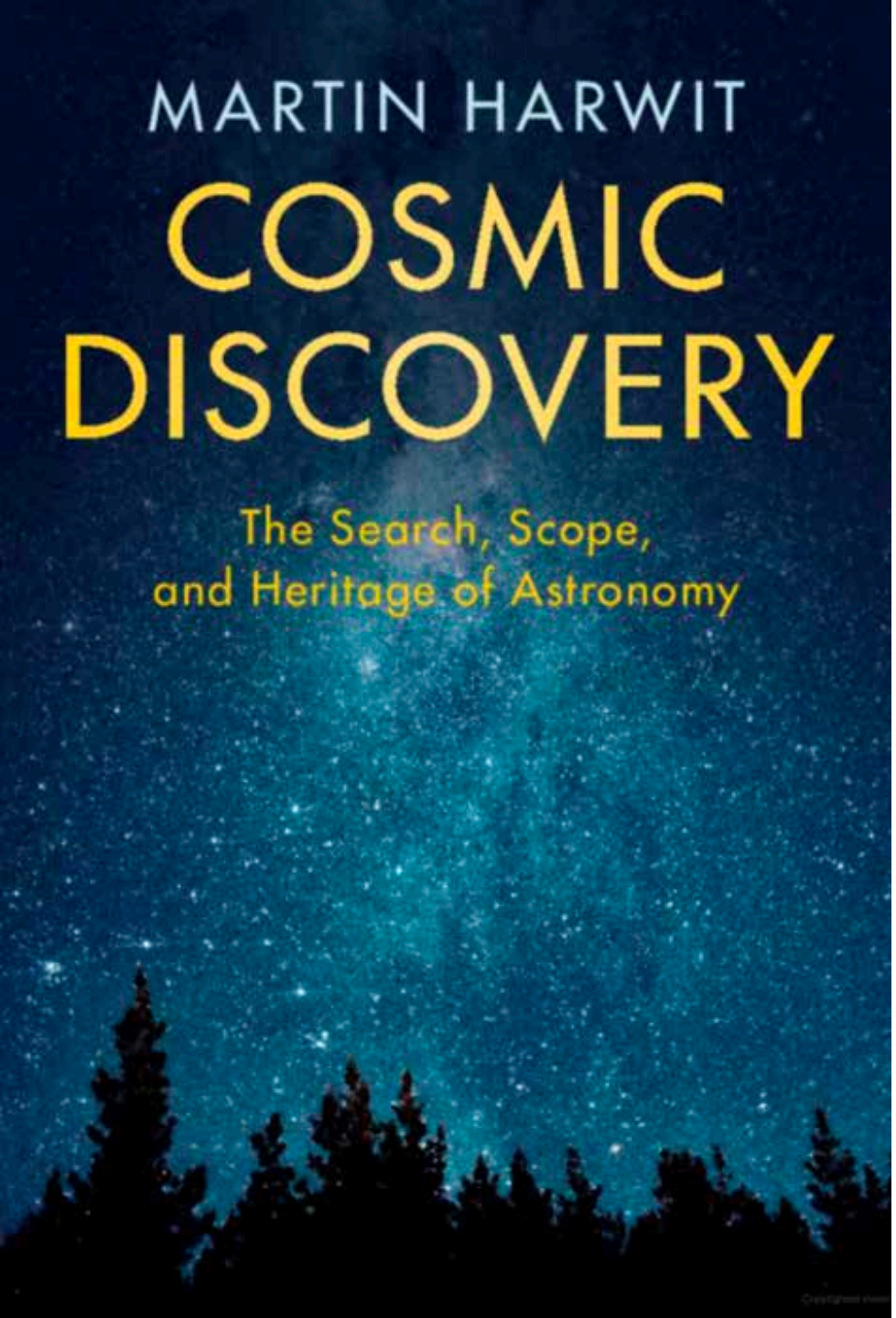


Astrophysics is humankind's scientific endeavor to understand the universe and our place in it.

X-ray Astronomy is young



M. Elvis, X-ray astronomy in 2019. *Nat Astron* (2019)



Cosmic Discovery by Martin Harwit (1981)

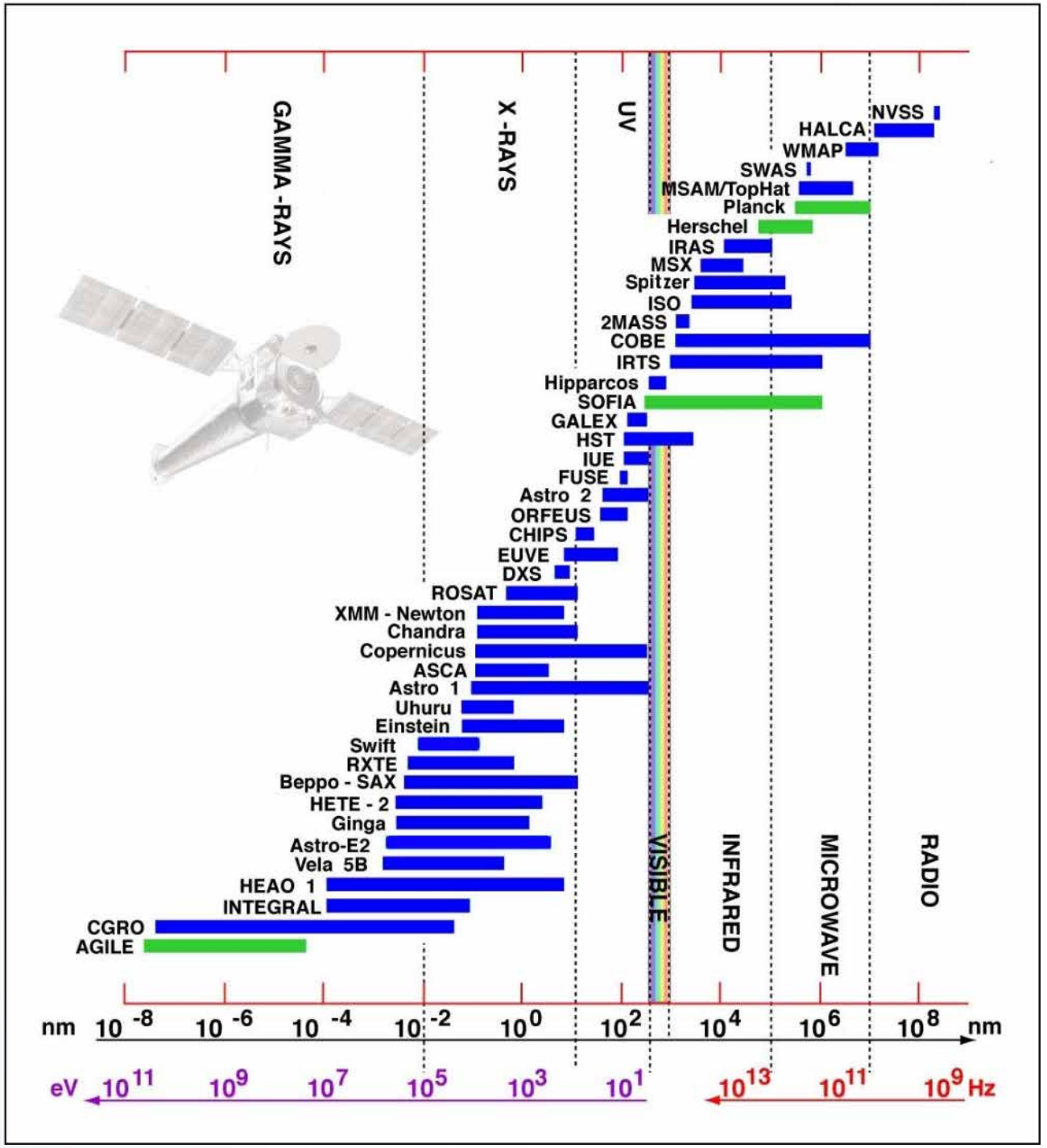
"When I wrote Cosmic Discovery, I wanted to dispel two mystiques. The first was that advances in astrophysics came about as a result of theoretical insight; the second was that further advances would require the building of ever-larger optical telescopes.

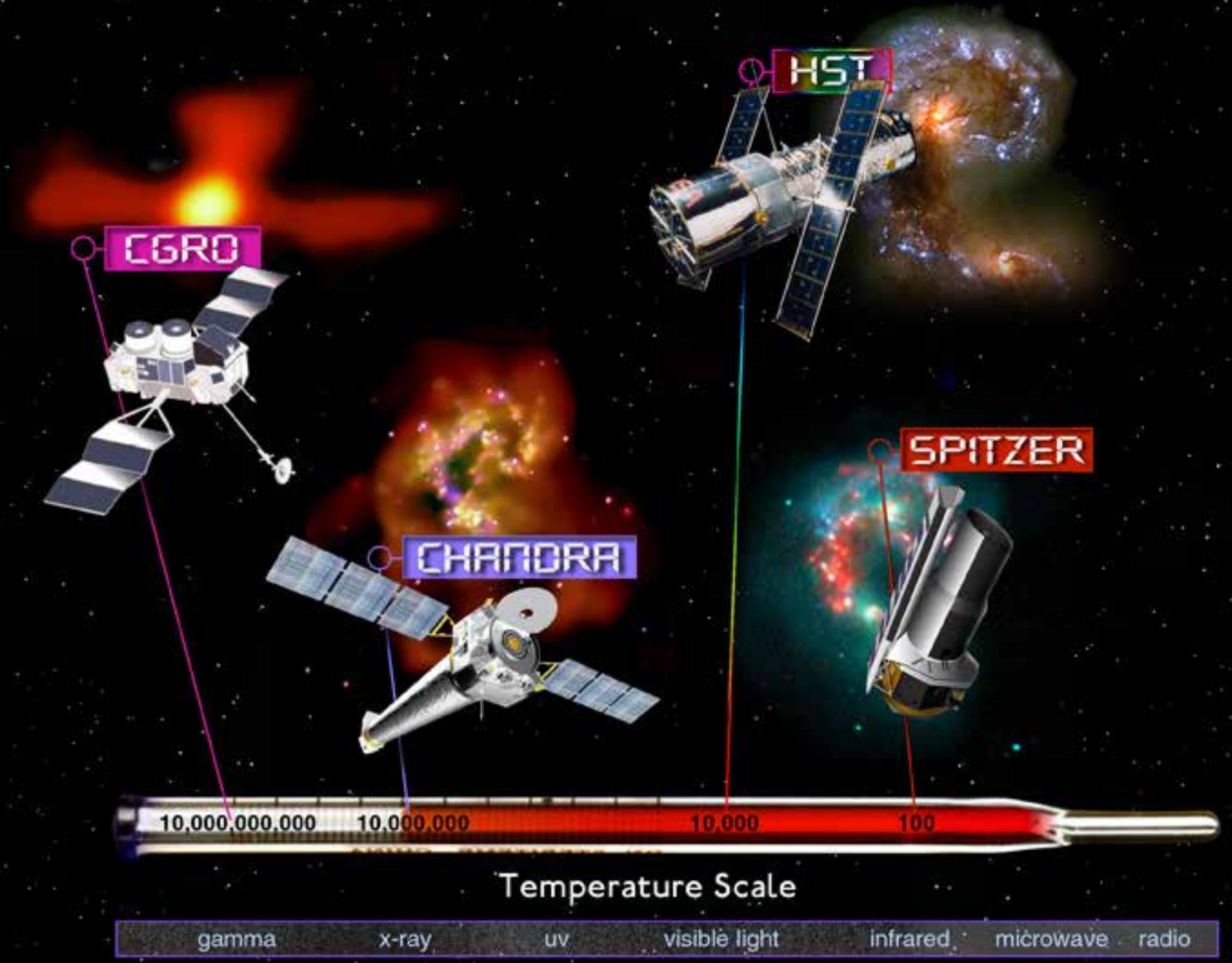
The only way I could show that neither was relevant was to document the [often] surprising discoveries brought about by small radio, infrared, x-ray, and gamma-ray telescopes.

Neither theory nor large optical telescopes had delivered anything like these novel technologies."

- Physics Today, Q&A with Martin Harwit, 10 October 2014

NASA has always been multiwavelength




HST
CGRO
CHANDRA
SPITZER
10,000,000,000
10,000,000
10,000
100
Temperature Scale
gamma
x-ray
uv
visible light
infrared
microwave
radio

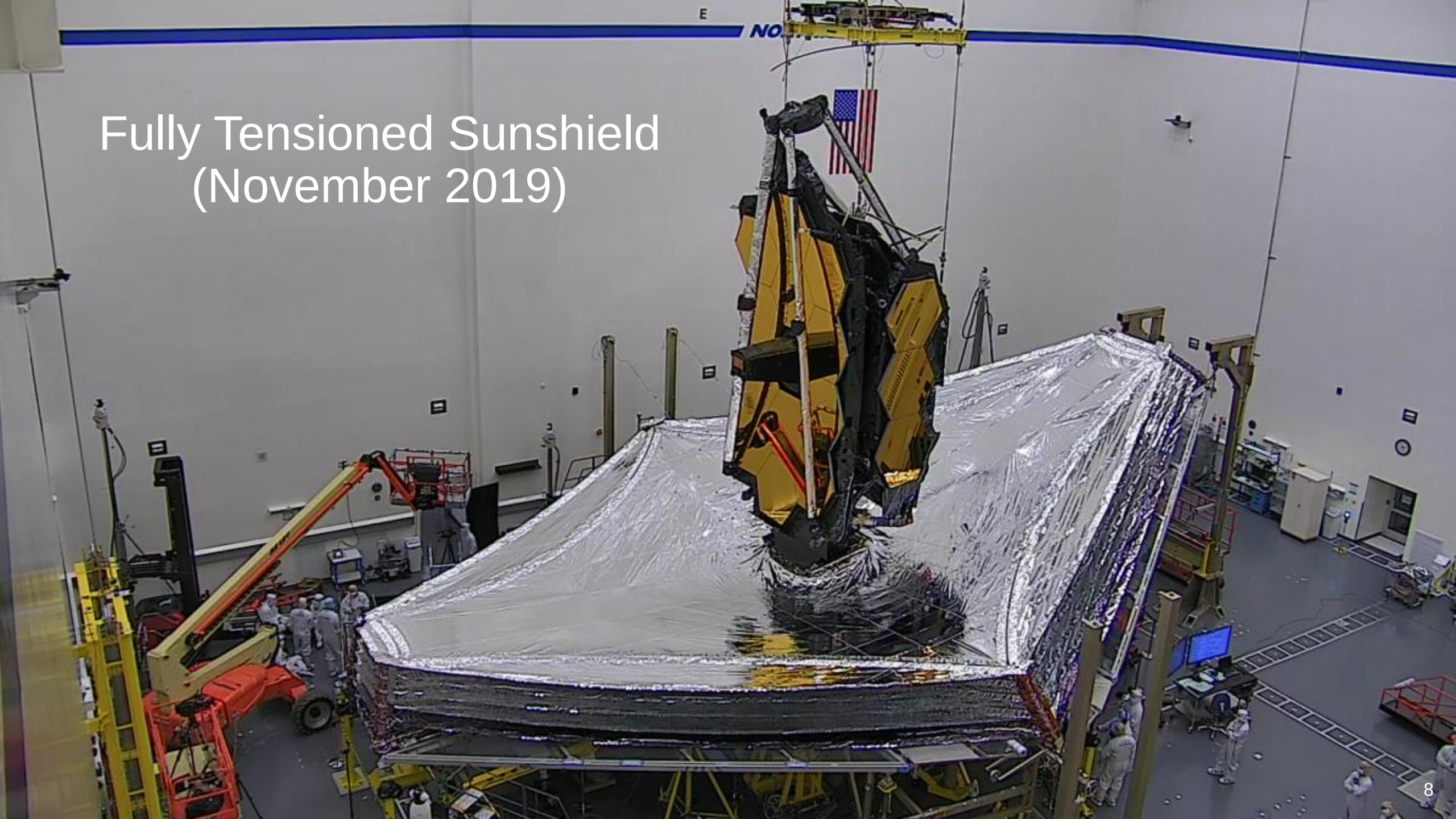
The Webb observatory in the clean room in Redondo Beach, CA before observatory environmental testing and observatory deployment tests

Webb

The James Webb Space Telescope

- Science payload completed three months cryogenic testing at end of 2017
- Spacecraft and sunshield integration completed January 2018
- Spacecraft element including sunshield completed environmental testing May 2019
- Science payload and spacecraft integration completed August 2019, to be 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

Fully Tensioned Sunshield (November 2019)



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 – Completed 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

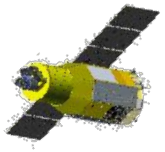
The High Energy Observatories

Chandra
7/23/1999

XMM-Newton (ESA)
12/10/1999

SXG (RSA)
7/13/2019

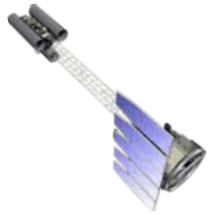
Athena (ESA)
2031



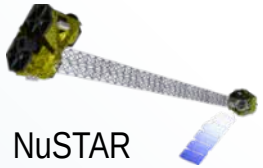
XRISM (JAXA)
2022

Fermi
6/11/2008

Swift
11/20/2004



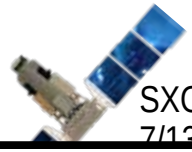
IXPE
2021



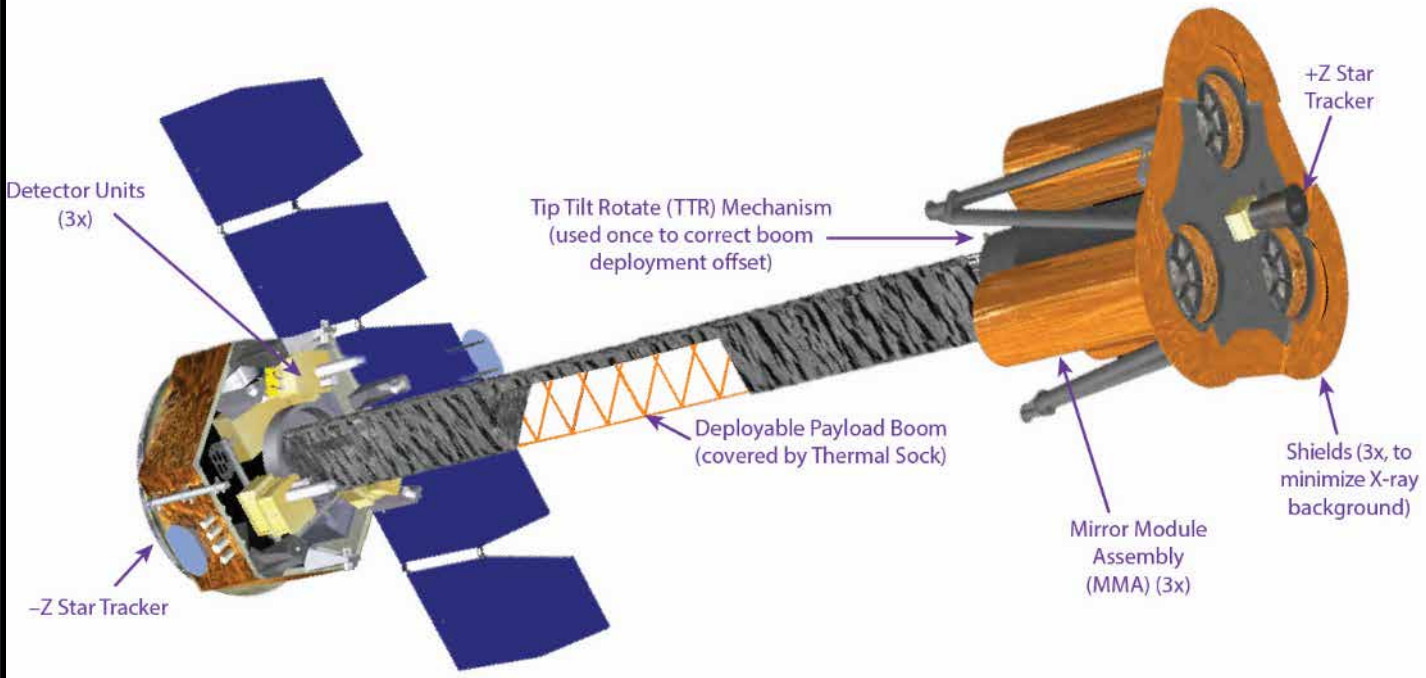
NuSTAR
6/13/2012

ISS-NICER
6/3/2017

The High Energy Observatories



SXG (RSA)
7/13/2019



Imaging X-ray Polarimetry Explorer (IXPE)

- PI: Martin Weisskopf (MSFC)
- Key partner: Italian Space Agency (ASI)
- Currently in Phase C, Launch planned for 2021

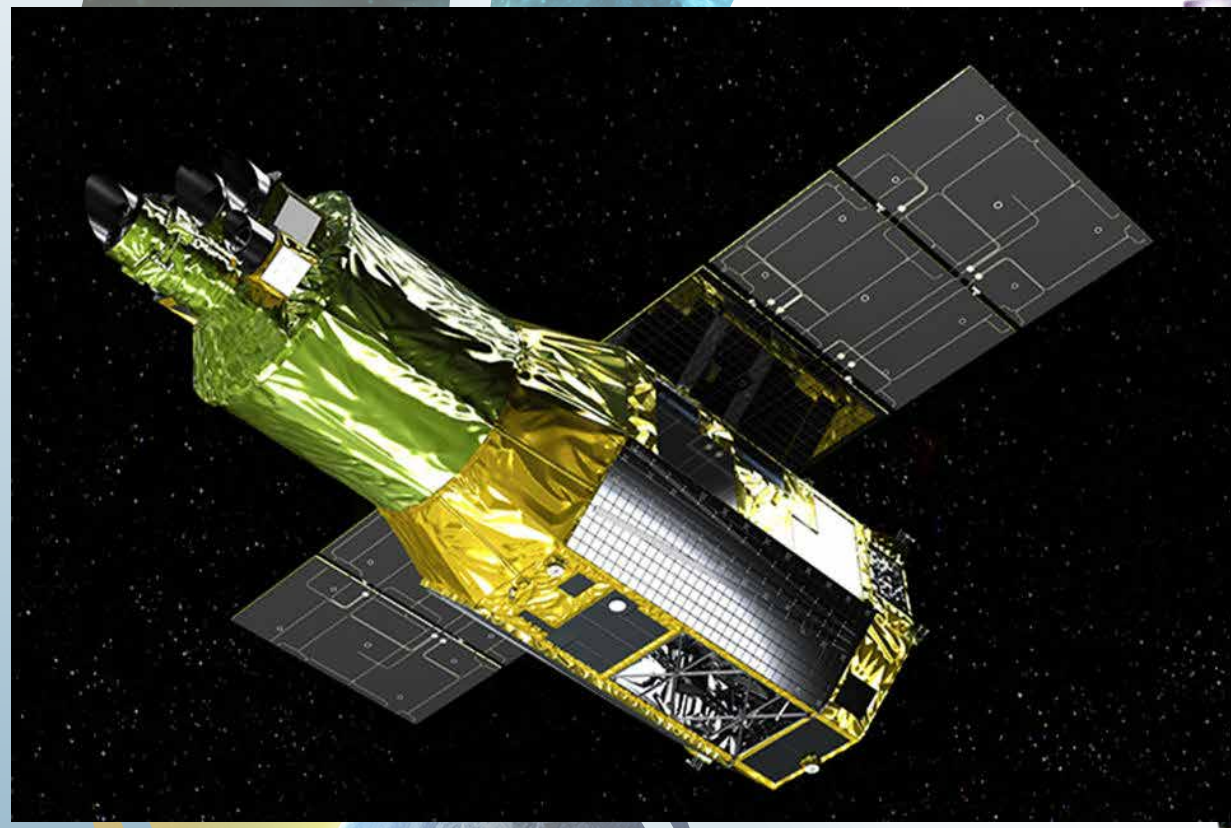
Opens a new window on the universe — imaging (30“) X-ray polarimetry

- Simultaneously provides imaging, spectral, timing, and polarization data
- Is free of false-polarization systematic effects at less than a fraction of a percent
- Enables meaningful polarization measurements for many sources of different classes

NuSTAR
6/13/2012

ISS-NICER
6/3/2017

The High Energy Observatories



X-ray Imaging and Spectroscopy Mission (XRISM)

- Japanese Space Agency (JAXA) Strategic Mission
- JAXA PI: Makato Tashiro (ISAS), NASA PI: Richard Kelley (GSFC)
- NASA providing key elements of Resolve Spectrometer and X-ray mirror assemblies
- NASA project currently in Phase D, Launch planned for 2022

The XRISM payload consists of two instruments:

- Resolve, a soft X-ray spectrometer that combines an X-Ray Mirror Assembly paired with an X-ray calorimeter spectrometer, provides non-dispersive 5-7 eV energy resolution in the 0.3-12 keV bandpass with a field of view of about 3 arcmin.
- Xtend, a soft X-ray imager that extends the observatory FOV to 38 arcmin over the energy range 0.4-13 keV, using a CCD detector and an identical X-Ray Mirror Assembly.

NuSTAR
6/13/2012

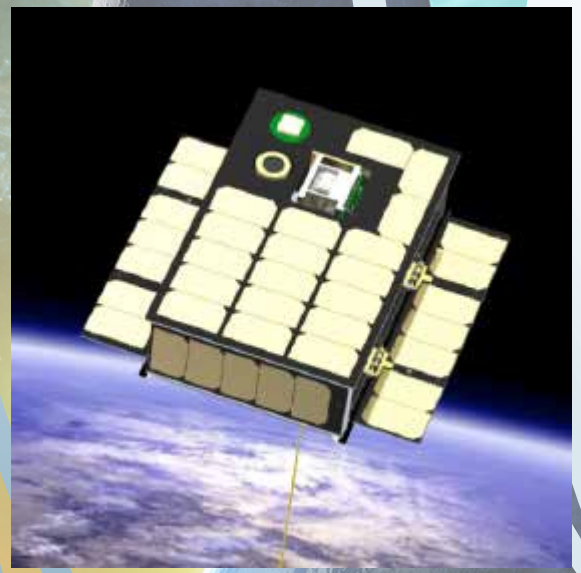
ISS-NICER
6/3/2017

XRISM/Resolve CSI - Dewar Integration • 2019 Nov 25 • Niihama, Japan

NASA

Sumitomo Heavy Industries, Ltd.

JAXA
Japan Aerospace Exploration Agency



Investing in the Future

NASA is making significant investments through its research and technology programs in the future of X-ray astronomy

5 of our 15 active sounding rocket experiments are X-ray investigations to test new technologies (e.g., microcalorimeters, hybrid CMOS detectors, light-weight optics, grating spectrometers).

3 of the 6 selected Astrophysics CubeSats have X-ray detectors (HaloSat/Kaaret/U Iowa, BurstCube/Perkins/Goddard, BlackCat/Falcone/PennState)

5 of the 9 SmallSat concept studies selected in 2018 are high energy missions addressing topics like ISM line emission, gamma-ray imaging, GW follow-up, ablation of exoplanet atmospheres, transient monitoring

Swarms of CubeSats and SmallSats have great science potential to address both strategic and focused science goals

Astrophysics Technology Program Elements

Technology Inception & Experimentation APRA/RTF

- *46 projects awarded in 2019*
- *Solicitations planned in FY20, delayed 9 months*
- *Average award: $600K (3-5 years)*
- *Average selection rate: 28%*
- *Portfolio:*
  - *Supporting 19 Balloons and 10 Sounding Rockets Payloads*
  - *Detectors across wavelengths*
  - *Mirrors, coatings and gratings*

Technology Maturation SAT & ISFM

Unified solicitation and selection starting in FY19 for the three Astrophysics themes. Portfolio has 49 active projects for $25M per year.

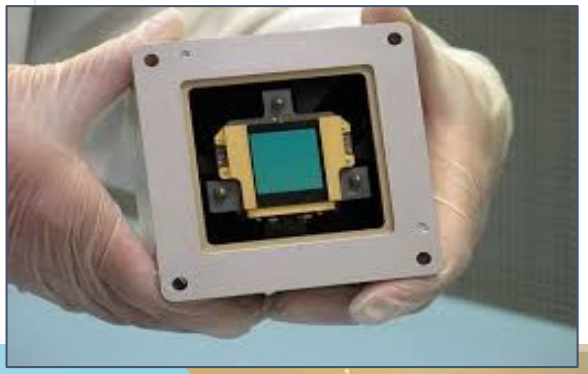
- *12 new projects awarded in FY19*
- *Next solicitation planned in FY20, currently TBD*
- *Average award: $1.6M (3 years)*
- *Average selection rate: 30%*

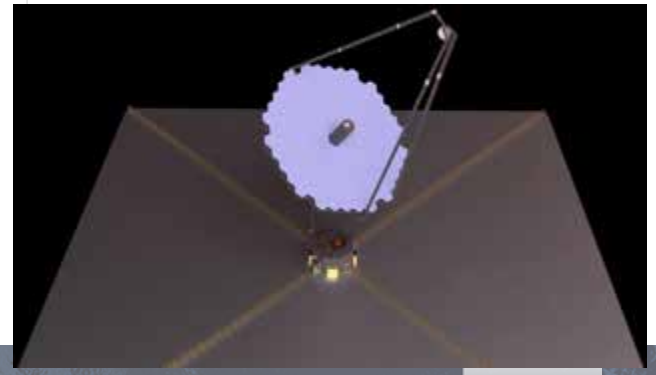
Directed Technologies

- *WFIRST Coronagraph*
- *Exoplanets Probes: Exo-C & Exo-S*
- *LISA*
- *Athena*
- *Euclid*
- *NN-Explore – NEID*
- *SmallSats and CubeSats*

Decadal Survey Initiatives

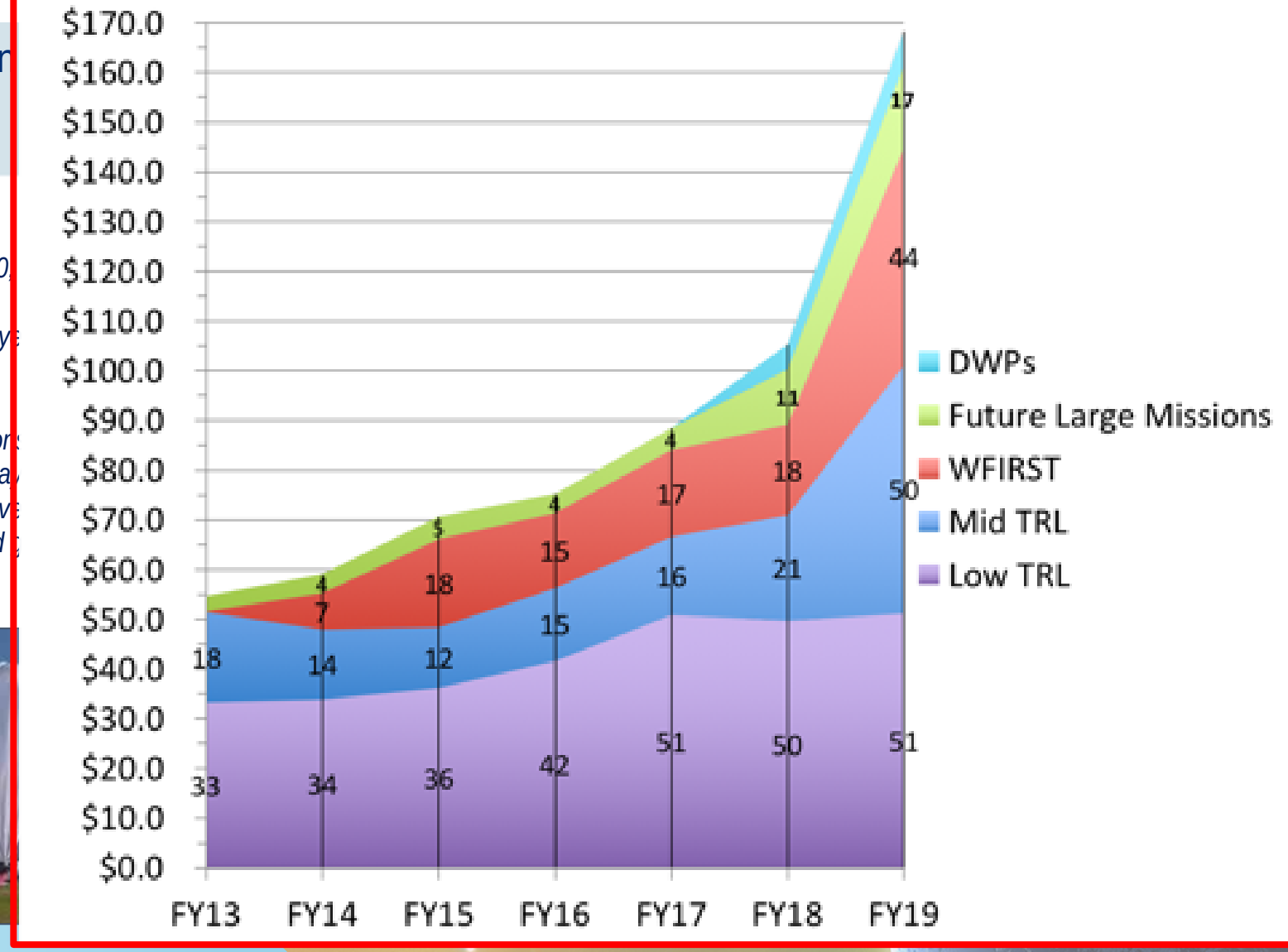
- *In-Space Assembled Telescope (iSAT)*
- *Coronagraph and UltraStable Testbeds*
- *Starshade Technology*
- *Four Large Mission Concepts – Technology Roadmaps*
- *Ten Probe Mission Concepts*
- *Segmented Mirror Telescope Program (STMP)*





Astroph

Astrophysics Technology Funding FY13-FY19



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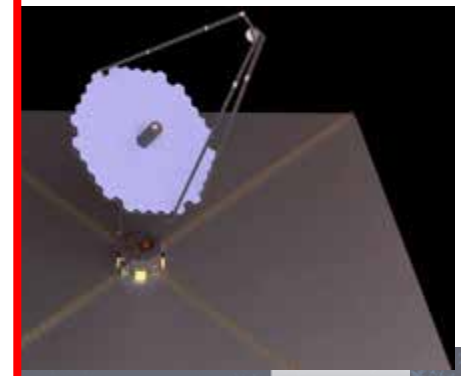
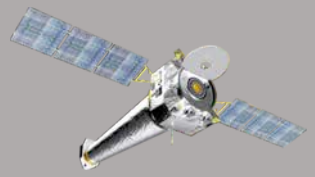
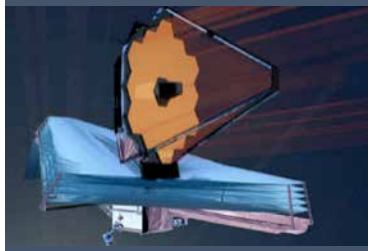
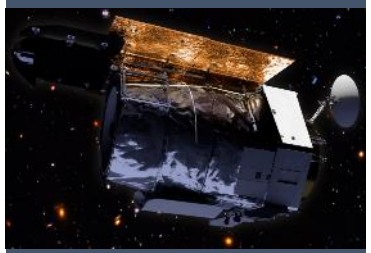


Why Flagships

Flagships drive science

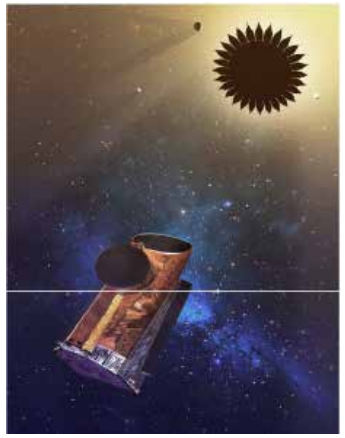
Flagships drive US capabilities and contribute to US leadership

Flagships create stakeholder support and drive the NASA budget

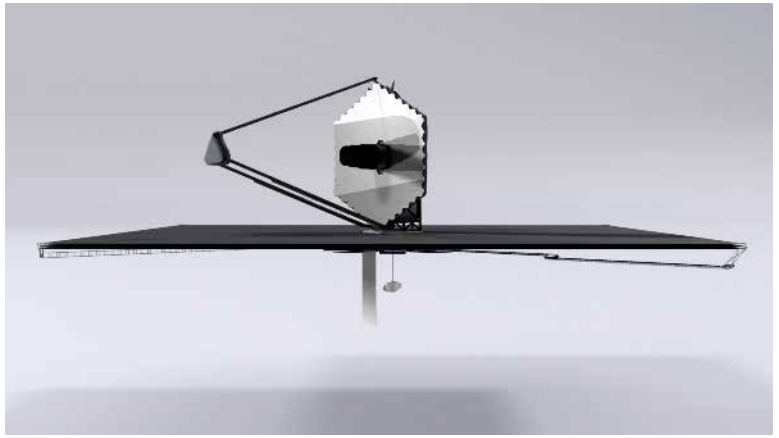
Hubble 04/90 NASA Great Observatory	Compton 05/91 NASA Great Observatory	Chandra 09/99 NASA Great Observatory	Spitzer 8/03 NASA Great Observatory	Webb 2021 NASA Mission	WFIRST Mid 2020s NASA Mission
					
Hubble Space Telescope	Compton Gamma Ray Observatory	Chandra X-ray Observatory	Spitzer Space Telescope	James Webb Space Telescope	Wide Field Infrared Survey Telescope

Large Mission Concepts

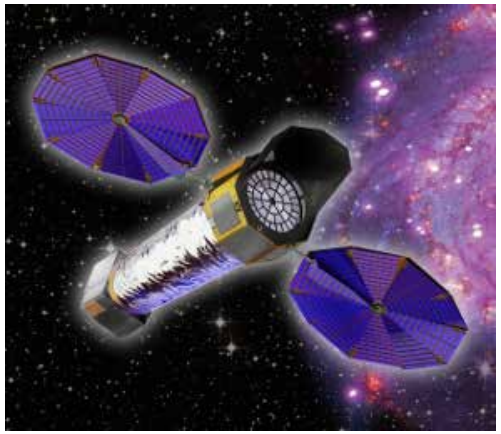
"NASA should ensure that robust mission studies that allow for trade-offs (including science, risk, cost, performance, and schedule) on potential large strategic missions are conducted prior to the start of a decadal survey. These trade-offs should inform, but not limit, what the decadal surveys can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



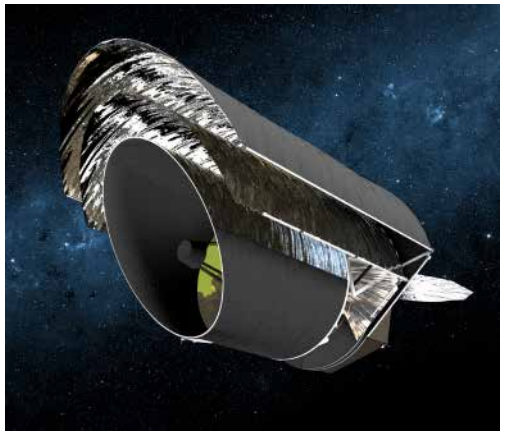
HabEx



LUVOIR

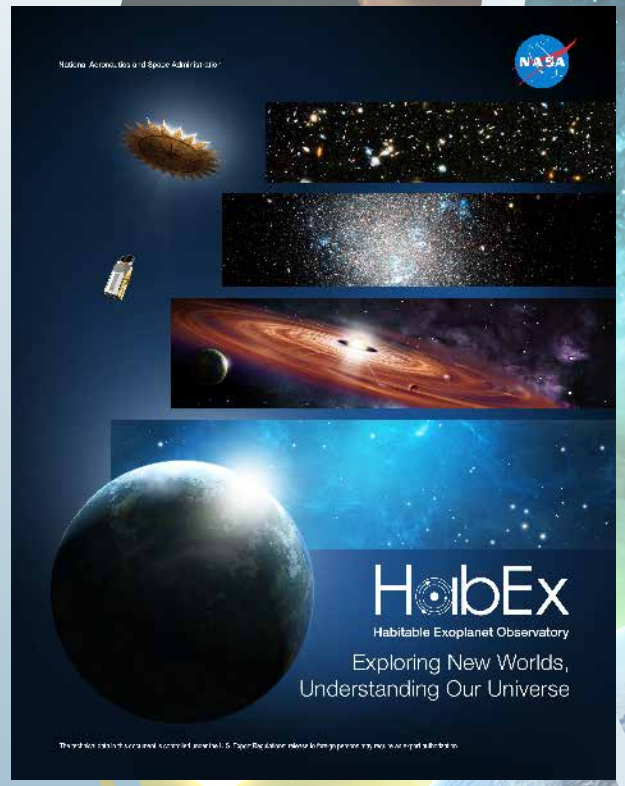


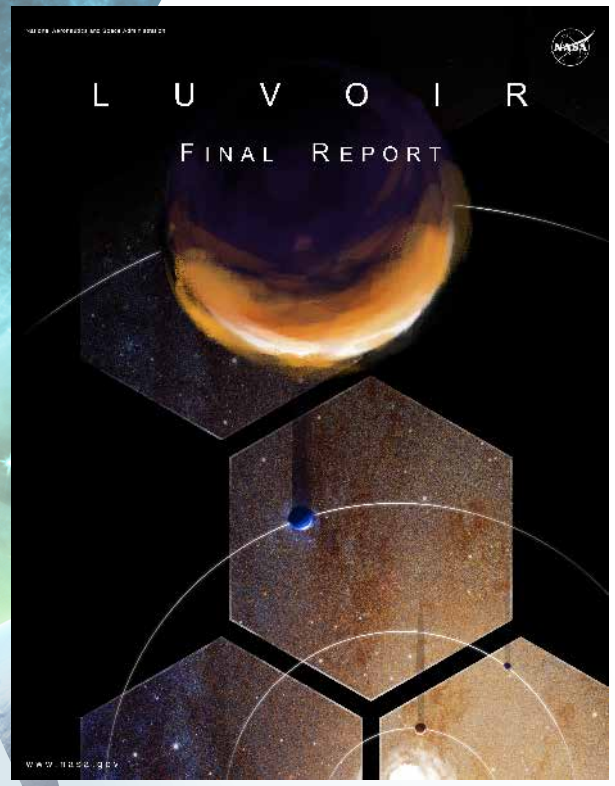
Lynx

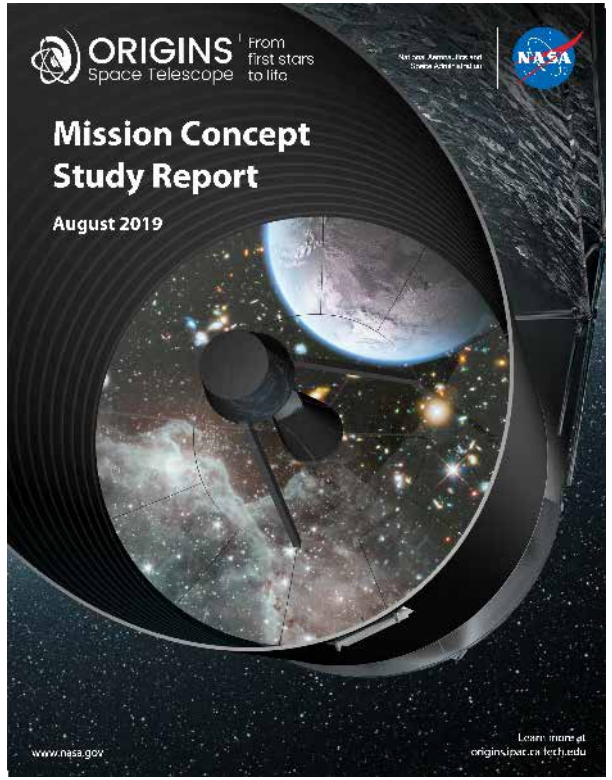


Origins

Large Mission Studies

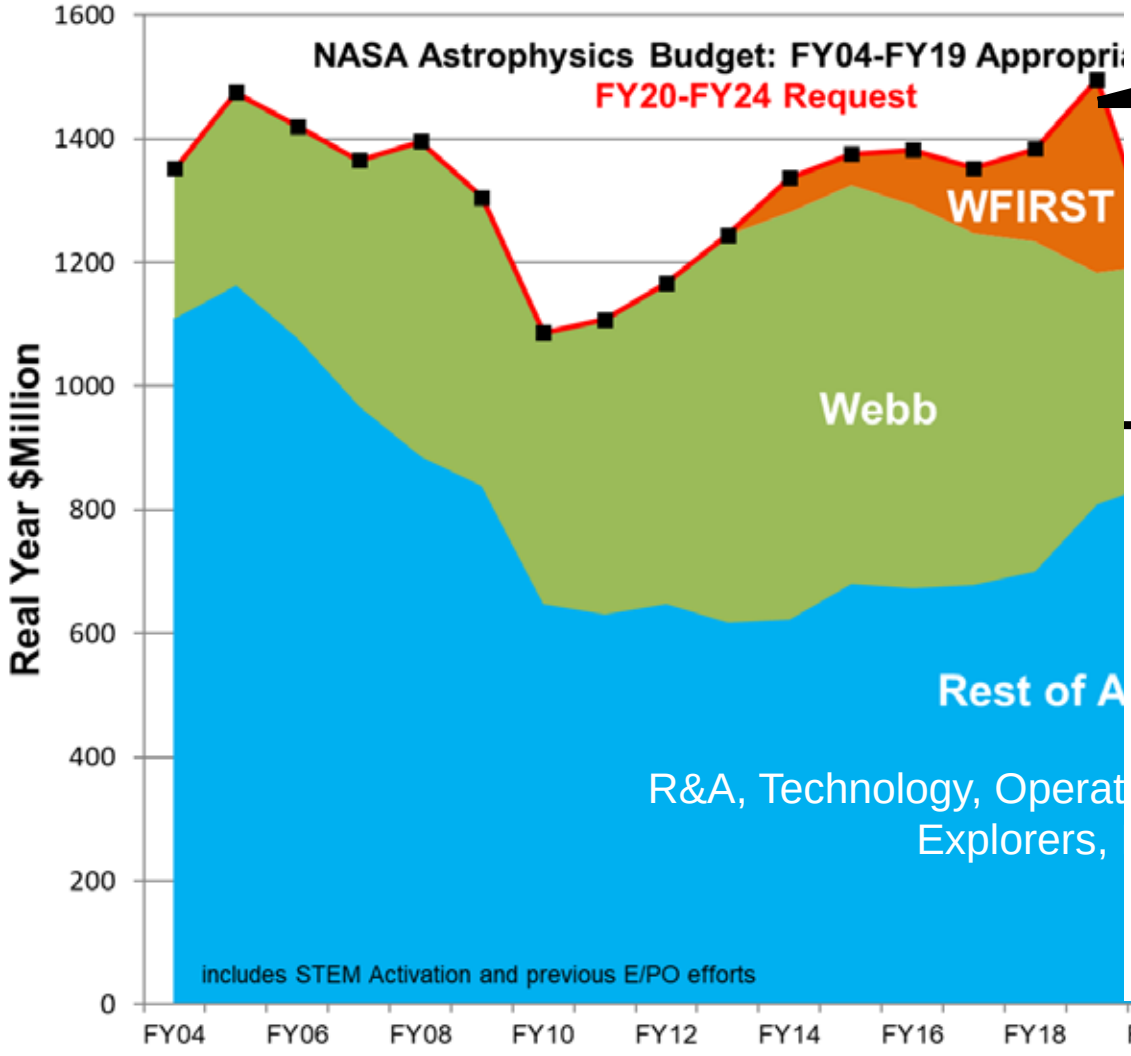


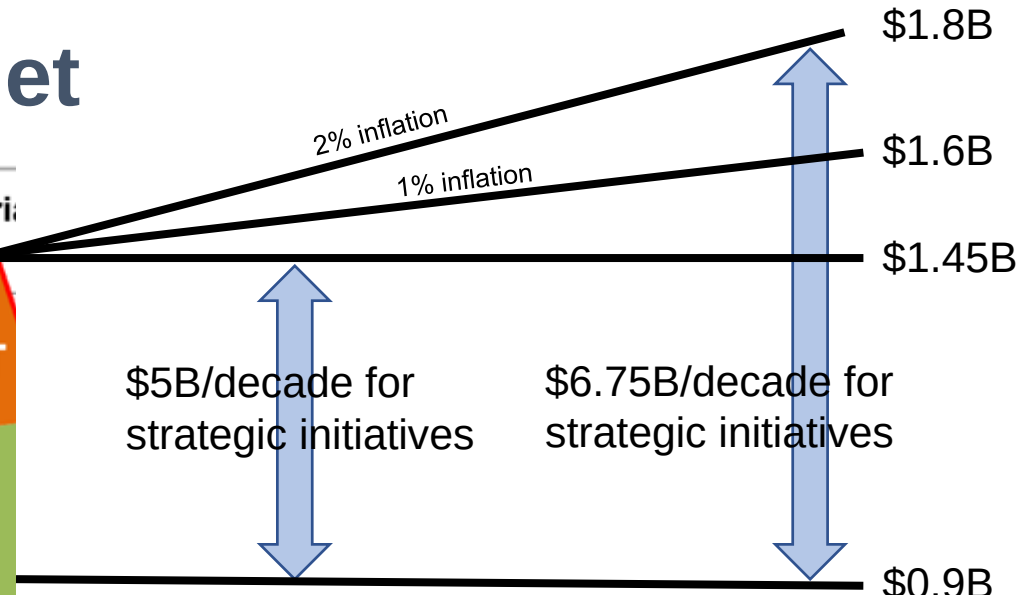




Links to the concept study reports are posted at
https://science.nasa.gov/astrophysics/2020-decadal-survey-planning
and at
https://www.greatobservatories.org/

NASA Astrophysics Budget





Current program including Webb operations and 4 Explorers/decade

The Future

This is an exciting time for Astrophysics – we are pursing the answers to the biggest questions

- How did the universe begin and evolve?
- How did galaxies, stars, and planets come to be?
- Are we alone?

Astrophysics is multiwavelength and multimessnger

- NASA has 11 operating astrophysics missions*
- NASA is developing 12 astrophysics missions*
- At least 10 (of 23) missions are high energy astrophysics missions

The community will select NASA's future observatories through the 2020 Decadal Survey and through peer review of competed missions

NASA is ready to realize the community's priorities

* includes partner-led missions

Carpe Posterum

+ SMEX/MO (2025), MIDEX/MO (2028), etc.

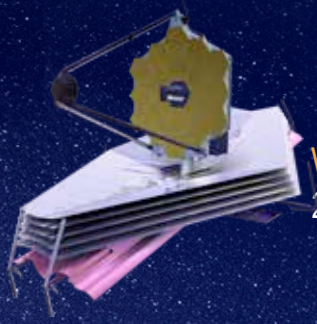
Formulation
Implementation
Primary Ops
Extended Ops


Spitzer
8/25/2003


WFIRST
Mid 2020s

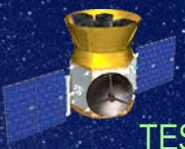

Euclid (ESA)
2022


SXG (RSA)
7/13/2019


Webb
2021


Ariel (ESA)
2028

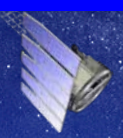

Chandra
7/23/1999

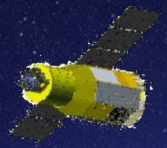

TESS
4/18/2018


Swift
11/20/2004

6/13/2012


Fermi
6/11/2008


IXPE
2021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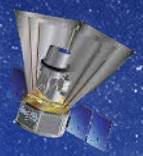
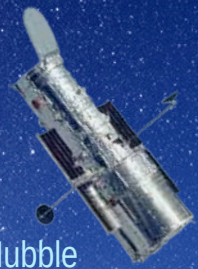
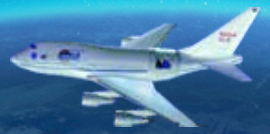
2022


SPHEREx
2023


Hubble
4/24/1990


ISS-NICER
6/3/2017


GUSTO
2021


SOFIA
Full Ops 5/2014

+ Athena (early 2030s), LISA (early 2030s)

Revised November 24, 2019