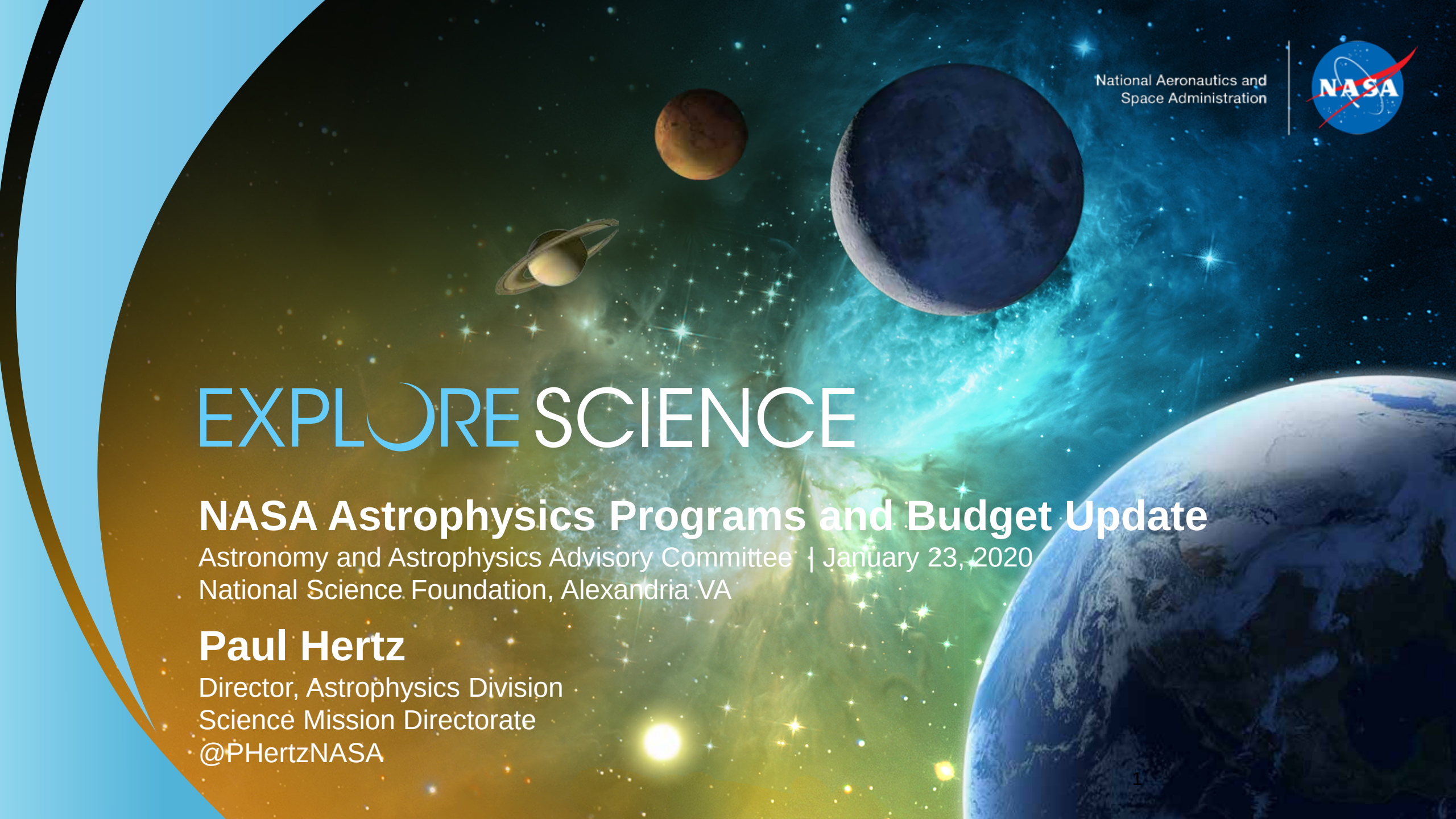


NASA Astrophysics Programs and Budget Update

Astronomy and Astrophysics Advisory Committee | January 23, 2020
National Science Foundation, Alexandria VA

Paul Hertz
Director, Astrophysics Division
Science Mission Directorate
@PHertzNASA

NASA Astrophysics Celebrate Accomplishments

https://www.nasa.gov/content/hubbles-30th-anniversary

After 16.5 yrs of science exploration on the infrared cosmic frontier as one of NASA's Great Observatories, Spitzer will end its mission on Jan 30, 2020, 2:30 PST.

Engineering feats extended mission life post- cryo in 2009 and overcame challenges due to Spitzer's increasing distance from Earth.

Spitzer Space Telescope

Spitzer enabled discovery near and far, to the edge of the universe, yielding 8,700+ refereed papers.

- First detection of light from an exoplanet
- First detection of molecules in exoplanet atmospheres
- Measurement of star formation history of the Universe to z>2, looking back >10 Gyr
- Measurement of the stellar mass of the Universe to z>8, looking back ~13 Gyr

www.spitzer.caltech.edu/final-voyage

Celebrating the Legacy of the Spitzer Space Telescope

- Hosted by the California Institute of Technology and sponsored by Ball Aerospace
- 11-13 February 2020

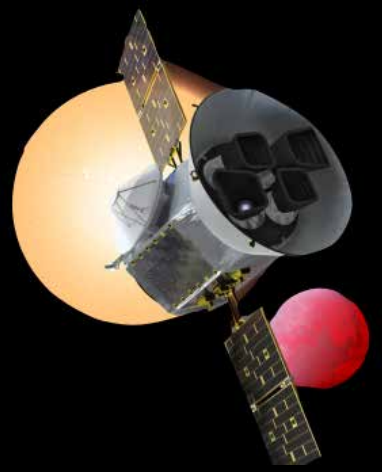
https://conference.ipac.caltech.edu/legacyofspitzer/

TESS Completes First Year of Prime Mission, Begins Year 2

1414 planet candidates
  34 confirmed planets
  + many discoveries in astrophysics
36 peer-reviewed publications
  +51 more submitted

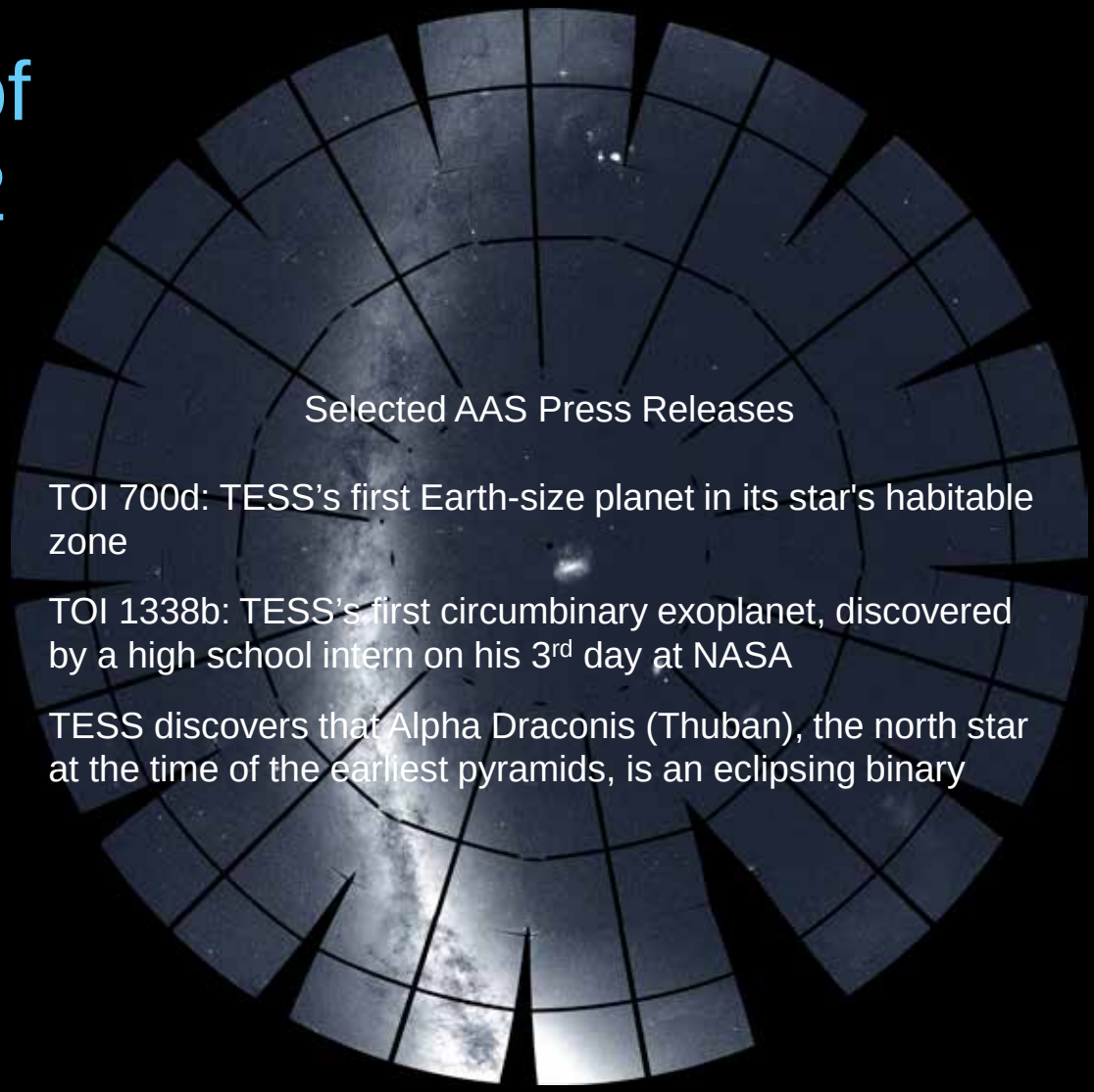
Successful Guest Investigators Program
Cycles 1 and 2 for Prime Mission

Extended mission approved!
Cycle 3 proposal deadline 1/16/2020



https://heasarc.gsfc.nasa.gov/docs/tess/

https://tess.mit.edu/



Selected AAS Press Releases

TOI 700d: TESS's first Earth-size planet in its star's habitable zone

TOI 1338b: TESS's first circumbinary exoplanet, discovered by a high school intern on his 3rd day at NASA

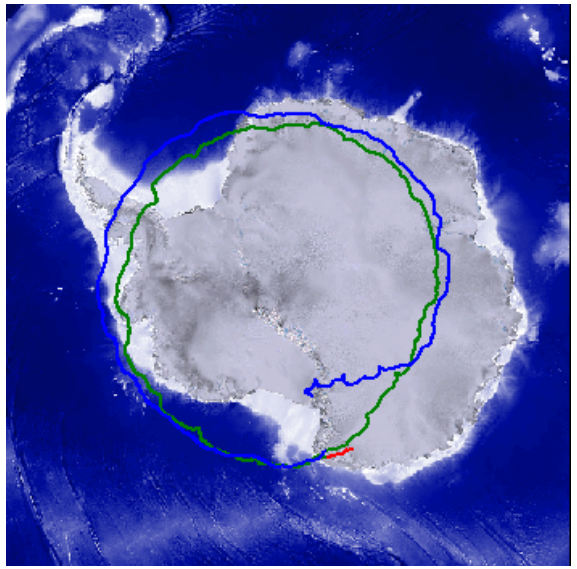
TESS discovers that Alpha Draconis (Thuban), the north star at the time of the earliest pyramids, is an eclipsing binary

TESS observed southern hemisphere in Yr 1
Currently observing northern hemisphere for Yr 2
Current Sector: 20 of 26 in Prime Mission
Data from Sectors 1-16 all publicly available at MAST

2019-2020 Antarctic Balloon Campaign

The Super Trans-Iron Galactic Element Recorder (SuperTIGER) instrument is used to study the origin of cosmic rays and was launched on Dec. 15, 2019. (Photo courtesy SuperTIGER team)

(Video courtesy SuperTIGER team)



Total Float Time
32 Days 11 hours 4 minutes

- **Upcoming balloon campaigns**: Winter 2019-2020 Antarctica, Spring 2020 New Zealand, Summer 2020 Palestine TX, Fall 2020 Fort Sumter NM, Winter 2020-2021 Antarctica

- **Upcoming sounding rocket campaigns**: 2020 White Sands Missile Range NM, 2021 Australia

https://www.csbf.nasa.gov/antarctica/ice.htm

Roman Technology Fellowship Program

- 19 current and recent fellows
- Typically in academia and National Laboratories
- Budget stable at about $1.3 M per year
- $300 K in startup funds for each fellow, over 3 years

Dr. Nancy Grace Roman
1925-2018

RTF fellows at the RTF Special Session held at the AAS meeting in June 2018: From the left: Erika Hamden (Caltech/U. Arizona), Cullen Blake (U. Pennsylvania), Brian Fleming (U. Colorado), and Abigail Vieregg (U. Chicago)

2019 Roman Technology Fellows selected in November 2019 (ROSES-2018):

Regina M. Caputo
(Ph.D. 2011), NASA-GSFC, Gamma-ray and Cosmic-ray astrophysics

Sarah N. Heine
(Ph.D. 2014), MIT, Bragg Reflector Optics and Gratings for Polarimetry

Gregory N. Mace
(Ph.D. 2014), UT Austin, Advanced Optics and Spectroscopy Applications

NASA Astrophysics Committed to Improving

PI RESOURCES WEBPAGE [1]

MISSION PI WORKSHOPS [2]

ASSURE DIVERSITY OF MISSION PEER REVIEW PANELS

WEBINAR BY THOMAS ZURBUCHEN ON WRITING SUCCESSFUL MISSION PROPOSALS

CODE OF CONDUCT FOR SMD-SPONSORED CONFERENCES

NEW AWARD TERMS AND CONDITIONS FOR GRANTS

DUAL-ANONYMOUS PEER REVIEW

PROPOSAL WRITING WORKSHOPS AT CONFERENCES

CODE OF CONDUCT & IMPLICIT BIAS TRAINING FOR ROSES PANELS

ASTRO2020 STATE OF THE PROFESSION

[1] https://science.nasa.gov/researchers/new-pi-resources [2] https://science.nasa.gov/researchers/pi-launchpad

Inspiring Future Leaders

- Achieve excellence by relying on diverse teams, both within and external to NASA, to most effectively perform SMD's work
- Attract and retain talent by promoting a culture that actively encourages diversity and inclusion and removes barriers to participation
- Encourage development of future leaders, including the next generation of mission principal investigators, through targeted outreach and hands-on opportunities
- Support early-career scientists to build careers working with NASA
- Engage the general public in NASA Science, including opportunities for citizen scientists

[1] https://science.nasa.gov/researchers/new-pi-resources [2] https://science.nasa.gov/researchers/pi-launchpad

Research and Analysis Initiatives

Dual Anonymous Peer Review

- SMD is strongly committed to ensuring that review of proposals is performed in an equitable and fair manner that reduces the impacts of any unconscious biases

High-Risk/ High-Impact (HR/HI)

- To reinforce SMD's interest in High-Risk/High-Impact research, a special review process will be implemented in ROSES 2020 to review and select HR/HI proposals

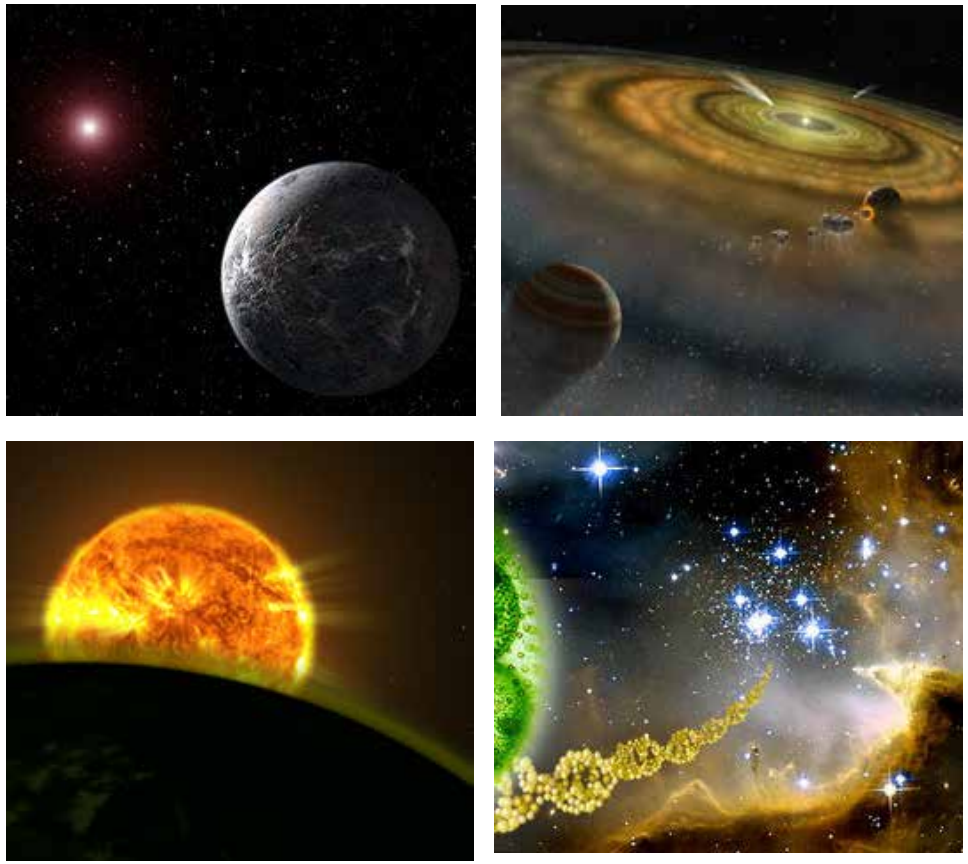
Proposal Selection Metrics for ROSES 2018

- Overall, just under 50% of selections featured new PIs
- Majority of division selection rates were between 25 – 30%, and we are continuing to evaluate

https://science.nasa.gov/researchers/dual-anonymous-peer-review

Request for Information:

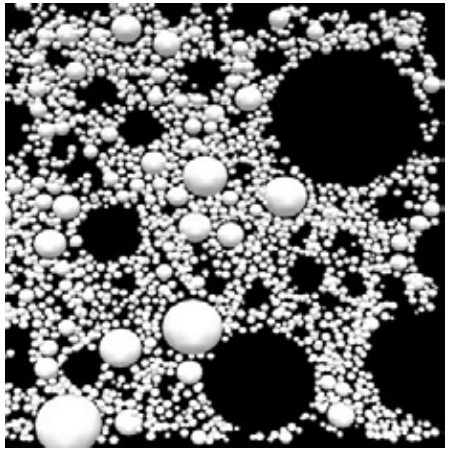
Research That Falls in Gap between current SMD Solicitations



- Release Date: Dec 2, 2019 (Solicitation: NNH20ZDA003L)
- Response Date: Jan 31, 2020
- NASA SMD is soliciting information on research aligned with agency mission and SMD's Science Plan but falls in a gap between current solicitations, possibly because it's interdisciplinary or interdivisional
- Responses will be used by NASA to inform decision as to whether portfolio of current program elements in ROSES needs to be modified and/or expanded to provide the proper avenue for such research
- Full text of RFI and response instructions on the NSPIRES website

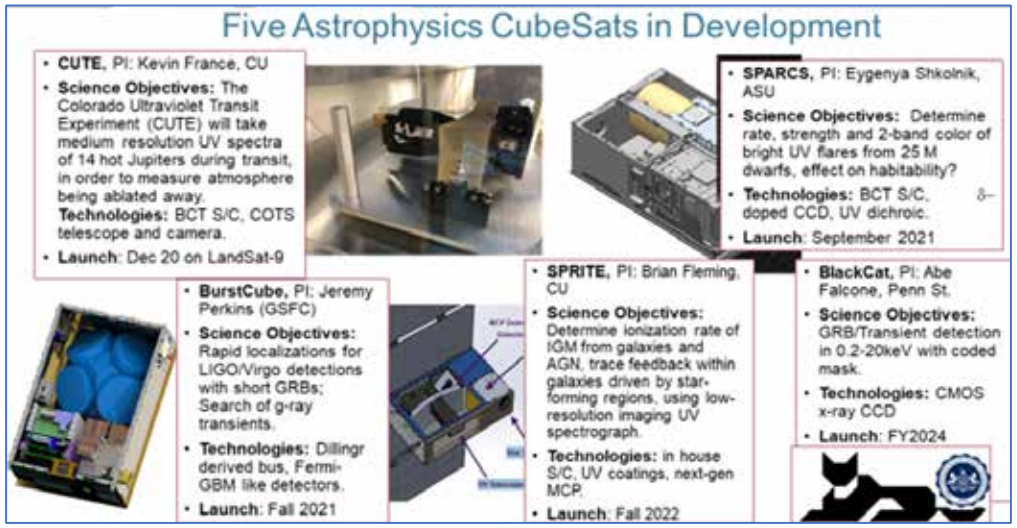
https://nspires.nasaprs.com/external/solicitations/summary.do;jsessionid=xiyrR-9Zu17thfxwGx4QqpWWSNcczOtI7lVVRmRg1nAdvgh3N9d9!690997205!wnp1.nasaprs.com!7006!-1!-863808402!wnp2.nasaprs.com!7006!-1?solId=%7BD82B2B9A-5F6D-B0C6-741A-6950D1D6F0E1%7D&path=&method=init!-1!-863808402!wnp2.nasaprs.com!7006!-1?solId=%7BD82B2B9A-5F6D-B0C6-741A-6950D1D6F0E1%7D&path=&method=init

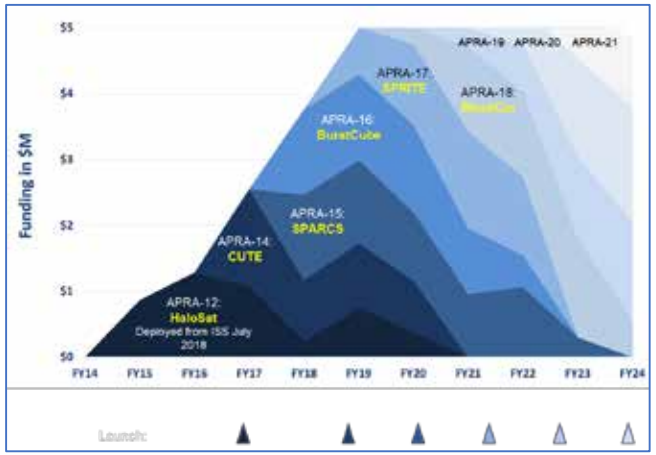
Strategic Data Management



- SMD will be implementing changes to enable open data, open source code, and open model
- Informed by community input through multiple workshops, RFI, and NASEM reports
- Recognize that this will be a step wise process with the first changes coming in ROSES 2020 and upcoming Senior Reviews
- Periodic evaluation to ensure effectiveness and consistency with current best practices
- Additional information on SMD's data activities is available at: https://science.nasa.gov/researchers/science-data

SmallSats and CubeSats

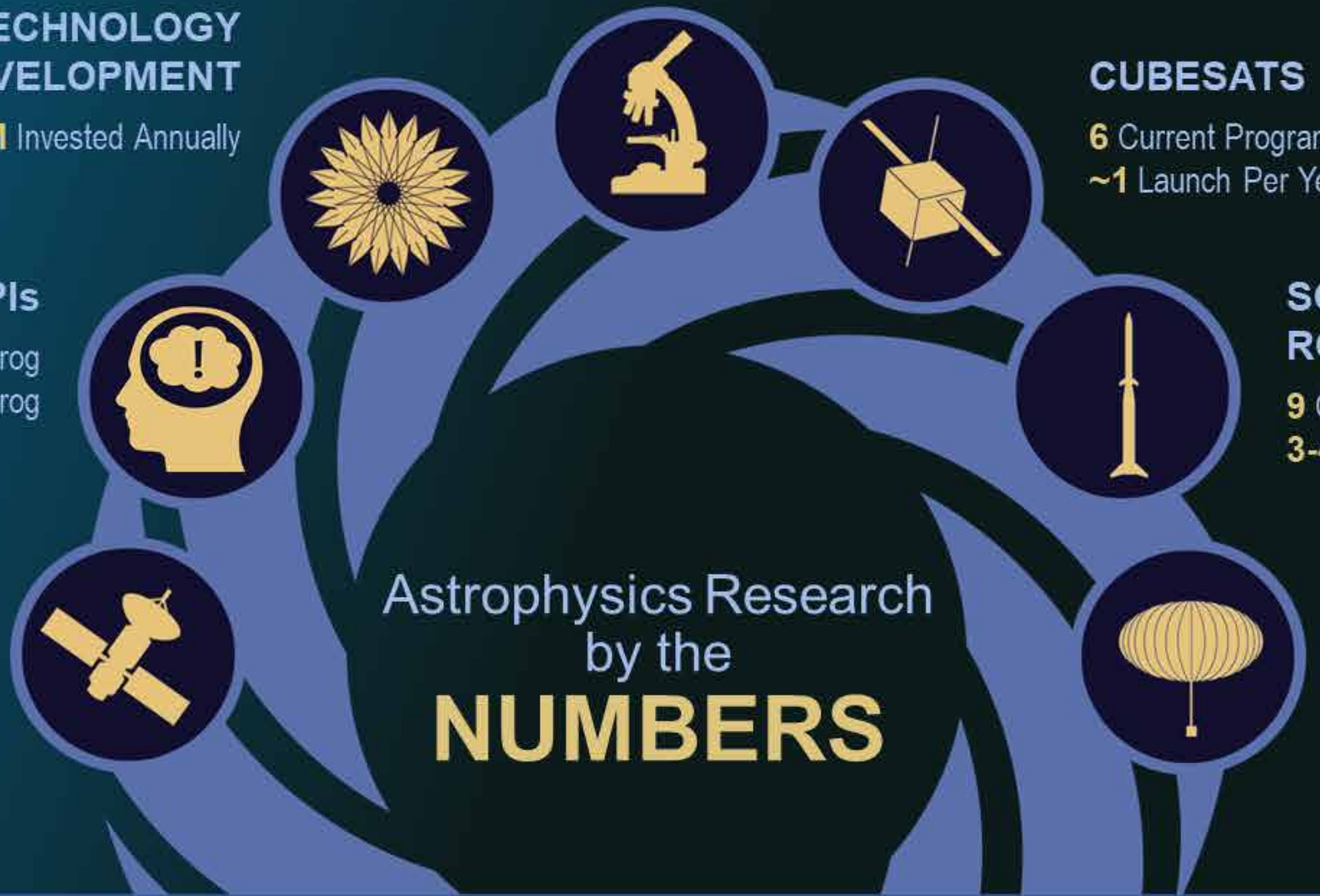




- NASA selected 9 Astrophysics Science SmallSat Studies in ROSES 2018. These studies were reported out at a special session of the June 2019 AAS meeting in St. Louis
- The 2019 Astrophysics Explorers Mission of Opportunity AO includes SmallSats and CubeSats launched using rideshare on ESPA or ESPA Grande; proposals are currently under evaluation along with other Small Explorer and Explorer Mission of Opportunity proposals
- A second Astrophysics Science SmallSat Studies solicitation is included in ROSES 2019; proposals are currently under evaluation
- NASA has selected 6 Astrophysics CubeSats through ROSES/APRA

NASA Astrophysics Program and Budget Update

Astrophysics Research by the NUMBERS



R&A PROGRAMS

>1,000 Proposals Received
26% Success Rate
~$100M Awarded Annually

TECHNOLOGY DEVELOPMENT

~$140M Invested Annually

CUBESATS

6 Current Programs
~1 Launch Per Year

NEW PIs

>180 Per Year in R&A Prog
>120 Per Year in GO Prog

SOUNDING ROCKETS

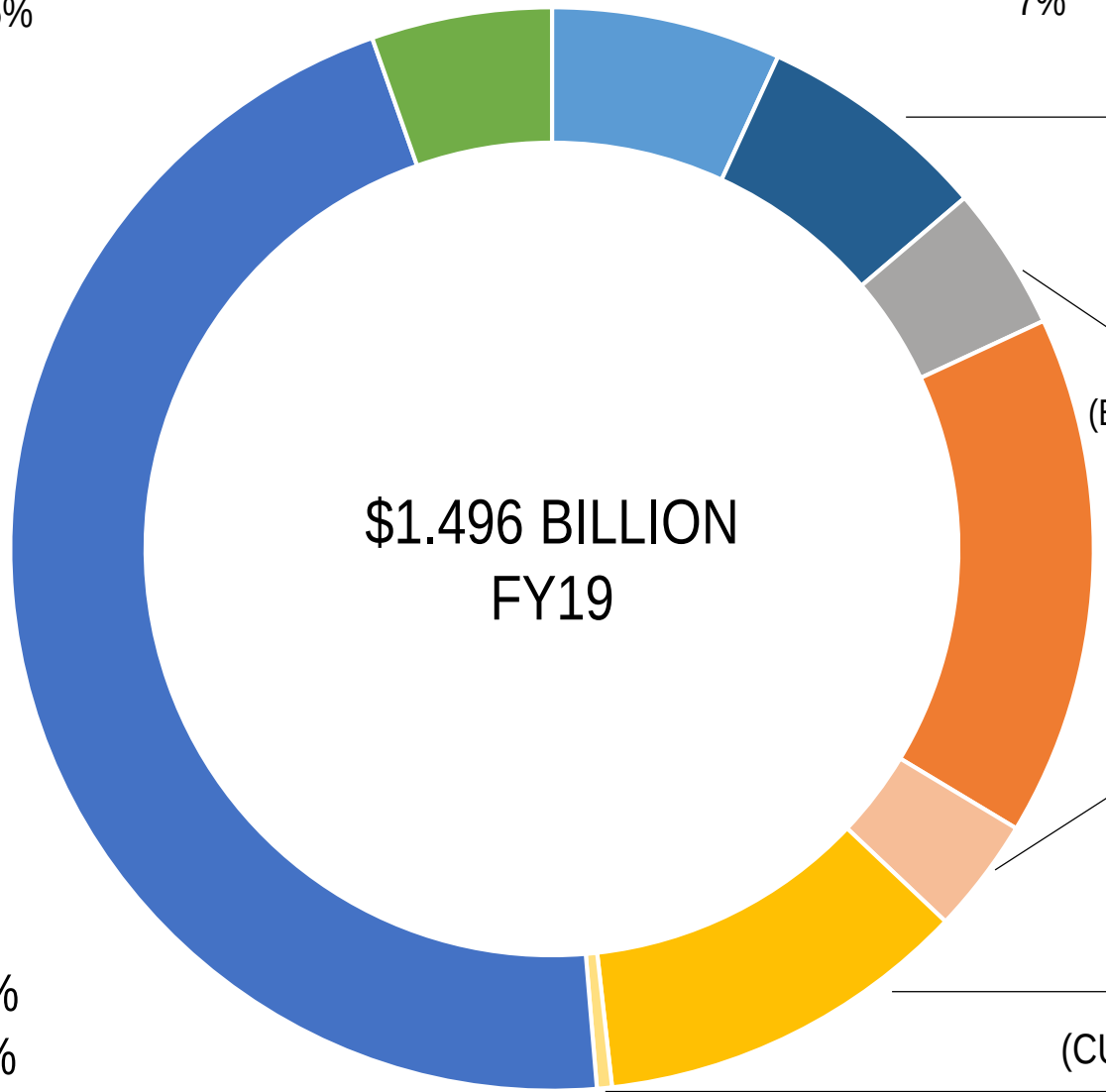
9 Current Programs
3-4 Launches Per Year

GO PROGRAMS

>2,000 Proposals Received
19% Success Rate
~$70M Awarded Annually

BALLOONS

18 Current Programs
3-6 Launches Per Year



MANAGEMENT
INCL. STEM ACTIVATION
5%

RESEARCH
(ADAP, APRA, ATP, ETC.)
7%

TECHNOLOGY
(SR&T, ATHENA, LISA, ETC.)
7%

INFRASTRUCTURE
(BALLOON PROGRAM, ARCHIVES, ETC.)
4%

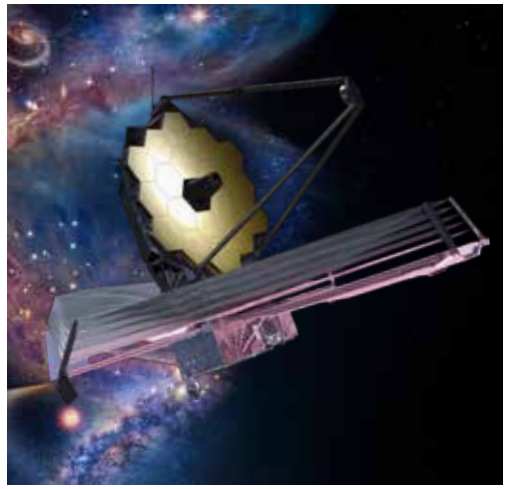
OP. MISSIONS
(INCL. GO PROGRAMS)
19%

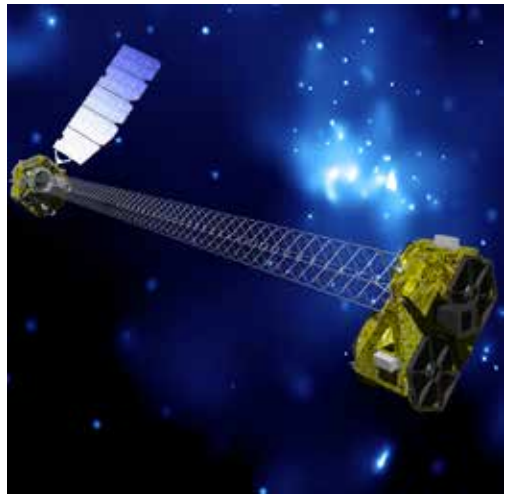
EXPLORERS
(CURRENT AND FUTURE, INCL. GO)
11%

DEVELOPMENT
(WEBB, WFIRST)
46%

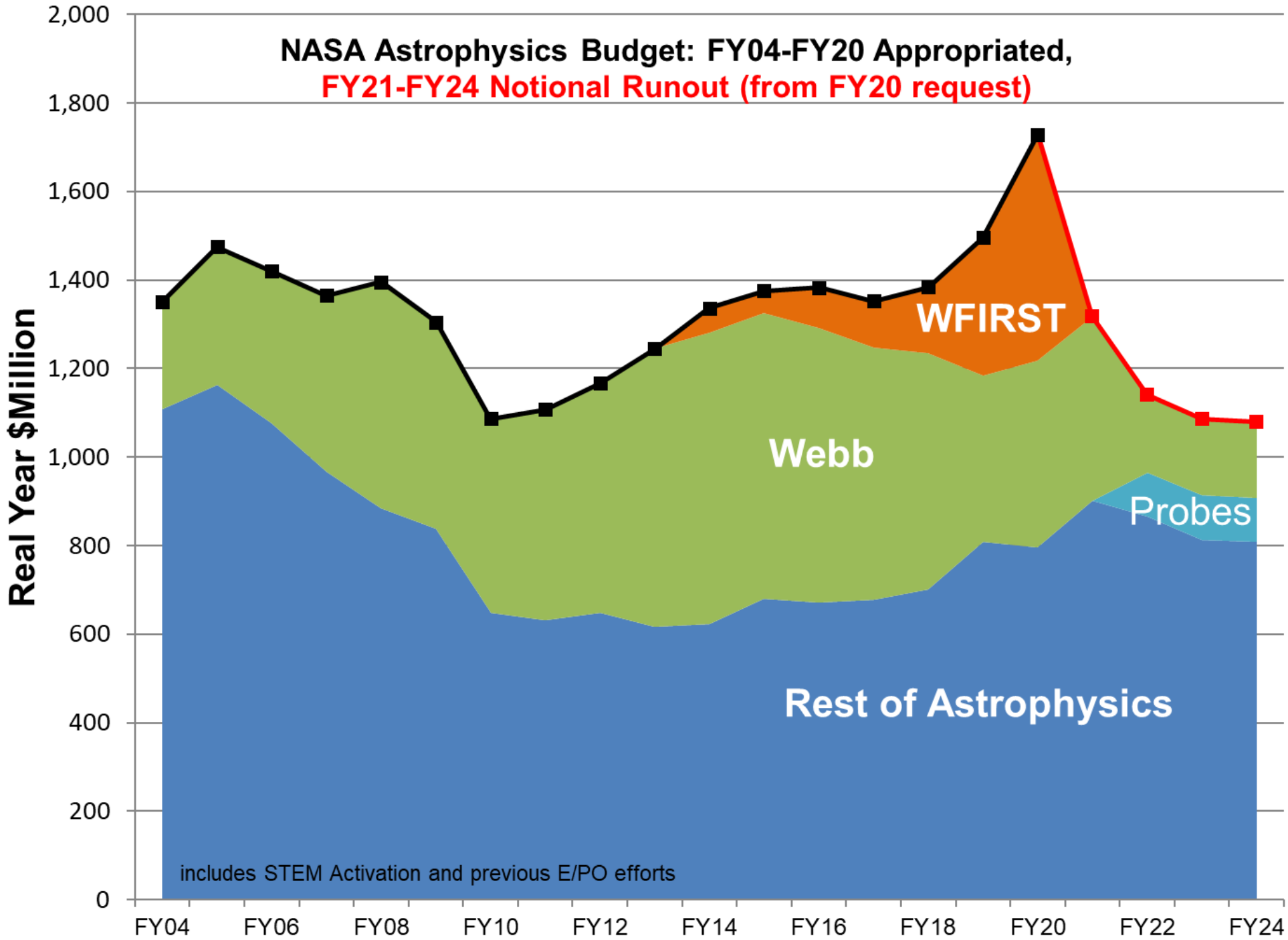
Quick Summary
Community support: 20%
Operating missions: 20%
Building missions: 55%
Management: 5%

FY20 Appropriation





- FY20 appropriation for NASA Astrophysics (including Webb Telescope) is $1.73B; up by $233M from FY19 appropriation and by $532M from FY20 President's Budget Request
- Fully funds Webb for replan to March 2021 launch date
- Fully funds WFIRST, including the coronagraph technology demonstration instrument, through KDP-C and into Phase C
- Specifies funding levels for Hubble, SOFIA, and the Astrophysics Research Program
- Provides adequate funding to continue with the rest of the planned Astrophysics programs and projects including:
  - Operating missions with GO programs as planned following the Senior Review
  - Development of Explorers missions (IXPE, GUSTO, SPHEREx) and international contributions (Euclid, XRISM, ARIEL, Athena, LISA)
  - Initiation of Phase A studies for selected SMEX and MO proposals from the 2019 Announcement of Opportunity
  - Continued technology development for the future


NASA Astrophysics Budget: FY04-FY20 Appropriated,
FY21-FY24 Notional Runout (from FY20 request)
Real Year $Million
2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
FY04
FY06
FY08
FY10
FY12
FY14
FY16
FY18
FY20
FY22
FY24
WFIRST
Webb
Probes
Rest of Astrophysics
includes STEM Activation and previous E/PO efforts

Astrophysics Research Elements

ROSES-20 Programs

Supporting Research and Technology

- Astrophysics Research & Analysis (APRA**)**
- Strategic Astrophysics Technology (SAT)
- Astrophysics Theory Program (ATP) (biennial, not this year)
- Theoretical and Computational Astrophysics Networks (TCAN) (triennial, this year)
- Exoplanet Research Program (XRP) (cross-div)
- Roman Technology Fellowships (RTF)
- FINESST Graduate Student Research Awards

Data Analysis

- Astrophysics Data Analysis (ADAP)
- GO/GI programs in ROSES for:
  - Fermi
  - NICER
  - NuSTAR
  - Swift
  - TESS

Mission Science and Instrumentation

- Sounding rocket, balloon, CubeSat, and ISS payloads solicited through APRA
- Astrophysics Science SmallSat Studies (occasional, not this year)
- XRISM Guest Scientists (one time)
- Astrophysics Explorers U.S. Participating Investigators (triennial, this year)

Separately Solicited

- GO/GI/Archive/Theory programs for:
  - Chandra
  - Hubble
  - SOFIA
  - Webb
- NASA Hubble Fellowship Program
- NASA Postdoctoral Program

Exoplanet Research Program (XRP)

Changes to the program in ROSES-19:

- Heliophysics and Earth Science joined the program
- Review managed collaboratively by all four divisions
- Selections are funding-blind (i.e. not tied to specific Divisions)
- 20 percent more proposals than last year!

Changes coming in ROSES-20:

- Consolidation of exoplanet proposals into XRP
  - Within Astrophysics (Appendix D): Exoplanet-related proposals from ADAP, ATP, etc. will move into XRP
    - Funding will move between programs to enable this
    - Exoplanet-related proposals will still be permitted in TCAN
  - Within Planetary Science (Appendix C): Exoplanet proposals in Habitable Worlds will move into XRP (better definition of the line between the two)
- Additional cross-divisional collaboration encouraged (Heliophysics and Earth Science participation, in particular)

Astrobiology Research

Research Coordination Networks

- Exoplanet System Science - NExSS
- Life Detection - NfoLD
- Prebiotic Chemistry and Early Earth Environments - PCE3
- Network for Ocean Worlds - NOW
- Earliest Cells to Multicellularity- ECM

Transition of NASA Astrobiology Institute (NAI) into Research Coordination Networks (RCNs)

The NAI concluded at the end of 2019; five RCNs will focus on different interdisciplinary science questions

Researchers may elect to become a member of one or more RCNs once they have received funding for a relevant project

New ROSES funding opportunity: Interdisciplinary Consortia for Astrobiology Research (ICAR)

Proposals that describe a multi-million dollar, five-year project with an interdisciplinary approach to a single, compelling question in astrobiology

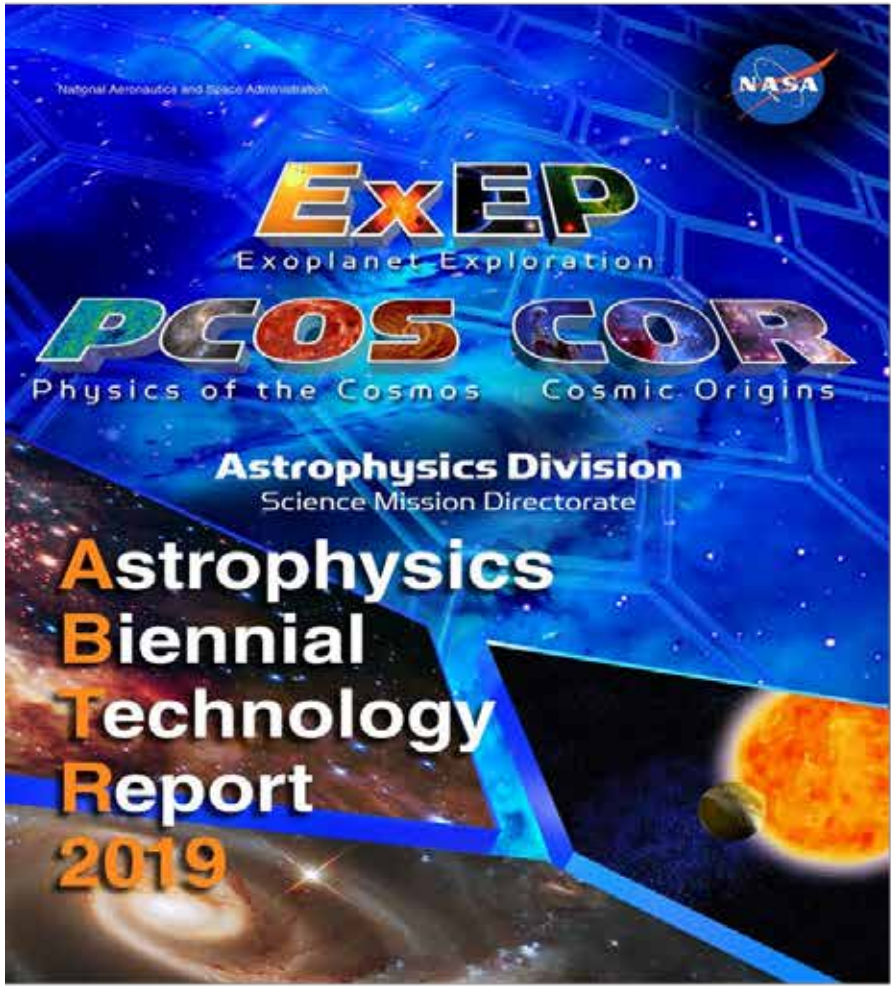
For projects larger than the scope of the individual research programs, but within the scope of the Research Coordination Networks.
Cycle 1 RCNs: NExSS, PCE3, ECM

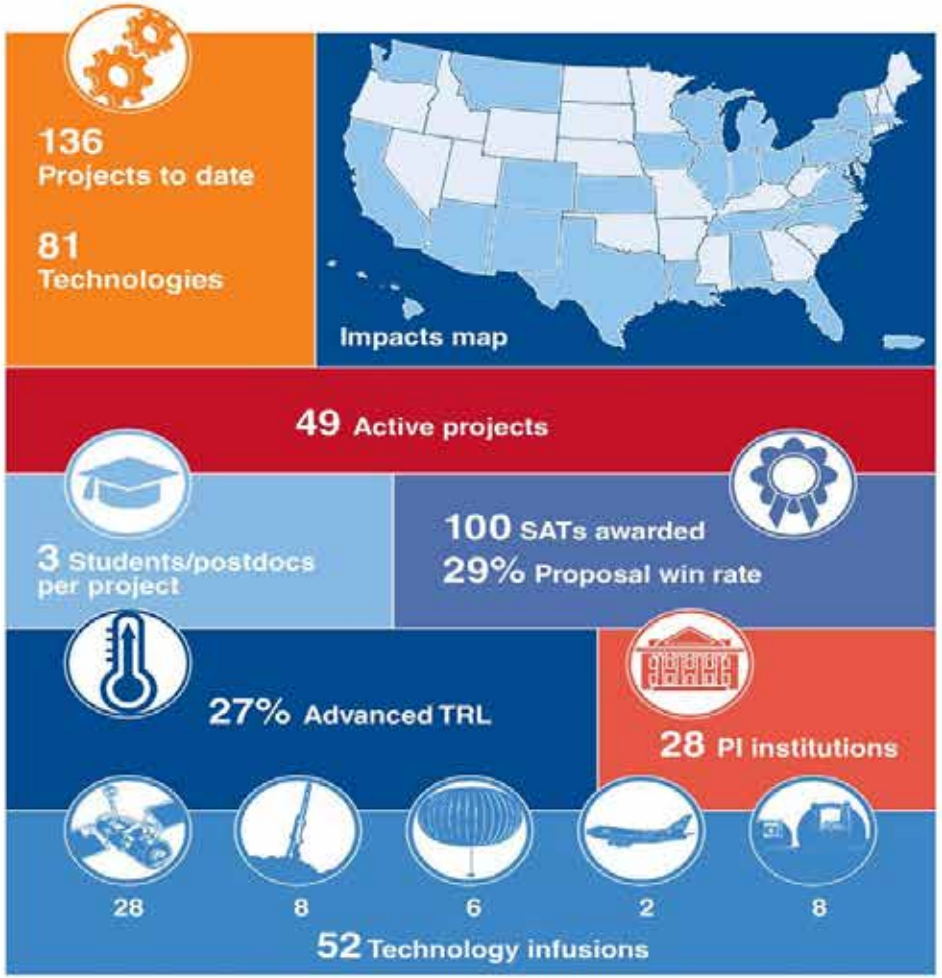
See ROSES-19, Appendix C.23
Step 1 proposals due – January 31, 2020
Step 2 proposals due – April 3, 2020

Selected proposals will become part of the Research Coordination Network

Calls will occur every two years and will stagger RCN topics

Integrated Strategic Technology Portfolio





Astrophysics Biennial Technology Report: https://apd440.gsfc.nasa.gov/technology.html

Database of Astrophysics technology projects: http://www.astrostrategictech.us/

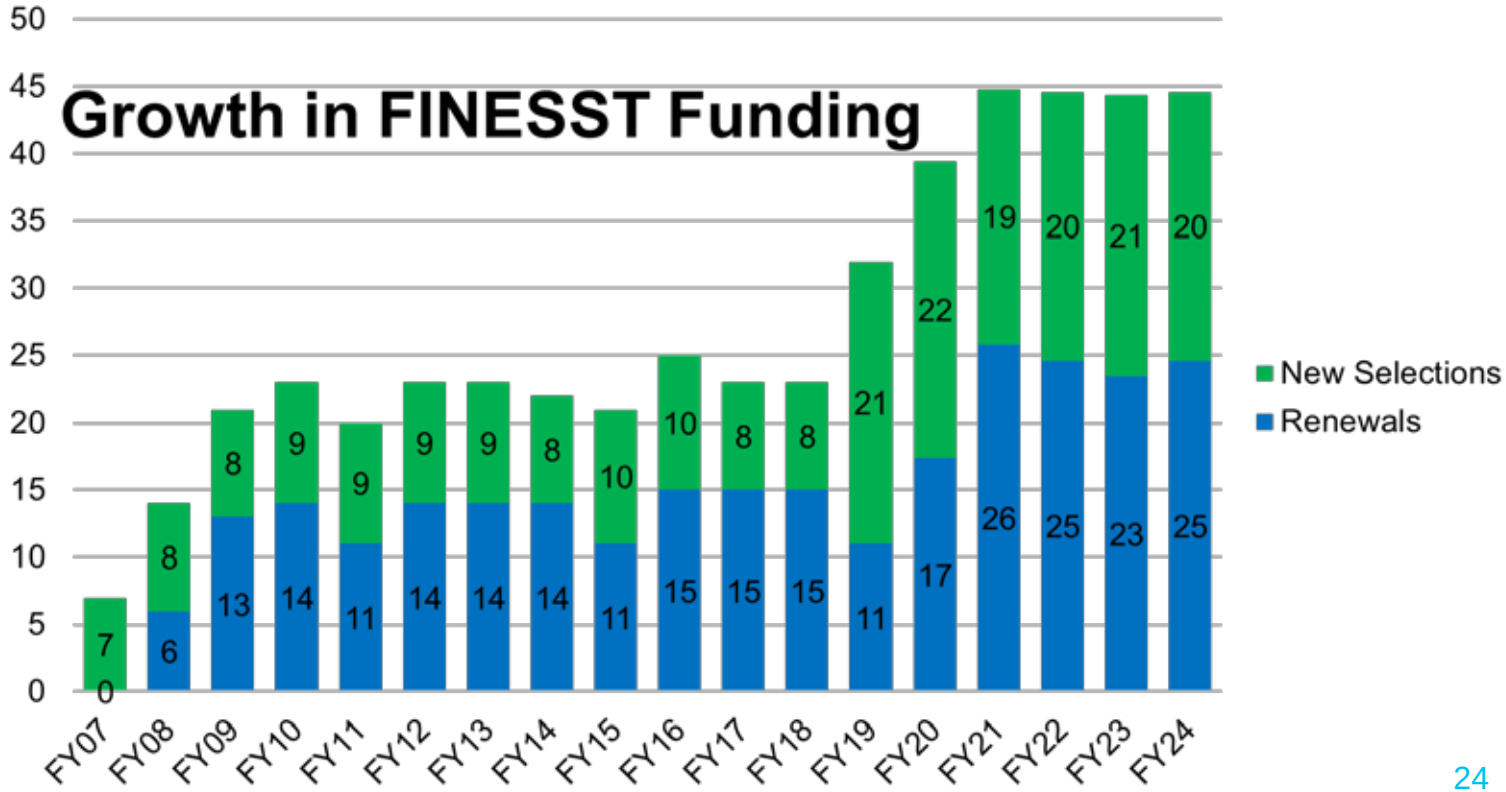
Graduate Student Research Awards

NASA Earth and Space Science Fellowship (NESSF) program name is changing to Future Investigators in NASA Earth and Space Science and Technology (FINESST) in 2019 to more accurately capture the nature of awards.

Historically Astrophysics has funded 24 NESSF / FINESST fellows at any given time. With 150-200 proposals received annually, the selection rate has been ~6%.

Community input has led to us doubling the Astrophysics NESSF / FINESST program effective in 2019.

Astrophysics will now be funding 45-48 NESSF / FINESST Fellows at any given time. The selection rate will be ~10%.



NASA Hubble Fellowship Program

It has been thirty years since the first Hubble Fellows were selected.

Fellows are asking for the assurance of parental leave and the option of saving for their eventual retirement with the assistance of their employer.

- Fellows who are employees of their host institutions typically have these benefits.
- Stipendiary fellows to do not receive employee benefits even though the NHFP is willing to pay the full cost of the employee benefits package.

The Space Telescope Science Institute (STScI) and NASA are proposing a change to the requirements for NHFP host institutions.

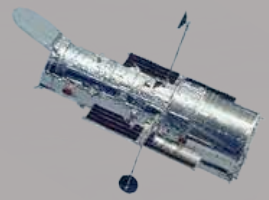
> *Starting with academic year 2022-2023, in order to host new NASA Hubble Fellowship Program (NHFP) Fellows, host institutions must offer their NHFP Fellows the opportunity to be employees. Employee status is being required to afford NHFP Fellows the same leave, vacation, retirement and health benefits (as applicable) given by these institutions to their postdoctoral fellows hired on grants or contracts as employees. Host institutions are also encouraged, but not required, to offer Fellows the option of choosing to be a stipendiary fellow rather than an employee if that is a better match to the Fellow's needs.*

STScI is soliciting comments from host institutions. Direct any questions or comments on this policy to nhfp@stsci.edu by March 18, 2020.

NASA Astrophysics Missions Update

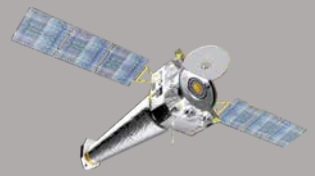
Astrophysics Operating Missions

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

Mission ending Jan 30, 2020

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

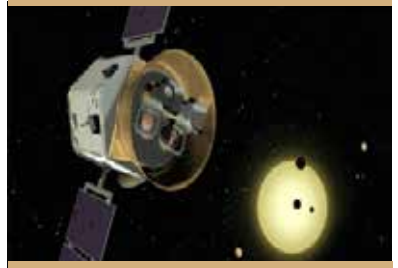
SOFIA 5/14
NASA Strategic Mission

Stratospheric Observatory for Infrared Astronomy

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

Neutron Star Interior Composition Explorer

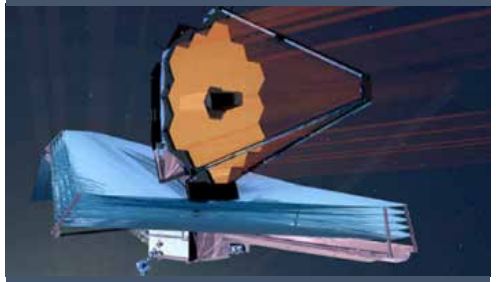
TESS 4/18
NASA MIDEX Mission



Transiting Exoplanet Survey Satellite

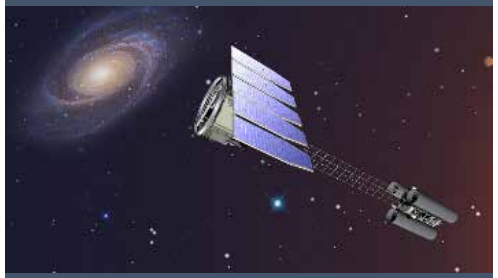
Astrophysics Missions in Development

Webb
2021
NASA Mission



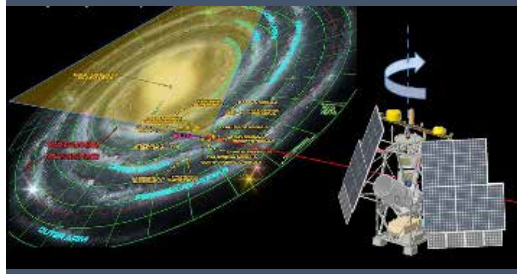
James Webb
Space Telescope

IXPE
2021
NASA Mission



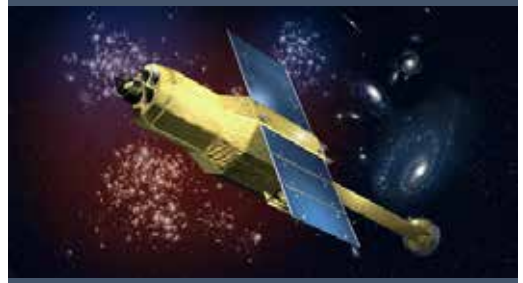
Imaging X-ray
Polarimetry Explorer

GUSTO
2021
NASA Mission



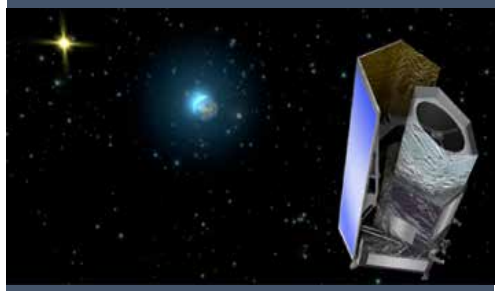
Galactic/ Extragalactic ULDB
Spectroscopic Terahertz Observatory

XRISM
2022
JAXA-led Mission



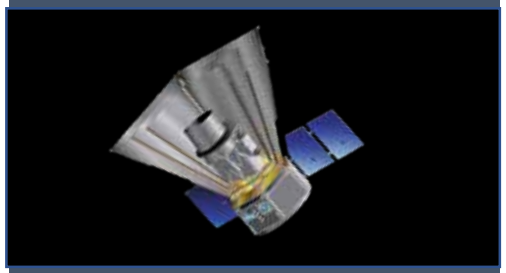
NASA is supplying the SXS
Detectors, ADRs, and SXTs

Euclid
2022
ESA-led Mission



NASA is supplying the NISP
Sensor Chip System (SCS)

SPHEREx
2023
NASA Mission



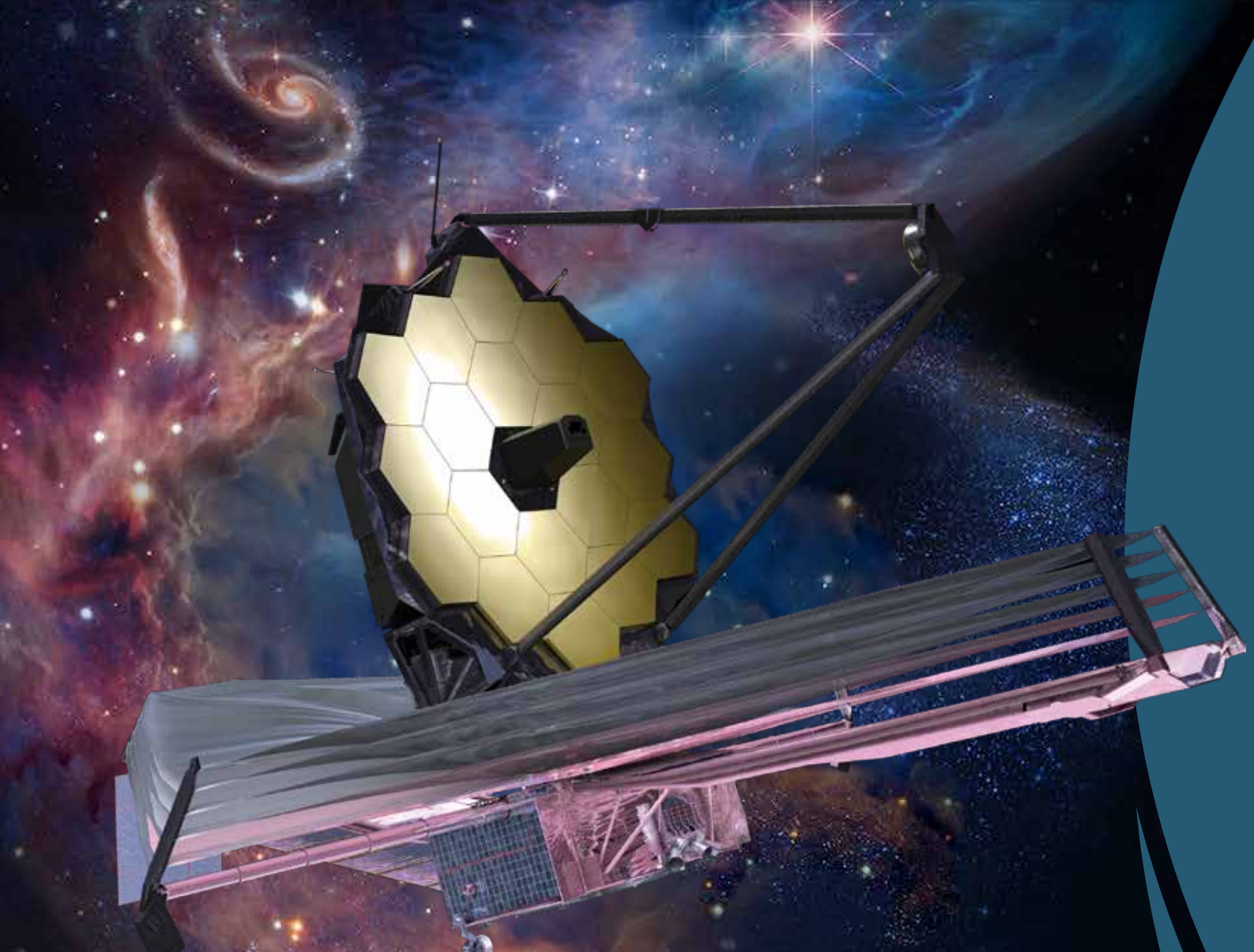
Spectro-Photometer for the History of
the Universe, Epoch of Reionization,
and Ices Explorer

WFIRST
Mid 2020s
NASA Mission

Wide-Field Infrared
Survey Telescope

ARIEL
2028
ESA-led Mission

NASA is supplying the CASE
fine guidance instrument



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

https://webb.nasa.gov/

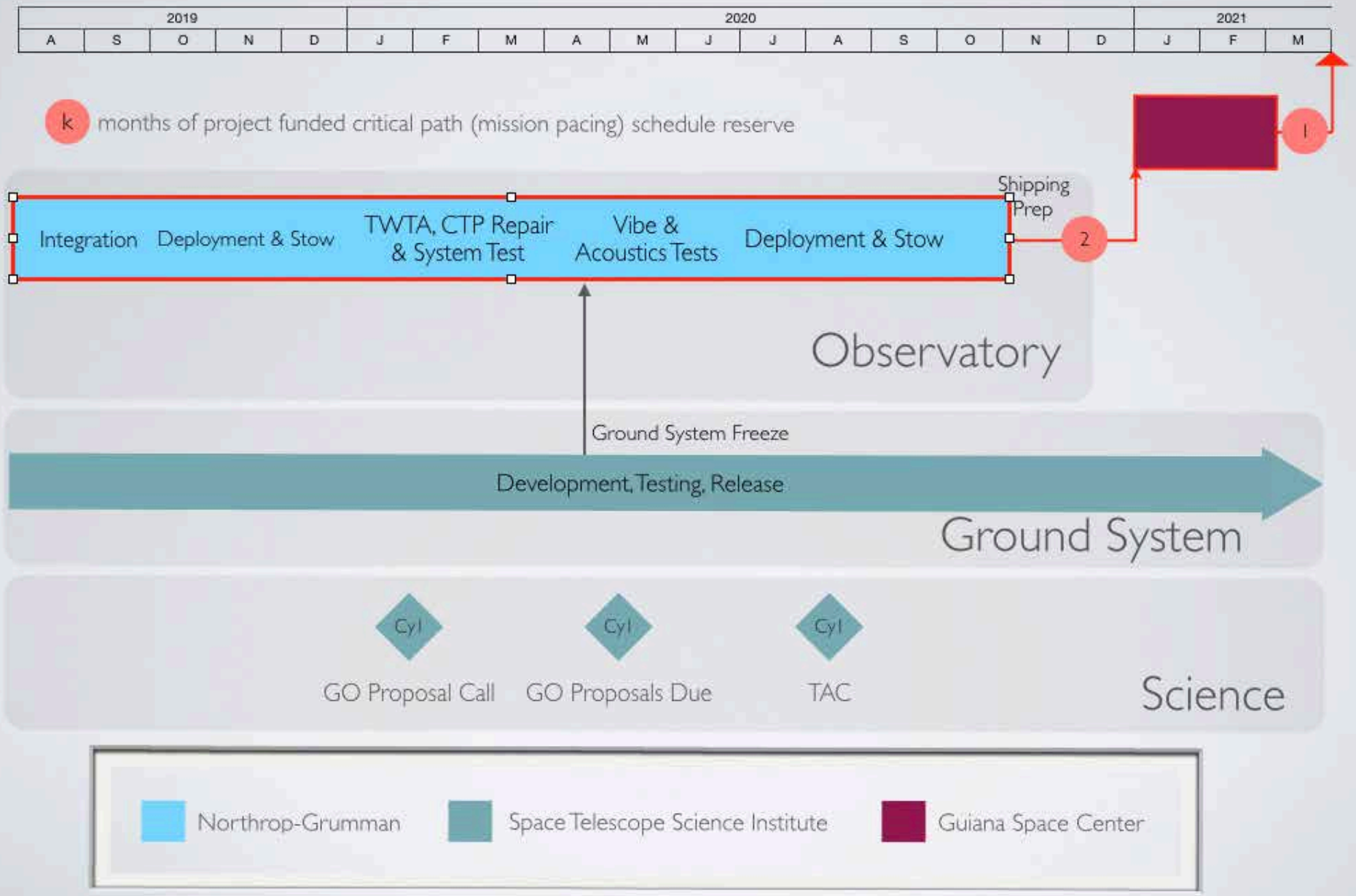
The Webb observatory in the clean room in Redondo Beach, CA in August 2019 before observatory environmental testing and observatory deployment tests

Webb

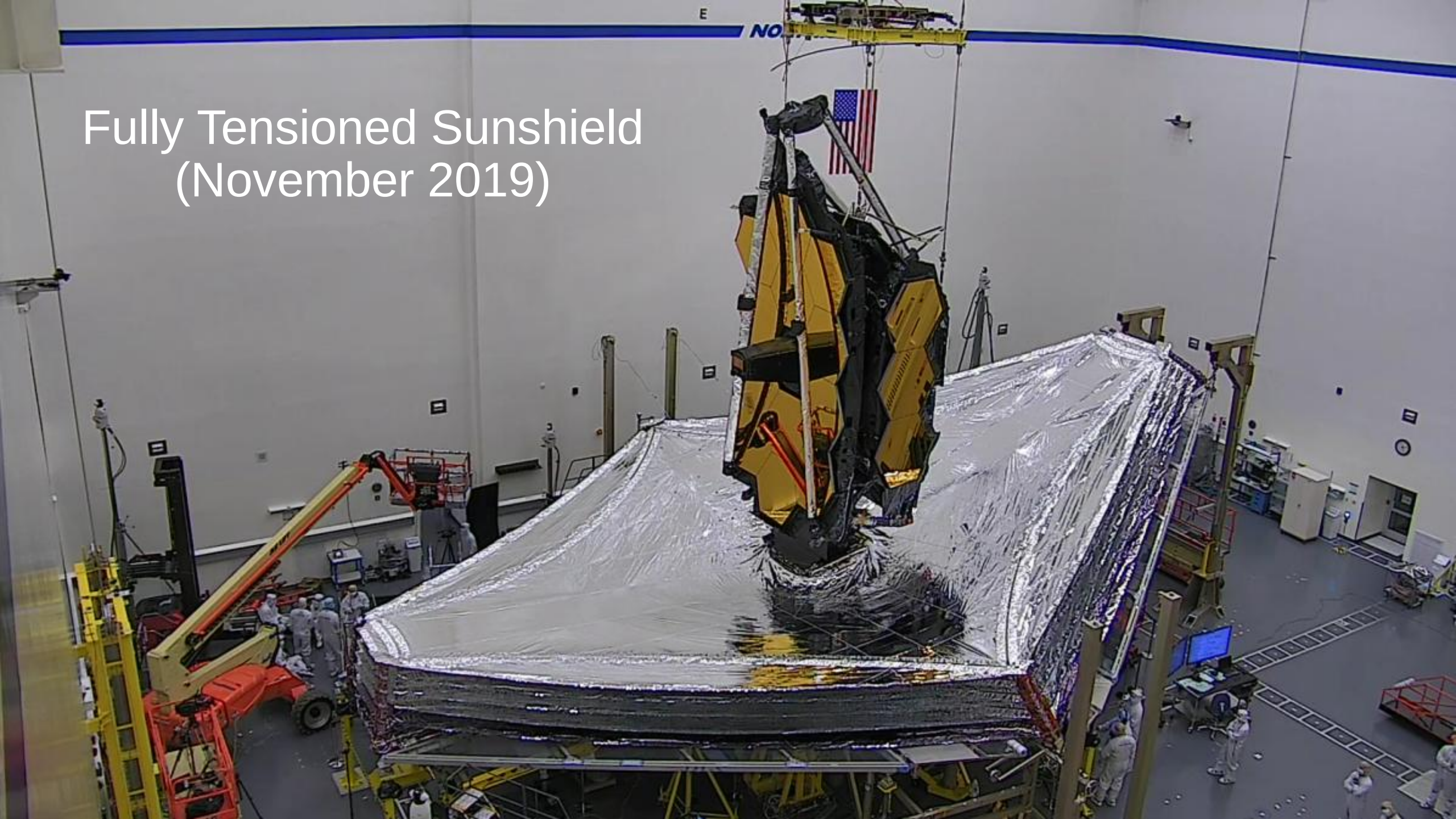
The James Webb Space Telescope

- 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
- Test deployment of sunshield completed November 2019
- Environmental testing of full observatory in Spring 2020
- Webb overrun covered using offsets from Astrophysics Probes

SIMPLIFIED SCHEDULE



Fully Tensioned Sunshield (November 2019)



Wide-Field Infrared Survey Telescope

Science Program

- Cosmology : Dark energy and the fate of the universe – wide field surveys to measure the expansion history and the growth of structure
- Exoplanet Demographics: The full distribution of planets around stars through a microlensing survey
- Astrophysics: 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

https://wfirst.gsfc.nasa.gov/

WFIRST: Wide-Field Infrared Survey Telescope

WFIRST is fully funded in FY20

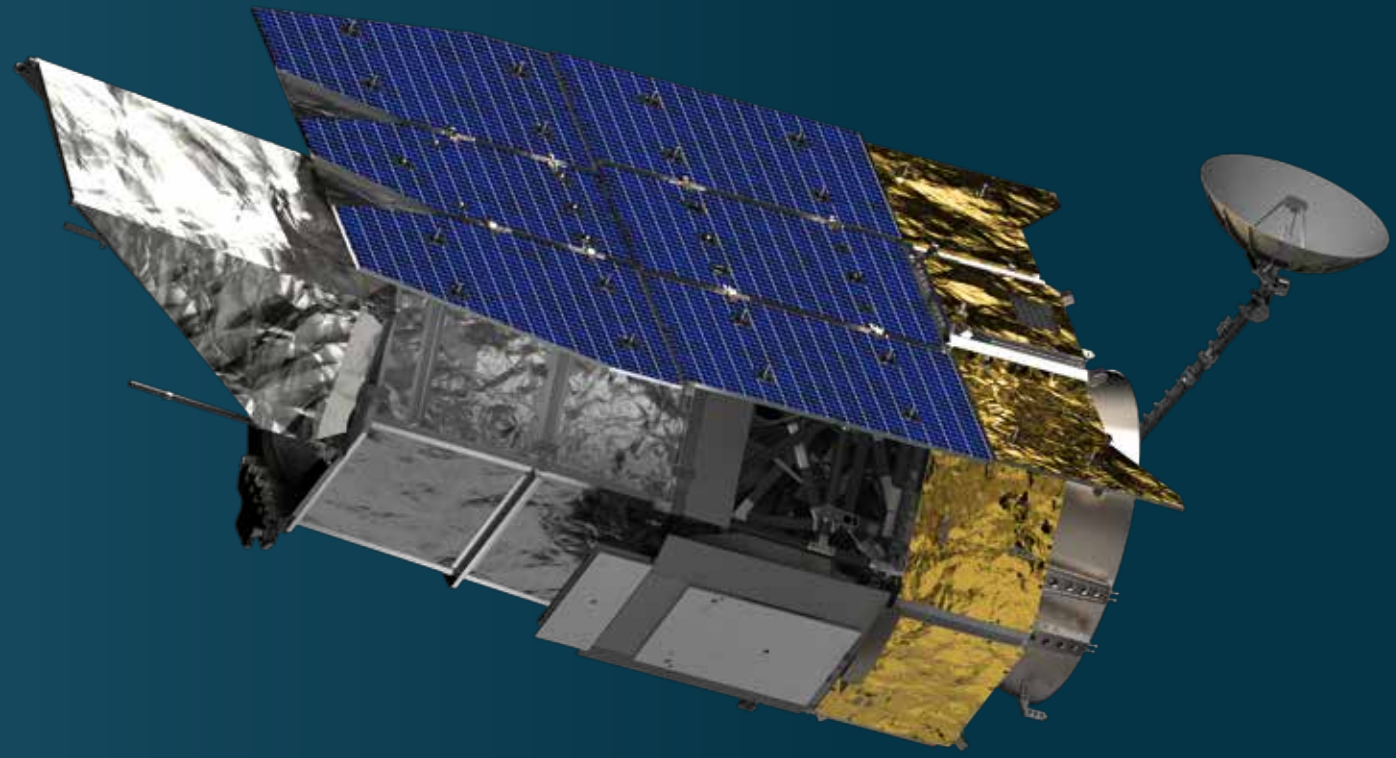
Nov 2019 -– Completed Preliminary Design Reviews

Early 2020 – Complete Confirmation Review and begin Implementation (Phase C)

2020: Flight hardware being developed: mirror being figured, detectors being fabricated, spacecraft subsystems being delivered, coronagraph demo unit in testbed

2021 – Complete Critical Design Reviews

Mid-2020s – Launch

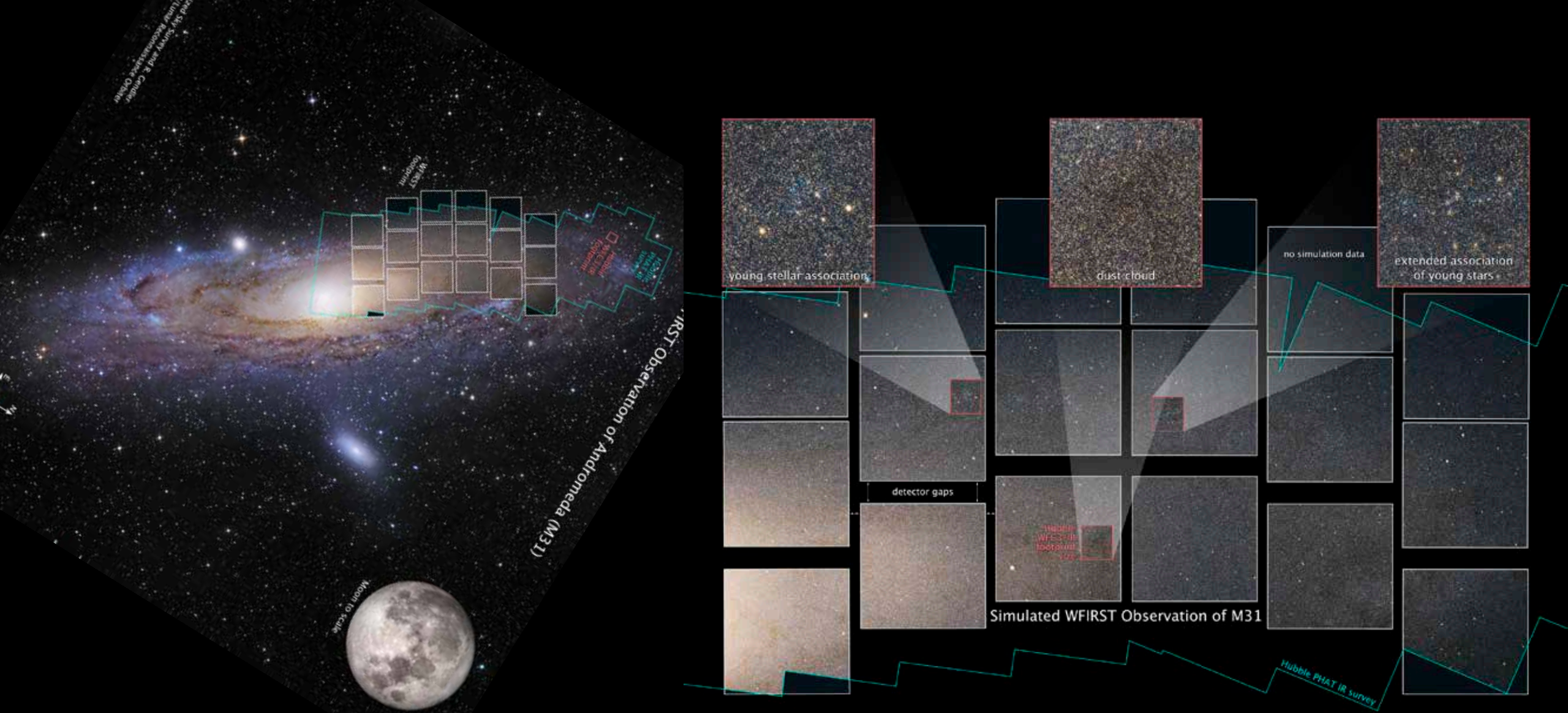


WFIRST field-of-view is 100x Hubble field-of-view

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

Wide-Field Infrared Survey Telescope

- **NASA continuing work on WFIRST as planned**
  - Work continues under CR in anticipation of FY20 appropriation; both Senate and House bills include robust support for WFIRST
  - WFIRST remains on the plan approved at the beginning of Phase B: Lifecycle cost range remains $3.2B -$3.9B, launch range remains late 2025 - 2026
  - Formal cost and schedule commitments, including Headquarters held reserves to increase confidence level to 70%, will be made at Confirmation in early 2020
- **Major milestones completed in 2019:**
  - Completed Preliminary Design Reviews for all primary mission elements (Wide Field Instrument, Coronagraph, Optical Telescope, Instrument Carrier, Spacecraft)
  - WFIRST mission passed Preliminary Design Review (gate for entering Phase C)
  - Additional major contracts awarded: Instrument Carrier (NGIS), Science Operations Center (STScI), numerous spacecraft components
  - Long-lead hardware making excellent progress; telescope refiguring proceeding as expected; several flight candidate detectors already in hand
- **Work Plan for 2020**
  - NASA confirmation of mission; enter implementation phase (Phase C)
  - Significant engineering test unit fabrication and testing



https://www.nasa.gov/feature/goddard/2020/simulated-image-demonstrates-the-power-of-nasa-s-wide-field-infrared-survey-telescope

WFIRST is for You

All WFIRST observing time is available through open competition

- Some WFIRST observing time will be used for the core dark energy and exoplanet surveys mandated by the Astro2010 Decadal Survey
- Some WFIRST observing time will be used for additional GO-driven key projects using WFIRST's unique wide-field imaging, spectroscopic, and time domain capabilities
- Some WFIRST observing time will be used for smaller, individual GO programs
- Some WFIRST observing time will be used for the Coronagraph technology demonstration
- All data will be available to the community with no period of limited access

WFIRST observing program will be based on community input

- Both NASA and STScI will be convening community groups to provide input on balance among observing programs and on trades during development, integration, and test

WFIRST General Observers / Archival Researchers Program

- Use WFIRST for conducting wide-field infrared surveys of the universe
- Use data from WFIRST legacy surveys to conduct compelling astrophysics investigations
- Calls for proposals to be issued before launch and subsequently

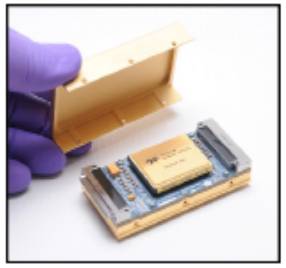
WFIRST Coronagraph Participating Scientist Program

- Develop observing plans for demonstrating coronagraph capabilities
- Work with instrument team to process data from tech demo observations
- Call for proposals to be issued well before launch

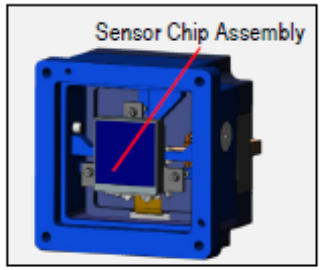
Partner Mission of Opportunity: ARIEL

Contribution to ARIEL Spectroscopy of Exoplanets

PI Mark Swain (JPL)

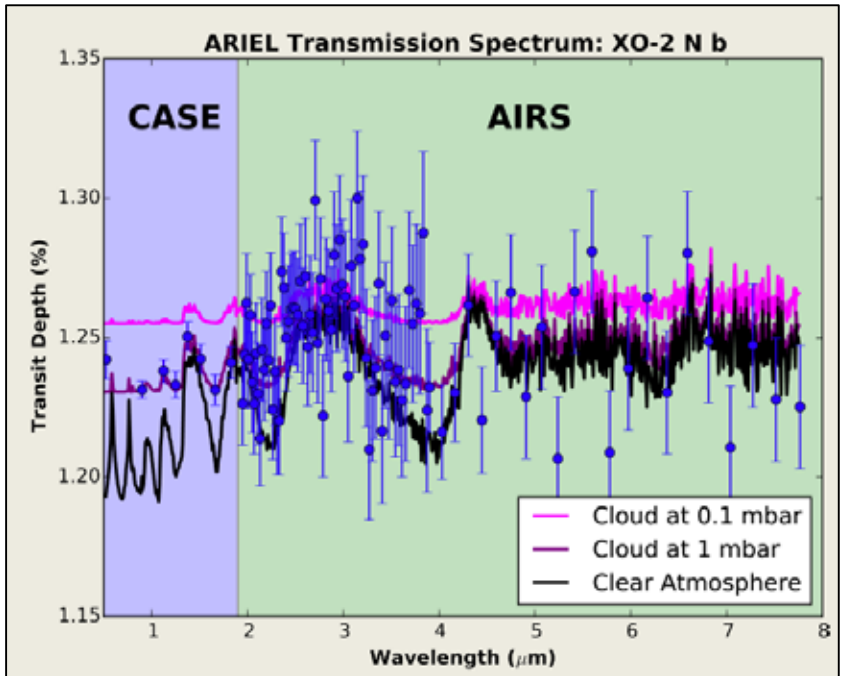


Cold Front End Electronics

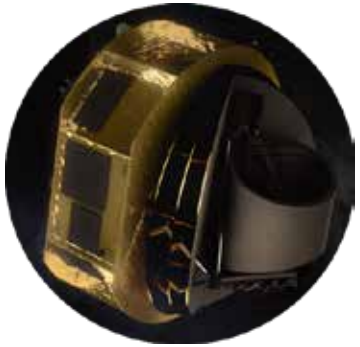


Focal Plane Module

CASE detectors and electronics would provide fine guidance for ARIEL; blueward data (0.5μm-2μm) enables studies of aerosols (clouds and hazes) which are important for the energy budget of the atmosphere.



CASE breaks the degeneracy between clear and cloudy atmospheres present at longer wavelengths. The blue dots are simulated, single-transit observations by CASE and AIRS, the two ARIEL instruments. Both instruments observe the object simultaneously. The target is a hot Jupiter planet with simulated clouds at 1 mbar.



ARIEL: ESA M4 mission for Infrared Spectroscopy of Exoplanet Atmospheres

PI Giovanna Tinetti (UK)

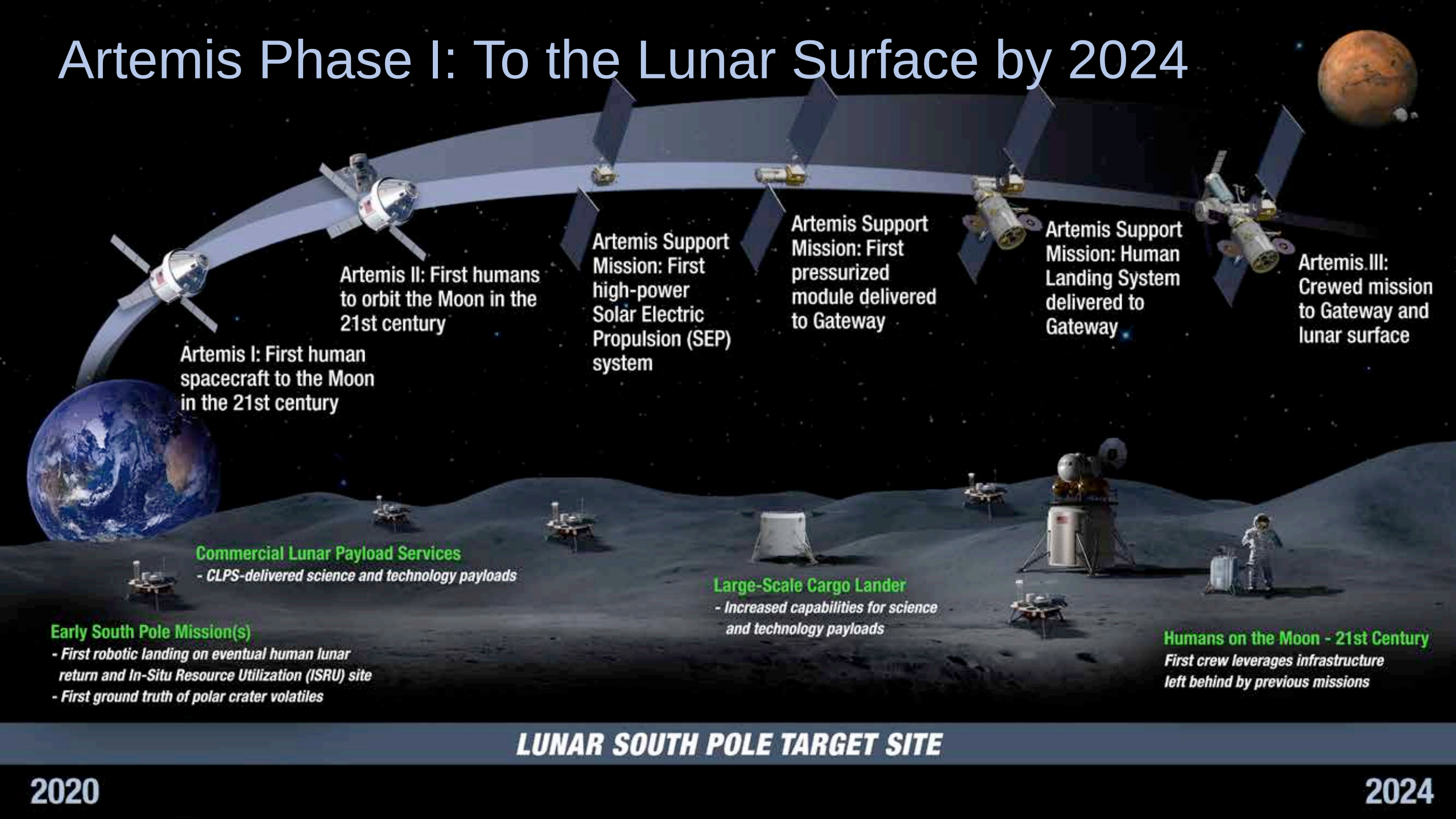
Launch in 2028 to L2 for 4-yr mission; primary mirror 1.1m x 0.7m; CASE photometry complements AIRS spectroscopy 2μm-8μm.

ARIEL is next step beyond Kepler and TESS; will obtain spectra of hundreds of warm transiting exoplanets to study atmospheric chemistry and energy budget

https://arielmission.space/

NASA Astrophysics Planning for the Future

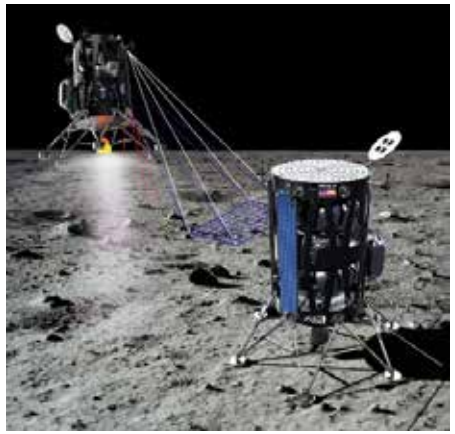
Artemis Phase I: To the Lunar Surface by 2024



Astrophysics and Artemis

All science opportunities enabled by Project Artemis will include astrophysics

- Commercial Lunar Payload Services (CLPS)
  - 14 U.S. companies selected to bid on specific task orders to deliver NASA payloads to Moon's surface
  - All payload calls include astrophysics; two astrophysics payloads selected to date
    - Internal NASA call: Low-frequency Radio Observations from the Near Side Lunar Surface instrument (PI: Robert MacDowall, GSFC)
    - ROSES call: Next Generation Lunar Retroreflectors (PI: Douglas Currie, University of Maryland)
    - Both are among five payloads manifest on Intuitive Machines Lander for NET July 2021
- Astrophysics Explorers Missions of Opportunity
  - 2019 AO included opportunities enabled by Project Artemis
  - Future calls will solicit proposals that leverage Artemis capabilities, such as Gateway as a platform and cis-lunar communications infrastructure, to conduct compelling astrophysics investigations



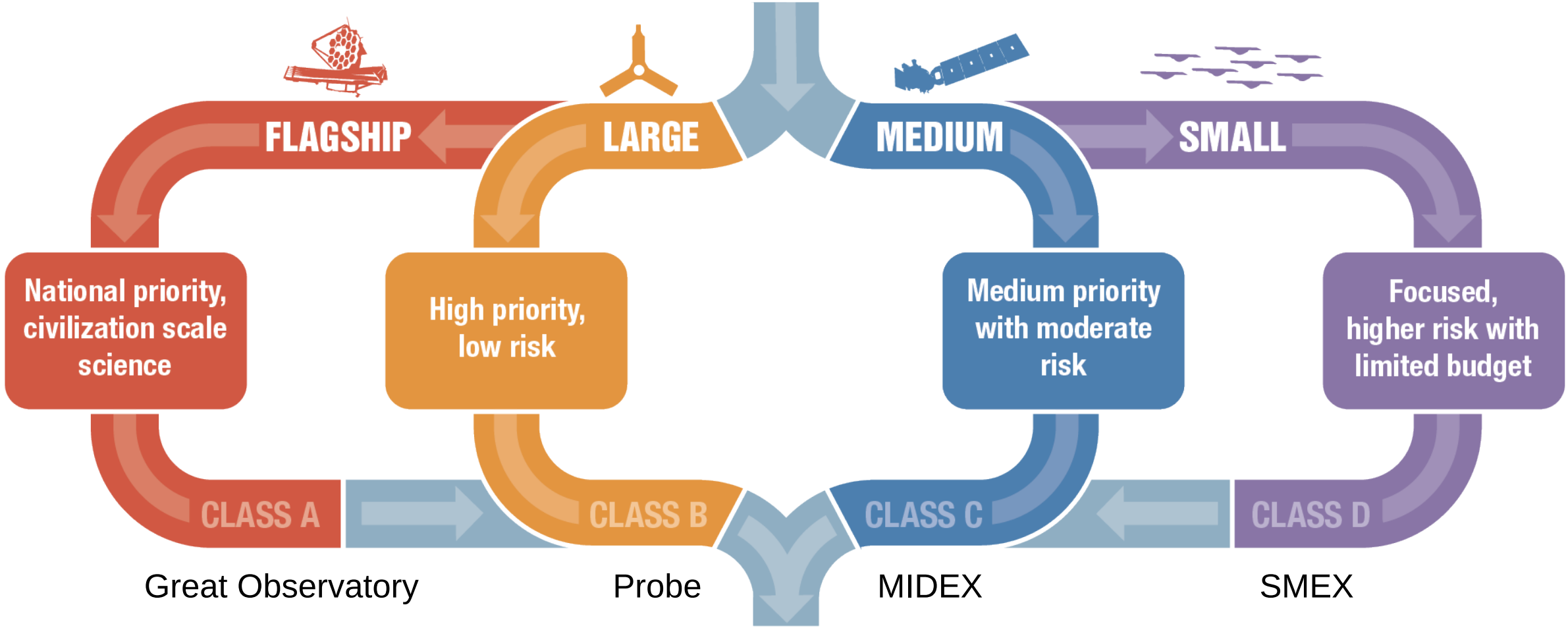
Intuitive Machines Lander

Most important criterion for all proposals that leverage Artemis remains the astrophysics science merit

Decadal Survey Planning

- 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

BALANCED MISSION PORTFOLIO



Great Observatory | Probe | MIDEX | SMEX

GREAT SCIENCE

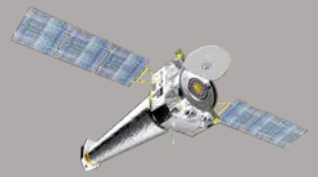
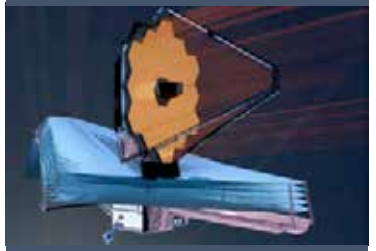
+ SmallSats (Class D Tailored)
  Suborbital-class (Research Class)

Why Flagships

Flagships enable paradigm shifting science

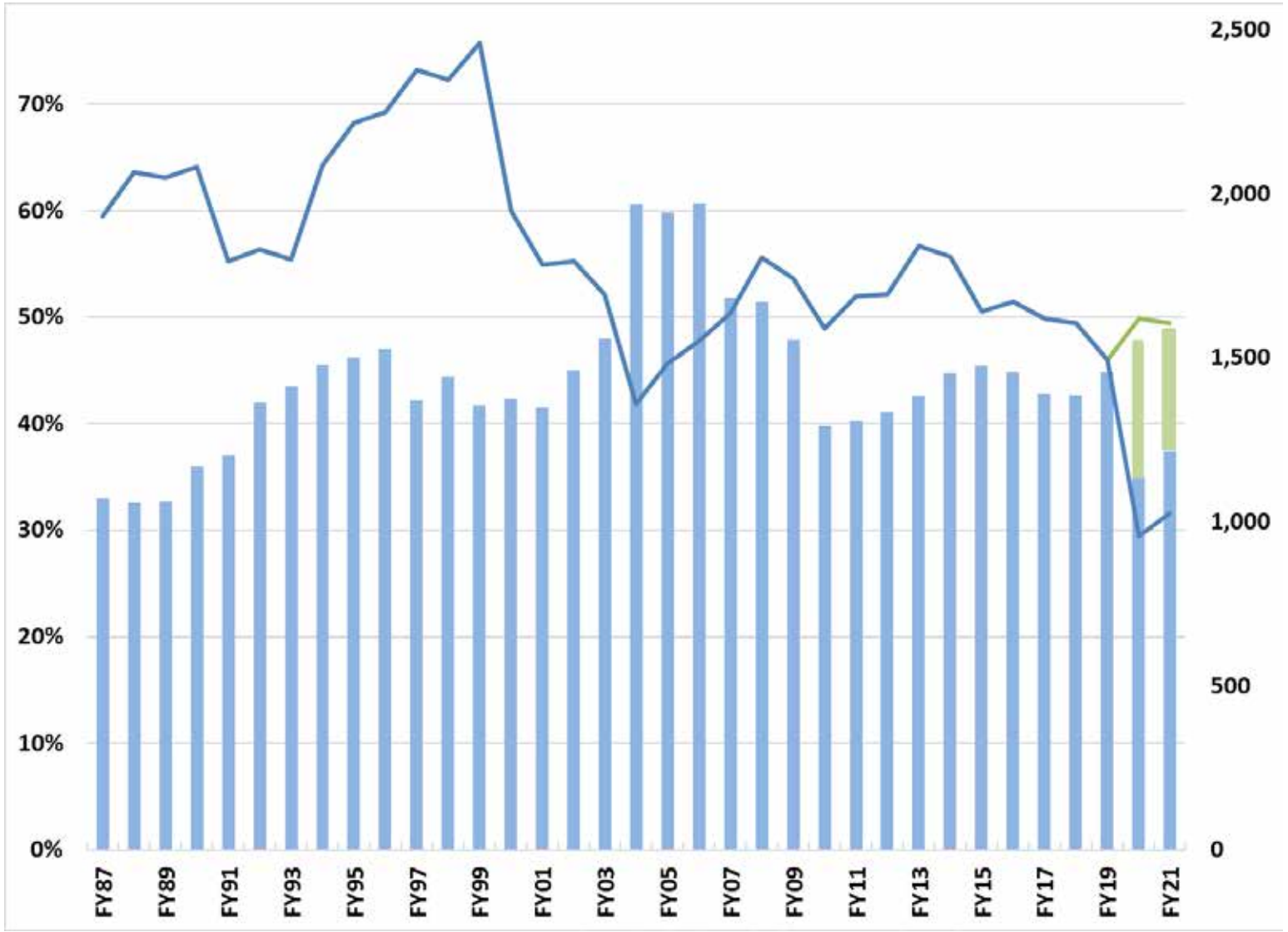
Flagships drive US capabilities and contribute to US leadership

Flagships create stakeholder support that drives 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

“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 (NASEM, 2017)

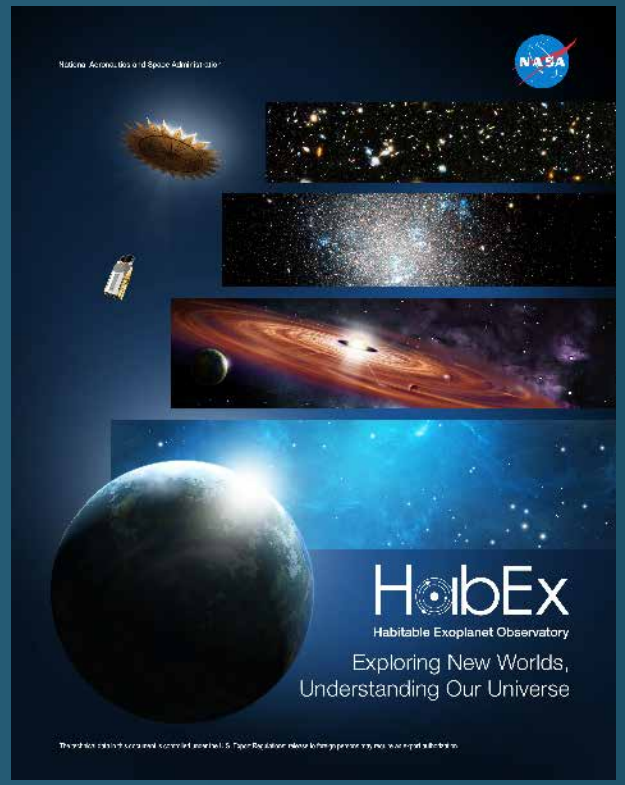
Flagship Fraction of Astrophysics Budget

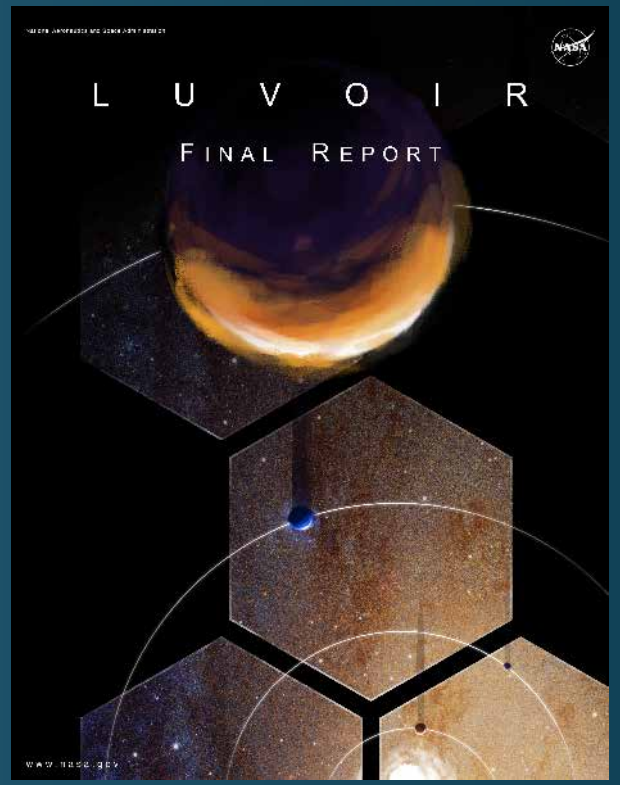


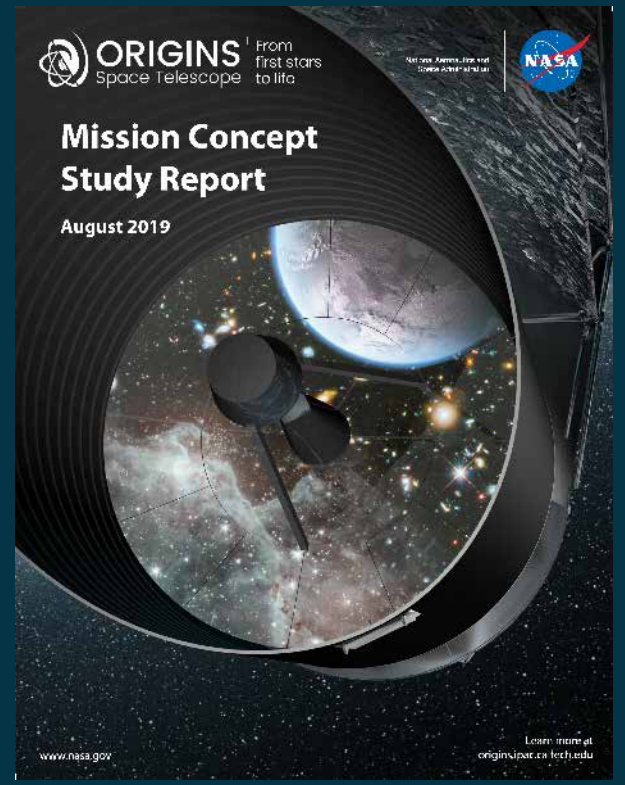
All dollars inflated to FY18$.
Development only, no ops.

- 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?

Large Mission Concepts



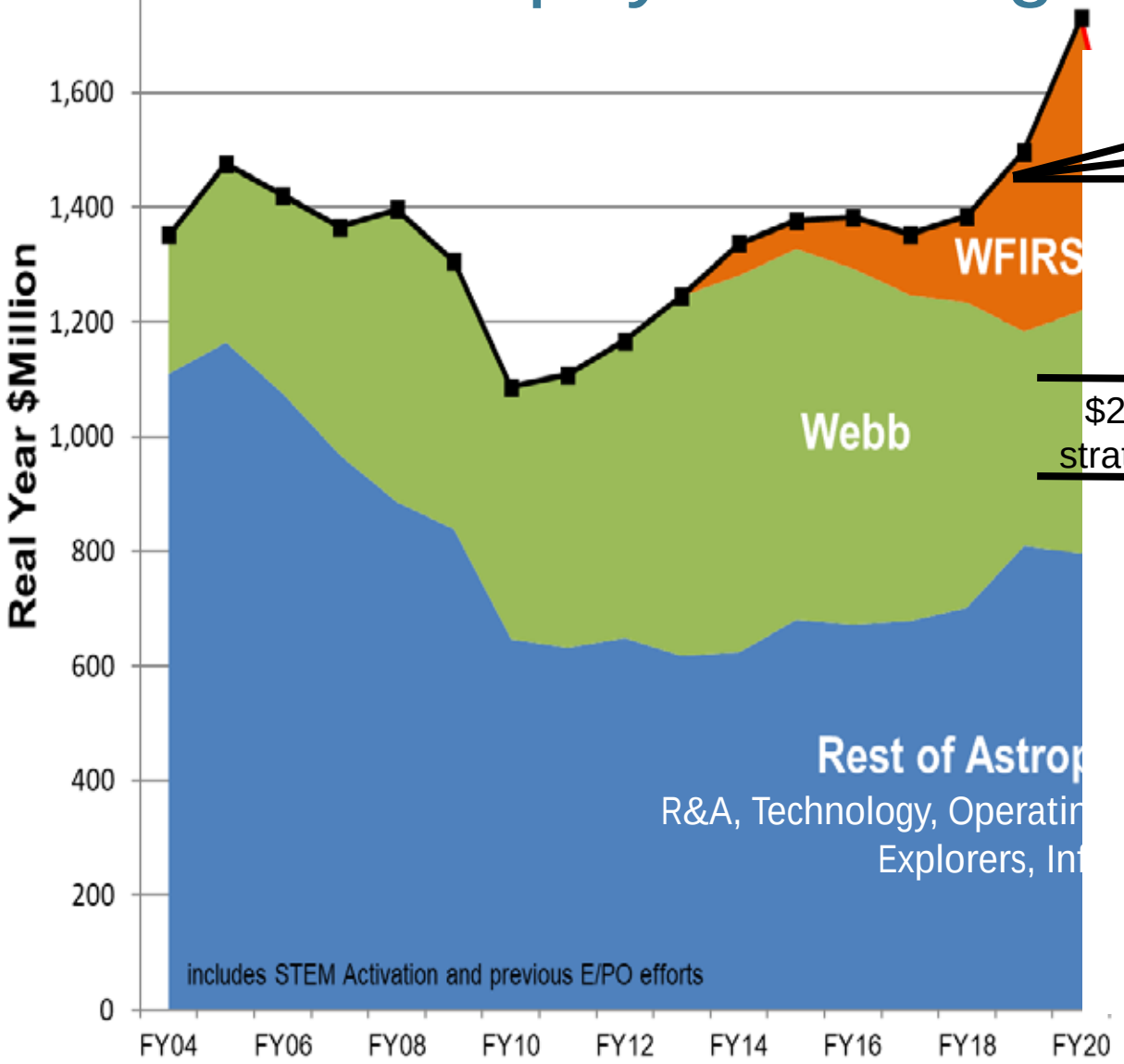


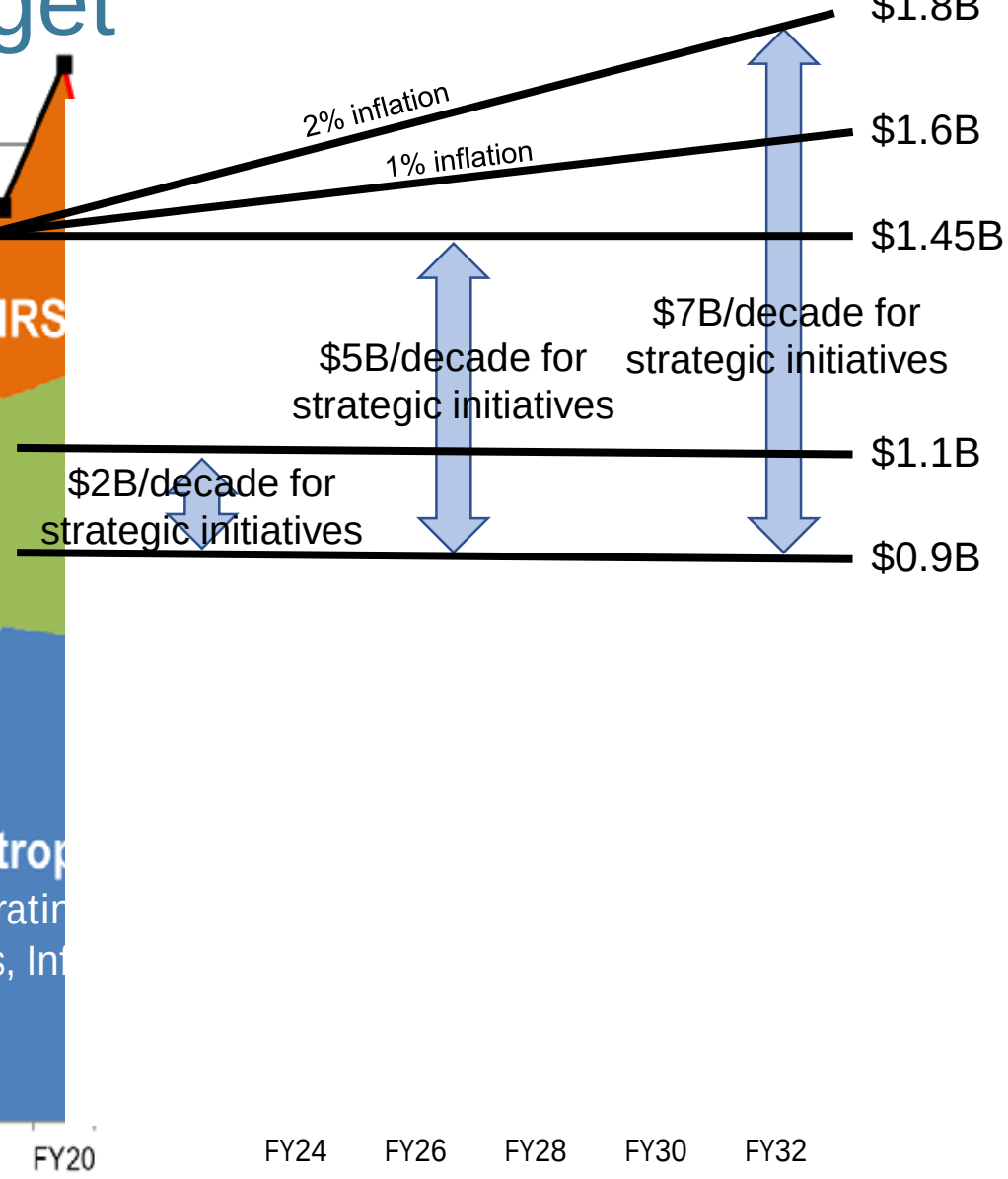


NASA's independent assessment of large mission concept studies by the Large Mission Concept Independent Assessment Team (LCIT) is available at https://science.nasa.gov/astrophysics/2020-decadal-survey-planning

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





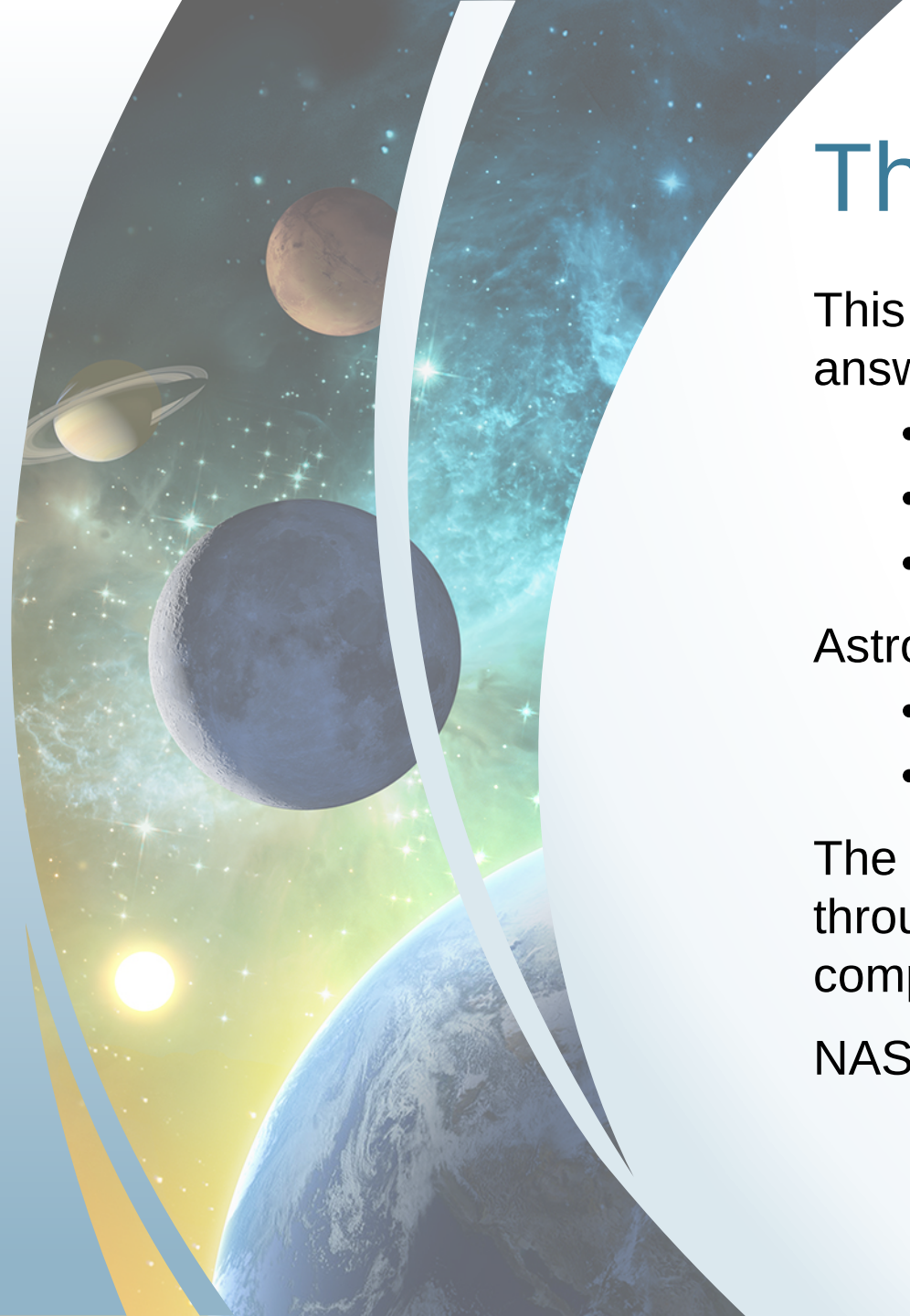
Average of recent* appropriations plus inflation

Average of recent* appropriations

Runout of FY20 Budget Proposal

Current program including Webb operations and 4 Explorers/decade

* Does not include FY20 appropriation



The Future

This is an exciting time for Astrophysics – we are pursuing 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 multimessenger

- NASA has 10 operating astrophysics missions*
- NASA is developing 11 astrophysics missions*

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

NASA is ready to realize the community's priorities

* includes partner-led missions


NASA
EXPLORE
with us

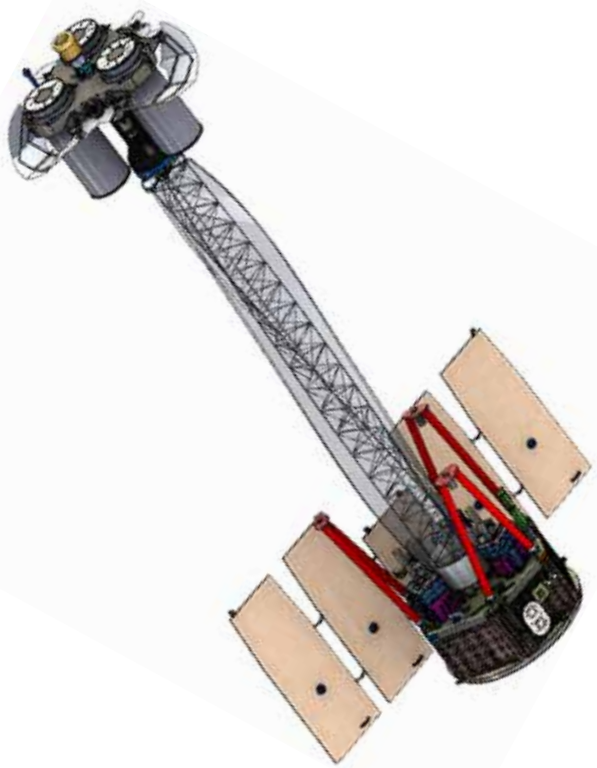
BACKUP

SOFIA

Stratospheric Observatory for Infrared Astronomy

- SOFIA's 5-year prime mission ended at the end of FY19 (Sep 30, 2019)
- NASA conducted two reviews of the SOFIA project in 2019 aimed at increasing the science productivity of SOFIA in FY20 and beyond
  - Review of SOFIA's maintenance and operations paradigm
  - Review of SOFIA's science progress and science prospects
- Summary of reviews and NASA response posted at: https://science.nasa.gov/astrophysics/documents
- Based on the reviews, SOFIA project is making change to improve productivity:
  - 8 hour flights for Cycle 8 for the months when the observing conditions are poor (Spring, Fall).
  - A larger fraction of observing time doing legacy programs – 5 diverse "pilot legacy" programs selected. If successful, project may do more and larger legacy programs.
  - Maximizing and emphasizing collection of high-quality data.
    - Efforts include: maximizing time in the stratosphere, strict/robust technical evaluation, prioritizing collection of large, and homogeneous data sets, exploring different operational models for SOFIA to maximize observing during the time of the year when observing conditions are optimal.
  - Starting Cycle 8, SOFIA will adopt a policy for finishing priority 1 & 2 programs, once started.
- HIRMES, the next SOFIA science instrument, continues development
  - After a continuation review in Dec 2018, delivery anticipated Dec 2020.

Imaging X-ray Polarimetry Explorer (IXPE)

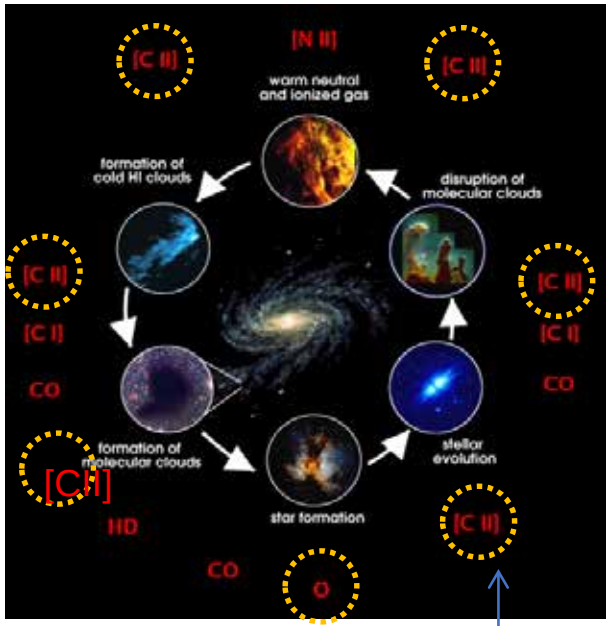


- IXPE Project successfully completed Critical Design Review (CDR) held on June 25-28 at Ball Aerospace.
- SpaceX Falcon 9 chosen as the launch vehicle for IXPE mission.
    - Falcon 9 launch from KSC (~28.5 degree latitude) will execute a major orbital plane change to IXPE science-required zero degree orbital inclination.
- Critical vibration re-testing of modified engineering Modular Mirror Assembly (MMA) successfully completed at MSFC.
- Development of Italian X-ray detector units (DU) is ongoing, with the delivery of first flight DU in December 2019
- Instrument and spacecraft integration beginning in Spring 2020
- Launch currently planned for April 2021

GUSTO Suborbital Explorer

GUSTO (Galactic/Extragalactic ULDB Spectroscopic Terahertz Observatory), led by PI Chris Walker (University of Arizona), is an Astrophysics Explorer (MO) balloon mission and is an advanced version of the STO-2 balloon payload.

GUSTO uses large-scale surveys & spectral diagnostics of the Interstellar Medium (ISM) to answer key questions about the full Life Cycle of the ISM and massive star formation.



GUSTO Lines

Brightest Line in the Far-IR over cosmic times.

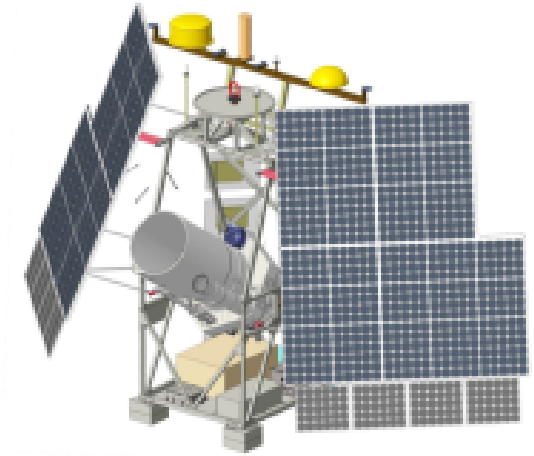
~300 dedicated SOFIA flights would be required to equal the GUSTO survey

<u>Milestones:</u>

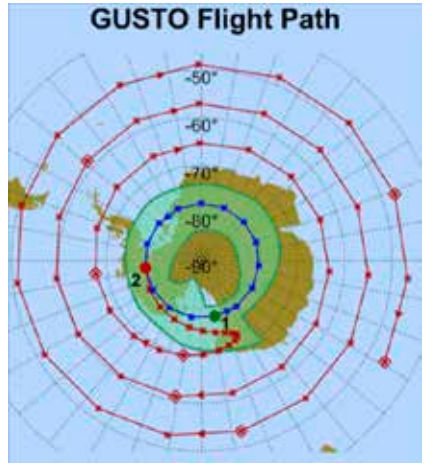
- ü Mission Preliminary Design Review: Nov 15, 2018
- ü Confirmation Review (KDP-C): Mar 12, 2019
- ü Mission Critical Design Review (CDR): Oct 2019

  Pre Ship Review / Mission Readiness Review: Jul 2021

  Launch from McMurdo Station, Antarctica: Dec 2021



GUSTO Payload



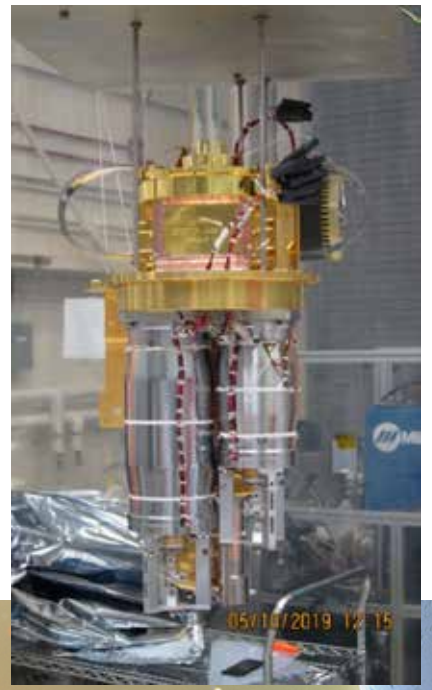
Flight Strategy, Launch (Dec 2021) from McMurdo on a superpressure balloon and allow payload to leave the continent. Instrument recovery preferred, but optional. Target survey duration 75 day, accept-able base-line 20 days, cryogenic for 100 days.

XRISM: X-ray Imaging and Spectroscopy Mission

XRISM/Resolve CSI – Dewar Integration
Nov 25, 2019 in Niihama, Japan

Sumitomo Heavy Industries, Ltd.

- Passed the Integrated Systems Preliminary Design Review which was held in Japan in March 2019.
- Resolve instrument currently integrated in flight Dewar in Japan, preparing for environmental testing.
- Remaining US-built hardware to be delivered to JAXA in stages throughout 2020.



- Call for US Performance Verification phase Participating Scientists planned for ROSES 2020.
- XRISM launch, by JAXA, currently planned for early 2022.

Euclid

Near Infrared Spectrometer and Photometer - fully populated focal plane includes NASA provided 16 (2K x 2K each) Sensor Chip Systems

Science Program Includes

- Dark Energy and Dark Matter
- Initial conditions of the Universe
- Conduct deep NIR survey to explore high redshift
- Relationship between dark matter and baryons

ESA led mission with NASA partnership

- Completed mission CDR in November 2018
- NASA completed all flight hardware Sensor Chip Systems deliveries in June 2019 for the NISP instrument focal plane
- Mission In Assembly, Integration and Test phase
- Mission Launch ~ June 2022

Science Participation

- US Euclid Science teams integrated into Euclid Consortium science planning activities
- General US science participation to be through archival data research after Euclid data products release

LISA Update

- The LISA mission successfully passed ESA's Mission Confirmation Review (MCR) in November 2019.
- One of NASA's contribution, the Charge Management System, developed at UFl, has passed its technology readiness level 5 review with flying colors in November 2019
  - The CMS TRL 4 device was delivered to U. Trento where it was integrated with the torsion pendulum for system-level testing of charge control
  - This is the 1st delivery of NASA to Europe
- The NASA LISA Science Study Team (NLST) was refreshed with the addition of 7 new members:

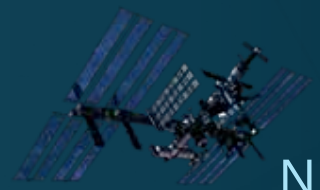
  Jeremy Darling (U Colorado / CASA)
  Matthew Digman (Ohio State)
  Kayhan Gultekin (Michigan)
  Zoltan Haiman (Columbia)
  Xin Liu (U. Illinois)
  Krista Lynne Smith (Stanford / SMU)
  Marcelle Soares-Santos (Brandeis)
- Many thanks to former members C. Hogan, B. Kamai, and G. Mueller*

*now member of the LISA Core Team

Astrophysics Explorers Program

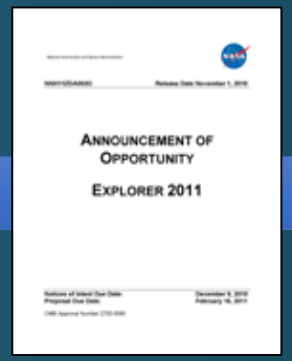
Swift

NuSTAR



NICER

TESS

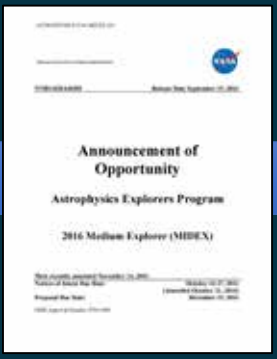


MIDEX
2011

SMEX
2014

MIDEX
2016

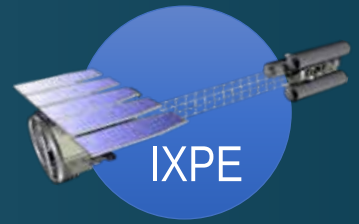
SMEX
2019



MIDEX
2021

Small and Mid-Size Missions

TESS



IXPE

SPHEREx

Directed
2017

Missions of Opportunity

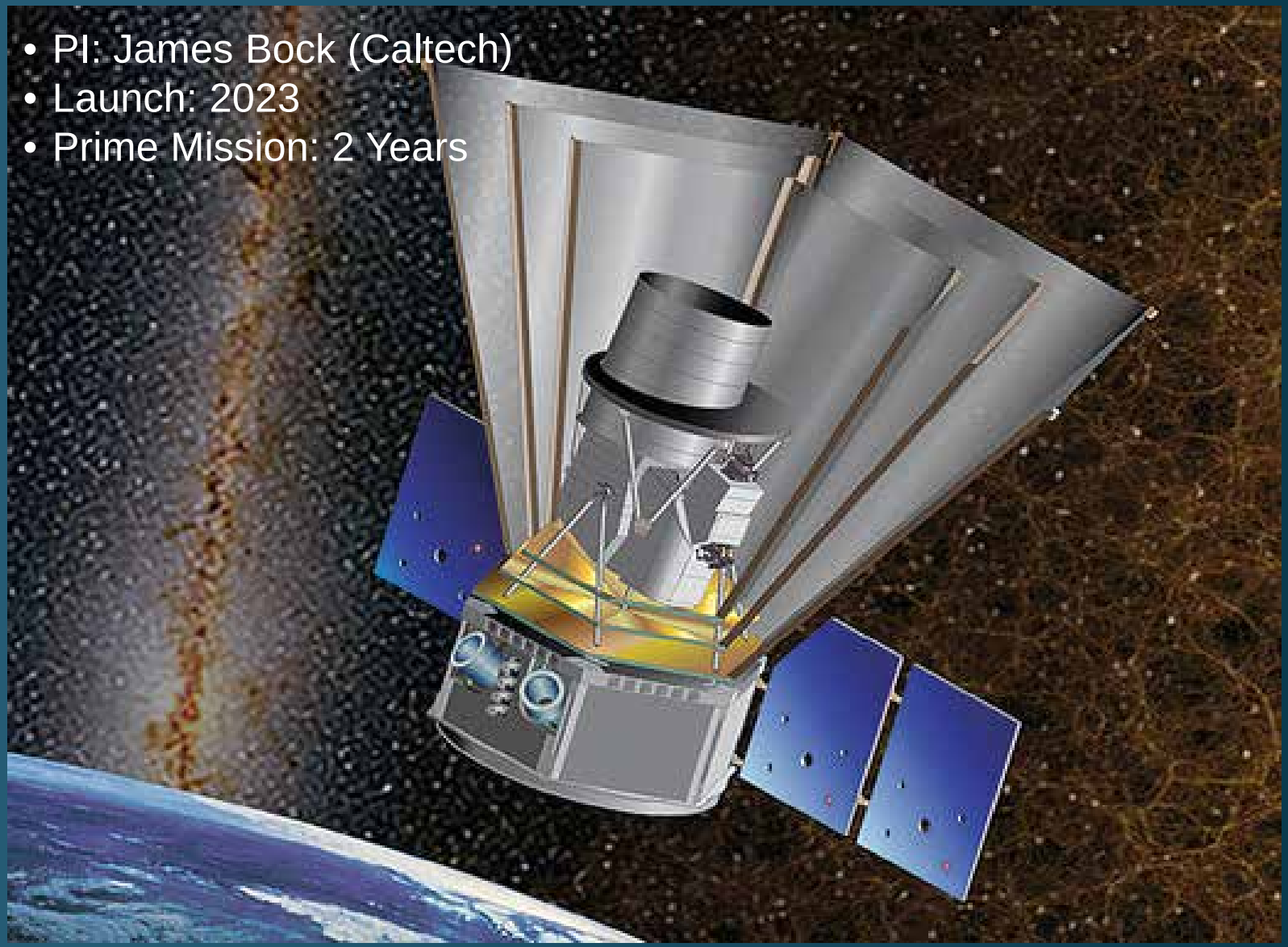
NICER

GUSTO

MO TBD

XRISM

Spectro-Photometer for the History of the Universe Epoch of Reionization and Ices Explorer (SPHEREx)



Science Highlights include:

- Survey the entire sky every 6 months
- Optical and infrared survey mission (96 bands/pixel)
- Observe hundreds of millions of galaxies
  - Measure redshifts to probe the statistical distribution of inflationary ripples
  - Measure spatial fluctuations in the Extragalactic Background Light to support studies of the origin and history of galaxy formation.
- Survey Galactic Molecular Clouds for water and organic molecules (H_2O, CO, CO_2, CH_3OH)

Astrophysics Program Content (FY20 Request)

	Actual FY 18	Enacted FY 19	Request FY 20	Out-years FY 21	FY 22	FY 23	FY 24
Astrophysics	**850.4**	**1,191.6**	**844.8**	**902.4**	**965.2**	**913.5**	**907.7**
Astrophysics Research	203.1	222.8	250.7	309.3	302.5	299.1	298.8
Astrophysics Research and Analysis	74.1	83.4	86.6	90.2	92.2	94.2	94.2
Balloon Project	36.6	40.2	44.8	44.8	44.8	44.8	44.8
Science Activation	44.0	45.0	45.6	45.6	45.6	45.6	45.6
Other Missions and Data Analysis	48.5	54.2	73.7	128.7	119.9	114.5	114.2
Astrophysics Data Curation and Archival	18.2	17.9	21.2	21.2	21.5	22.0	22.0
Astrophysics Data Program	17.6	19.1	20.4	21.6	22.6	23.6	23.6
Astrophysics Senior Review				33.5	20.5	27.3	31.6
Contract Administration, Audit & QA Svcs	12.7	4.5	12.7	12.7	12.7	12.7	12.7
Astrophysics Directed R&T		12.7	19.4	39.7	42.7	28.9	24.3
Cosmic Origins	211.2	222.8	185.3	173.9	181.7	121.7	121.7
Hubble Space Telescope (HST)	98.3	98.3	83.3	93.3	98.3	98.3	98.3
Stratospheric Observatory for Infrared Astronom	85.2	85.2	73.0	60.0	60.0		
Other Missions and Data Analysis	27.7	39.3	29.0	20.6	23.4	23.4	23.4
Cosmic Origins SR&T	15.5	24.9	17.1	18.4	18.4	18.4	18.4
SIRTF/Spitzer	11.2	13.0	8.5	1.0			
Cosmic Origins Future Missions	1.0	0.8	2.2	0.0	3.8	3.8	3.8
Astrophysics Strategic Mission Prog Mgmt		0.5	1.2	1.2	1.2	1.2	1.2

Astrophysics Program Content (FY20 Request)

	Actual FY 18	Enacted FY 19	Request FY 20	Out-years FY 21	FY 22	FY 23	FY 24
Physics of the Cosmos	118.0	151.2	148.4	128.5	123.3	117.8	117.4
Euclid	19.8	17.2	13.7	11.0	8.9	9.9	10.3
Physics of the Cosmos Future Missions	0.2	0.9	2.0	1.1	3.8	3.5	3.7
Chandra X-Ray Observatory	56.9	60.9	58.4	58.4	58.4	58.4	58.4
Fermi Gamma-ray Space Telescope	13.0	16.5	14.0				
XMM	2.5	4.5	3.5				
Physics of the Cosmos SR&T	20.9	45.7	50.9	52.1	46.3	40.1	39.0
PCOS/COR Technology Office Management	4.6	5.6	5.9	5.9	6.0	6.0	6.0
Exoplanet Exploration	200.8	367.9	46.4	44.3	45.6	46.1	48.5
WFIRST	150.0	312.2					
Kepler	10.0	8.9	1.3				
Keck Operations	6.2	6.4	6.7	6.9	7.0	7.2	7.4
Large Binocular Telescope Interferometer	1.8						
Exoplanet Exploration SR&T	26.4	32.3	29.1	30.0	28.9	28.9	28.6
Exoplanet Exploration Tech Office Mgmt	5.3	7.5	6.5	6.8	7.3	7.7	7.7
Exoplanet Exploration Future Missions	1.0	0.6	2.8	0.6	2.4	2.2	4.7

Astrophysics Program Content (FY20 Request)

	Actual FY 18	Enacted FY 19	Request FY 20	Out-years FY 21	FY 22	FY 23	FY 24
Astrophysics Explorer	117.4	227.0	214.1	246.4	312.0	328.8	321.4
Imaging X-Ray Polarimetry Explorer	23.5	57.0	70.2	45.3	7.4	4.5	0.5
X-Ray Imaging and Spectroscopy Mission	22.0	27.8	29.7	25.7	22.5	17.6	15.8
GUSTO	4.7	12.6	11.1	7.8	6.3	1.0	
Nuclear Spectroscopic Telescope Array	4.8	8.5	7.8				
Neil Gehrels Swift Observatory	3.9	7.0	5.5				
Transiting Exoplanet Survey Satellite	33.5	7.7	5.0	0.2			
Neutron Star Interior Composition Explor	2.1	3.8					
Astrophysics Explorer Future Missions	11.8	95.1	84.8	154.2	267.0	295.1	299.2
Astrophysics Explorer Program Managemen	11.1	7.6		13.3	8.8	10.7	5.9
James Webb Space Telescope	**533.7**	**304.6**	**352.6**	**415.1**	**175.4**	**172.0**	**172.0**

SMD Organization Chart