

National Aeronautics and
Space Administration



EXPLORE SCIENCE

NASA Astrophysics Update

Astronomy and Astrophysics Advisory Committee
Telecon Meeting
June 3, 2019

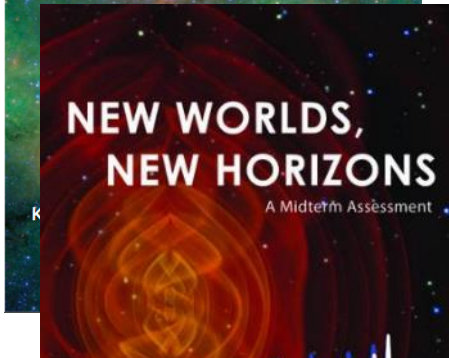
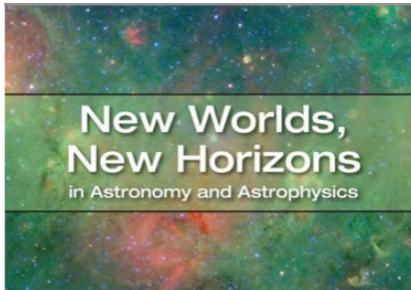
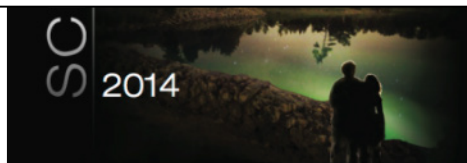
Paul Hertz

Director, Astrophysics Division
Science Mission Directorate
@PHertzNASA 

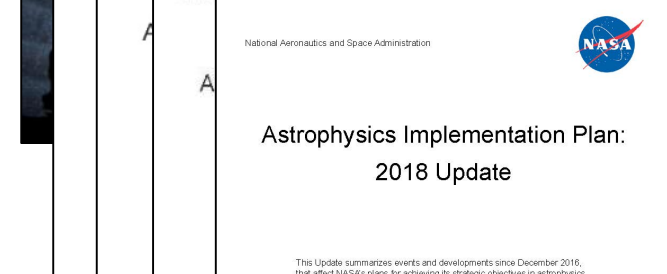
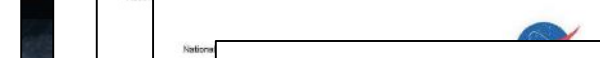
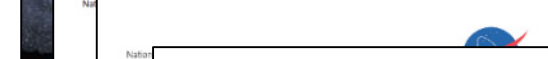
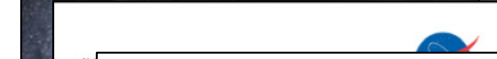
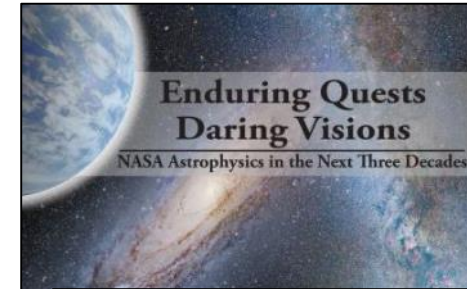
Astrophysics Strategic Planning



To be updated in 2019
(per GPRAMA)



Astro2020 Decadal Survey
underway

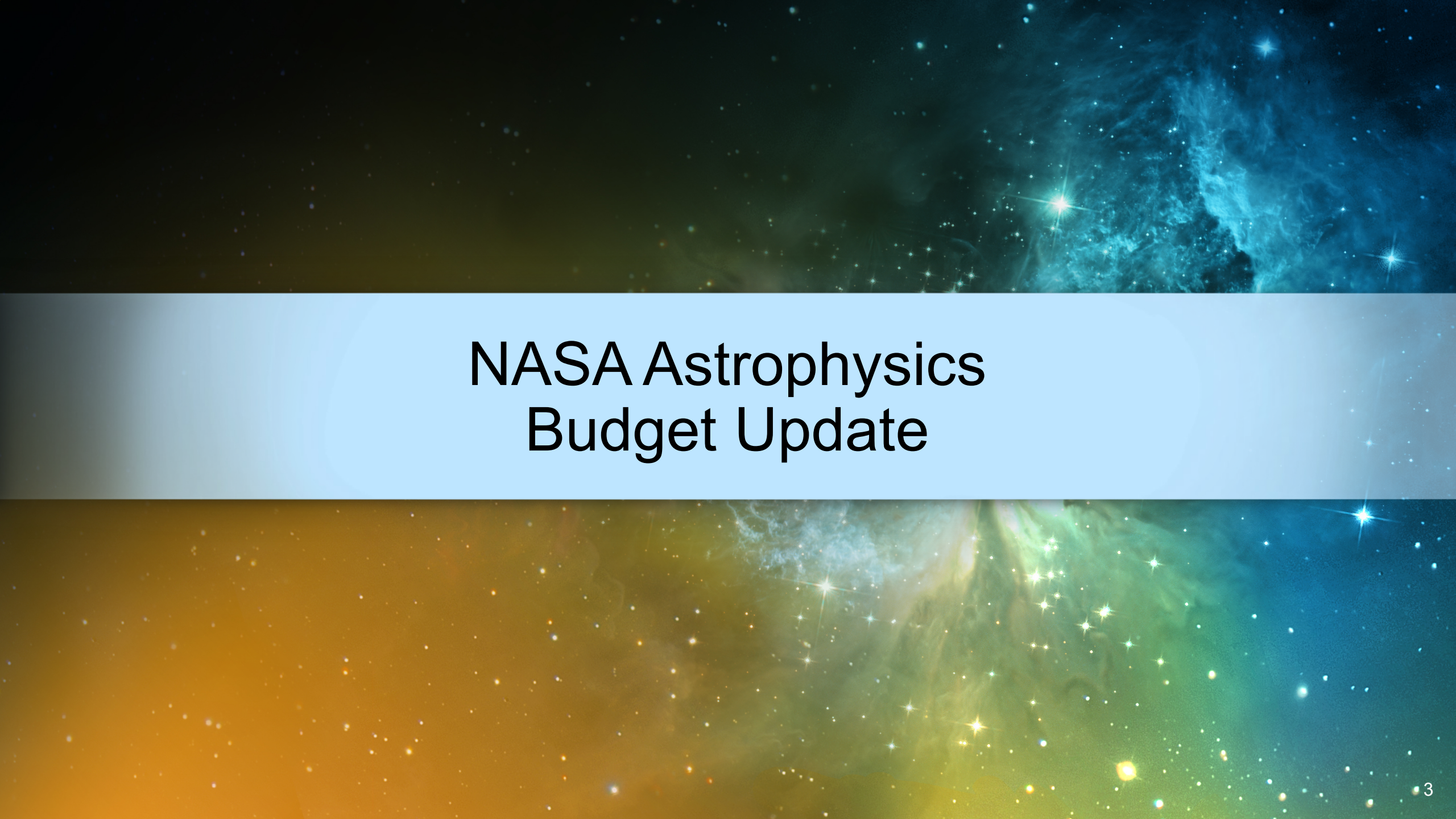


2018 update includes:

- Independent reviews of Webb & WFIRST
- Planning for 2020 Decadal Survey

NASA Headquarters
December 17, 2018

<https://science.nasa.gov/astrophysics/documents>

The background of the slide is a composite of two astronomical images. The top half features a dark blue and black space scene with a prominent, glowing blue nebula on the right side and several bright stars with diffraction spikes. The bottom half shows a vibrant orange and yellow nebula on the left, transitioning into a greenish-blue nebula on the right, with numerous stars scattered throughout. A semi-transparent light blue horizontal band is positioned across the middle of the slide, containing the title text.

NASA Astrophysics Budget Update



FY20 Budget Request

The FY20 President's Budget Request requests a decreased level of funding for NASA Astrophysics.

Total funding requested for FY20 (Astrophysics including Webb) is ~1.197B, a decrease of \$187M (14%) from the FY18 appropriation and a decrease of \$299M (20%) from the FY19 appropriation.



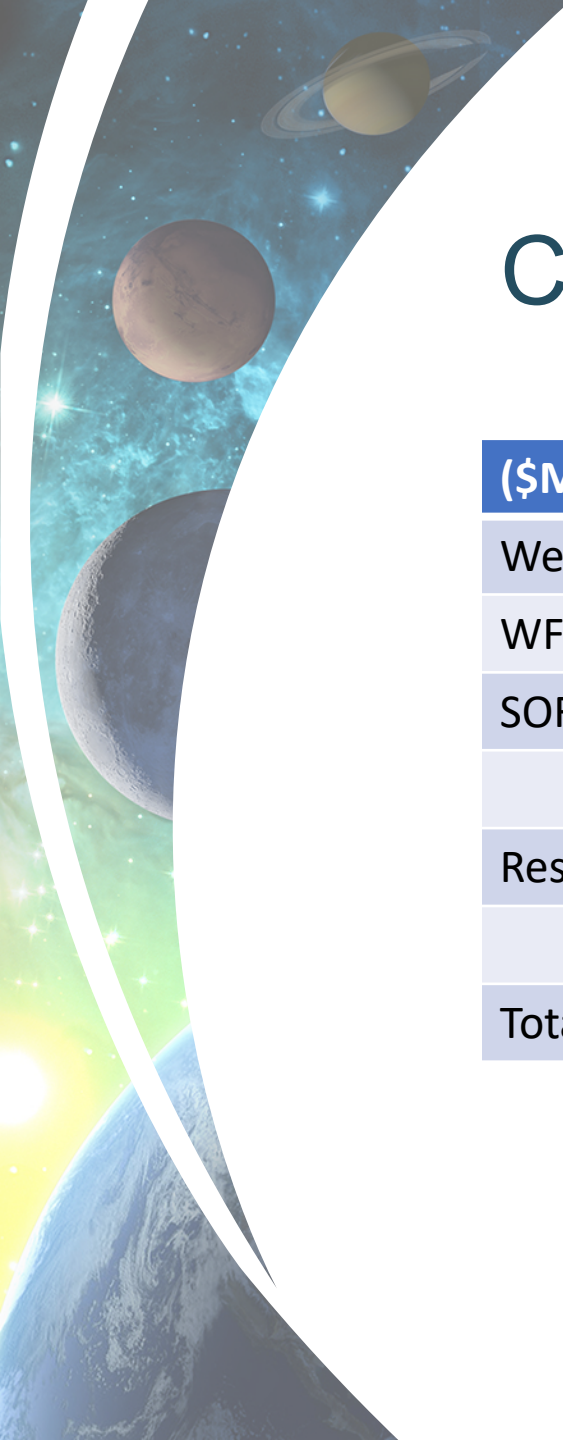
FY20 President's Budget Request for Astrophysics including Webb Telescope

What's Changed

- Webb budget increased consistent with 2018 replan, Webb proceeding toward launch in 2021
- Probe program deferred to fund Webb replan
- SPHEREx begun within Explorers program as next Astrophysics MIDEX
- SOFIA mission funded beyond end of 5-year prime mission in 2019, details pending 2019 independent reviews
- Provides no funding for WFIRST space telescope

What's the Same

- Cadence of four Explorer and Mission of Opportunity AOs per decade
- Spitzer ends operations January 2020 per 2016 Senior Review
- Phase A studies of Small Explorers (SMEX) and Missions of Opportunity from 2019 AO
- IXPE, GUSTO, XRISM, and Euclid development remains on track and within budget
- Hubble, Chandra, and 6 smaller operating missions continue pending 2019 Senior Review
- CubeSat initiative and four balloon campaigns within healthy research program
- Mission concept studies and technology investments to support Astro2020



Congressional Markup of FY20 Budget

(\$M)	Request	House	Senate	Comment
Webb	352.6	352.6		Supports replan
WFIRST	0	510.7		Includes \$65M for CGI
SOFIA	73.0	85.2		
Rest of Astrophysics	772.8	771.8		\$1M (0.1%) reduction
Total	1,197.4	1,720.3		

A Budget Increase for the Artemis Program

- The FY2020 budget amendment provides an **increase** of **\$1.6 billion** above the president's initial **\$21 billion** budget request with no money taken from existing NASA programs. This is the **boost** NASA needs.
 - \$1 billion to accelerate development of human lunar transportation systems to take astronauts to the surface and back to Gateway*
 - \$651 million towards the completion of SLS and Orion to support a 2024 landing.
 - \$132 million for new technologies to help astronauts live and work on the lunar surface and in deep space.
 - \$90 million for Science to increase robotic exploration at the lunar South Pole in advance of astronauts.

** Focusing Gateway on just the capabilities needed for Phase 1 allowed for a \$321M scope reduction and shifts potential development and expanded capabilities for Gateway into Phase 2.*

Artemis Phase 1: To the Lunar Surface by 2024

MARS 2020

ARTEMIS 1: FIRST HUMAN SPACECRAFT
TO THE MOON IN THE 21st CENTURY

ARTEMIS 2: FIRST HUMANS TO
THE MOON IN THE 21st CENTURY

FIRST HIGH POWER
SOLAR ELECTRIC
PROPULSION (SEP)
SYSTEM

FIRST PRESSURIZED
CREW MODULE
DELIVERED TO
GATEWAY

ARTEMIS 3: CREWED
MISSION TO GATEWAY
AND LUNAR SURFACE

Commercial Lunar Payload Services

- CLPS delivered science and technology payloads

Descent Element Test

- First large-scale lander on the Moon

Early South Pole Crater Rim Mission(s)

- First robotic landing on eventual human lunar return and ISRU site
- First ground truth of polar crater volatiles

Humans on the Moon - 21st Century

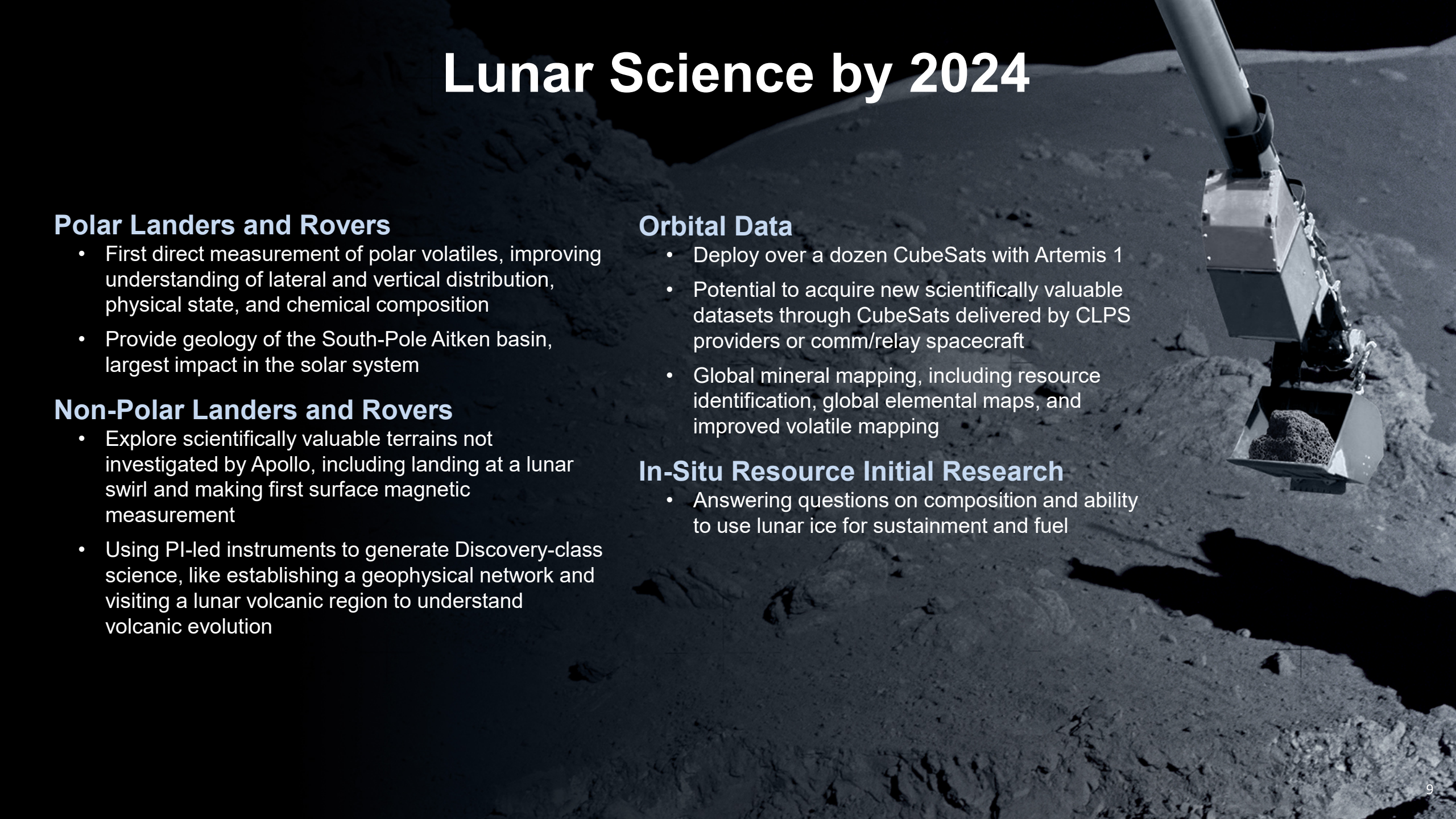
First crew leverages infrastructure
left behind by previous missions

LUNAR SOUTH POLE CRATER TARGET SITE

2019

2024

Lunar Science by 2024



Polar Landers and Rovers

- First direct measurement of polar volatiles, improving understanding of lateral and vertical distribution, physical state, and chemical composition
- Provide geology of the South-Pole Aitken basin, largest impact in the solar system

Non-Polar Landers and Rovers

- Explore scientifically valuable terrains not investigated by Apollo, including landing at a lunar swirl and making first surface magnetic measurement
- Using PI-led instruments to generate Discovery-class science, like establishing a geophysical network and visiting a lunar volcanic region to understand volcanic evolution

Orbital Data

- Deploy over a dozen CubeSats with Artemis 1
- Potential to acquire new scientifically valuable datasets through CubeSats delivered by CLPS providers or comm/relay spacecraft
- Global mineral mapping, including resource identification, global elemental maps, and improved volatile mapping

In-Situ Resource Initial Research

- Answering questions on composition and ability to use lunar ice for sustainment and fuel

Science After 2024

Human and Robotic Missions Provide Unique Science Opportunities

On Gateway

- Deep space testing of Mars-forward systems
- Hosts groundbreaking science for space weather forecasting, full-disc Earth observation, astrophysics, heliophysics, lunar and planetary science
- Mars transit testbed for reducing risk to humans

Surface Exploration

- Understanding how to use in-situ resources for fuel and life
- Revolutionizing the understanding of the origin and evolution of the Moon and inner solar system by conducting geophysical measurements and returning carefully selected samples to Earth
- Studying lunar impact craters to understand physics of the most prevalent geologic process in the solar system, impact cratering
- Setting up complex surface instrumentation for astrophysics, heliophysics and Earth observation
- Informing and supporting sustained human presence through partial gravity research in physical and life sciences, from combustion to plant growth

Surface Telerobotics to Provide Constant Science

- Sending rovers into areas too difficult for humans to explore; rovers can be teleoperated from Earth to maximize the scientific return



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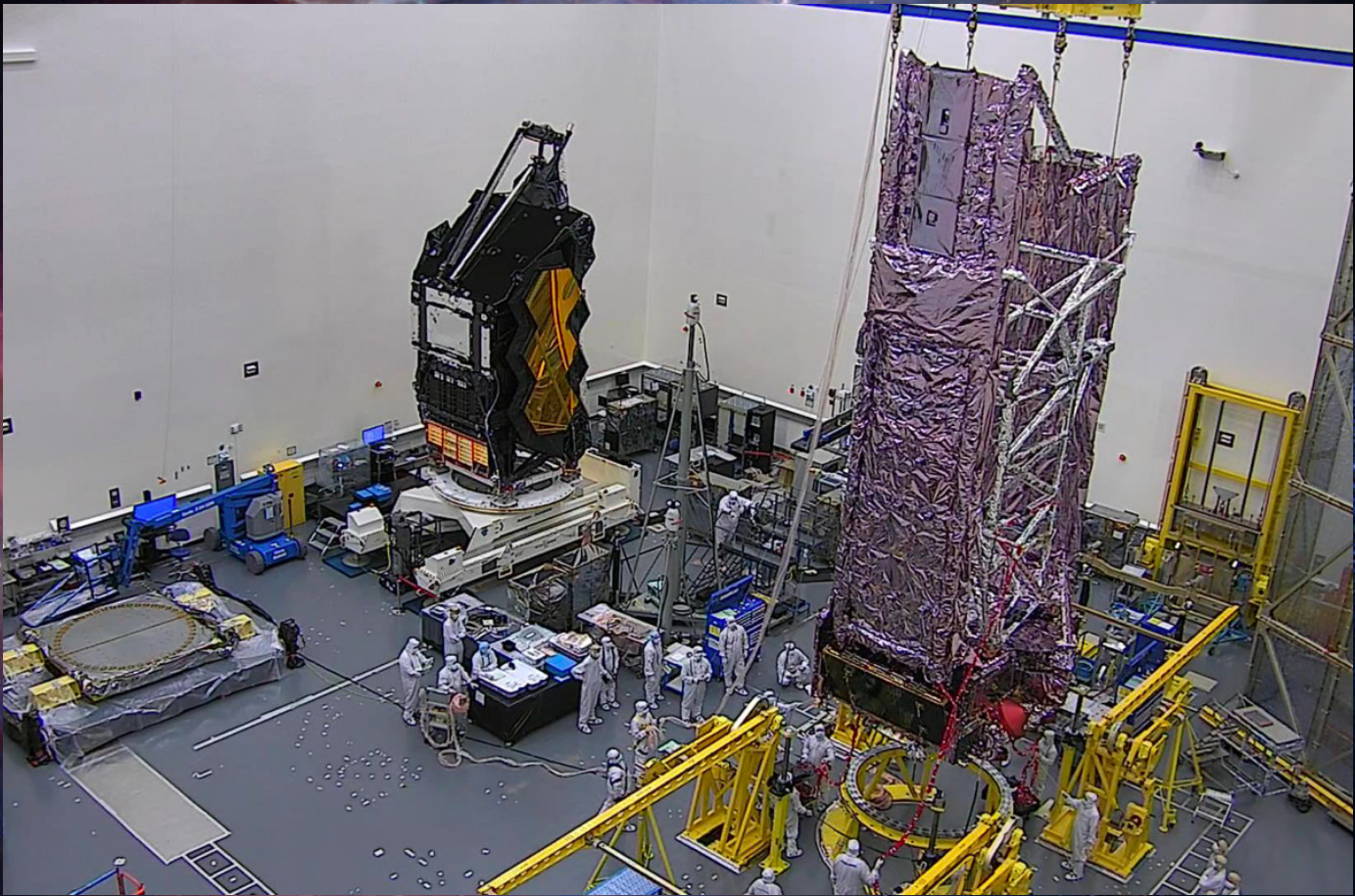
NASA Astrophysics Missions Update

Webb

The James Webb Space Telescope



- Science payload completed three months cryogenic testing at end of 2017
- Spacecraft and sunshield integration complete January 2018
- Spacecraft element including sunshield completed environmental testing May 2019
- Science payload and spacecraft integration planned for Fall 2019
- Launch scheduled for 2021
- Webb overrun covered using offsets from Astrophysics Probes

A large-scale photograph of the James Webb Space Telescope components inside a clean room. On the left, the telescope's primary mirror and instruments are mounted on a complex black structure. On the right, a tall, rectangular spacecraft element, completely covered in a crinkled, reflective gold sunshield, is being hoisted by a yellow crane. Several technicians in white cleanroom suits are visible on the floor, providing a sense of scale to the massive equipment.

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

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

Mid-2020s -- Launch

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

Science Program includes

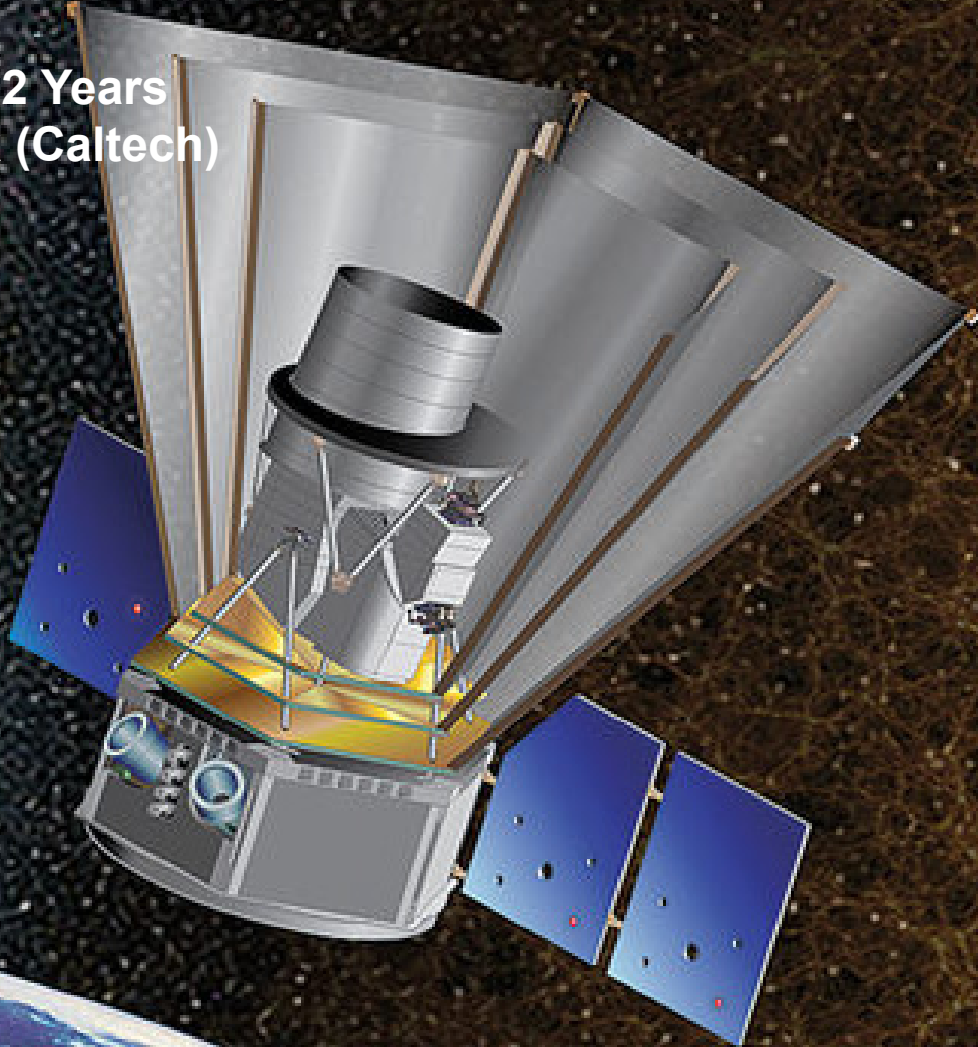
- Dark energy and the fate of the universe through surveys measuring the expansion history of the universe and the growth of structure
- The full distribution of planets around stars through a microlensing survey
- Wide-field infrared surveys of the universe through General Observer and Archival Research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

Wide-Field Infrared Survey Telescope

- **NASA continuing work on WFIRST as planned**
 - Work continues under recently approved FY19 appropriation; appropriation enacted in February 2019 includes \$312M for WFIRST
 - WFIRST remains on the plan approved at the beginning of Phase B: Cost is \$3.2-3.8B, launch is in late 2025
 - 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 in 2018**
 - WFIRST passed System Requirements Review / Mission Design Review
 - Approved in May 2018 to enter Phase B (preliminary design phase)
 - Completed System Requirements Reviews for all primary mission elements (Wide Field Instrument, Coronagraph, Optical Telescope)
 - All major contracts awarded: Telescope (Harris), Wide Field Instrument (Ball), Detectors (Teledyne)
- **Work Plan for 2019**
 - Significant flight hardware in production
 - Significant engineering work in progress
 - Four element Preliminary Design Reviews by September 2019
 - Proceeding during FY19 toward Mission Preliminary Design Review and Confirmation

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

- Awarded: February 2019
- Launch: 2023
- Prime Mission: 2 Years
- PI: James Bock (Caltech)



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 Explorers Program



Swift



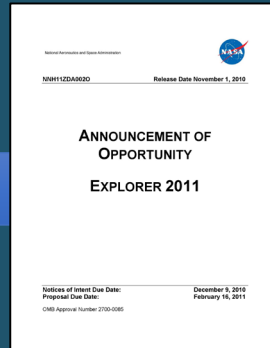
NuSTAR



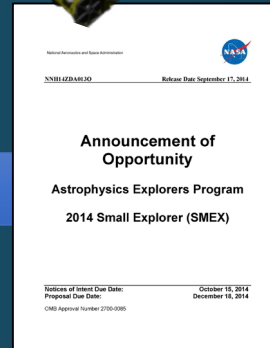
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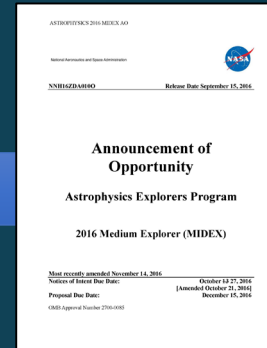
TESS



MIDEX
2011



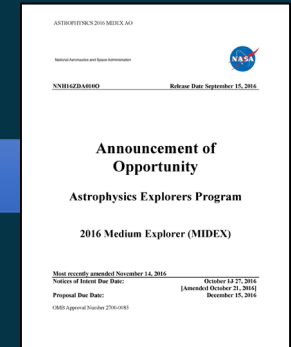
SMEX
2014



MIDEX
2016



SMEX
2019



MIDEX
2021

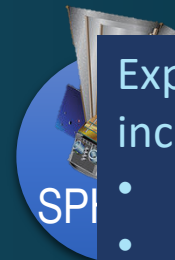
Small and
Mid-Size
Missions



TESS



IXPE



SPHEREx

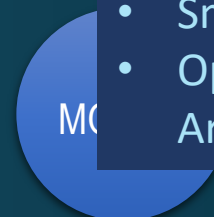
Missions of
Opportunity



NICER



GUSTO



MWA

Explorers Mission of Opportunity AO includes:

- Contributions to Partner Mission
- Small Complete Mission on ISS
- SmallSat Secondary Payloads
- Opportunities enabled by Project Artemis

XRISM

Astrophysics Missions in Development

TESS 4/2018
NASA Mission



Transiting Exoplanet Survey Satellite

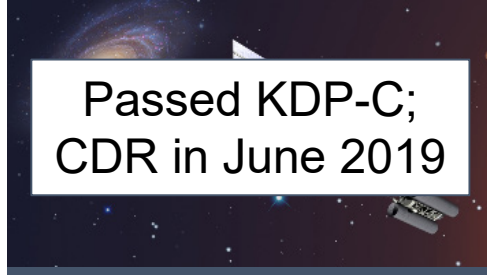
Webb 2021
NASA Mission



Replanned SIR now in Sep 2019

James Webb Space Telescope

IXPE 2021
NASA Mission



Passed KDP-C; CDR in June 2019

Imaging X-ray Polarimetry Explorer

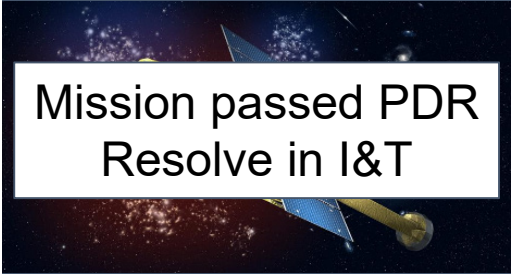
GUSTO 2021
NASA Mission



Passed KDP-C; CDR in July 2019

Galactic/ Extragalactic ULDB Spectroscopic Terahertz Observatory

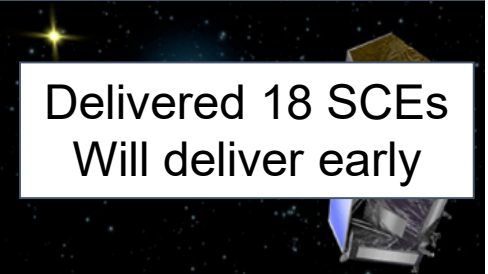
XRISM 2022
JAXA-led Mission



Mission passed PDR Resolve in I&T

NASA is supplying the SXS Detectors, ADRs, and SXTs

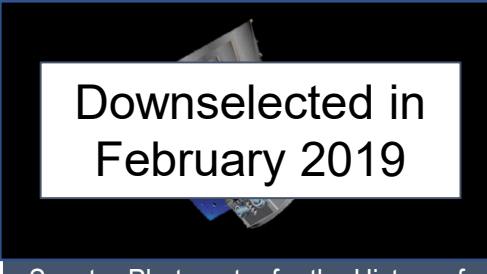
Euclid 2022
ESA-led Mission



Delivered 18 SCEs Will deliver early

NASA is supplying the NISP Sensor Chip System (SCS)

SPHEREx 2023
NASA Mission



Downselected in February 2019

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

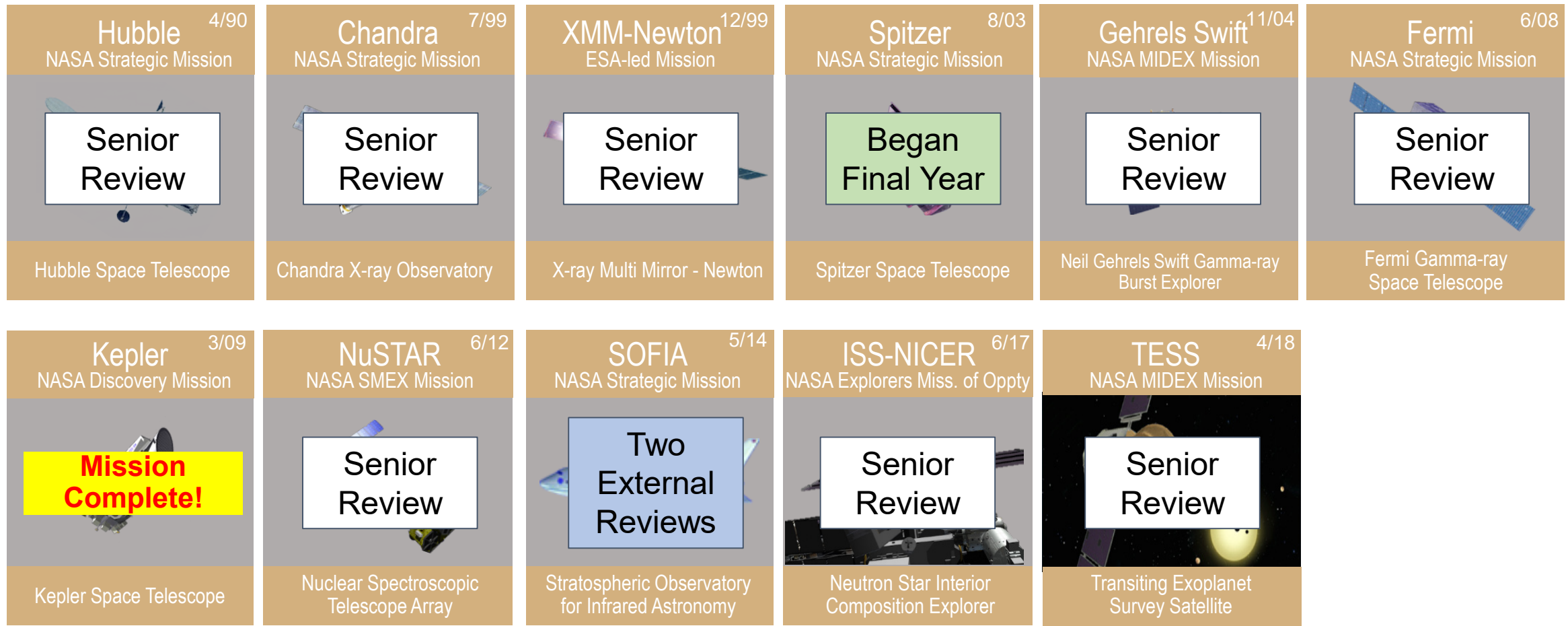
WFIRST Mid 2020s
NASA Mission



Mission PDR in October 2019

Wide-Field Infrared Survey Telescope

Operating Missions (including GO programs)



TESS

Transiting Exoplanet
Survey Satellite

Recent Announcements

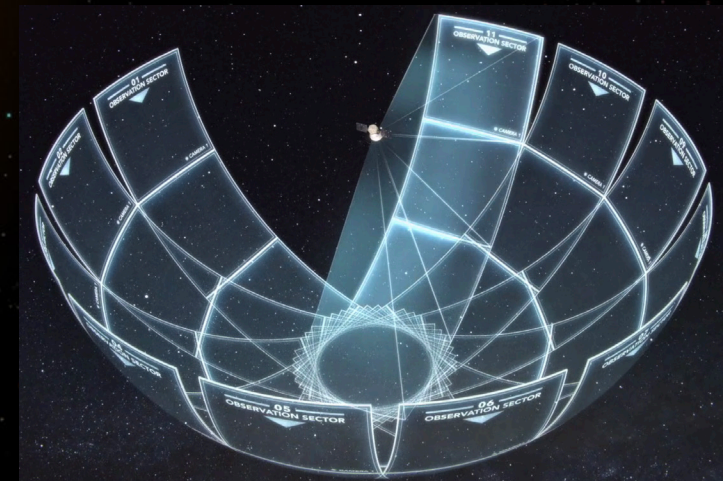
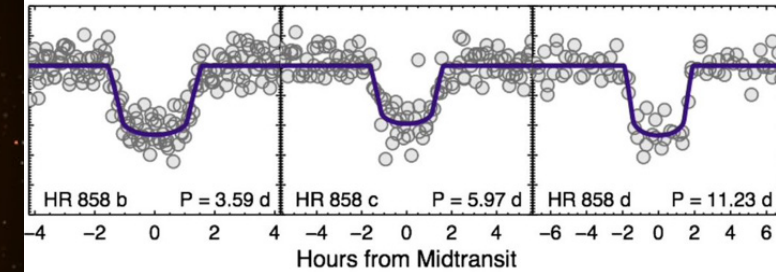
- TESS spots a system of Super-Earths around the Naked-Eye Star HR 858



HR 858
simbad.u-strasbg.fr

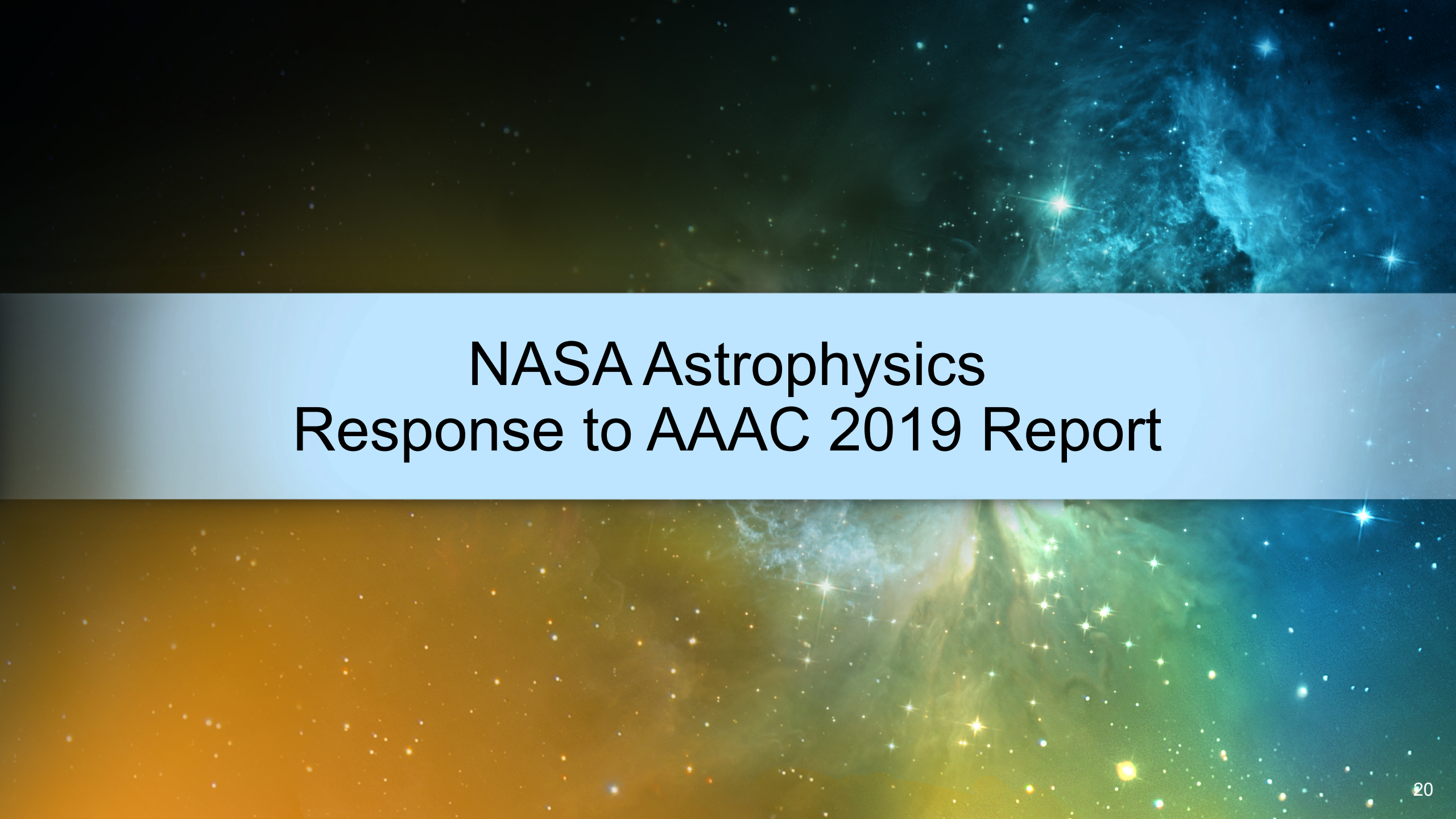
Hugh Osborn @exohugh

Whoah! @NASA_TESS has detected a triumvirate of small planets around a 6th magnitude (i.e. almost naked-eye) star. That makes this sun-like star one of the brightest in the sky to have ever been found hosting transiting planets! And it's has three of them! arxiv.org/abs/1905.05193

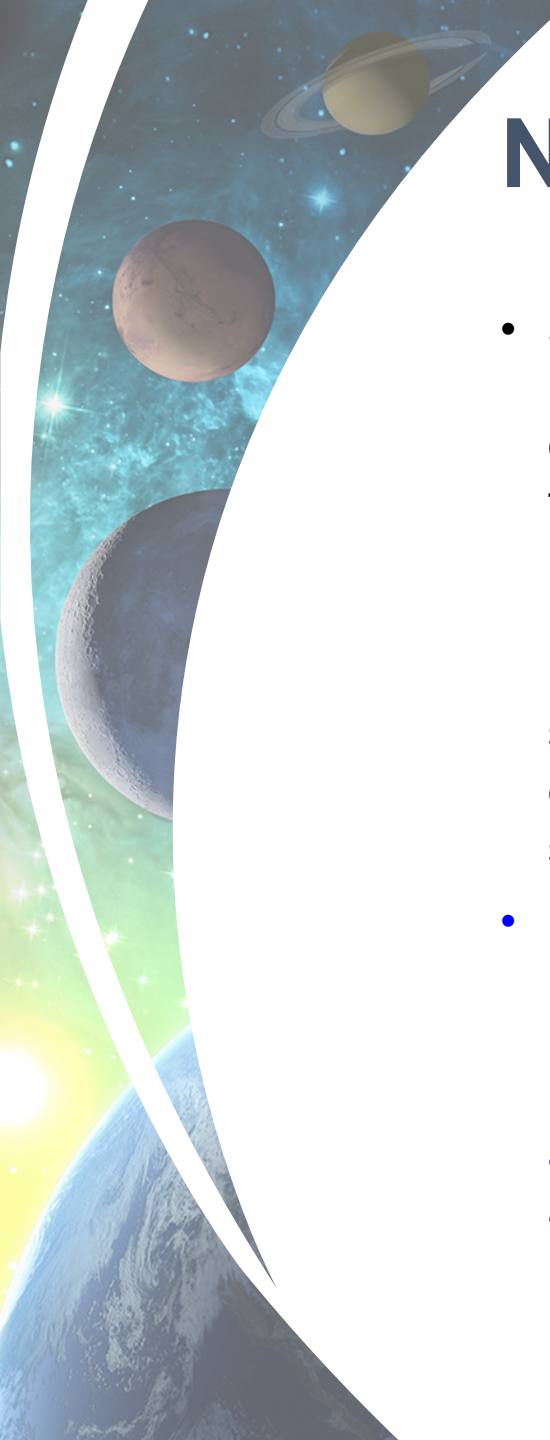


Observation Sector 11 in progress, 11 of 26 observing sectors complete, 9 sectors publicly available ahead of schedule

- 639 new TESS planet candidates available for follow-up
- 15 confirmed planets
- 130 publications; 77 through peer-review. 56% works relate to exoplanets, 44% pertain to other areas of astrophysics

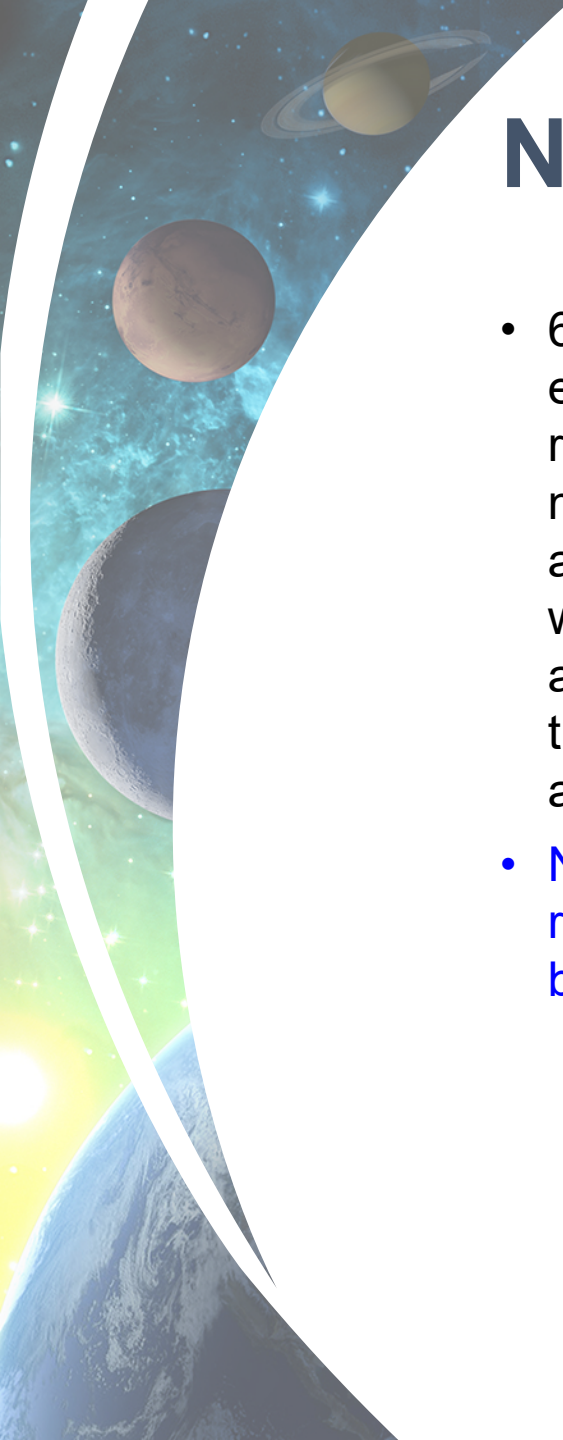
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NASA Astrophysics Response to AAAC 2019 Report



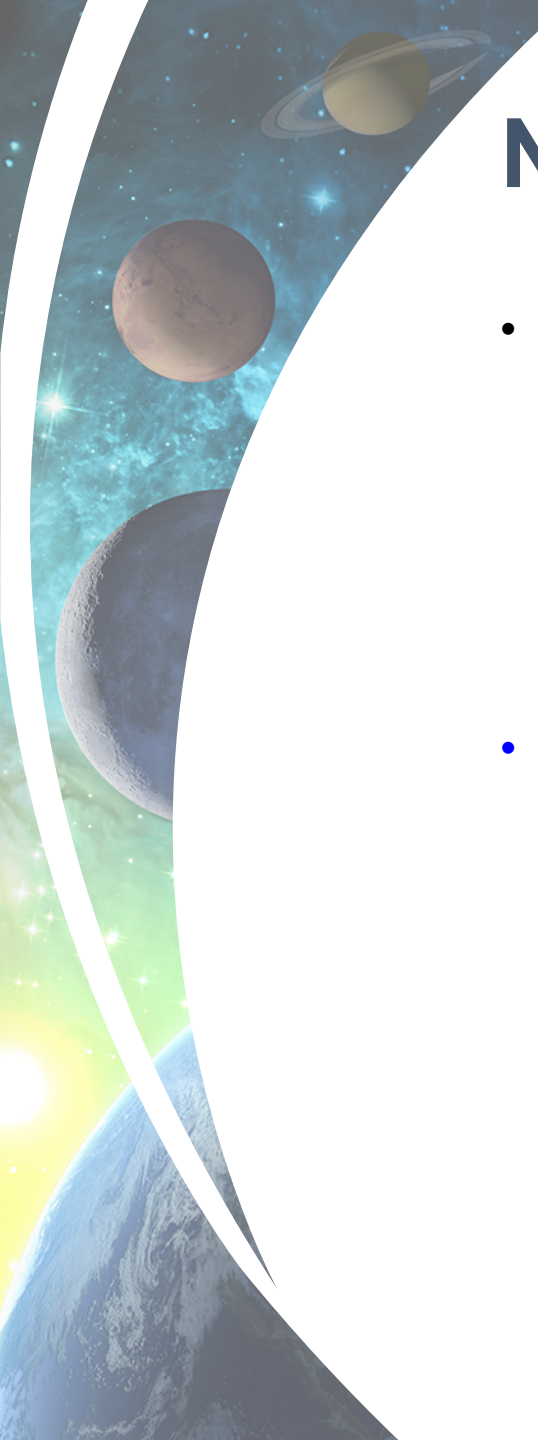
NASA Response to 2019 AAAC Report

- 5. Recommendation: All current and planned surveys supported by NSF, NASA and DOE/Cosmic Frontier should publicly release their data with suitable access tools and documentation. This is consistent with the AAAC Principles of Access recommended by the AAAC in their 2013-2014 annual report. In addition, the surveys should endeavor to use open source code to create the data products in order that the community can learn how those data products were created. We are aware that support for continued use of the source code is a much larger endeavor, and the additional benefit of such support is not clear at this time. Agencies should include in survey budgets funding to enable adequate public access to the data, software, and data products of these surveys.
- NASA response: NASA concurs. SMD data policy is consistent with this recommendation for data and tools. The NASEM report *Open Source Software Policy Options for NASA Earth and Space Sciences* (2018) recommends that “NASA Science Mission Directorate should consider a variety of policy options depending on discipline and software type and transition to greater openness over time.” NASA is currently assessing the recommendations of this study and formulating both a response and policies for open source code.



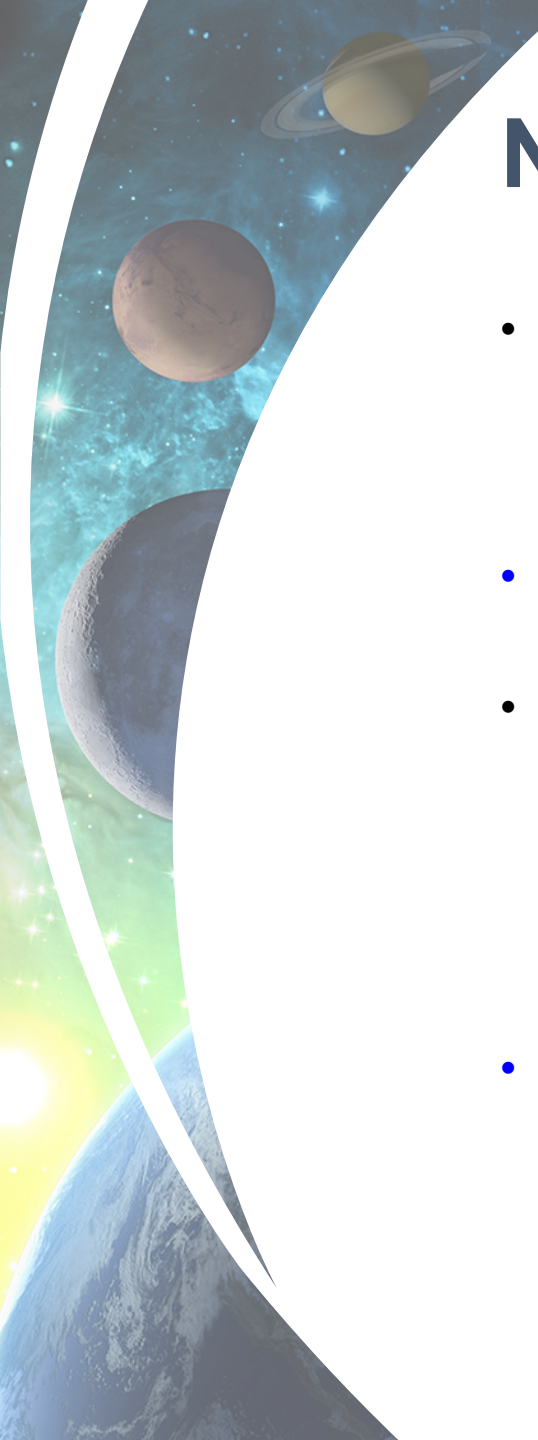
NASA Response to 2019 AAAC Report

- 6. Recommendation: The three agencies should coordinate on the guidelines and expectations for the public releases of data sets, data products, data access tools, and related software used to produce future surveys, astrophysical simulations, and missions. The goal of this coordination should be to help researchers efficiently provide access to the data they produce through tools useful for the broad scientific community with minimal duplication of effort between agencies and stakeholder groups. Release and documentation of the software used to generate and analyze the data will enhance the quality of current and future science by enabling more cost effective reproducibility and extension of the scientific results from the initial studies.
- NASA response: NASA will work with NSF and DOE to respond to this recommendation. There already exist data standards (VO protocols) and tools that are built on top of these protocols.



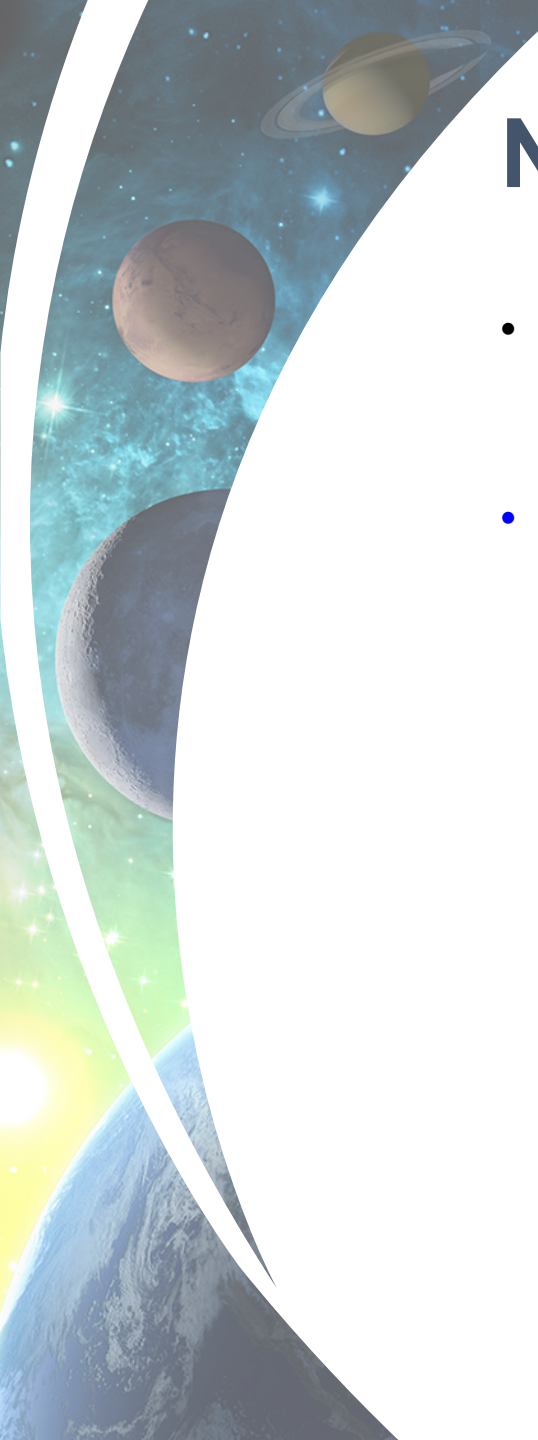
NASA Response to 2019 AAAC Report

- 11. Recommendation: We continue to recommend that the three agencies either broaden the current discussions or create parallel discussions to consider broadly the costs and benefits of coordination on the science areas of interest to both the Euclid and LSST communities. We recognize that if a decision is made to plan for coordination between LSST and Euclid during construction of LSST and to execute such a plan during LSST operations, the budgets for both the construction and operation of LSST would likely need an augmentation.
- NASA response: NASA concurs. We are awaiting the final report from the joint Agency detailed study over two years to assess the benefits, approach, and cost of implementing joint processing.



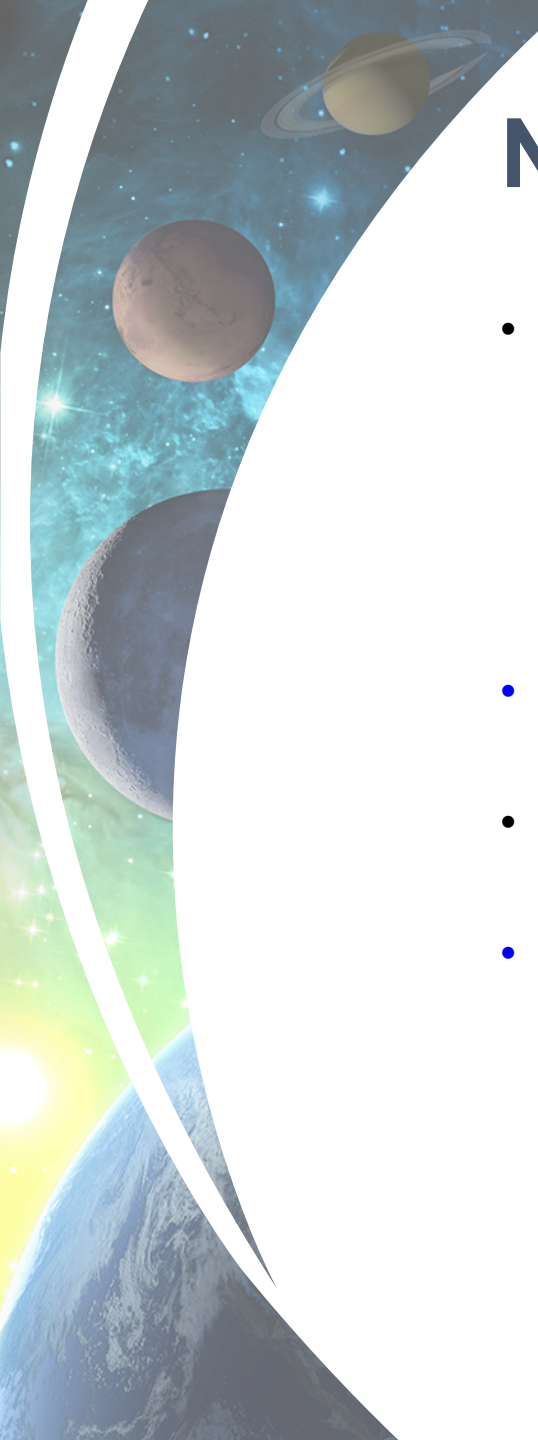
NASA Response to 2019 AAAC Report

- 14. Recommendation: Given their common interests in access to the spectrum, NASA and NSF should enhance their collaboration with each other and with other groups, including international agencies and commercial interests, to protect the accessibility of essential astronomical wavelengths to researchers.
- NASA response: NSF has the lead on spectrum management for radio astronomy. NASA will work with NSF.
- 15. Recommendation: Efforts, ideally coordinated with all three agencies, should be made to increase awareness of spectrum management issues among astronomers, the general public, and government agencies. Possible agents for meeting this recommendation might include the NSF-funded national facilities for operations at radio and optical wavelengths. Efforts to engage and coordinate with other international agencies should continue.
- NASA response: NSF has the lead on spectrum management for radio astronomy. NASA will work with NSF.



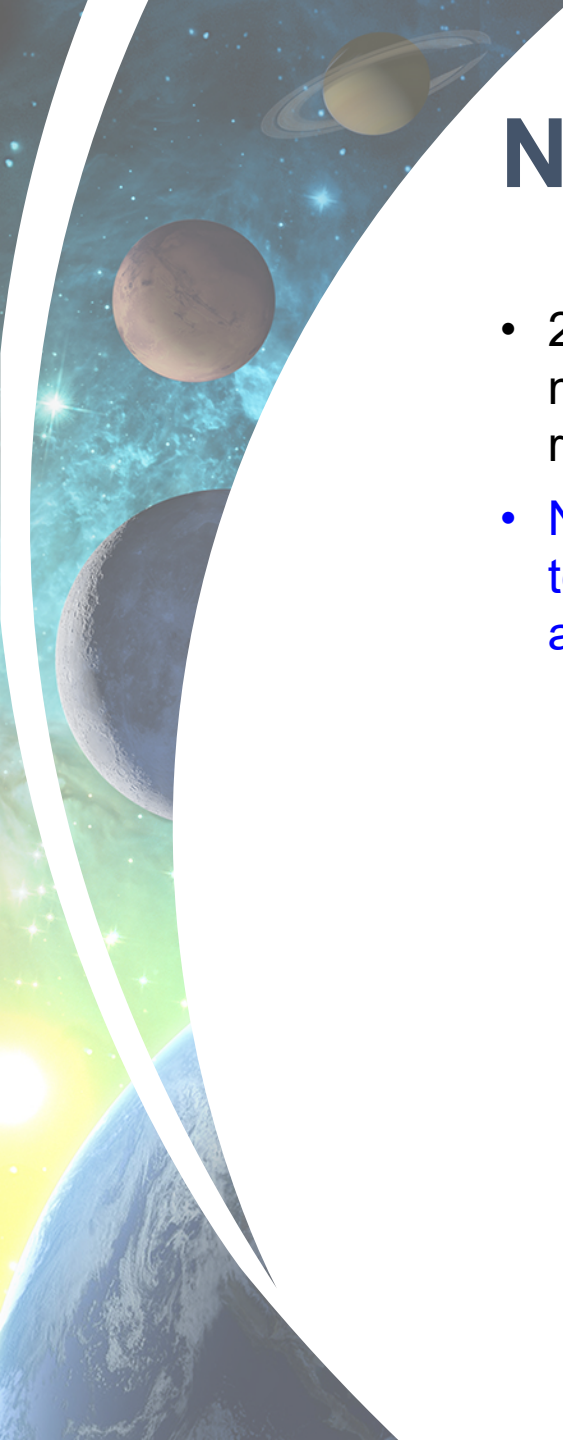
NASA Response to 2019 AAAC Report

- 17. Recommendation: The AAAC continues to recommend ongoing cost assessment and mission review of the Wide Field Infrared Survey Telescope (WFIRST) prior to and after Preliminary Design Review.
- NASA response: NASA concurs. NASA policies and procedures require this. An independent standing review board evaluates the WFIRST mission throughout its lifecycle at significant gate reviews. For the upcoming PDR, this includes a major cost and schedule assessment, which informs NASA of the estimated cost-to-complete at that point. In addition, an internal review team consisting of technical authorities and programmatic representatives evaluates the project on a monthly basis. Finally, the Astrophysics Strategic Missions Program (ASMP) office, which answers directly to the Director of Astrophysics, is responsible for day-to-day oversight and insight. The ASMP participates in all the monthly and lifecycle processes as well as assessing progress and analyzing technical and programmatic trends on an ongoing basis.



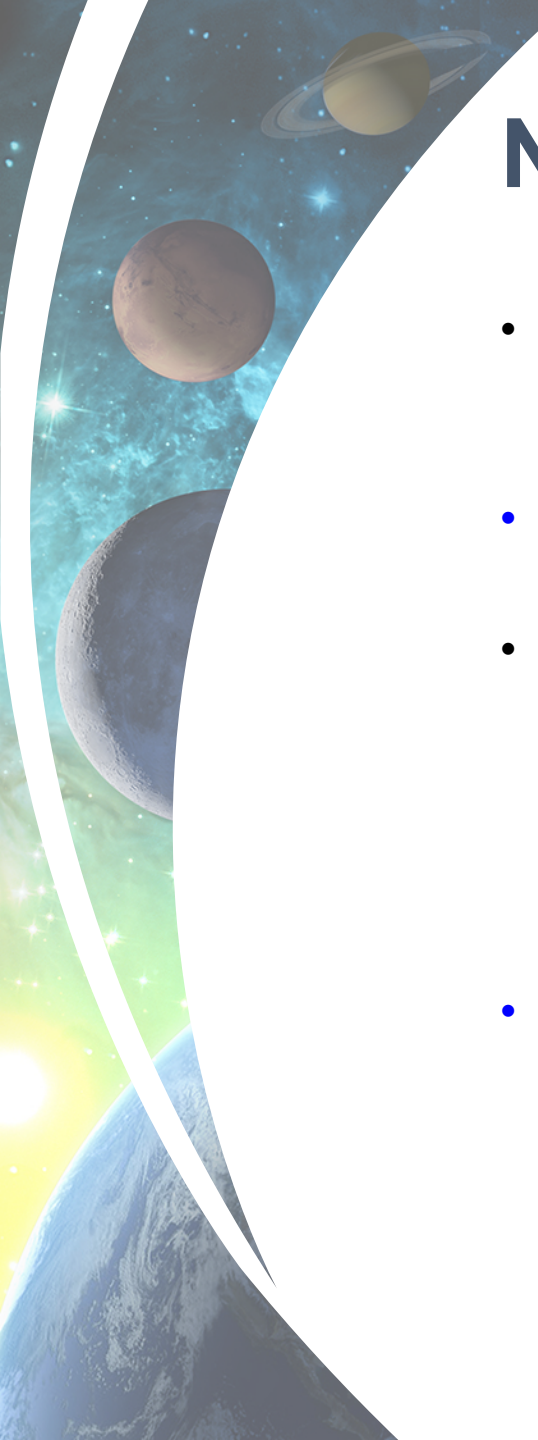
NASA Response to 2019 AAAC Report

- 22. Recommendation: In order to maintain a balanced investment in astrophysical research while continuing to support WFIRST, the highest ranked priority for NASA by the most recent decadal survey, NWNH, we recommend that the NASA budget be increased above the President's request to allow a funding level for the astrophysics division that would enable the funding of WFIRST to continue in the context of a balanced portfolio of investment.
- NASA response: Congress appropriates the NASA budget and provides spending direction.
- 28. Recommendation: NASA should continue to allocate resources to successfully launch JWST at the earliest possible date.
- NASA response: NASA concurs. The NASA FY19 appropriation provides adequate funding to support JWST development during FY19. The budget required for a March 2021 launch has been allocated to JWST in the NASA FY20 budget request and its runout.



NASA Response to 2019 AAAC Report

- 29. Recommendation: The AAAC recommends to Congress that SOFIA's prime mission be considered complete at the end of FY2019, and that SOFIA undergo senior review in the next regular review cycle, in line with normal NASA review procedures.
- **NASA response: NASA has conducted two independent reviews of SOFIA during 2019 to inform a more productive extended mission for SOFIA. NASA plans to review SOFIA again in 2022, after three years of extended operations.**



NASA Response to 2019 AAAC Report

- 55. Recommendation: The AAAC urges Congress to increase the proposed FY 2020 appropriation for NASA above the Administration's request to continue to provide a balanced program within astrophysics in line with the recommendations of NWNH.
- **NASA response: Congress appropriates the NASA budget and provides spending direction.**
- 59. Recommendation: the AAAC recommends that the annual report deadline be changed from a fixed date to a deadline 45-60 days following the submission of the President's budget, so as to enable sufficient opportunity for the committee to interact with the funding agencies, understand the impact of the President's budget, and formulate recommendations. The AAAC would endeavor to still meet the current deadline of March 15th when possible.
- **NASA response: NASA endorses this recommendation.**

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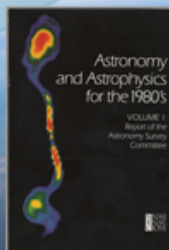
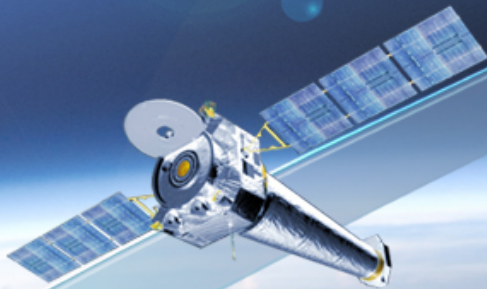
NASA Astrophysics Preparation for 2020 Decadal Survey

Astrophysics

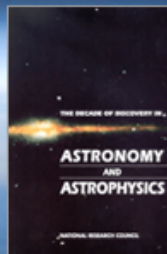
Decadal Survey Missions



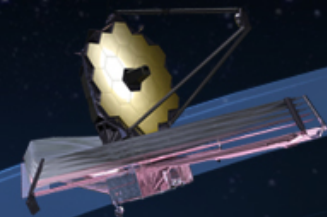
1972
Decadal
Survey
Hubble



1982
Decadal
Survey
Chandra



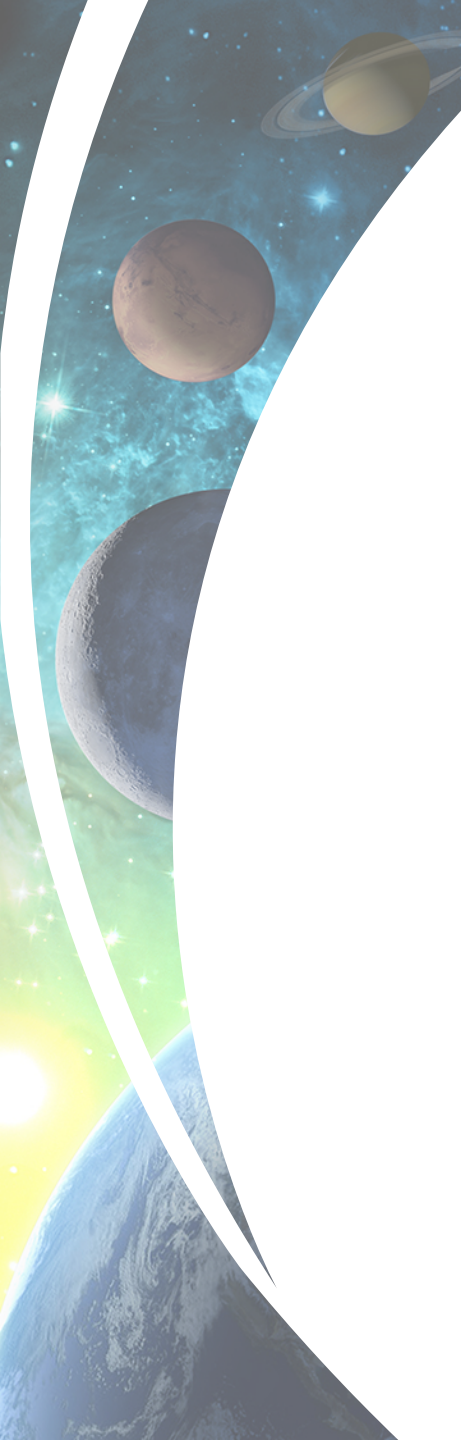
1991
Decadal
Survey
Spitzer, SOFIA



2001
Decadal
Survey
JWST



2010
Decadal
Survey
WFIRST

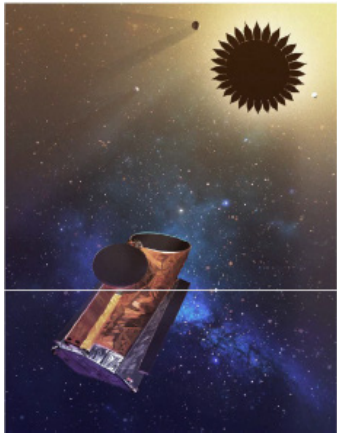


NASA Assessment: Probe Concept Studies

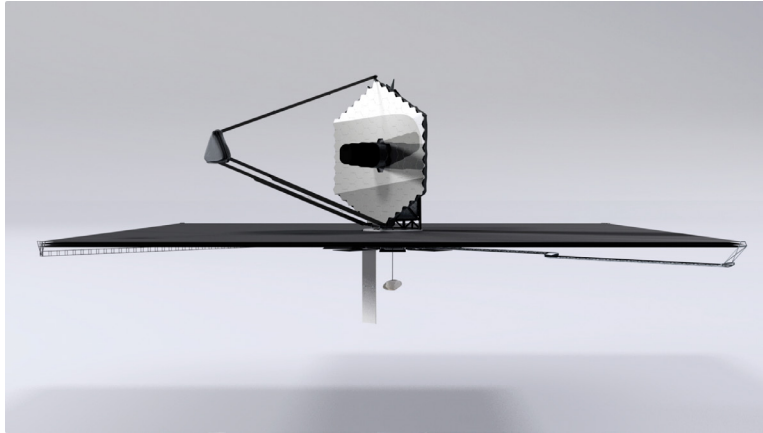
- NASA has requested GSFC and JPL's costing offices to perform independent cost assessments of the Probe mission concepts that used the resources of their respective Centers
- In order to provide an independent, non-advocate assessment of the costing offices' results, NASA is assembling an independent Probes Concept Assessment Team (PCAT)
 - The PCAT will validate the cost estimates provided by the costing offices, the design labs, and the PI-led studies
 - The PCAT is composed of scientists and subject matter experts who will work with the costing offices and the study teams
- The purpose of conducting a cost and technical validation of the Probe mission concept studies is to provide NASA Headquarters confidence in the science, technical, cost, and risk conclusions of the Probe Mission Concept Reports that will be presented to the Decadal Survey
- The Terms of Reference for the PCAT are posted at <https://science.nasa.gov/astrophysics/2020-decadal-survey-planning>

Large Mission Concepts

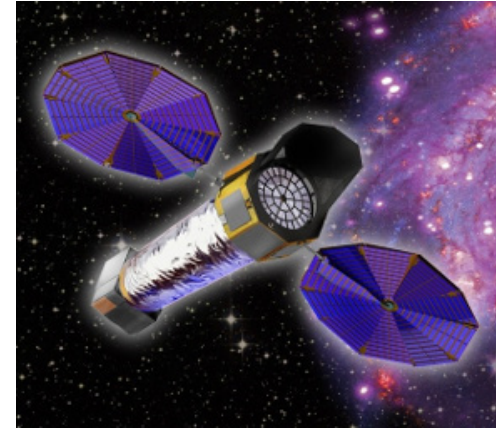
“NASA should ensure that robust mission studies that allow for trade-offs (including science, risk, cost, performance, and schedule) on potential large strategic missions are conducted prior to the start of a decadal survey. These trade-offs should inform, but not limit, what the decadal surveys can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



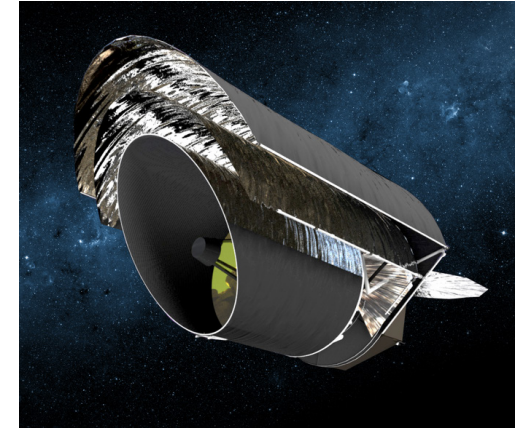
HabEx



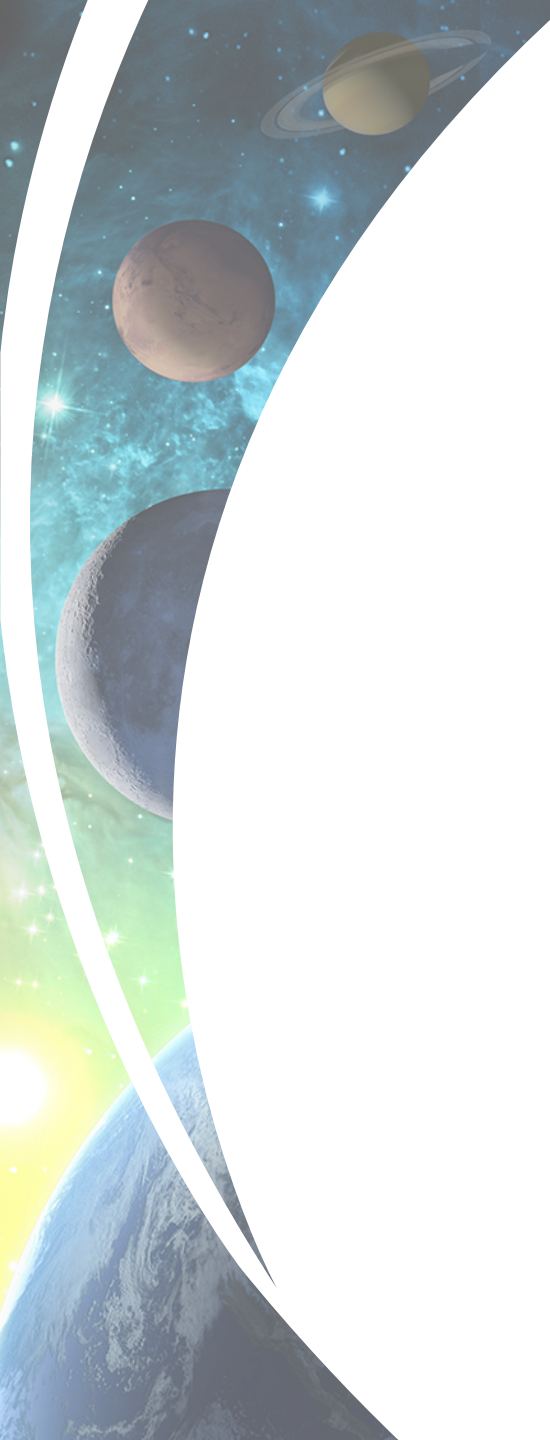
LUVOIR



Lynx



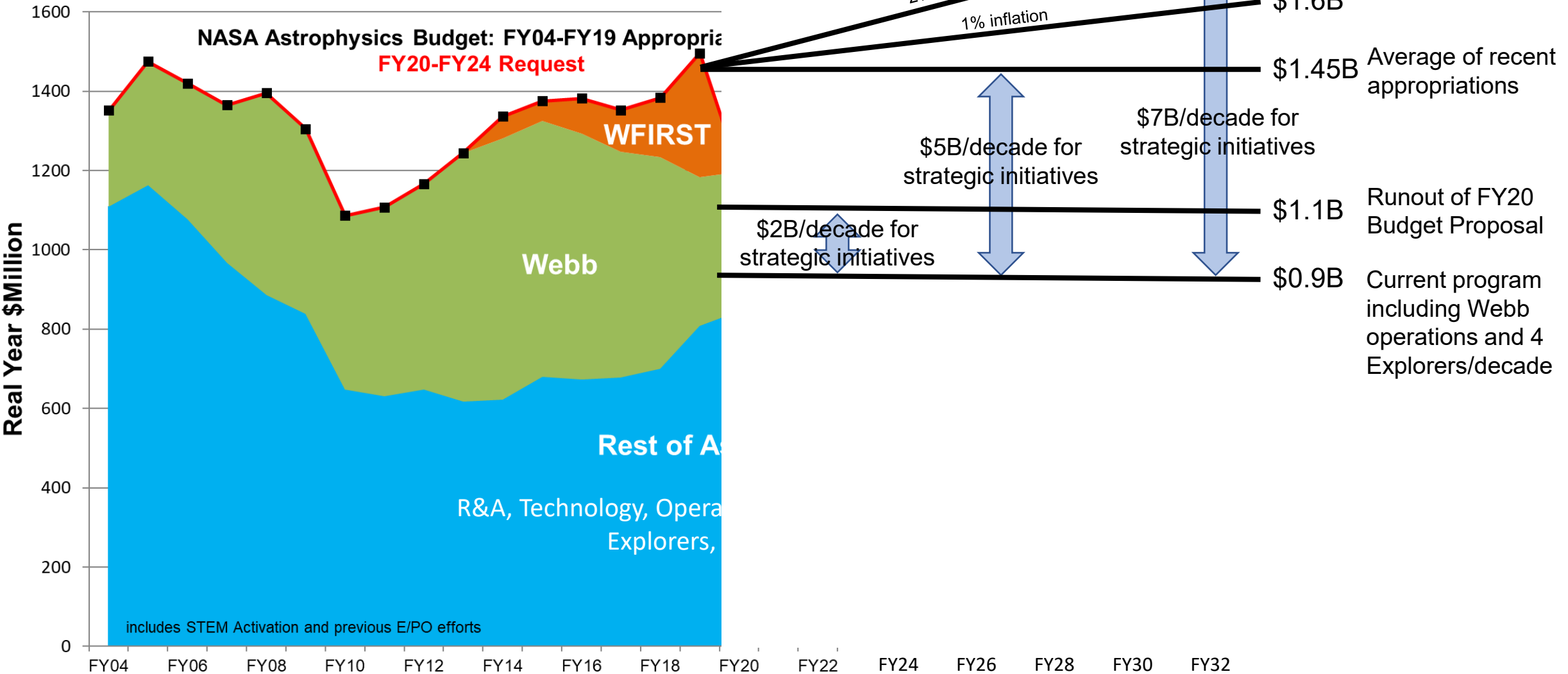
Origins

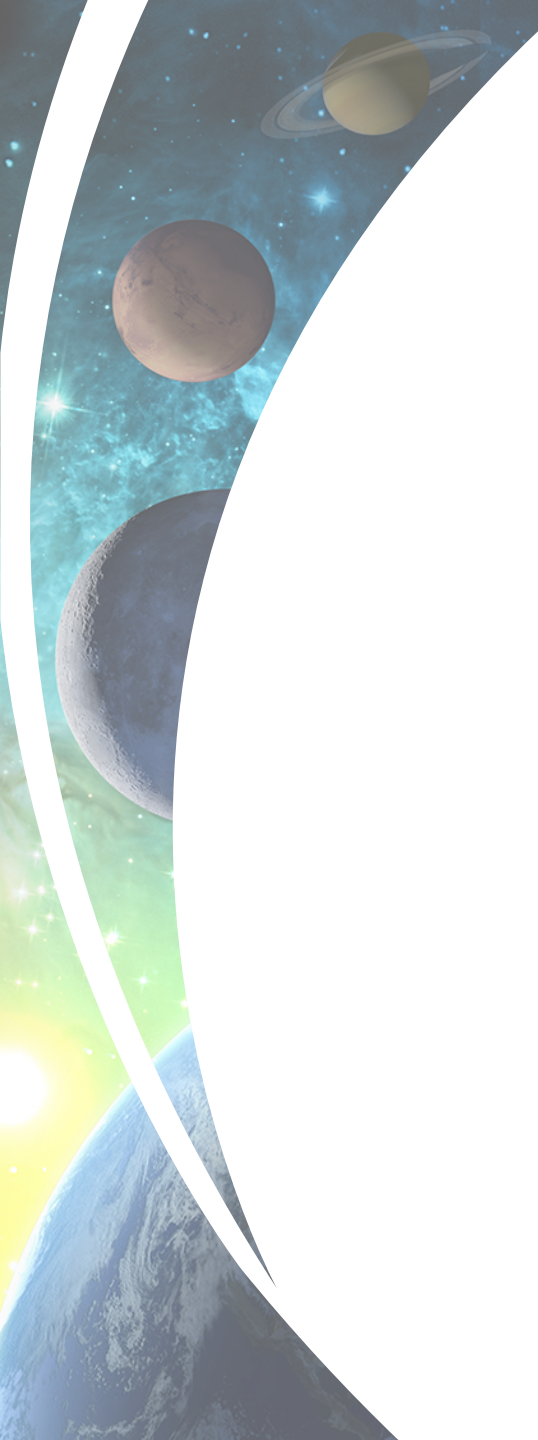


NASA Assessment: Large Mission Concept Studies

- NASA has assembled a Large Mission Concept Independent Assessment Team (LCIT) to conduct a technical, risk, and cost assessment of the four large-scale mission concept studies
 - The LCIT includes experienced technical and cost reviewers with expertise in large space missions and in science, instrumentation, and technology
- The purpose of the LCIT is twofold:
 - Provide feedback to the STDTs that can be used to improve the Final STDT Reports that will be presented to the Decadal Survey
 - Provide NASA Headquarters confidence in the science, technical, cost, and risk conclusions of the Final STDT Reports that will be presented to the Decadal Survey
- The Terms of Reference for the LCIT are posted at <https://science.nasa.gov/astrophysics/2020-decadal-survey-planning>

NASA Astrophysics Budget





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
- If you plan to a diminishing budget, you get a diminishing program
 - Great visions inspire great budgets

Carpe Posterum

The background of the slide is a cosmic scene. The top half features a dark blue and black space filled with numerous small, bright stars and a prominent, wispy blue nebula on the right side. The bottom half is a gradient of orange and yellow, also filled with stars and a faint, glowing greenish-yellow nebula. A horizontal light blue band runs across the middle of the image, containing the word 'BACKUP' in black capital letters.

BACKUP

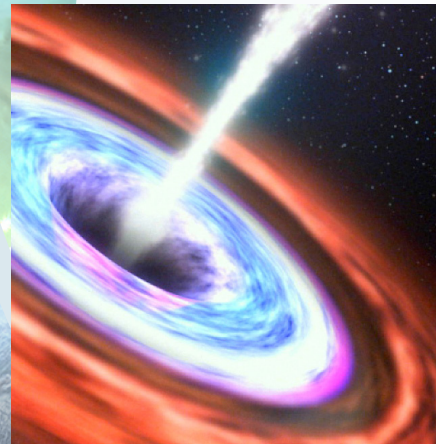
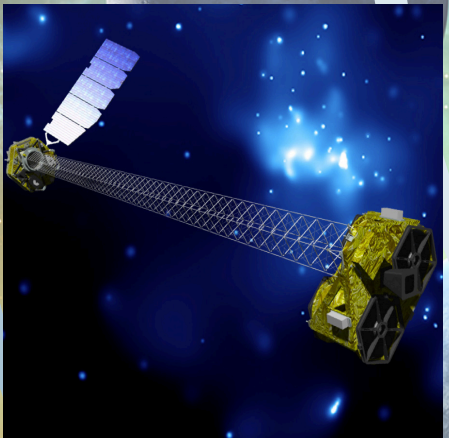
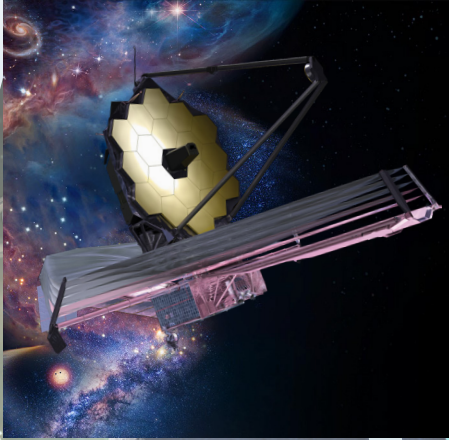
SOFIA

Stratospheric Observatory for Infrared Astronomy

- SOFIA's 5-year prime mission will be completed at the end of FY19
- At the end of a prime mission, NASA usually assesses the science performance and management of a program and proposed future science to decide on an extension of the program through a Senior Review Process, as required by the NASA Authorization Act of 2005
- The Explanatory Statement accompanying the FY2018 Consolidated Appropriations Act, however, forbade NASA from placing SOFIA in the 2019 Senior Review
- Given that the program has finished 5 years of operations, the time is appropriate to review two aspects of the SOFIA Project:
 - SOFIA's maintenance and operations paradigm
 - SOFIA's science progress and science prospects
- The reviews will not consider closeout or cancellation of SOFIA



Astrophysics in FY20 PBR



- Accommodates Webb replan to March 2021 LRD
- Supports formulation of a probe mission as early as 2022, conditional on Decadal Survey recommendations
- Maintains decadal cadence of four AOs per decade for Astrophysics Explorers and Missions of Opportunity
- Funds SOFIA for three years beyond end of prime mission in FY19 at reduced budget; two alternate reviews conducted in 2019 in lieu of inclusion in 2019 Senior Review
- Extends operating missions (other than Hubble and Chandra) at reduced budget beyond FY20 following 2019 Senior Review
- Supports mission concept studies and technology investments required to implement Astrophysics Decadal Survey priorities starting in 2022
- Given its significant cost and competing priorities within NASA, provides no funding for WFIRST space telescope

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
<u>Astrophysics Research</u>	<u>203.1</u>		<u>250.7</u>	<u>309.3</u>	<u>302.5</u>	<u>299.1</u>	<u>298.8</u>
Astrophysics Research and Analysis	74.1	83.4	86.6	90.2	92.2	94.2	94.2
Balloon Project	36.6		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
<u>Other Missions and Data Analysis</u>	<u>48.5</u>		<u>73.7</u>	<u>128.7</u>	<u>119.9</u>	<u>114.5</u>	<u>114.2</u>
Astrophysics Data Curation and Archival	18.2		21.2	21.2	21.5	22.0	22.0
Astrophysics Data Program	17.6		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		12.7	12.7	12.7	12.7	12.7
Astrophysics Directed R&T			19.4	39.7	42.7	28.9	24.3
<u>Cosmic Origins</u>	<u>211.2</u>		<u>185.3</u>	<u>173.9</u>	<u>181.7</u>	<u>121.7</u>	<u>121.7</u>
Hubble Space Telescope (HST)	98.3	98.3	83.3	93.3	98.3	98.3	98.3
Stratospheric Observatory for Infrared Astronomy	85.2	85.2	73.0	60.0	60.0		
<u>Other Missions and Data Analysis</u>	<u>27.7</u>		<u>29.0</u>	<u>20.6</u>	<u>23.4</u>	<u>23.4</u>	<u>23.4</u>
Cosmic Origins SR&T	15.5		17.1	18.4	18.4	18.4	18.4
SIRTF/Spitzer	11.2		8.5	1.0			
Cosmic Origins Future Missions	1.0		2.2	0.0	3.8	3.8	3.8
Astrophysics Strategic Mission Prog Mgmt			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
<u>Physics of the Cosmos</u>	<u>118.0</u>		<u>148.4</u>	<u>128.5</u>	<u>123.3</u>	<u>117.8</u>	<u>117.4</u>
Euclid	19.8		13.7	11.0	8.9	9.9	10.3
Physics of the Cosmos Future Missions	0.2		2.0	1.1	3.8	3.5	3.7
Chandra X-Ray Observatory	56.9		58.4	58.4	58.4	58.4	58.4
Fermi Gamma-ray Space Telescope	13.0		14.0				
XMM	2.5		3.5				
Physics of the Cosmos SR&T	20.9		50.9	52.1	46.3	40.1	39.0
PCOS/COR Technology Office Management	4.6		5.9	5.9	6.0	6.0	6.0
<u>Exoplanet Exploration</u>	<u>200.8</u>		<u>46.4</u>	<u>44.3</u>	<u>45.6</u>	<u>46.1</u>	<u>48.5</u>
WFIRST	150.0	312.2					
Kepler	10.0		1.3				
Keck Operations	6.2		6.7	6.9	7.0	7.2	7.4
Large Binocular Telescope Interferometer	1.8						
Exoplanet Exploration SR&T	26.4		29.1	30.0	28.9	28.9	28.6
Exoplanet Exploration Tech Office Mgmt	5.3		6.5	6.8	7.3	7.7	7.7
Exoplanet Exploration Future Missions	1.0		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
<u>Astrophysics Explorer</u>	<u>117.4</u>		<u>214.1</u>	<u>246.4</u>	<u>312.0</u>	<u>328.8</u>	<u>321.4</u>
Imaging X-Ray Polarimetry Explorer	23.5		70.2	45.3	7.4	4.5	0.5
X-Ray Imaging and Spectroscopy Mission	22.0		29.7	25.7	22.5	17.6	15.8
GUSTO	4.7		11.1	7.8	6.3	1.0	
Nuclear Spectroscopic Telescope Array	4.8		7.8				
Neil Gehrels Swift Observatory	3.9		5.5				
Transiting Exoplanet Survey Satellite	33.5		5.0	0.2			
Neutron Star Interior Composition Explor	2.1						
Astrophysics Explorer Future Missions	11.8		84.8	154.2	267.0	295.1	299.2
Astrophysics Explorer Program Managemen	11.1			13.3	8.8	10.7	5.9
 <u>James Webb Space Telescope</u>	 <u>533.7</u>	 <u>304.6</u>	 <u>352.6</u>	 <u>415.1</u>	 <u>175.4</u>	 <u>172.0</u>	 <u>172.0</u>