National Aeronautics and Space Administration

ASTROPHYSICS




EMBARGOED UNTIL MARCH 27, 2018

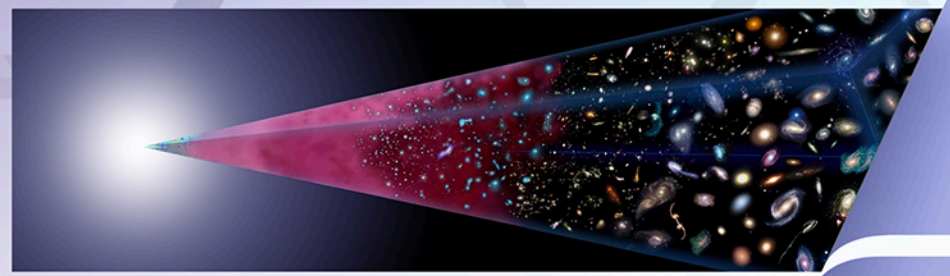
NASA Astro[illegible]s Update

Presented to:
Committee on Astronomy and Astrophysics
Space Science Week

Paul Hertz
Director, Astrophysics Division
Science Mission Directorate
@PHertzNASA

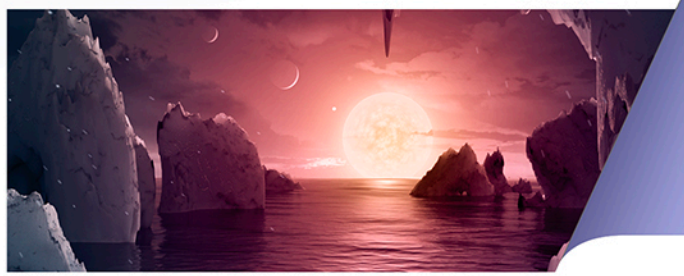
March 27-28, 2018

Why Astrophysics?



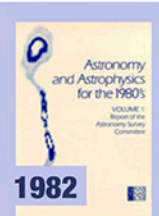
How did our universe begin and evolve?

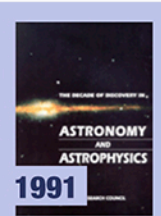
How did galaxies, stars, and planets come to be?



Are we alone?

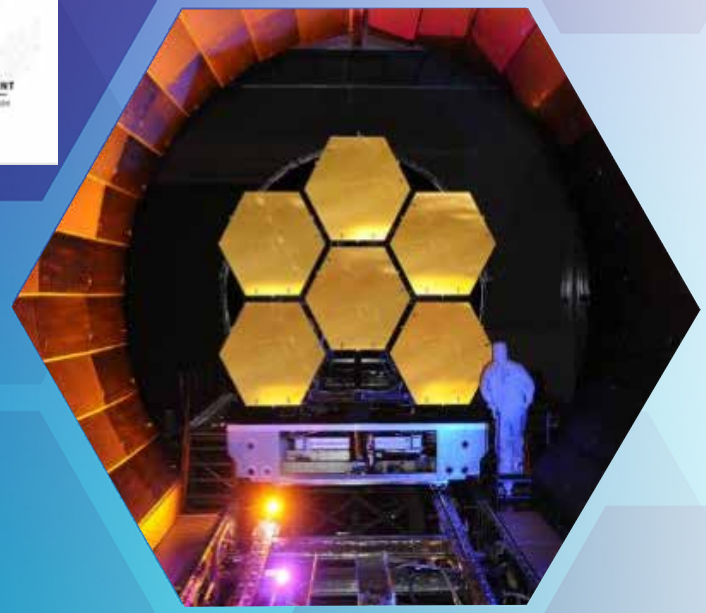
Enduring National Strategic Drivers





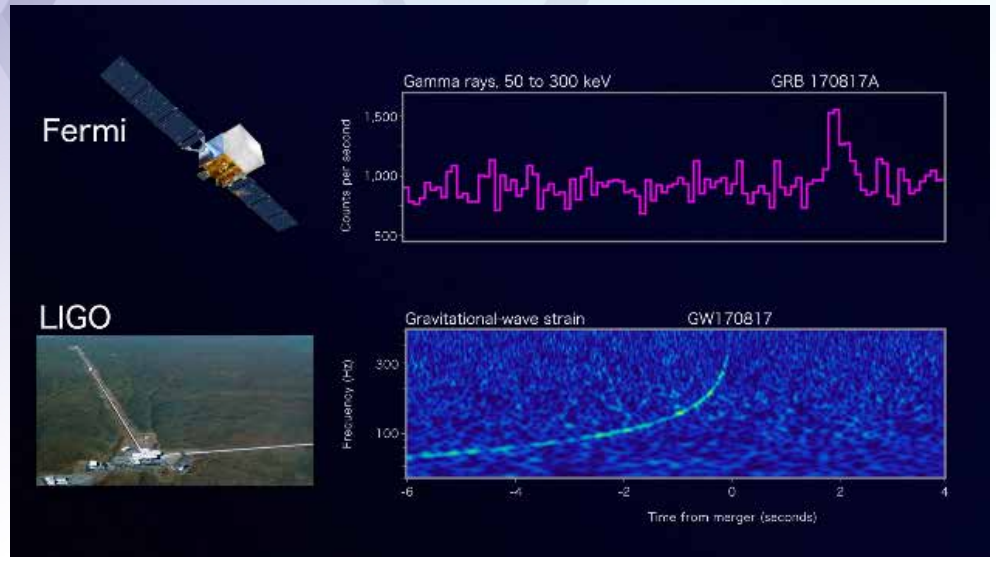
Astrophysics is humankind's scientific endeavor to understand the universe and our place in it.

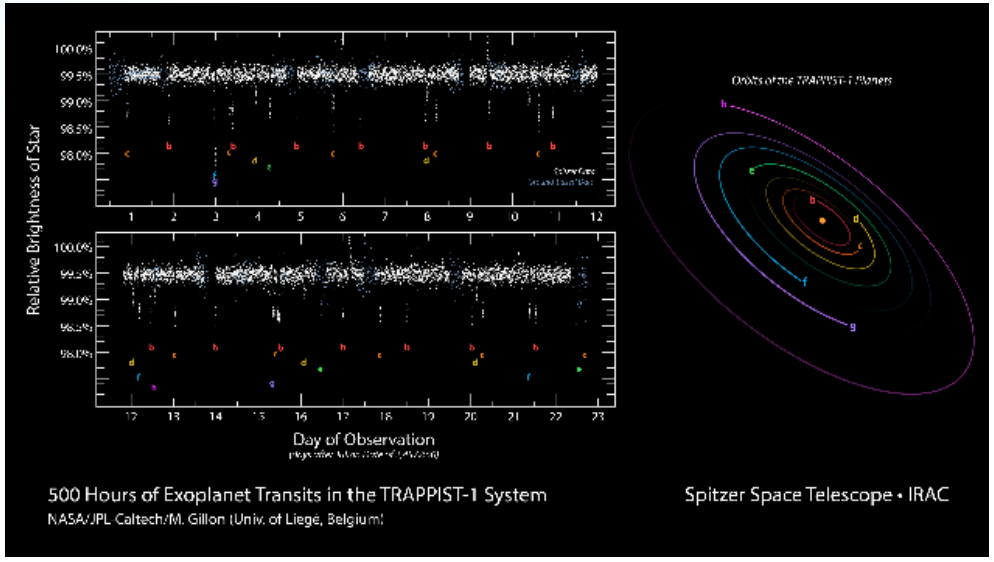
Outline

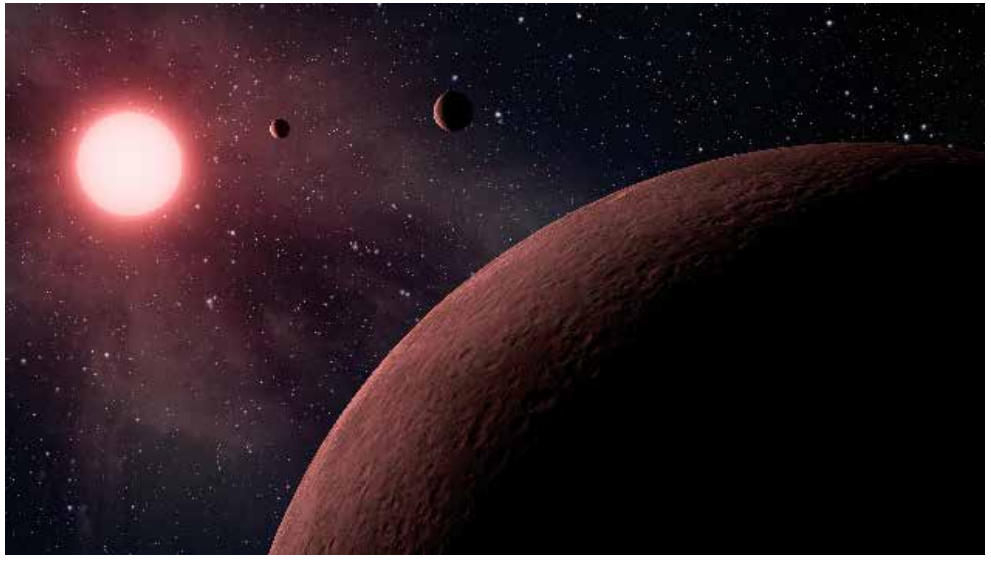


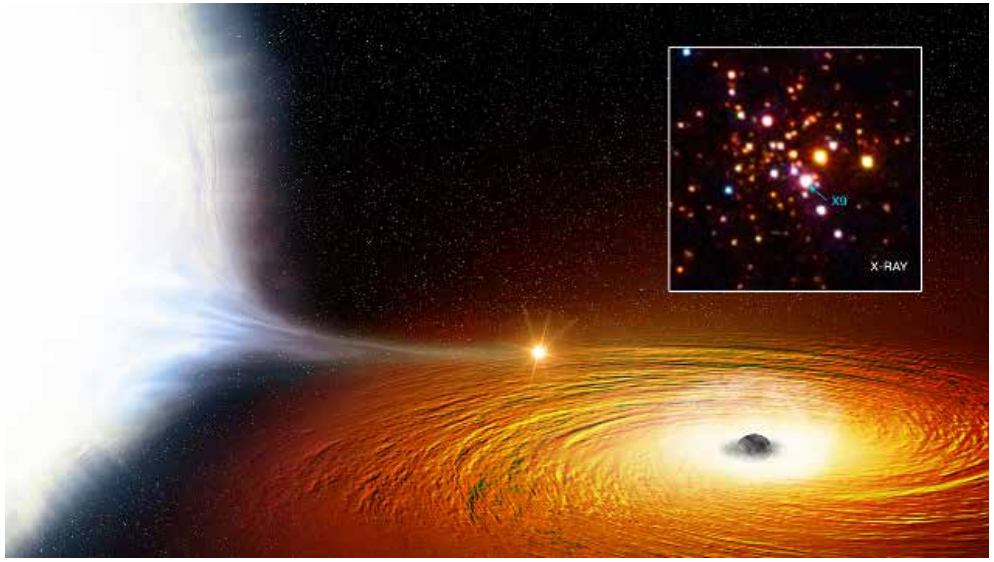
NASA Astrophysics
Program and Budget Update

Some NASA Science Stories of 2017









Major Recent Accomplishments

- Imaging X-ray Polarimetry Explorer (IXPE) downselected January 2017 as next Astrophysics Small Explorer (SMEX) mission
- Two missions launched to International Space Station (ISS)
  - Neutron Star Interior Composition Explorer (NICER) June 2017
  - Cosmic Ray Energetics and Mass (CREAM) August 2017
- Three Medium-class Explorer (MIDEX) and three Mission of Opportunity (MO) proposals selected August 2017 for competitive Phase A concept studies
- Widefield Infrared Survey Telescope (WFIRST) Independent External Technical/Management/Cost Review (WIETR) completed October 2017; WFIRST directed to reduce cost
- Webb payload completed cryotesting December 2017; Webb sunshield integrated with spacecraft January 2018; Webb payload shipped January 2018
- X-ray Astronomy Recovery Mission (XARM) passed KDP-C January 2018 and began implementation
- Transiting Exoplanet Survey Satellite (TESS) completed testing and delivered to KSC, on track for April 2018 launch
- WFIRST passed SRR/MDR February 2018; on track for April 2018 KDP-B

NASA Astrophysics Diversity and Inclusion

- The NASA Astrophysics Division is actively taking steps to advance diversity, inclusion, and equal opportunity in the NASA workforce and among NASA grantee institutions.
- NASA Astrophysics is committed to:
  - Setting the expectancy of diversity and inclusion in the composition of: proposal teams, peer review panels, science and technology definition teams, and mission and instrument teams.
  - Promoting diversity on NASA-selected groups (e.g., advisory groups, peer review panels, science teams, etc.).
  - Recruiting a diverse Astrophysics Division staff.
  - Working with the NASA Office of the Chief Scientist and our peer review contractors to address unconscious bias in peer reviews.
  - Sharing best practices in peer reviews with other agencies.
  - Observing the demographics of R&A proposers and awardees as an indicator of issues.
- The demographics of R&A proposers and awardees – we notice that:
  - The inferred gender balance of awardees does reflect that of proposers.
  - The inferred gender balance of proposers does not always reflect that of the community.

Astrophysics Budget Overview

- The FY18 consolidated appropriation provides funding for NASA astrophysics to continue its planned programs, missions, projects, research, and technology.
  - Total funding provided for FY18 (Astrophysics including Webb) rises from $1.352B in FY17 to 1.384B in FY18, an increase of ~$32M (2.4%) from FY17.
  - The NASA Astrophysics FY18 appropriation funds Webb for progress toward launch, WFIRST formulation into Phase B, Explorers mission development, increased funding for R&A, continued operating missions, suborbital missions, technology development, and mission studies.
- The FY19 budget request proposes a reduced level of funding for NASA astrophysics.
  - Total requested funding for FY19 (Astrophysics including Webb) is ~$1.185B, a reduction of $200M (14%) from FY18 appropriation.
  - Webb included as project within Astrophysics budget, integration and testing continues toward launch.
  - Given its significant cost within a proposed lower budget for Astrophysics and competing priorities within NASA, WFIRST is terminated with remaining WFIRST funding redirected towards competed astrophysics missions and research.

FY18 Omnibus Appropriation

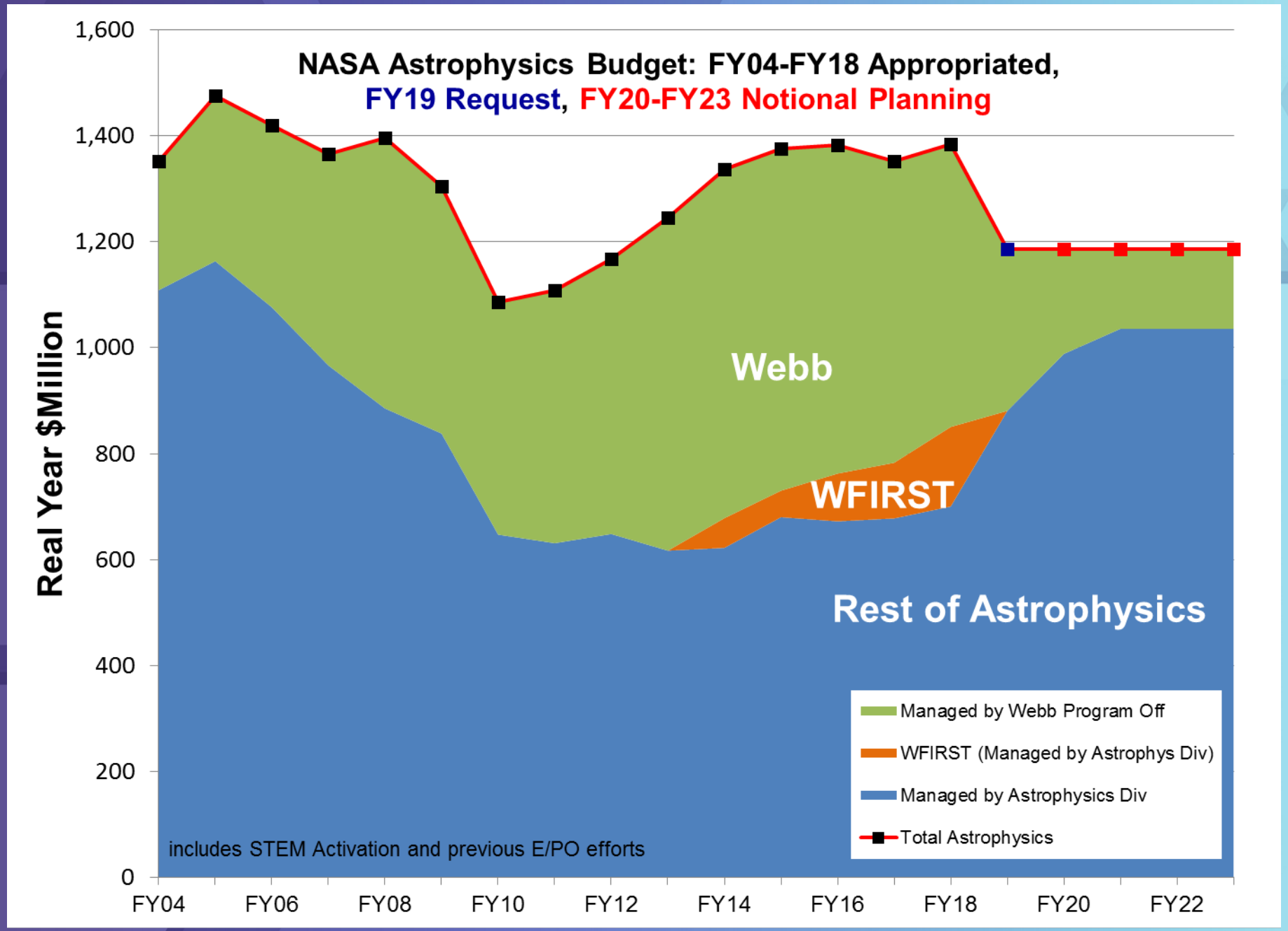
- The Consolidated Appropriations Act of 2018 and the explanatory statement provide the following appropriations for Astrophysics (including Webb)

	FY18 PBR	FY18 Appropriation	Direction (paraphrased)
Total Astrophysics	$ 1,350.5 M	$ 1,384.1 M	
Webb	$ 533.7 M	$ 533.7 M	Shall not exceed $8B through development.
WFIRST	$ 126.6 M	$ 150.0 M	Provide within 60 days a life cycle cost including additions needed to make Class A.
Hubble	$ 83.3 M	$ 98.3 M	
SOFIA	$ 79.9 M	$ 85.2 M	Shall not prepare for 2019 senior review; prime mission is 20 years starting in 2014. Issue a call for instrument proposals. Undertake at least 100 science flights.
Research & Analysis	$ 74.1 M	$ 74.1 M	Supportive of university-led research into protoplanetary discs and nebulae.
Exoplanet technology			Includes no less than $15M for exoplanet technology development.
Astrophysics observatories			Provide within 180 days NASA's plans for maintaining U.S. leadership in high energy astrophysics following the Chandra and Fermi missions.
Rest of Astrophysics	$ 452.9 M	$ 442.8 M	$10M (2.2%) undistributed reduction.

Astrophysics FY2019 Budget Features

- What's Changed
  - Webb included as project within Astrophysics budget
  - Given its significant cost within a proposed lower budget for Astrophysics and competing priorities within NASA, WFIRST terminated with remaining WFIRST funding redirected towards competed astrophysics missions and research
  - Euclid budget increased to recover from failed sensor electronics design
  - XARM begun within Explorers program
  - Spitzer ops extended until Webb is operational, consistent with 2016 Senior Review

- What's the Same
  - TESS, IXPE, and GUSTO remain on track and within budget
  - All operating missions continue; next Senior Review in 2019
  - CubeSat initiative and four balloon campaigns within healthy research program

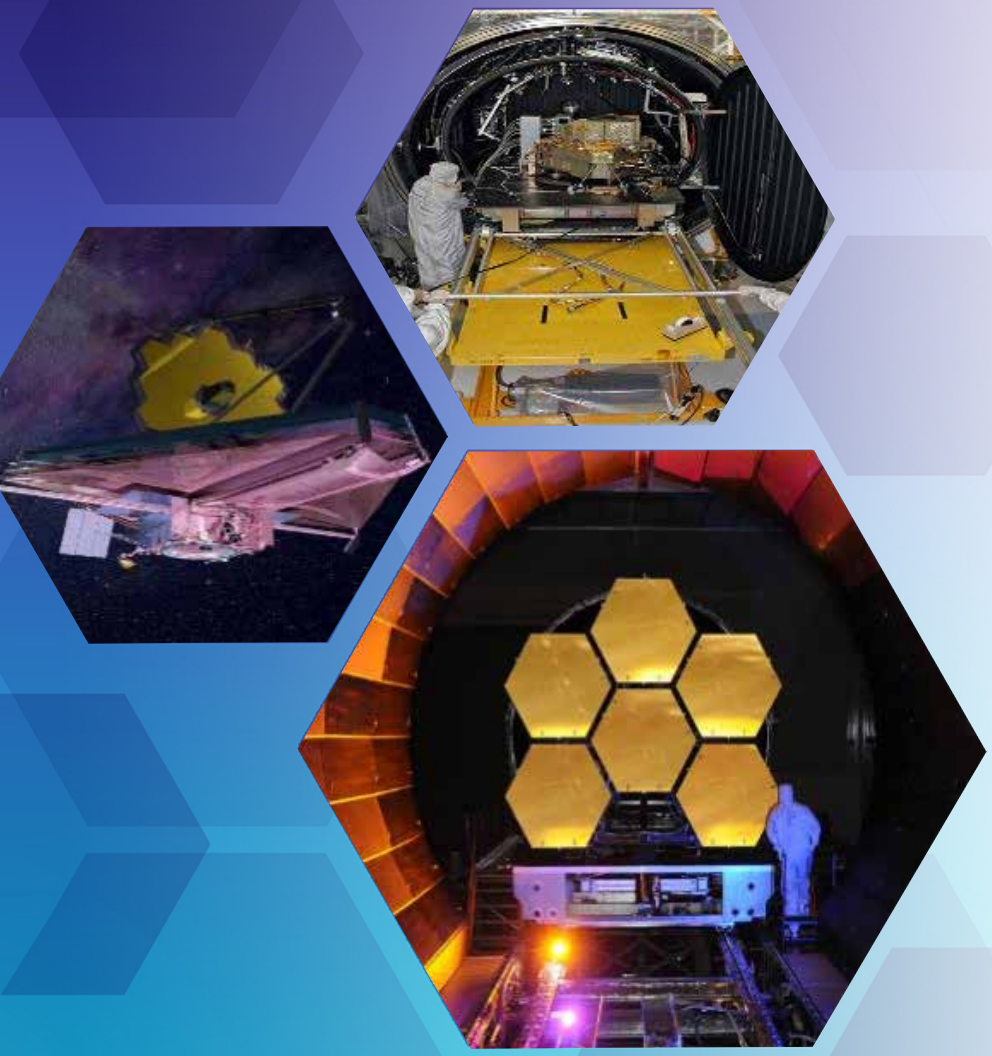

NASA Astrophysics Budget: FY04-FY18 Appropriated,
FY19 Request, FY20-FY23 Notional Planning
Real Year $Million
1,600
1,400
1,200
1,000
800
600
400
200
0
FY04
FY06
FY08
FY10
FY12
FY14
FY16
FY18
FY20
FY22
Webb
WFIRST
Rest of Astrophysics
includes STEM Activation and previous E/PO efforts
Managed by Webb Program Off
WFIRST (Managed by Astrophys Div)
Managed by Astrophysics Div
Total Astrophysics

TESS

Transiting Exoplanet Survey Satellite

Launch April 16, 2018

https://tess.gsfc.nasa.gov/
https://tess.mit.edu/



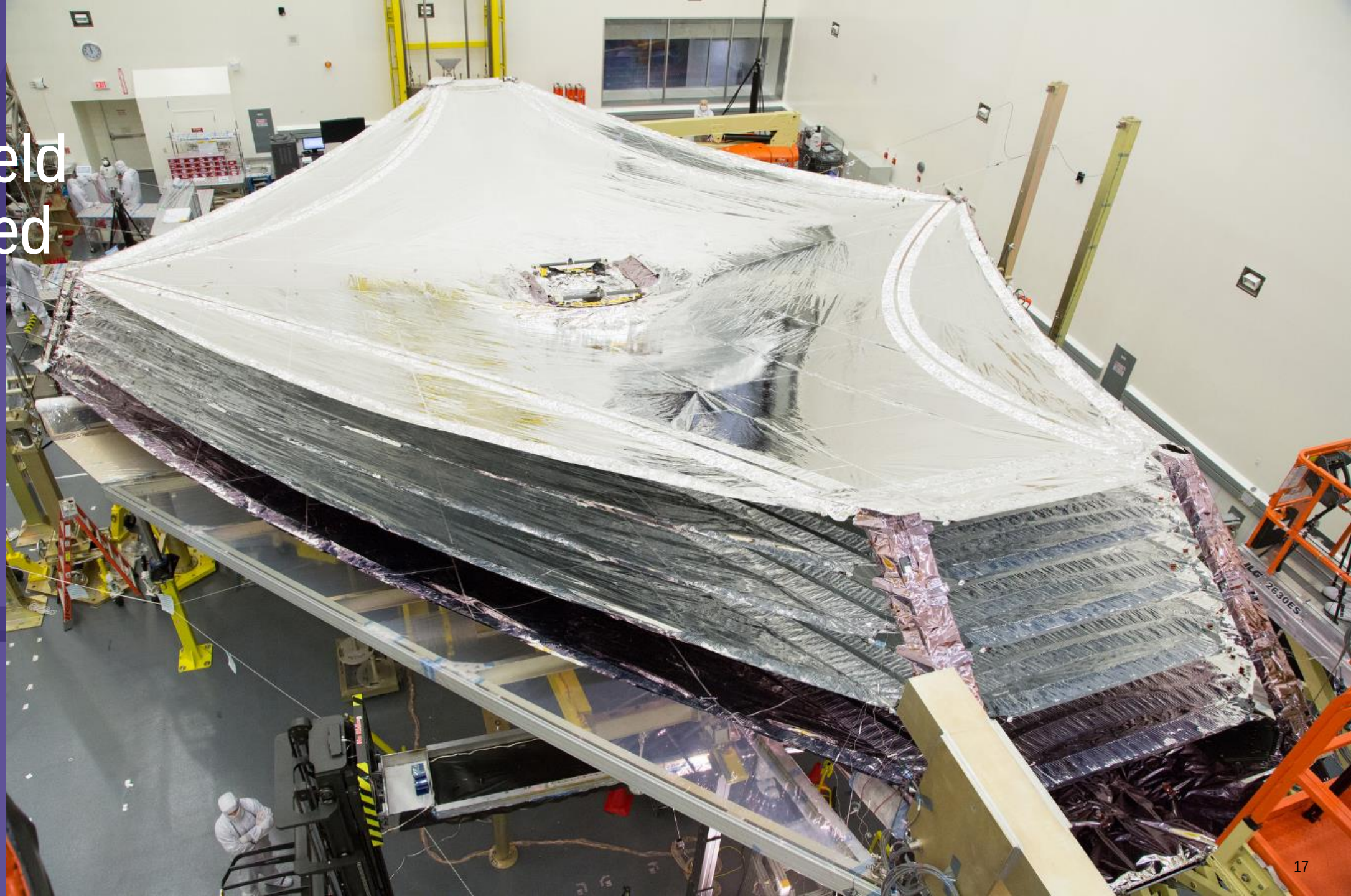
James Webb Space Telescope

- Included as project within Astrophysics starting in FY2019
- Civilization-scale mission to observe first galaxies formed after Big Bang
- Science payload completed three months cryogenic testing at end of 2017
- Spacecraft and sunshield integration completed January 2018
- Independent schedule review completed March 2018
- Independent Review Board report by June 2018
- Science payload and spacecraft integration planned Summer 2018

Webb OTIS after Thermal Vacuum Testing

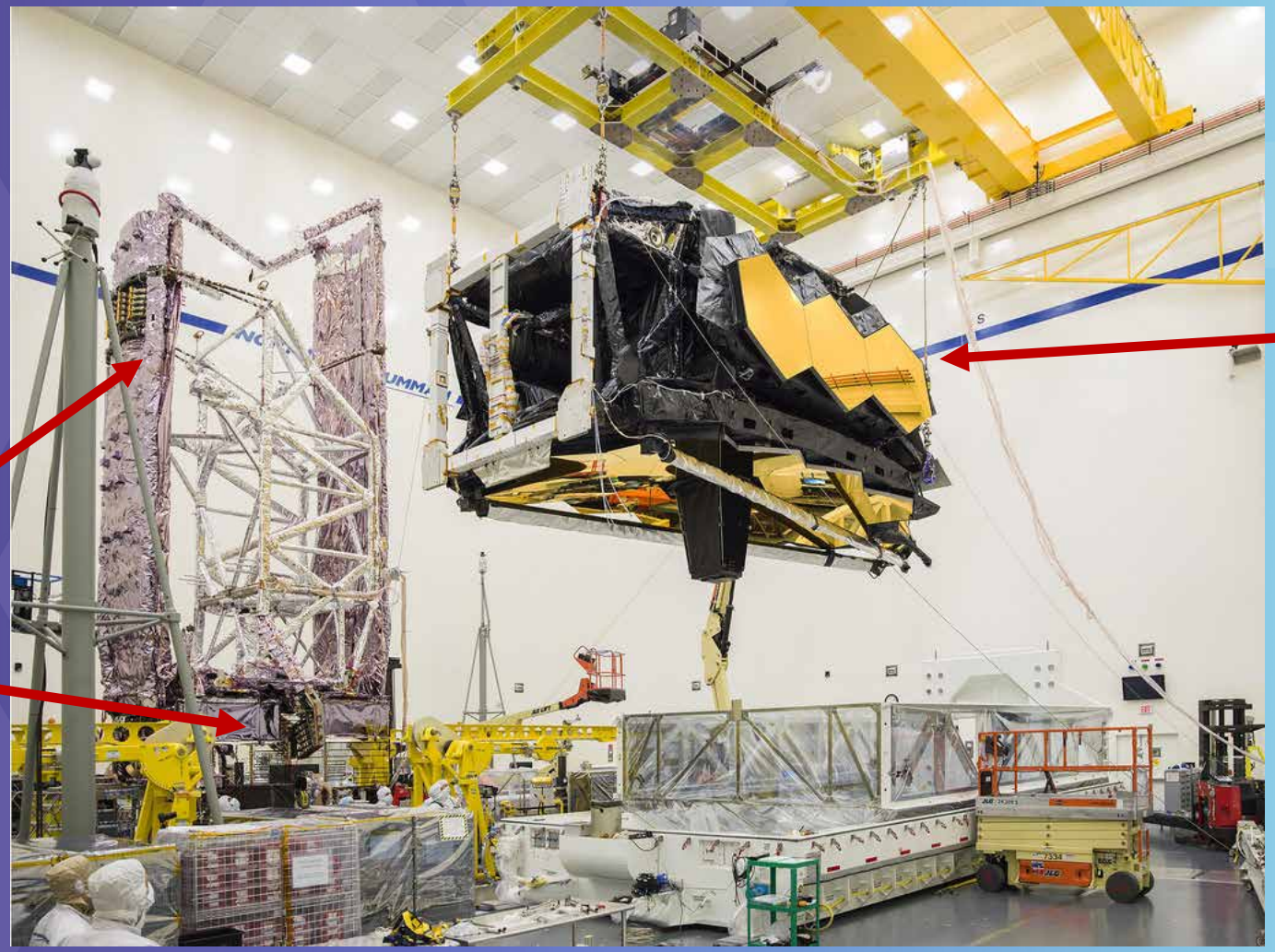
Transporting Webb OTIS to NGAS California

Webb Sunshield Deployed



Webb Mission Status - March 23, 2018

Webb Observatory Elements at Northrop Grumman (NGAS) Redondo Beach, CA



Spacecraft Element

Sun-Shield

Spacecraft

Optical Telescope Element (with instruments)

Webb Mission Status - March 23, 2018

- Spacecraft Element (SCE) completed, stowed into launch configuration
  - Performance testing complete and ready for environmental testing
  - Sunshield
    - 7 small tears in the sunshield and sunshield covers have been repaired
    - Lessons learned from first deploy/fold & stow were significant
  - Spacecraft
    - Major impact to schedule due to propulsion valve and transducer rework
    - Dual Thruster Modules removed, valves refurbished, DTM's reinstalled, pressure check was good
- Optical Telescope Element (Telescope & Instruments)
  - Full performance and environmental testing complete and OTE delivered for Integration and Test
- Launch Readiness Date (LRD) of March - June 2019 not possible due to lessons learned during SCE Integration & Test (I&T) and propulsion system rework
- Standing Review Board (SRB) has reviewed project schedule and their analysis yields an LRD of ~May 2020 at 70% confidence
- Independent Review Board, chaired by Tom Young; final report ~May 2018
- NASA's final agency decision in June 2018

Webb 18 Month LRD Impact
from October 2018 LRD

- 15 months of technical issues (**impacts do not add linearly**)
  - Spacecraft critical path dominated by the propulsion system – 13 months
    - 3 Months - Transducer problem
    - Dual Thruster Module rework slip of 9 months (much of this was worked in parallel with Sunshield issues)
    - 1 Month - Recovery from incorrect voltage applied to the catalyst bed heater
  - Sunshield Complications – 7 months
    - 4 months – Deploy/Fold/Stow (2 months to go)
    - 2 months – Tear repairs (1 month to go)
    - 1 month – Snag guard implementation (0.5 months to go)
  - Observatory I&T Replan – 3 months
    - 3 months – OTE lessons learned and applied to SCE & reduction in parallel task activities
- 3 months additional funded schedule reserve

Blue font indicates “first time” activities

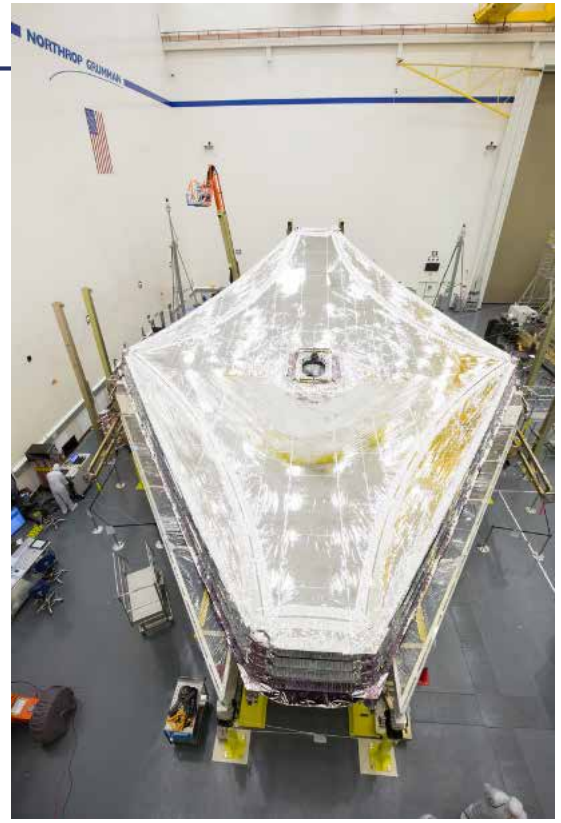
Remaining I&T Activities

Science Payload

- OTIS Deployments at NGAS (secondary mirror & ISIM radiator)

Spacecraft Element

- *Acoustics, vibe, and thermal vacuum tests*
- Post-Environment deployment and stow



Observatory Integration

- Pre-environmental Observatory deployments
- Observatory fold & stow
- *Observatory system (electrical) test*
- Observatory vibration, acoustics tests
- *Observatory deployment*
- Observatory stow for launch
- Observatory final system test

Standing Review Board Schedule Review Summary

National Aeronautics and Space Administration

Summary of SRB Schedule Risk Assessment

- Summary/Historical view of large, complex NASA SMD program and project schedule overruns
- Analysis of historical JWST I&T schedule margin burn rates since 2011
- SRB Delphi analysis
- SRB Assessment of project's grassroots schedule analysis and threats
- JWST Project SRA model and parametric analysis
- Comparison of similarly complex NGAS "Project X" to JWST I&T work to go

- **Based on the above analyses, the SRB assessment results in a probable JWST LRD range of 1/29/20 to 4/30/20 (increasing probability with latter date)**
- **Caveats:**
  - **NGAS schedule performance improves as planned**
  - **No significant hardware anomalies during remaining I&T**

Steps Taken to Improve Performance

- NASA HQ (Program)
  - ü Additional SMD Front office oversight and direct interaction with NGAS senior management (President/COO)
  - ü Adding Deputy Associate Administrator of Programs to JWST Program Office
  - ü Tracking daily & weekly NGAS I&T reports
  - ü Established IRB
- NASA Goddard (Project)
  - ü Senior project management resident at NGAS on permanent basis
  - ü Additional NASA I&T personnel at NGAS planned for specific activities
  - ü Bi-weekly senior NASA/NGAS (HQ, Center Director, President/COO) schedule reviews
  - ü JWST Project Manager reporting directly to Deputy Center Director who will actively support the Project Manager
- NGAS (Observatory Contractor)
  - P Project Manager to President/COO direct communication path established
  - P Reporting channels opened to Project & Program (as mentioned above)
  - ■ I&T personnel and organizational structure changes
  - ■ Reviewing technical processes/procedures

Independent Review Board

- Purpose
  - External team that will evaluate all factors, including
    - Those identified by the SRB
    - Integration and test (I&T) plan
    - Assuming a Ship & Launch Processing window (75 days) and the commissioning (6 months) of the telescope
  - The IRB will
    - Document the results of its review in a presentation and final report
    - The IRB may develop observations, findings, concerns, and recommendations as part of its assessment.
- Final Report to SMD AA ~May 31, 2018
- Chair, Tom Young

WFIRST
status

- Conducted WFIRST Independent External Technical/Cost/Management Review (WIETR) in response to National Academies' Midterm Assessment
- WFIRST directed by SMD AA to reduce cost and complexity sufficient to have a cost estimate consistent with $3.2B cost target set at the beginning of Phase A.
  - Coronagraph is technology demonstration instrument
  - Independent cost assessment are being conducted to validate the estimated cost of rescoped mission as being consistent with the $3.2B cost target.
- WFIRST moved to (new) Strategic Astrophysics Missions Program
- SRR/MDR completed February 2018.
- KDP-B planned for March/April 2018.

WFIRST
cost

- Project estimate of cost to Science Mission Directorate has been reduced from ~$3.6B to <$3.2B.
- Changes include the following:
  - Coronagraph Instrument treated as technology demonstration instrument
  - Contribution to coronagraph technology demonstration instrument by NASA Space Technology Mission Directorate
  - Reduced some Wide Field Instrument capabilities
  - Simplified subsystem designs including C&DH box, high gain antenna, telescope door
  - Contributions to mission by international partners
  - Improved budget profile and accelerated schedule; pulls in launch date 6 months
  - Additional mission risk reduction (sparing, testing, parts, etc.)

Comparison of Webb and WFIRST Development Risk at KDP-B

Webb @ KDP-B	WFIRST @ KDP-B
Novel, complex segmented Be mirror development	Existing 2.4m monolithic ULE mirror
Numerous technology developments	High TRL: basis of Decadal selection, recent investments
Complex cryo-cooler	Passive Al radiator
ISIM structure materials development (30 K)	Reuse of Webb design in instrument carrier (190K)
IR detector manufacturing problem uncovered after KDP-C	IR detectors presently at TRL-6, flight growth initiated at start of Phase B; Greater maturity and understanding of Webb-derived detector technologies reduces risk of encountering problems late in the WFIRST program
Four highly configurable instruments (inherent complexity), major international roles, separate guider	Single primary instrument + tech demo, no separate guider
Many complex deployments	Standard deployments

WFIRST risks are lower than those retired on Webb, and typical of high TRL missions. Incorporated numerous Webb lessons learned.

WFIRST
science

- NASA is considering changes in the way WFIRST key programs and observing time will be determined
  - The three key science pillars (Dark Energy, Exoplanets, Great Observatory Astrophysics) are all important. There is no expectation that specific amounts of observing time are reserved for any specific science pillar, survey, or observing program.
  - Allocation of WFIRST observing time will be done through open-access, nonproprietary, peer-reviewed competition of programs that address the scientific imperatives of the 2020s, including dark energy and exoplanets. The observing program will be selected as close in time to the observations as possible.
  - Investigate alternate ways of organizing community-based key project teams.
  - Consider openly-competed “Early Release Demonstration Programs” performed at the start of WFIRST operations to inform the peer-reviewed time allocation process during the prime mission.
- WFIRST Formulation Science Working Group (FSWG) is reviewing this proposed change

WFIRST
budget

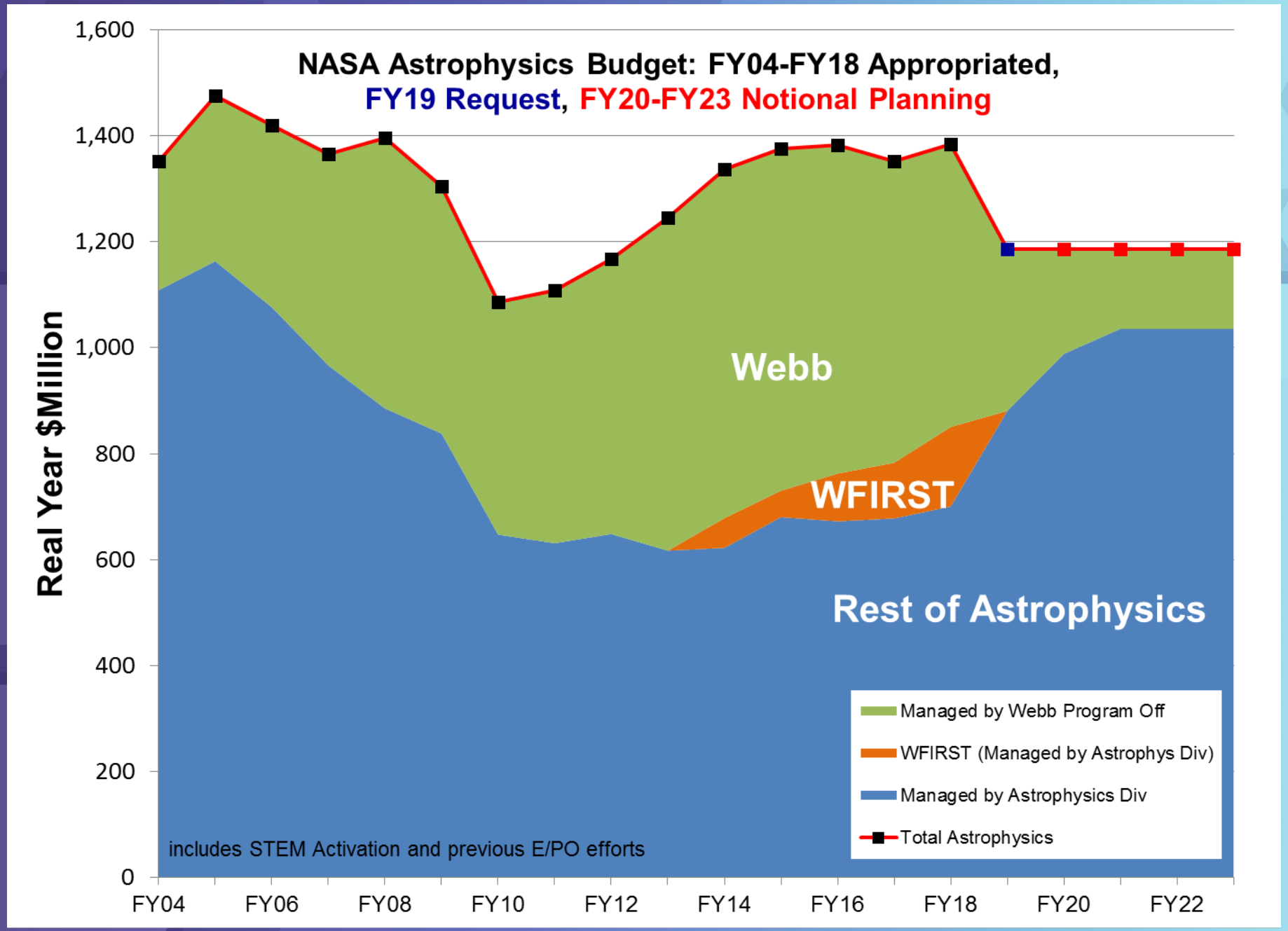
- Given its significant cost within a proposed lower budget for Astrophysics and competing priorities within NASA, WFIRST terminated with remaining WFIRST funding redirected towards competed astrophysics missions and research
- Funds appropriated by Congress in FY18 will allow WFIRST to enter Phase B in April 2018
- If Congress adopts the Administration's request to terminate WFIRST, the funds made available would enable a competed mission AO in FY19

WFIRST Terminated

- "Given competing priorities at NASA, and budget constraints, developing another large space telescope immediately after completing the $8.8 billion James Webb Space Telescope is not a priority for the Administration."
  - — White House FY19 Budget Request document (https://www.whitehouse.gov/wp-content/uploads/2018/02/msar-fy2019.pdf)

- "We did have to make some hard decisions in science. This budget proposes cancelling our WFIRST mission and taking those resources and redirecting them to other agency priorities."
  - — Robert Lightfoot, Acting Administrator, "State of NASA" address, February 12, 2018

- "Given its significant cost and higher priorities within NASA, the budget proposes termination of the WFIRST mission. Remaining WFIRST funding is redirected towards other priorities of the astrophysics community, including competed astrophysics missions and research."
  - NASA FY19 Budget Estimates (https://www.nasa.gov/sites/default/files/atoms/files/fy19_nasa_budget_estimates.pdf)


NASA Astrophysics Budget: FY04-FY18 Appropriated,
FY19 Request, FY20-FY23 Notional Planning
Real Year $Million
1,600
1,400
1,200
1,000
800
600
400
200
0
FY04
FY06
FY08
FY10
FY12
FY14
FY16
FY18
FY20
FY22
Webb
WFIRST
Rest of Astrophysics
includes STEM Activation and previous E/PO efforts
Managed by Webb Program Off
WFIRST (Managed by Astrophys Div)
Managed by Astrophysics Div
Total Astrophysics

NASA Astrophysics

CAA Short Report: Planning for Astro2020

Introduction

- NASA has initiated studies for large and medium (a.k.a. Probe) size mission concepts to inform the 2020 Decadal Survey Committee in an organized and coherent way
  - Main purpose is to provide the Decadal Survey Committee with several well-defined mission concepts to facilitate their deliberations
- Specifically, NASA is:
  - Sponsoring 4 community-based Science and Technology Definition Teams (STDTs) to partner with a NASA Center-based engineering team and study large (strategic) mission concept studies selected from the NASA Astrophysics 30-year Visionary Roadmap, a community-based report, and the 2010 Decadal Survey
  - Supporting 10 PI-led Study Teams for Probe-size mission concept studies, selected competitively
  - Supporting several other planning activities / studies / white papers
- All material related to NASA's 2020 Decadal Survey planning activities are posted at https://science.nasa.gov/astrophysics/2020-decadal-survey-planning

Task of the CAA

Timeline	Milestone
February 24	NASA delivers material to CAA
February 26	Kick off telecon with the CAA
March 27-29	NASA presentations to the CAA
August 1	CAA delivers final report to NASA

- NASA is asking the CAA to review its planned activities for delivering the mission concept studies to the Decadal Committee and prepare a short report for NASA
- Specifically, the CAA will
  - Review NASA's plans for delivering mission concept studies (large and medium) to the Decadal Survey Committee,
  - Assess the appropriateness of NASA's plans and, if needed,
  - Provide findings for the purpose of improving the value of NASA's preparations to the Decadal Survey Committee.
- NASA is delivering to the CAA the following material:
  - A Statement of Task
  - A list of URLs to documents for the Decadal activities
  - This presentation & presentations at the Space Science Week CAA meeting

Preparing for the 2020 Decadal Survey Large Mission Concepts

	Community STDT Chairs	Center Study Scientist	Study Lead Center	HQ Program Scientist
Habitable Exoplanet Imaging Mission www.jpl.nasa.gov/habex	Scott Gaudi Sara Seager	Bertrand Mennesson	JPL	Martin Still
Large UV/Optical/IR Surveyor asd.gsfc.nasa.gov/luvoir	Debra Fischer Bradley Peterson	Aki Roberge	GSFC	Mario Perez
Lynx X-ray Surveyor wwwastro.msfc.nasa.gov/lynx	Feryal Ozel Alexey Vikhlinin	Jessica Gaskin	MSFC	~~Dan Evans~~* Rita Sambruna
Origins Space Telescope asd.gsfc.nasa.gov/firs	Asantha Cooray Margaret Meixner	David Leisawitz	GSFC	Kartik Sheth

* Dan Evans is on detail to OMB through July 2018

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

STDTs Deliverables

The Decadal Studies Management Plan, page 18, lists the deliverables of the STDTs. In particular:

- A detailed study Plan was delivered to NASA in August 2016
- An Interim Report is due to NASA by March 31, 2018
  - The reports will be reviewed by a Large Mission Report Team (LRT) assembled by NASA HQ and including members of the Program Office and community experts in science, technology, engineering, and mission development. The LRT also includes an Aerospace former member. Several of these members have experience with previous Decadal submissions
  - The LRT is chartered by HQ to provide an assessment of the Interim Reports for progress towards a comprehensive Decadal submission
- An Updated Technology Requirements list is due in June 2018
- The Final Report is due to HQ no later than June 2019
  - NASA will submit the reports and the ICAs to the Decadal

Preparing for the 2020 Decadal Survey Technology Development

HabEx

- 12 of 12 gaps being addressed
- Mirror coatings, starshade starlight suppression, starshade controlling scattered sunlight, starshade lateral formation sensing, starshade petal position accuracy, starshade petal shape and stability, *telescope vibration control*, deformable mirrors, **visible detectors**, *large aperture primary mirror*, **wavefront sensing and control**, *coronagraph optics and architecture*

LUVOIR

- 7 of 9 gaps being addressed
- Closed-loop segment phasing, *vibration isolation*, ***wavefront sensing and control***, *mirror segments*, ***high-contrast segmented-aperture coronagraphy***, deformable mirrors, near infrared detectors, **visible detectors**, mirror coatings

Lynx X-ray Surveyor

- 4 of 5 gaps being addressed
- Lightweight X-ray optics, non-deforming X-ray reflecting coatings, megapixel X-ray imaging detectors, **large-format, high resolution** X-ray detectors, X-ray grating arrays

Origins Space Telescope

- 2 of 5 gaps being addressed
- far-infrared (FIR) detectors, cryogenic readouts for large-format FIR detectors, warm readout electronics for large-format FIR detectors, sub-Kelvin Coolers, cryogenic FIR mirror segments

- Purple: Technologies being advanced through SAT or directed development,
- **Bold**: Technologies being advanced by WFIRST or ATHENA
- *Italics*: Technologies being worked on through the STDT's design studies
- Additional gaps being addressed through APRA but not tallied here

Independent Cost Assessment

- NASA will engage an independent expert/company who specializes in assessing the cost of large space missions
- This task for NASA will be independent of the National Academies CATE process
  - NASA will not conduct a CATE
  - If the same independent expert/company provides CATEs for the NAS, strict firewalls be put in place to ensure independence
- NASA plans to conduct this activity after the final delivery of the report

Selected Probe Mission Concept Studies

PI	Affiliation	Short title
Jordan Camp	NASA GSFC	Transient Astrophysics Probe
Asantha Cooray	Univ. California, Irvine	Cosmic Dawn Intensity Mapper
Bill Danchi	NASA GSFC	Cosmic Evolution through UV Spectroscopy Probe
Jason Glenn	Univ. of Colorado	Galaxy Evolution Probe
Shaul Hanany	Univ. of Minnesota	Inflation Probe
Richard Mushotzky	Univ. of Maryland	High Spatial Resolution X-ray Probe
Angela Olinto	Univ. of Chicago	Multi-Messenger Astrophysics Probe
Peter Plavchan *	Missouri State Univ.	Precise Radial Velocity Observatory
Paul Ray	Naval Research Lab	X-ray Timing and Spectroscopy Probe
Sara Seager *	MIT	Starshade Rendezvous Mission

* Partial Selections

The Selection Document and Probes Implementation Plan are posted at
https://science.nasa.gov/astrophysics/2020-decadal-survey-planning

Other NASA Planning for Decadal Survey Input

NASA HQ is sponsoring, planning, or contemplating several additional studies as input to the 2020 Decadal Survey

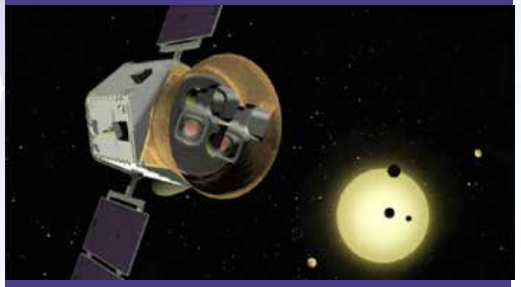
- These are independent of studies being initiated and conducted by NASA scientists at NASA Centers without HQ sponsorship

- Balloon Program Roadmap
  - Conducted by community-based Roadmap team chaired by Peter Gorham (U Hawaii)
- Evolution of NASA Data Centers
  - In planning stage, draws on efforts including STScI study on big data, NASA Big Data Task Force on adapting archives to technology, and IPAC leading on joint data processing from LSST/Euclid/WFIRST
- SmallSats
  - RFI for Astrophysics science and technology concepts
- In-Space Servicing/In-Space Assembly
  - NASA-led study being initiated, joint SMD/STMD/HEOMD
- System-Level Segmented Telescope Technology Program
  - Initial selections announced March 2018 (selected teams led by Ball Aerospace and Lockheed Martin)

NASA Astrophysics
Missions Update

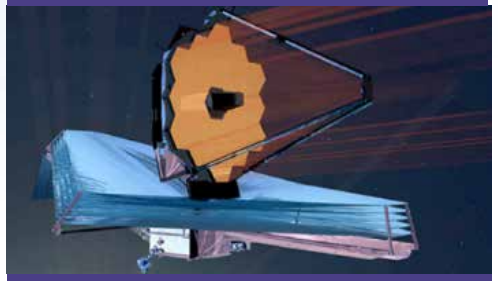
Astrophysics Missions in Development

TESS — NASA Mission — 4/2018



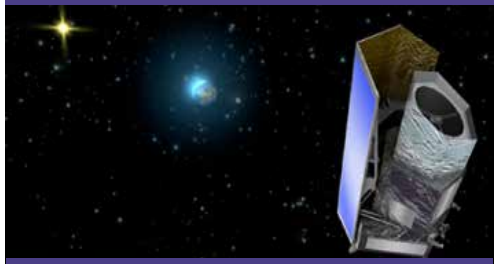
Transiting Exoplanet Survey Satellite

Webb — NASA Mission — 2020



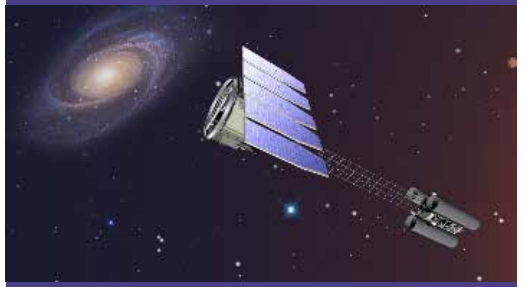
James Webb Space Telescope

Euclid — ESA-led Mission — 2020



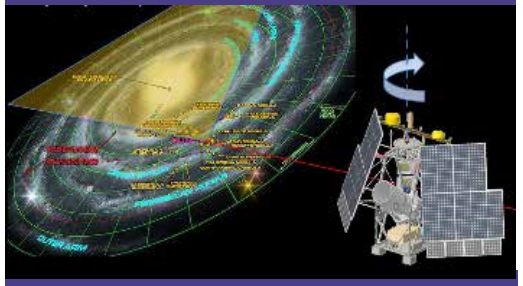
NASA is supplying the NISP Sensor Chip System (SCS)

IXPE — NASA Mission — 2021



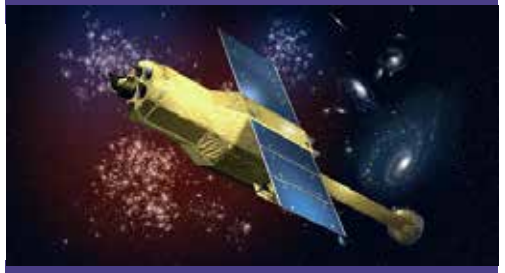
Imaging X-ray Polarimetry Explorer

GUSTO — NASA Mission — 2021



Galactic/ Extragalactic ULDB Spectroscopic Terahertz Observatory

XARM — JAXA-led Mission — 2021



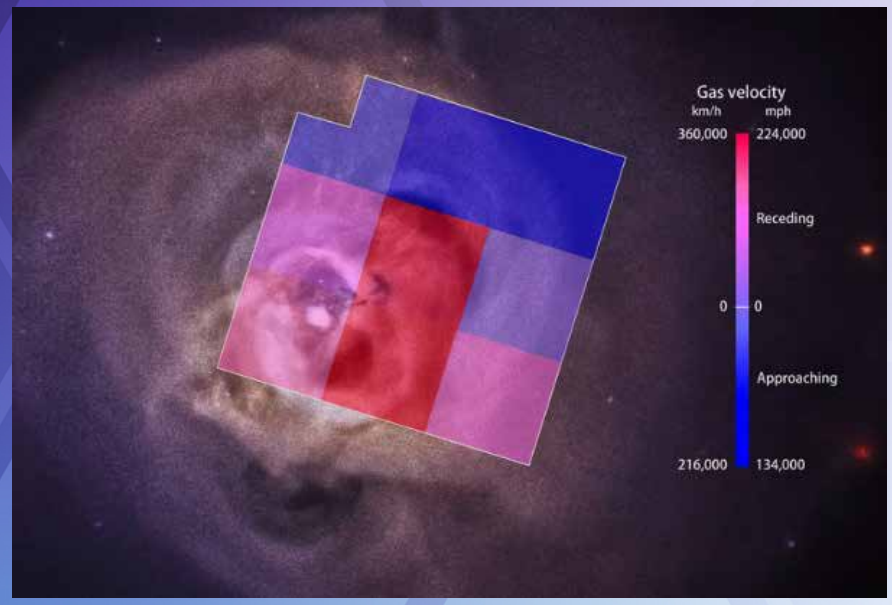
NASA is supplying the SXS Detectors, ADRs, and SXTs

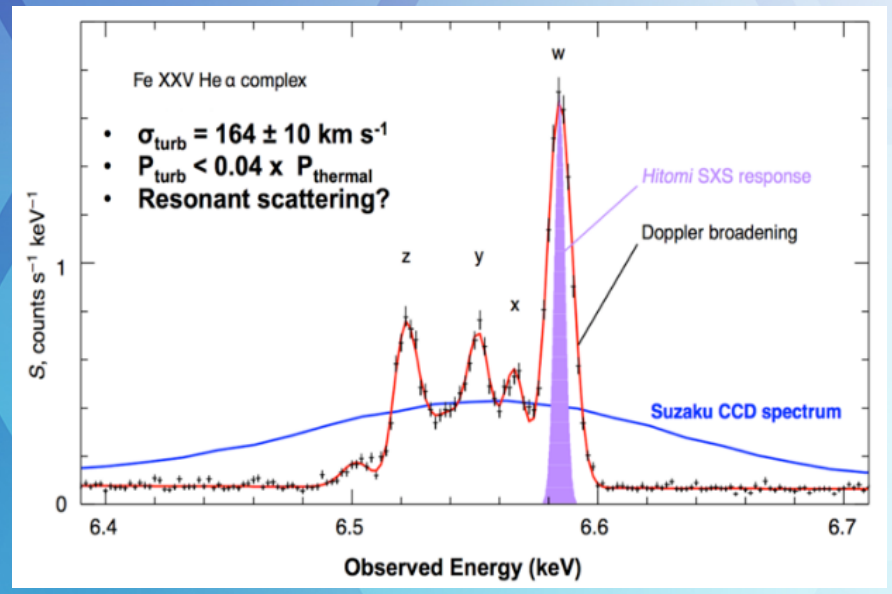
MIDEX/MO — NASA Mission — 2022/ 2023

Arcus, FINESSE, or SPHEREx CASE, COSI-X, or ISS-TAO

WFIRST — NASA Mission — Mid 2020s

Wide-Field Infrared Survey Telescope



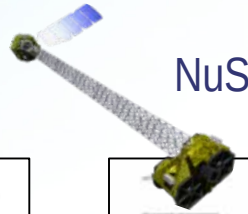


X-ray Astronomy Recovery Mission (XARM)

- XARM is the successor to ASTRO-H/Hitomi. Mission will include an X-ray microcalorimeter and an X-ray imager.
- NASA will provide same hardware contribution as for Hitomi: X-ray microcalorimeter and X-ray mirrors.
- Critical Design Review completed in November 2017
- Confirmation Review (KDP-C) completed in January 2018; XARM now in Phase C.
- U.S. Community Involvement
  - Five U.S. Participating Scientists selected to be on XARM Science Team.
  - U.S. Scientists on Guaranteed Time Observing (GTO) Target Teams: to be selected approx. 1 year before launch.
  - General Observing (GO) Program: Open to U.S. scientists starting 6-9 months after launch.

Astrophysics Explorers Program

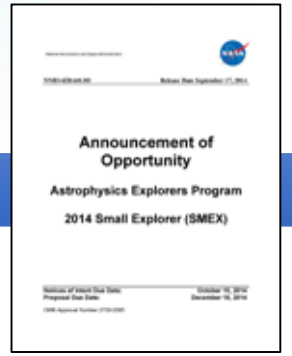
Swift



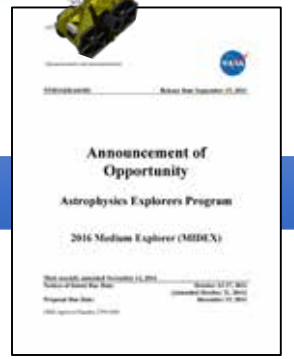
NuSTAR

NICER

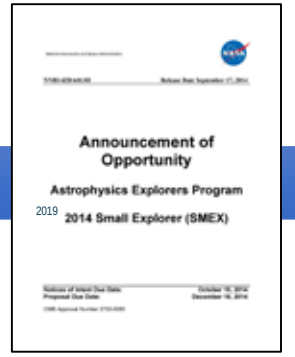
MIDEX
2011



SMEX
2014

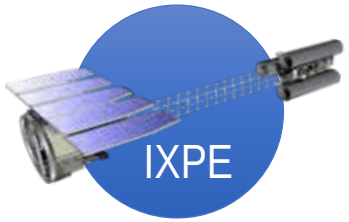


MIDEX
2016



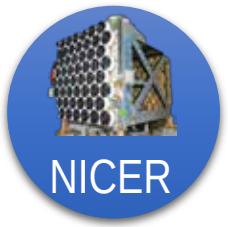
SMEX
2019
(planned)

Small and Mid-Size Missions



Arcus
FINESSE
SPHEREx

Missions of Opportunity

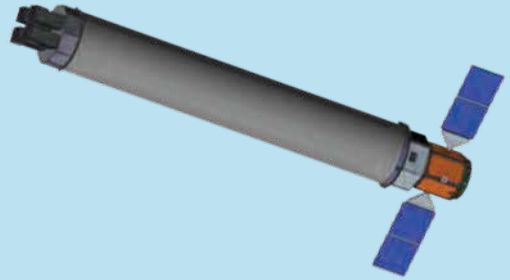


CASE
COSI-X
ISS-TAO

Directed
2017

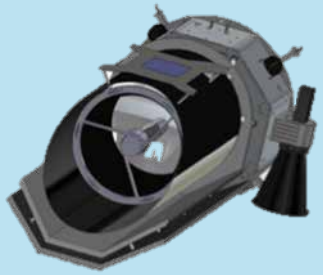
Astrophysics Explorers in Competitive Phase A

Arcus
PI: R. Smith/SAO



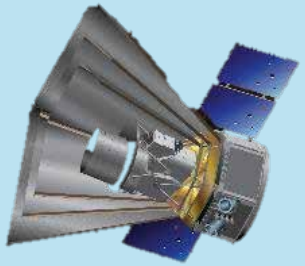
High resolution x-ray spectroscopy to explore the origin of galaxies

FINESSE
PI: M. Swain/JPL



NIR transit spectroscopy to explore exoplanet atmospheres

SPHEREx
PI: J. Bock/Caltech



NIR spectral survey addressing cosmology, galaxy evolution, and origin of ices

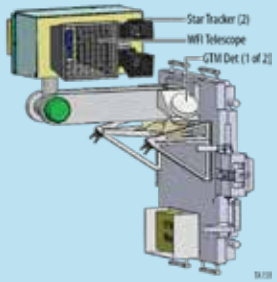
CASE
PI: M. Swain/JPL

Contribution of detectors to ESA's ARIEL

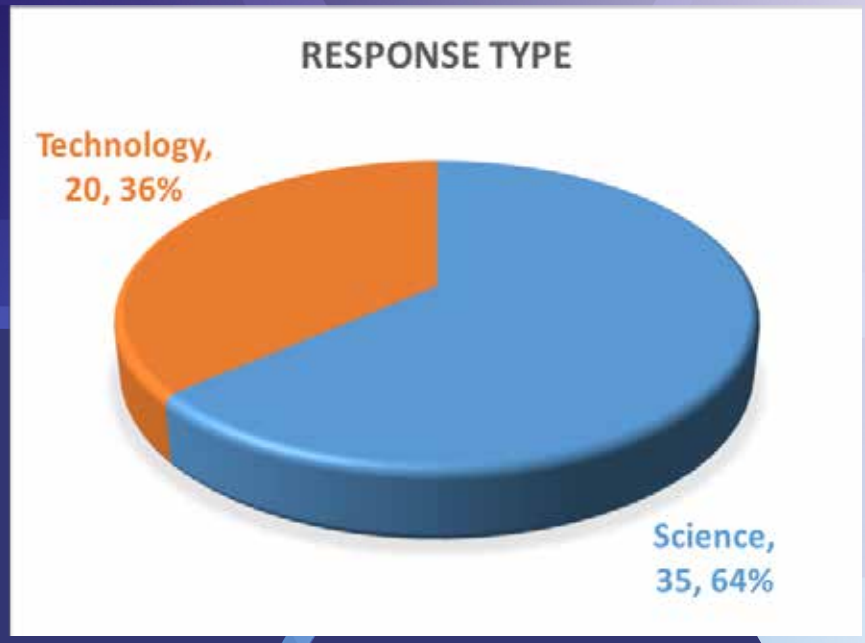
COSI-X
PI: S. Boggs/UCB

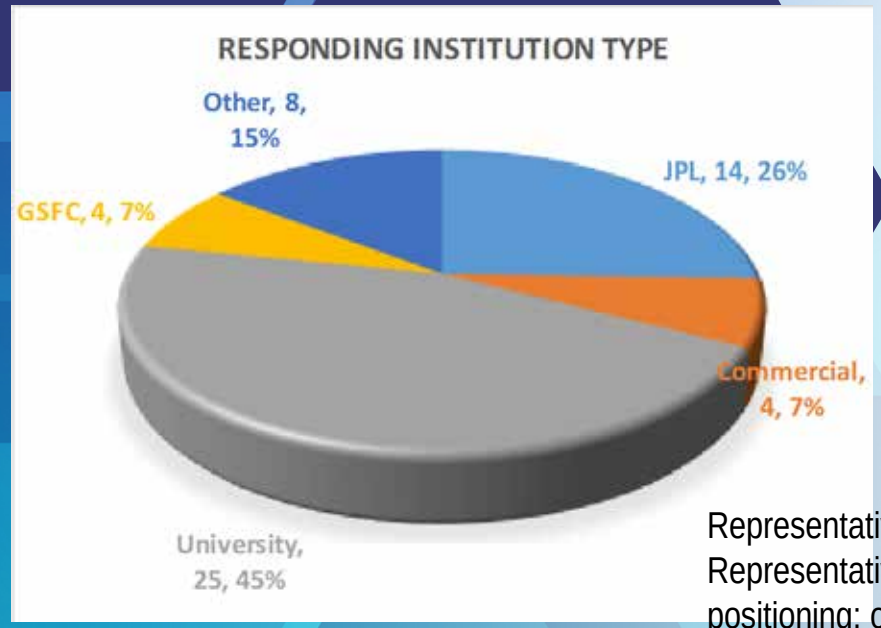
ULDB balloon mission to study origin of elements in the galaxy

ISS-TAO
PI: J. Camp/GSFC



All-sky x-ray survey to study transients and search for GW sources

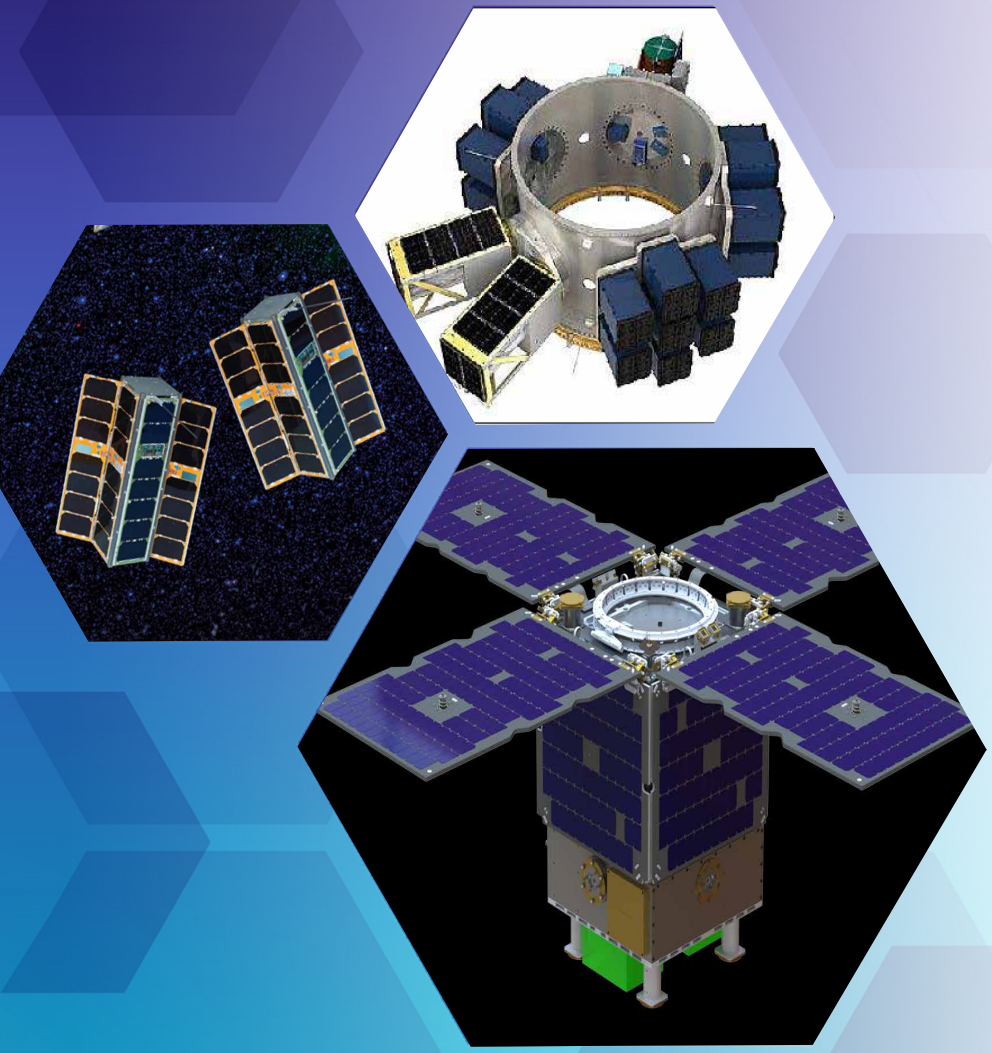




Astrophysics SmallSats

- SMD is interested in exploring ways that CubeSats/SmallSats can do highly valued science for lower price points.
- Astrophysics RFI for SmallSats asked for ideas to do high priority Astrophysics science projects at a price point between typical R&A and Explorer MOO projects ($10M-$35M).
- The RFI also asked for advanced mission concepts for which “significant” investments in instrument and/or platform technologies would be required, without budget constraints, in order to inform future STMD solicitations.
- 55 replies were responsive to Astrophysics science and/or technology.

Representative Science Areas: Exoplanets, GRM/EM Counterparts, UV/X-ray Surveys, WHIM, 21cm
Representative Technology Areas: Power systems, antennas, miniaturized cryo-coolers, communication; positioning; on-board processing, and advanced propulsion systems for formation flying



Astrophysics SmallSats

Step 1: Funded mission concept studies

- NASA will conduct funded SmallSat mission concept studies (via ROSES) in advance of the 2019 SMEX AO

Step 2: NASA is considering adding SmallSats to the 2019 Explorer MO AO

- Potential new class of MO: SmallSats ($35M cost cap)
- NASA would offer to find launch for standard CubeSat and ESPA*-ring forms

* EELV Secondary Payload Adapter

Astrophysics Missions in Pre-Formulation

Athena

Late 2020s

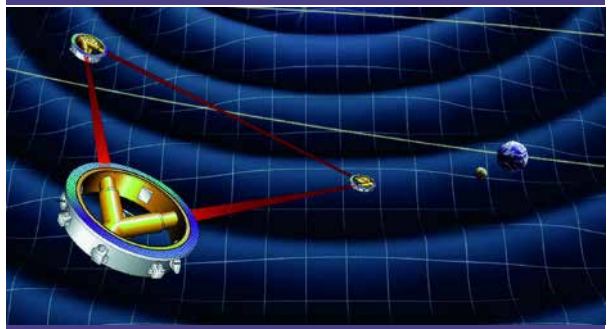
ESA-led Mission

NASA is supplying elements for both instruments

LISA

Mid 2030s

ESA-led Mission



NASA is developing technology for both the payload and the mission

Selected Mission Updates

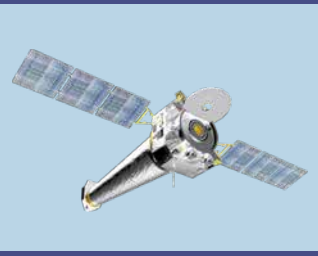
- Athena
  - NASA budgeting for a $100M-$150M hardware contribution, plus a U.S. GO program and a U.S. data center.
  - NASA will contribute to both the X-IFU and the WFI instruments.
  - NASA and U.S. community participating in Athena Science Study Team (including its Science Working Groups) and Instrument Teams.
  - Transitioning to a NASA project in 2018/2019.
- LISA
  - NASA has established a LISA Study Office at GSFC.
  - NASA is funding five US-based technologies with the aim of reaching TRL 5/6 by Adoption.
  - NASA and U.S. community participating in LISA Science Study Team and the LISA Consortium.
  - NASA established a NASA LISA Study Team to interface with NASA LISA Study Office, LISA Consortium, and Decadal Survey.
  - NASA issued call for LISA Preparatory Science proposals in ROSES.
  - Transitioning to a NASA project in 2018/2019.

Astrophysics Missions in Operation

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

Spitzer Space Telescope

SOFIA 5/14
NASA Strategic Mission

Stratospheric Observatory for Infrared Astronomy

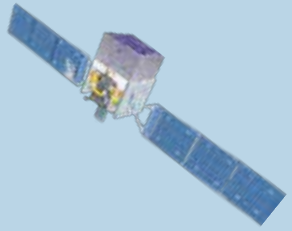
ISS-CREAM 8/17
NASA Research Mission

Cosmic Ray Energetics And Mass

Gehrels-Swift 11/04
NASA MIDEX Mission

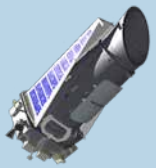
Swift Gamma-ray Burst Explorer

Fermi 6/08
NASA Strategic Mission



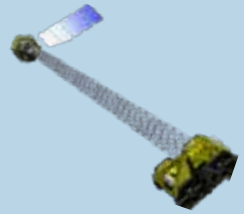
Fermi Gamma-ray Space Telescope

Kepler 3/09
NASA Discovery Mission



Kepler Space Telescope

NuSTAR 6/12
NASA SMEX Mission



Nuclear Spectroscopic Telescope Array

ISS-NICER 6/17
NASA Explorers Mission of Oppty

Neutron Star Interior Composition Explorer

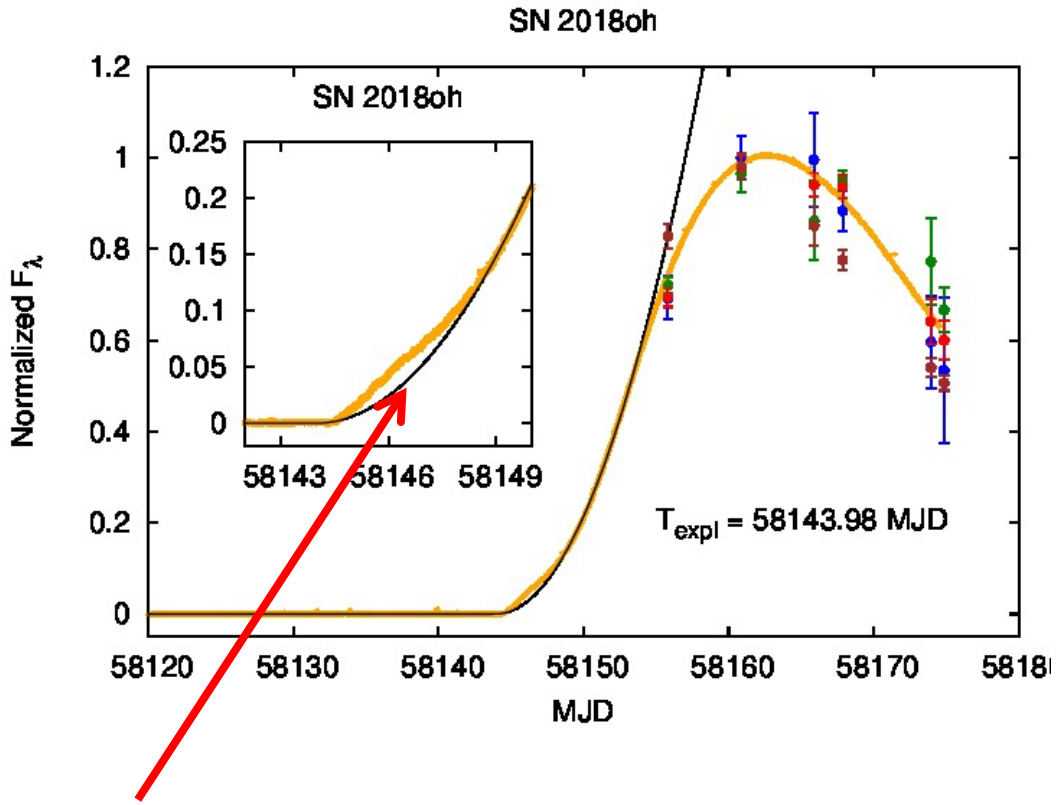
SOFIA

Stratospheric Observatory for Infrared Astronomy

- Instrument suite being enhanced
  - HAWC+ now in regular usage by GOs
  - HIRMES instrument past CDR
  - Next Gen instrument solicitation issued March 2018
- SOFIA maintenance period extended
  - SOFIA remains in Hamburg, Germany, to address a repair that was discovered during a routine inspection and repair cycle, known as a C-Check.
  - After completion of the inspection and maintenance by technicians at Lufthansa Tecknik AG, a fuel leak was discovered where the outer engine on the left side attaches to the wing.
  - Return of SOFIA to science flights has been delayed since January to address several repairs. SOFIA is currently scheduled to depart Germany in early April, and will resume science flights shortly after its return to NASA Armstrong Flight Research Center's aircraft operations facility in Palmdale, California.
  - Impacts to the observatory's science schedule are currently being assessed and will be mitigated through contingency flight dates built into SOFIA's schedule.
- FY18 Consolidated Appropriations Explanatory Statement excludes SOFIA from 2019 Senior Review
  - Defines prime mission to be 20 years (starting in 2014)

Kepler/K2: Campaign 16 early highlights

- Forward facing campaign to facilitate contemporaneous ground observations.
  - Observations from December 7, 2017 – February 25, 2018.
  - Raw data available March 1. Pipeline data products expected early summer.
- Monitored 9,241 galaxies for supernova.
  - ~20 SN identified
  - ~15 ground telescopes made contemporaneous observations
  - Many types including Ia, Ic, II, IIb, IIP
  - Initial analysis of brightest Ia show signatures of white dwarf / red giant progenitor system
- Observed ~ 20,000 stars
  - ~12 ground telescopes made contemporaneous observations
  - Paper released March 12 (Yu et al) identified 32 planet candidates



K2 lightcurve (yellow) reveals excess flux in the first 2 days, consistent with interaction with red giant companion.

Senior Review 2019

- Chandra X-ray Observatory (Chandra)
- Fermi Gamma-ray Space Telescope (Fermi)
- Hubble Space Telescope (Hubble)
- Neutron star Interior Composition ExploreR (NICER)
- Nuclear Spectroscopic Telescope Array (NuSTAR)
- ~~Stratospheric Observatory for Infrared Astronomy (SOFIA)~~
- Neil Gehrels Swift Observatory (Swift)
- Transiting Exoplanet Survey Satellite (TESS)
- X-ray Multi-mirror Mission-Newton (XMM-Newton)

Senior Review 2019

NASA Astrophysics Advisory Committee

Senior Review Subcommittee

- Rest-of-Missions Panel
- Chandra Panel
- Hubble Panel
- ~~SOFIA Panel~~

Senior Review 2019

2018:

- APAC approves Terms of Reference for the Senior Review Subcommittee
- Establish Senior Review Subcommittee, including appointment of subcommittee members compliant with FACA
- Draft call for proposals issued
- Final call for proposals issued

2019:

- Senior Review proposals due
- Rest-of-missions, Chandra, Hubble, and ~~SOFIA~~ panels meet.
- Reports from Rest-of-missions, Chandra, Hubble, and ~~SOFIA~~ panels due to Senior Review Subcommittee
- Senior Review Subcommittee meets.
- Senior Review Subcommittee reports to APAC.
- APAC delivers formal recommendations to NASA.
- NASA response to Senior Review and direction to projects.

Planned Accomplishments FY18-19

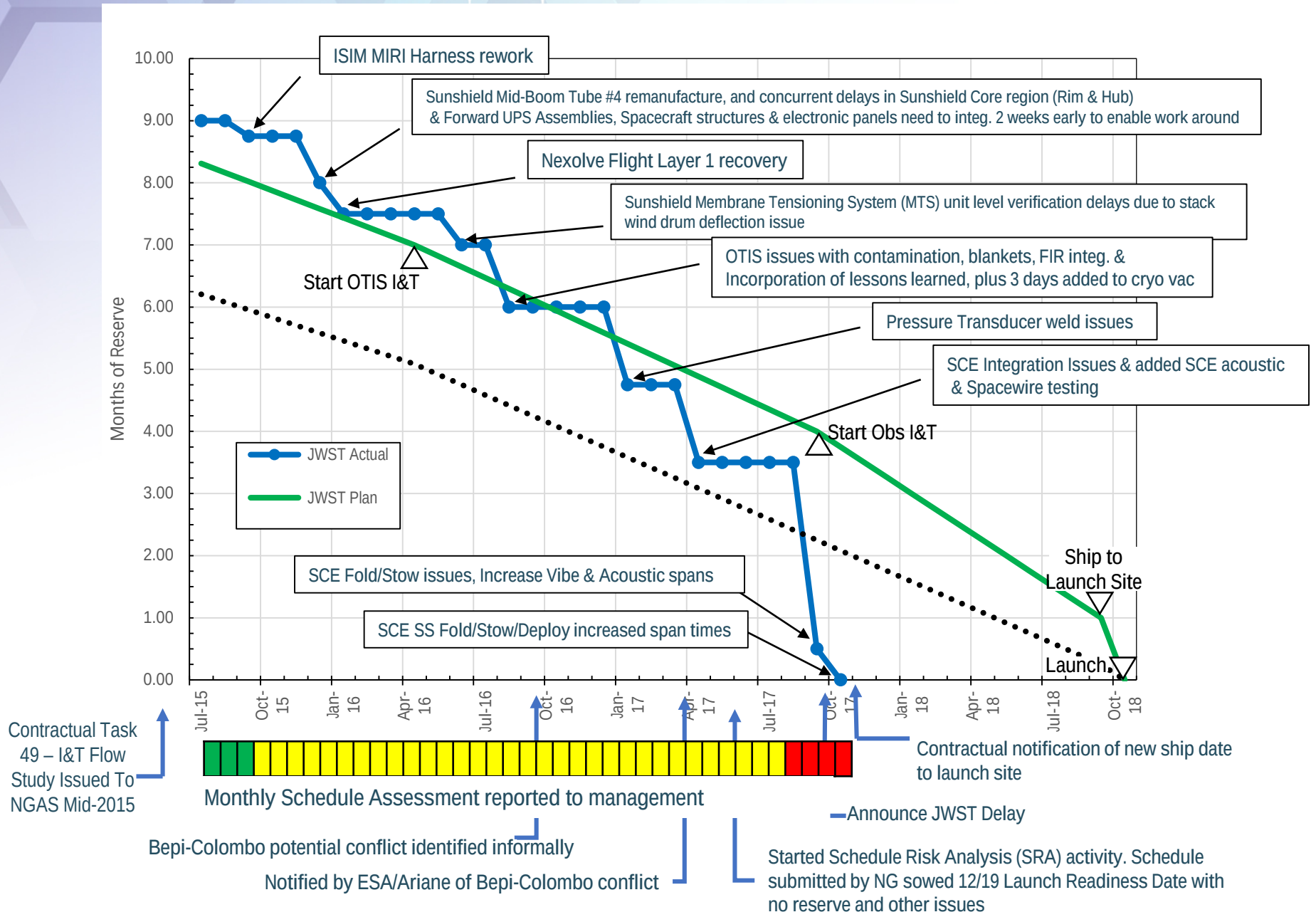
- TESS will launch April 2018
- Funds appropriated by Congress in FY18 will allow WFIRST to enter Phase B in April 2018
- IXPE will complete preliminary design review and enter Phase C Fall 2018
- Next MIDEX and Mission of Opportunity missions will be downselected by January 2019
- Decadal Survey will begin January 2019
- Webb will complete observatory integration in 2019
- Senior Review will be conducted Spring 2019
- If Congress approves the Administration's request to terminate WFIRST, the funds made available would enable a competed mission AO in FY19


+ MIDEX/MO (2023), SMEX/MO (2025), etc.
Spitzer 8/25/2003
Kepler 3/7/2009
Formulation
Implementation
Primary Ops
Extended Ops
WFIRST Mid 2020s
Webb 2020
Euclid (ESA) 2020
Chandra 7/23/1999
XMM-Newton (ESA) 12/10/1999
TESS 2018
Swift 11/20/2004
NuSTAR 6/13/2012
Fermi 6/11/2008
IXPE 2021
Hubble 4/24/1990
XARM (JAXA) 2021
ISS-NICER 6/3/2017
ISS-CREAM 8/14/2017
GUSTO 2021
SOFIA Full Ops 5/2014
Revised February 1, 2018
+ Athena (late 2020s), LISA (mid 2030s)

NASA Astrophysics

Backup

Webb Schedule Reserve Usage 2015-mid-2017



Science FY19 Budget Request Summary ($M)

	Actual	Enacted	Request	Notional			
	FY 17	FY 18	FY 19	FY 20	FY 21	FY 22	FY 23
Science	5,762.2	6,221.5	5,895.0	5,859.9	5,841.1	5,822.4	5,803.6
Earth Science	1,907.7	1,921.0	1,784.2	1,784.2	1,784.2	1,784.2	1,784.2
Earth Science Research	462.0		451.4	457.4	483.8	507.7	537.8
Earth Systematic Missions	929.7		788.1	729.5	689.1	646.5	595.0
Earth System Science Pathfinder	208.8		235.0	273.7	268.2	274.3	287.7
Earth Science Multi-Mission Operations	204.9		196.9	208.7	225.0	231.6	237.1
Earth Science Technology	62.9		59.7	61.6	64.2	67.8	69.6
Applied Sciences	39.4		53.1	53.3	53.9	56.3	57.0
Planetary Science	1,827.5	2,227.9	2,234.7	2,199.6	2,180.8	2,162.1	2,143.3
Planetary Science Research	230.1		258.0	247.6	247.6	247.6	247.6
Planetary Defense	60.0		150.0	150.0	150.0	150.0	150.0
Lunar Discovery and Exploration	19.0		218.0	218.0	218.0	218.0	218.0
Discovery	194.6	335.8	381.2	476.6	375.0	355.6	348.5
New Frontiers	134.0	90.0	130.2	163.7	245.0	327.6	388.4
Mars Exploration	647.0	660.0	601.5	529.7	371.9	290.8	215.3
Outer Planets and Ocean Worlds	359.5		285.6	213.8	373.3	372.5	375.5
Technology	183.3		210.2	200.2	200.0	200.0	200.0
Astrophysics	1,352.3	1,384.1	1,185.4	1,185.4	1,185.4	1,185.4	1,185.4
Astrophysics Research	190.1		259.2	280.8	321.5	318.4	310.0
Cosmic Origins	779.4		491.4	354.5	311.9	312.7	312.7
Physics of the Cosmos	106.2		136.8	139.1	113.3	108.3	105.0
Exoplanet Exploration	152.6		52.4	44.5	44.6	44.4	44.9
Astrophysics Explorer	124.1		245.6	366.5	394.0	401.6	412.8
Heliophysics	674.7	688.5	690.7	690.7	690.7	690.7	690.7
Heliophysics Research	180.8		242.7	234.3	226.7	217.9	220.6
Living with a Star	368.4		247.8	103.4	83.5	93.2	127.8
Solar Terrestrial Probes	38.8		91.0	89.9	177.7	175.6	247.9
Heliophysics Explorer Program	86.7		109.2	263.1	202.9	204.1	94.4

Astrophysics FY19 Budget Request ($M)

	Actual FY 17	Enacted FY 18	Request FY 19	Notional FY 20	Notional FY 21	Notional FY 22	Notional FY 23
Astrophysics	**1,352.3**	1,384.1	**1,185.4**	**1,185.4**	**1,185.4**	**1,185.4**	**1,185.4**
Astrophysics Research	190.1		259.2	280.8	321.5	318.4	310.0
Science Activation	37.0	44.0	44.6	44.6	44.6	44.6	44.6
Astrophysics Research and Analysis	73.5	74.1	83.4	86.6	90.2	92.2	94.2
Balloon Project	34.0		39.2	41.7	40.4	40.5	40.6
Other Missions and Data Analysis	45.6		92.0	108.0	146.4	141.1	130.7
Astrophysics Data Curation and Archival	15.4		21.2	20.5	21.5	21.5	21.5
Astrophysics Data Program	17.6		19.1	20.4	21.6	22.6	23.6
Astrophysics Senior Review					31.5	33.0	33.0
Contract Administration, Audit & QA Svcs	12.6		12.7	12.7	12.7	12.7	12.7
Astrophysics Directed R&T			39.0	54.4	59.1	51.3	39.9
Cosmic Origins	779.4		491.4	354.5	311.9	312.7	312.7
Hubble Space Telescope	97.3	98.3	78.3	88.3	93.3	98.3	98.3
SOFIA	85.2	85.2	74.6	39.8	16.6		
James Webb Space Telescope	569.4	533.7	304.6	197.2	149.8	150.0	150.0
Other Missions and Data Analysis	27.5		33.9	29.1	52.2	64.4	64.4
Cosmic Origins Future Missions	0.0		2.7	2.2	28.7	43.8	43.8
Spitzer	11.0		11.0	8.0	3.0		
Herschel	1.0						
Cosmic Origins SR&T	12.8		17.6	16.8	18.4	18.4	18.4
Cosmic Origins Program Management	2.7		2.7	2.2	2.2	2.2	2.2

Astrophysics FY19 Budget Request ($M) (cont'd)

	Actual FY 17	Enacted FY 18	Request FY 19	Notional FY 20	Notional FY 21	Notional FY 22	Notional FY 23
Physics of the Cosmos	106.2		136.8	139.1	113.3	108.3	105.0
Euclid	12.9		20.2	16.4	9.4	9.5	8.9
Physics of the Cosmos Future Missions	0.1		2.3	3.4	3.7	4.0	4.4
Chandra X-Ray Observatory	50.7		58.9	58.4	58.4	58.4	58.4
Fermi Gamma-ray Space Telescope	12.5		15.5	14.0			
XMM	3.5		3.5	3.5			
Planck	0.6						
Physics of the Cosmos SR&T	23.3		33.5	41.1	39.4	34.1	30.9
Physics of the Cosmos Program Mgmt	2.6		2.9	2.4	2.4	2.4	2.4
Exoplanet Exploration	152.6		52.4	44.5	44.6	44.4	44.9
WFIRST	105.0	150.0					
Exoplanet Exploration Future Missions	0.9		1.5	1.6	1.4	1.2	1.0
Kepler	11.0		7.9	1.3			
Keck Operations	6.1		6.5	6.7	6.9	7.0	7.2
Large Binocular Telescope Interferometer	2.6						
Exoplanet Exploration SR&T	21.2		28.5	27.2	28.4	28.3	28.3
Exoplanet Exploration Program Mgmt	5.9		8.0	7.8	8.0	7.9	8.3

Astrophysics FY19 Budget Request ($M) (cont'd)

	Actual FY 17	Enacted FY 18	Request FY 19	Notional FY 20	Notional FY 21	Notional FY 22	Notional FY 23
Astrophysics Explorer	124.1		245.6	366.5	394.0	401.6	412.8
Transiting Exoplanet Survey Satellite	74.0		27.5	3.8	0.0		
Imaging X-Ray Polarimetry Explorer	11.3		65.9	67.3	40.7	5.0	4.2
Other Missions and Data Analysis	38.8		152.2	295.5	353.3	396.6	408.6
GUSTO	2.4		13.2	11.6	7.5	3.5	
Astrophysics Explorer Future Missions	15.2		112.1	262.9	334.1	385.2	398.5
Nuclear Spectroscopic Telescope Array	5.0		8.3	7.0			
Swift	5.5		5.4	5.5			
NICER	4.6		2.4				
Astrophysics Explorer Program Mgmt	6.1		10.9	8.5	11.8	7.9	10.1