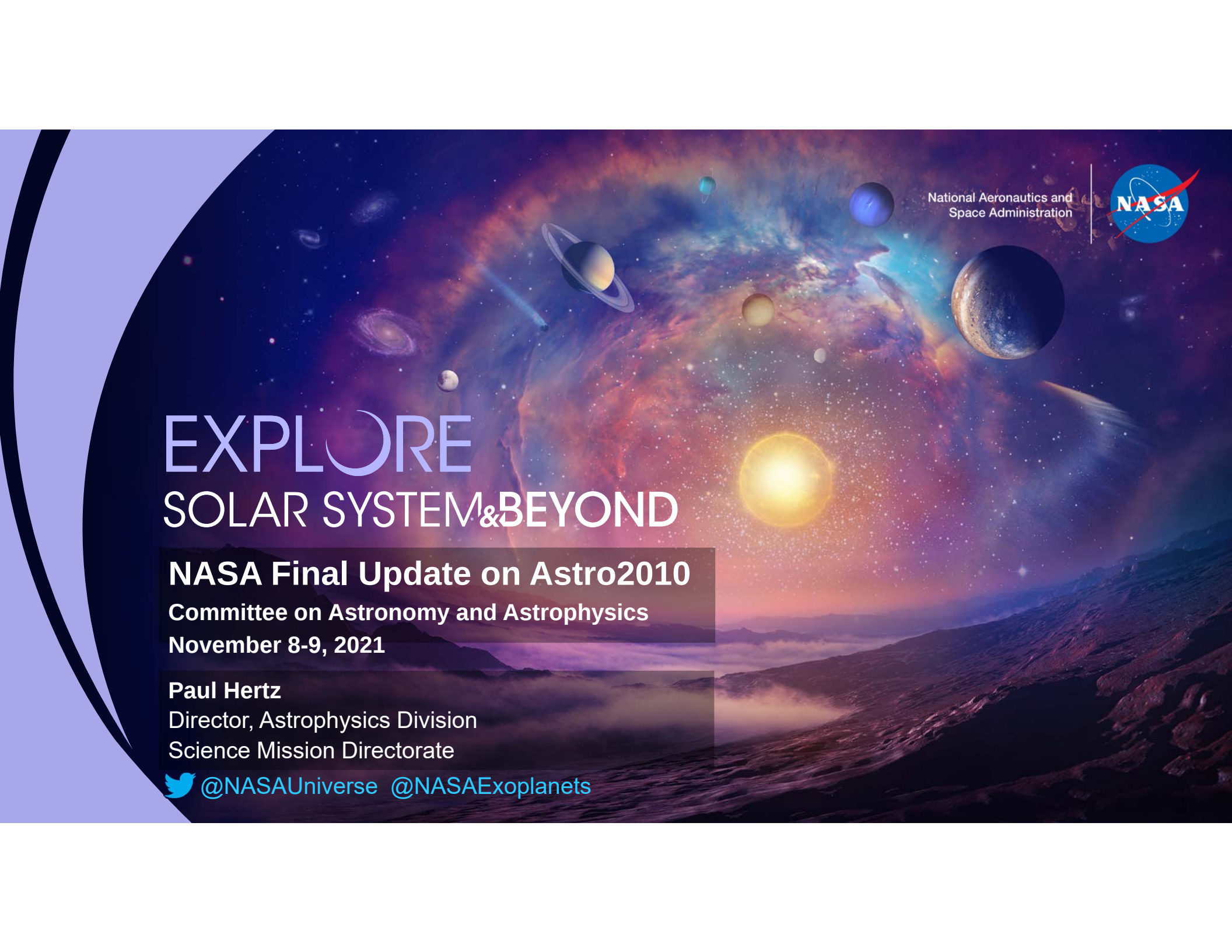




National Aeronautics and
Space Administration



EXPLORE SOLAR SYSTEM&BEYOND

NASA Final Update on Astro2010

Committee on Astronomy and Astrophysics

November 8-9, 2021

Paul Hertz

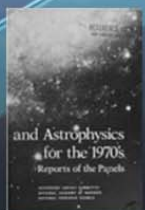
Director, Astrophysics Division

Science Mission Directorate

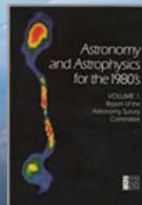
 [@NASAUniverse](https://twitter.com/NASAUniverse) [@NASAEoplanets](https://twitter.com/NASAEoplanets)

Astrophysics

Decadal Survey Missions



1972
Decadal
Survey
Hubble



1982
Decadal
Survey
Chandra



1991
Decadal
Survey
Spitzer



2001
Decadal
Survey
JWST



2010
Decadal
Survey
WFIRST



Implementing the 2010 Decadal Survey

Prioritized Recommendation	NASA plans (as presented to Astro2020 in Jul 2019)
LARGE ACTIVITIES	
WFIRST	Element & mission PDR in CY2019, KDP-C in early CY2020
Explorers	4 AOs per decade (SMEX 2014, MIDEX 2016, SMEX 2019, MIDEX 2021 (planned), SMEX 2024 (planned))
LISA	Partnering on ESA's LISA gravitational wave observatory
IXO	Partnering on ESA's Athena x-ray observatory
MEDIUM ACTIVITIES	
Exoplanet technology & precursor science	WFIRST coronagraph, starshade and coronagraph technology development, NN-EXPLORE (PRV instrument, EPRV WG), LBTI
Inflation Probe technology	Balloon-borne technology experiments, detector technology investments
SMALL ACTIVITIES	
R&A augmentations	R&A up 60% from FY10 to FY24; added RTF, TCAN, evolved XRP
Mid-TRL technology	Initiated SAT program, includes competed and directed technologies
Suborbital (class) missions	Added New Zealand, offering super-pressure balloon, added CubeSats

Implementing the 2010 Decadal Survey

Prioritized Recommendation	NASA plans (updated Nov 2021)
LARGE ACTIVITIES	
WFIRST Roman	KDP-A in 2016, KDP-C in 2020, ABC LRD in 2027
Explorers	4 AOs per decade (MIDEX 2011 , SMEX 2014, MIDEX 2016, SMEX 2019, MIDEX 2021 (planned), SMEX 2024 (planned))
LISA	Partnering on ESA's LISA gravitational wave observatory
IXO	Partnering on ESA's Athena x-ray observatory
MEDIUM ACTIVITIES	
Exoplanet technology & precursor science	WFIRST coronagraph, starshade and coronagraph technology development, NN-EXPLORE (PRV instrument, EPRV WG), LBTI
Inflation Probe technology	Balloon-borne technology experiments, detector technology investments
SMALL ACTIVITIES	
R&A augmentations	R&A up 60% from FY10 to FY24; added RTF, TCAN, evolved XRP
Mid-TRL technology	Initiated SAT program, includes competed and directed technologies
Suborbital (class) missions	Added New Zealand, offering super-pressure balloon, added CubeSats, added Pioneers
SPICA	Not supported as a strategic contribution; declined as Explorer MO

Implementing the 2016 Midterm Assessment

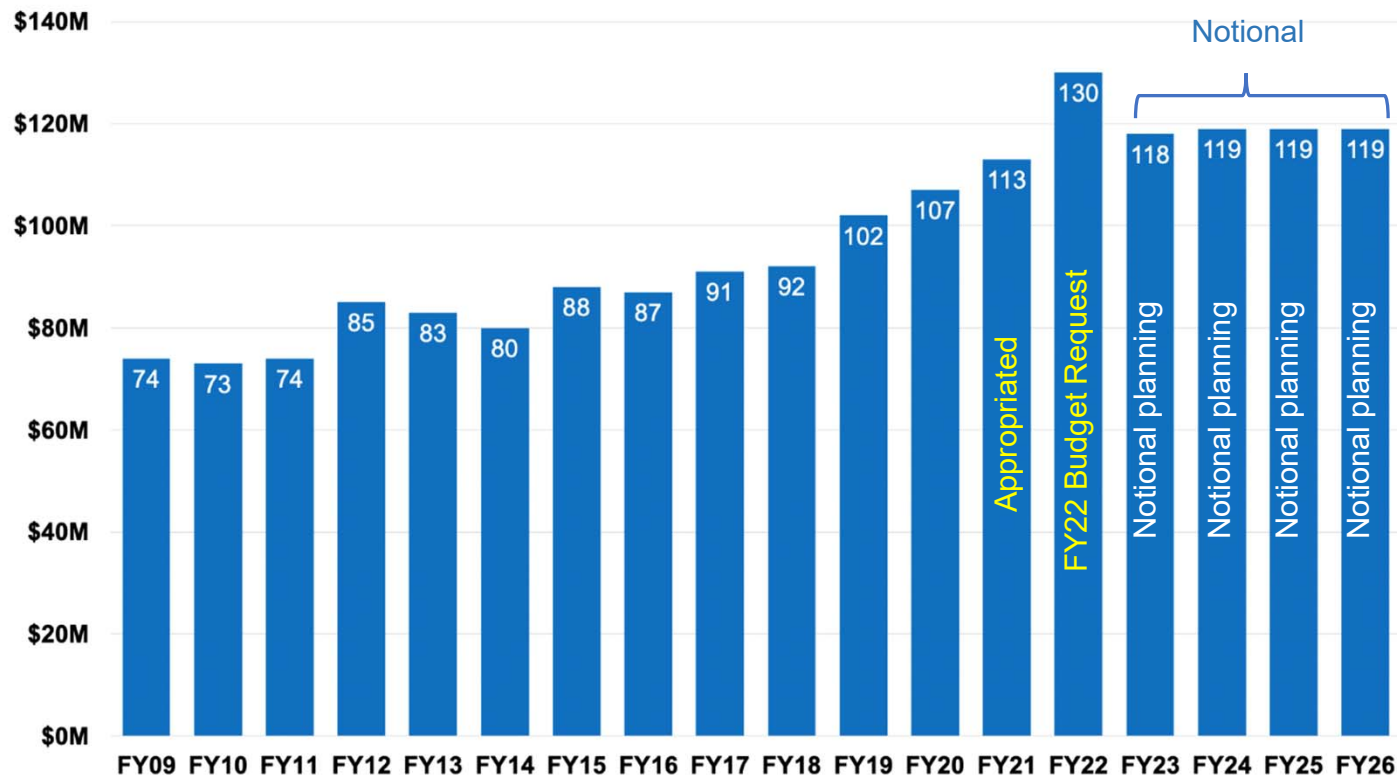
Recommendation	NASA plans (as presented to Astro2020 in Jul 2019)
4-1 Commission the WIETR; if cost growth threatens decadal priorities and program balance, then descope WFIRST	Done. WIETR completed; descopes taken before KDP-B, further descopes being taken during Phase B as part of PDR process.
4-2 Treat Euclid beyond commitments to ESA as lower priority than Decadal Survey priorities	Done. Euclid commitments to ESA met, unused UFE returned to the Astrophysics budget, no growth in non-hardware elements of Euclid.
4-3 Execute at least four Explorer AOs during the 2012-2021 decade, each with a MO call and a mission selection	Done. AOs in 2014, 2016, 2019, and 2021 (planned), selected missions (IXPE, SPHEREx), and selected MOs (GUSTO, CASE [TBD]) all in-guide budget.
4-4 Restore support for GW research to enable a partnership on LISA that restores the full LISA capability.	Done. LISA Preparatory Science program initiated. NASA contribution to LISA enables 3-arm architecture.
4-5 Participate in Athena, with contributions enhancing mission scientific capabilities.	Done. NASA contributions enhance both instrument scientific capabilities and make use of unique XRCF capabilities.



NASA's response to Astro2010



R&A Research Funding



Sustained growth in R&A research funding since the 2010 Decadal Survey

Since the last Decadal Survey:
+38% R&A funding growth

Notional Planning:
+60% over 17 years.

For the last 12 months (August 2020 – August 2021), the selection rates were 23% for R&A programs and 46% for smaller mission's general observer (GO)/guest investigator (GI) programs*, with a total average selection rate of 35% for all our ROSES programs

* Does not include Hubble, Chandra, SOFIA

TABLE ES.1 (1 of 2)

Space and Ground: Recommended Activities—Small Scale (Alphabetical Order)

Recommendation	Budget	Response	Budget (FY12-21)
(Augmentation to) Astrophysics Theory Program (ATP)	\$35M additional	Increased from \$12M/yr in FY10 to \$14M/yr in FY22 (plus TCAN plus LPS plus XRP; see notes)	\$132M
	Notes: (i) TCAN did not come at expense of ATP. (ii) One time supplement of \$1.7M in FY14 from WFIRST Preparatory Science (WPS) program. (iii) \$1M/yr supplement starting in FY18 for LISA Preparatory Science. (iv) \$0.4M transfer of funding to XRP in FY21, rising to \$1.2M in FY23.		
(Definition of) A future ultraviolet-optical space capability	\$40M	APRA, SAT, mission concept studies, mirror technology program (see notes)	\$85M
	Notes: (i) APRA and SAT technology investments (\$54M). (ii) Mission concept studies included LUVUOIR, HabEx, CETUS, EarthFinder, and 7 SmallSat studies (\$11M). (iii) Segmented Mirror Technology Program (\$5M/yr for FY18-FY21).		

TABLE ES.1 (1 of 2)

Space and Ground: Recommended Activities—Small Scale (Alphabetical Order)

Recommendation	Budget	Response	Budget (FY12-21)
(Augmentation to) Intermediate Technology Development	\$2M/year now to \$15M/year by 2021	SAT program, mirror technology program, high contrast imaging technology program (coronagraphs and starshades)	SAT rose from \$4M/yr in FY11 to \$25M/yr in FY20
	Notes: (i) SAT rose from \$4M/yr in FY11 to \$25M/yr in FY20. (ii) Segmented Mirror Technology Program (\$5M/yr for FY18-FY21). (iii) High contrast imaging testbeds and starshade technology development are counted under New Worlds Technology Program.		
(Augmentation to) Laboratory Astrophysics	\$2M/year additional	Added one large lab astro investigation in FY12-FY14; new equipment augmentation started in FY21	Flat around \$4.5M/yr
	Notes: (i) Added one large lab astro investigation in FY12-FY14. (ii) New equipment augmentation started in FY21.		

TABLE ES.1 (2 of 2)

Space and Ground: Recommended Activities—Small Scale (Alphabetical Order)

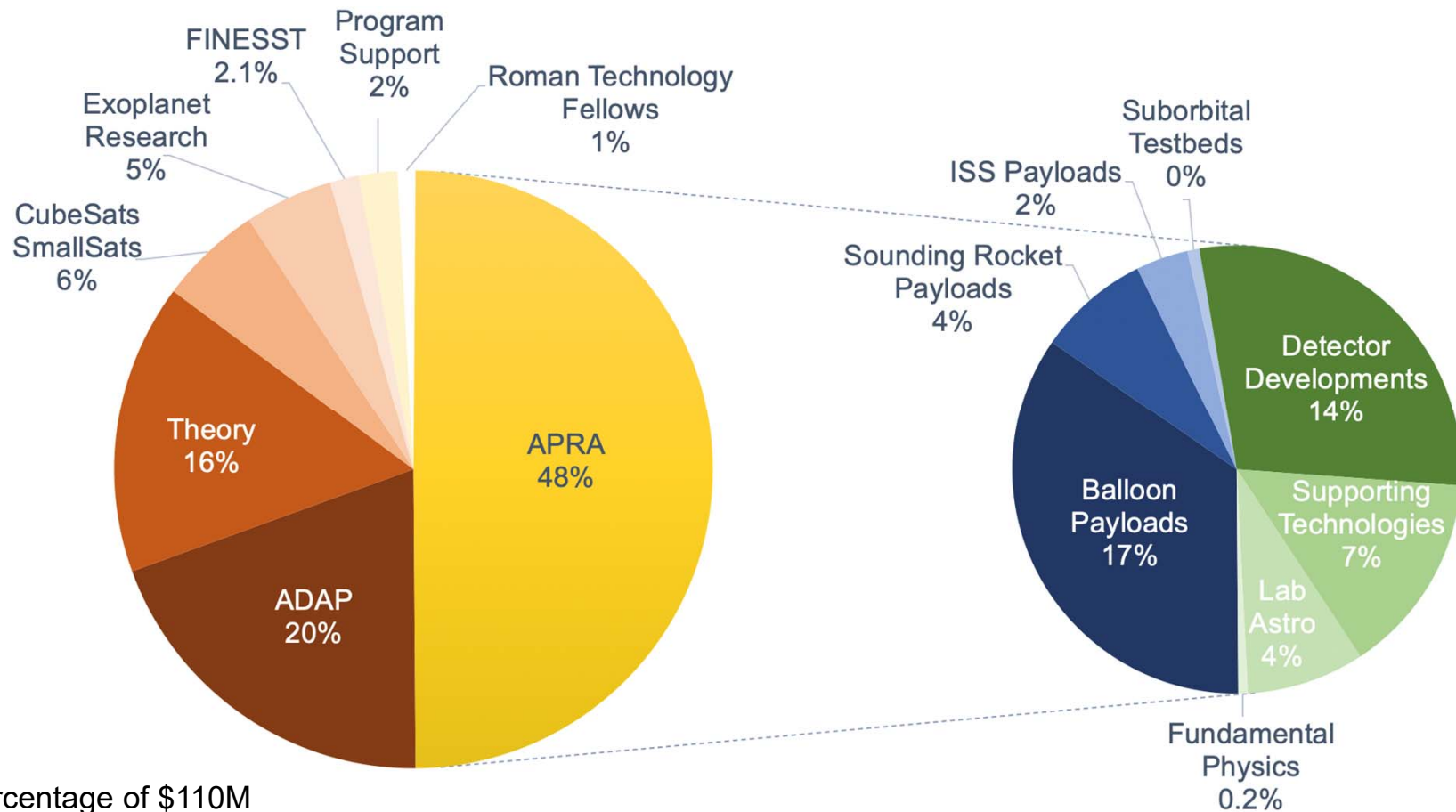
Recommendation	Budget	Response	Budget (FY12-21)
(U.S. contribution to JAXA-led) SPICA mission	\$150M	NASA declined to participate for both budgetary and programmatic reasons	zero
Notes: (i) Due to budgetary pressure, NASA declined to make a strategic commitment for a contribution to SPICA. SPICA advocates were permitted to propose as an Explorer Mission of Opportunity. (ii) In 2020, NASA declined to select a proposed contribution to SPICA for programmatic reasons.			
Theory and Computation Networks (TCAN)	\$5M/year NASA	Competed in 2012 (with NSF), 2017, 2020	\$1.5M/yr in FY13 to \$2.2M/yr in FY22
Notes: (i) NASA and NSF provided equal funding of \$1.5M/yr over 3 years for 2012 competition. NASA conducted 2017 and 2020 competitions without partners. Next competition is in 2022. (ii) Funding allows for 3 or 4 selections at \$500K per network per year.			

TABLE ES.1 (2 of 2)

Space and Ground: Recommended Activities—Small Scale (Alphabetical Order)

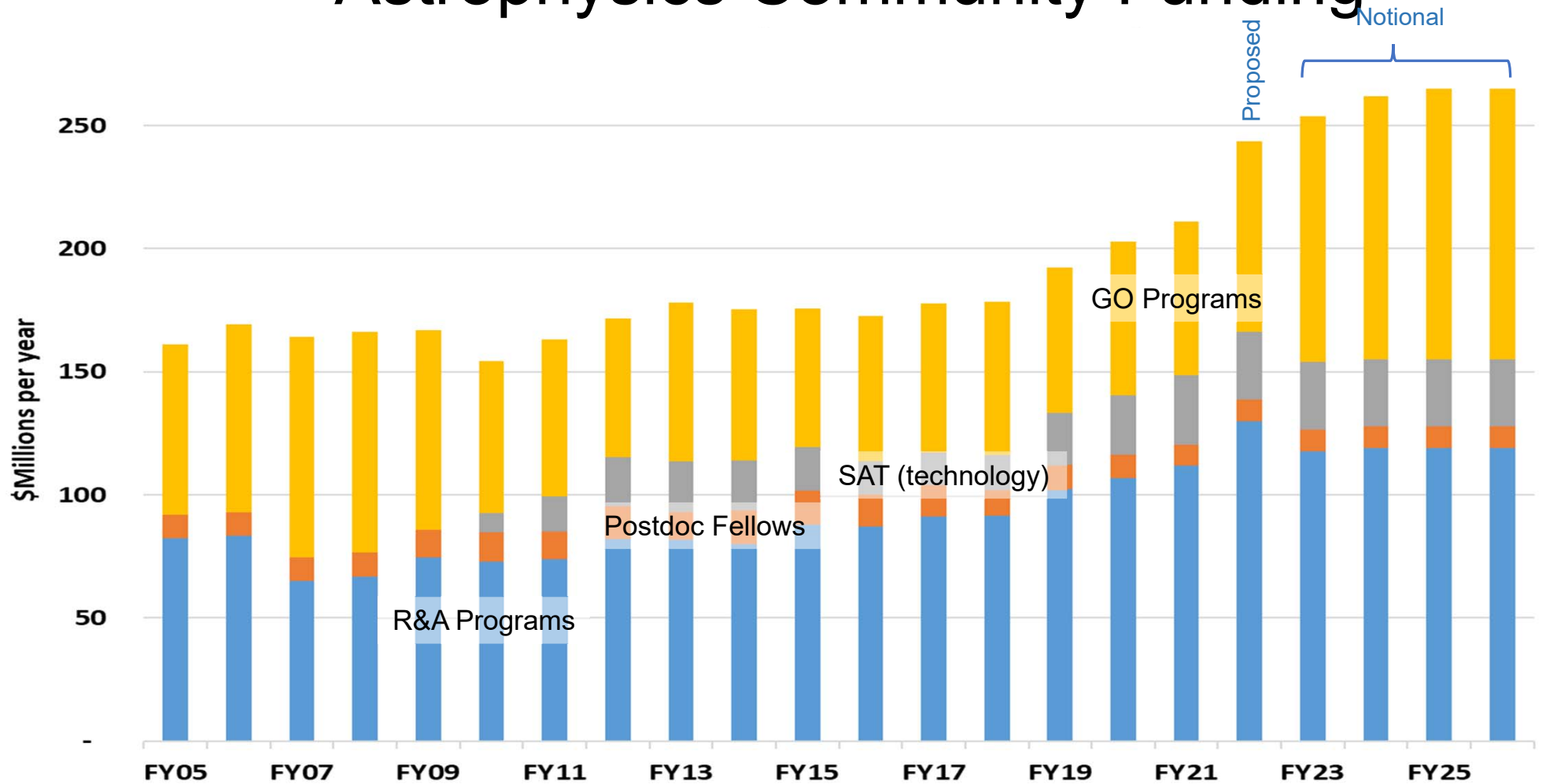
Recommendation	Budget	Response	Budget (FY12-21)
(Augmentation to) the Suborbital Program	\$15M/year additional	Payload funding up from \$22M (FY10) to \$31M (FY20). Balloon program funding up from \$28M (FY10) to \$45M (FY20)	\$26M/yr additional
Notes: (i) Payload funding in APRA for balloon payloads, sounding rocket payloads, and cubesats increased from \$22M in FY10 to \$31M in FY20. Cubesats added to program. (ii) Balloon program budget increased from \$28M in FY10 to \$45M in FY20. Improvements to program include development of superpressure balloons for ultralong duration ballooning, development and use of new launch site in New Zealand, development of arcsecond pointing platform for balloons, refresh of facilities at Columbia Scientific Balloon Facility. (iii) New sounding rocket launch site being developed in Australia; 2022 southern hemisphere sounding rocket campaign will be the first since 1995.			

Balance of R&A Elements

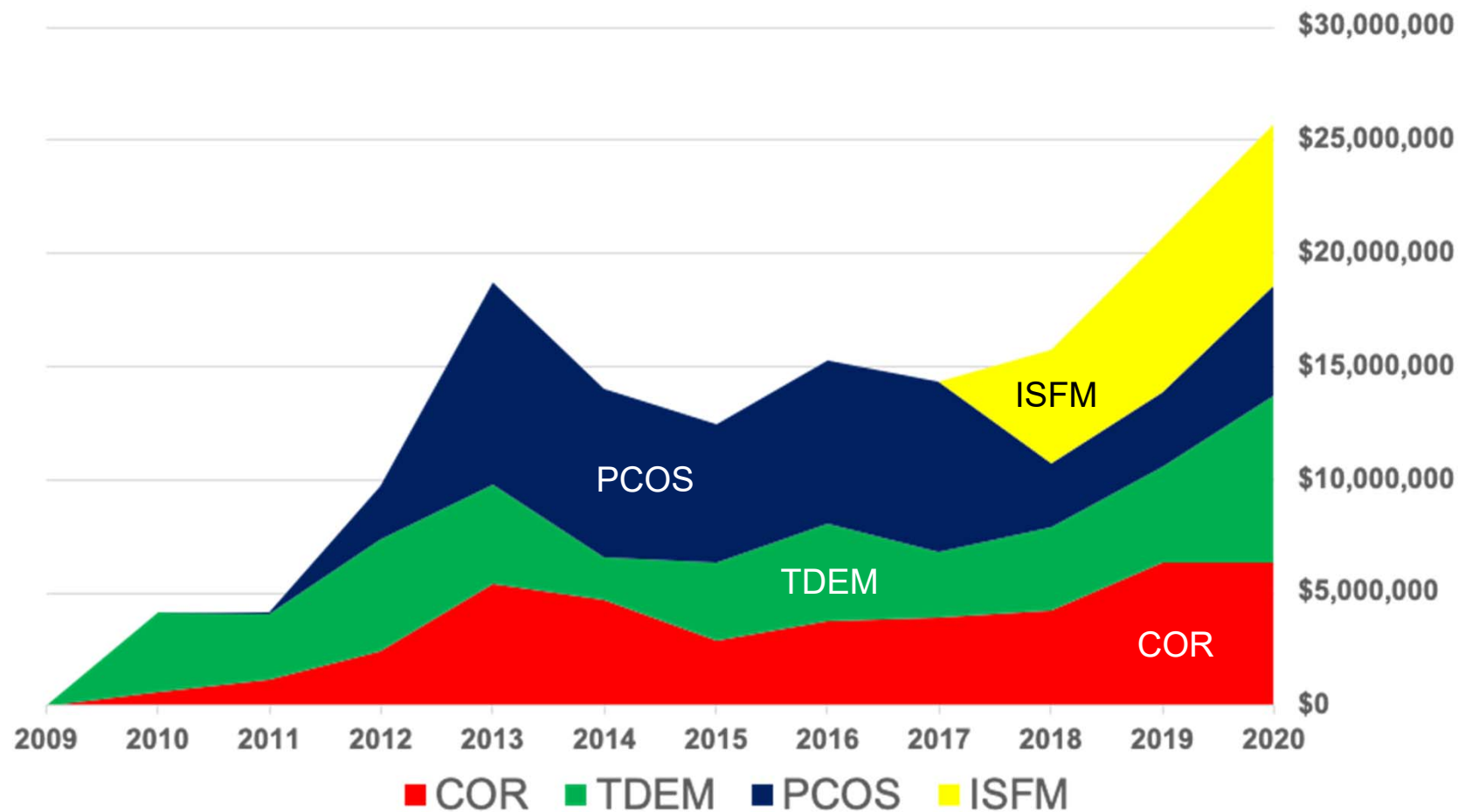


* FY21 percentage of \$110M

Astrophysics Community Funding



Strategic Astrophysics Technology



Laboratory Astrophysics

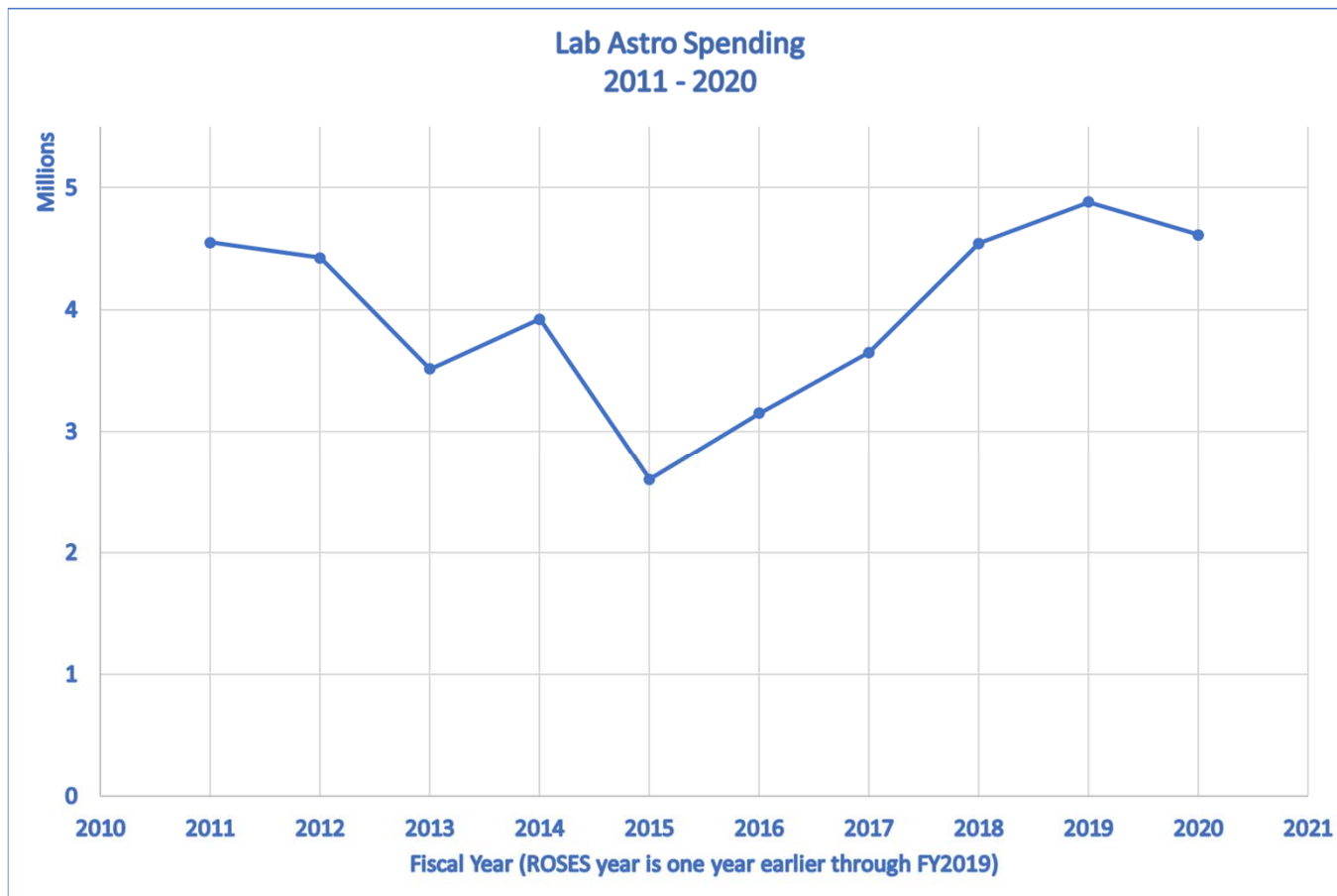


TABLE ES.4

Space: Recommended Activities—Medium Scale (Priority Order)

Recommendation	Budget	Response	Budget
1. New Worlds Technology Development Program	\$100M - \$200M	CGI tech demo, High contrast imaging testbeds, Starshade technology, Competed technology (SAT/DEM), Competed R&A (XRP, EPRV), NEID, NN-EXPLORE, NExSci, LBTI/HOSTS, Probe studies, Flagship studies	\$597M (see follow-up chart)
2. Inflation Probe Technology Development Program	\$60M to \$200M	Suborbital investigations, Competed technology (APRA, SAT), Tech development for LiteBIRD, Probe study, Planck mission	\$98M (see follow-up chart)

New Worlds Technology & Science

Program elements addressing New Worlds technology development, including precursor science, in preparation for a planet imaging mission	Budget (FY12-FY21)
CGI tech demo on Roman Space Telescope, including tech development ¹	\$283M
Directed technology: High contrast imaging testbeds	\$43M
Directed technology: Starshade tech development	\$40M
Competed technology: SAT/TDEM	\$39M
Competed technology: Segmented Mirror Technology Program	\$20M
Competed PRV instrument: NEID @ WIYN telescope	\$26M
NN-EXPLORE collaboration with NSF (excluding NEID)	\$0.3M
NASA Exoplanet Science Institute (NExSci)	\$32M
LBTI development including competed HOSTS survey	\$20M
Competed R&A: XRP (\$10M in FY21) and EPRV (\$2M in FY21)	\$42M (APD) + \$27M (PSD)
Mission studies: Exoplanet Probes, HabEx, LUVOIR	~\$25M

1. Only includes costs for this decade (through FY21), launch NLT 2027

Inflation Probe Technology & Science

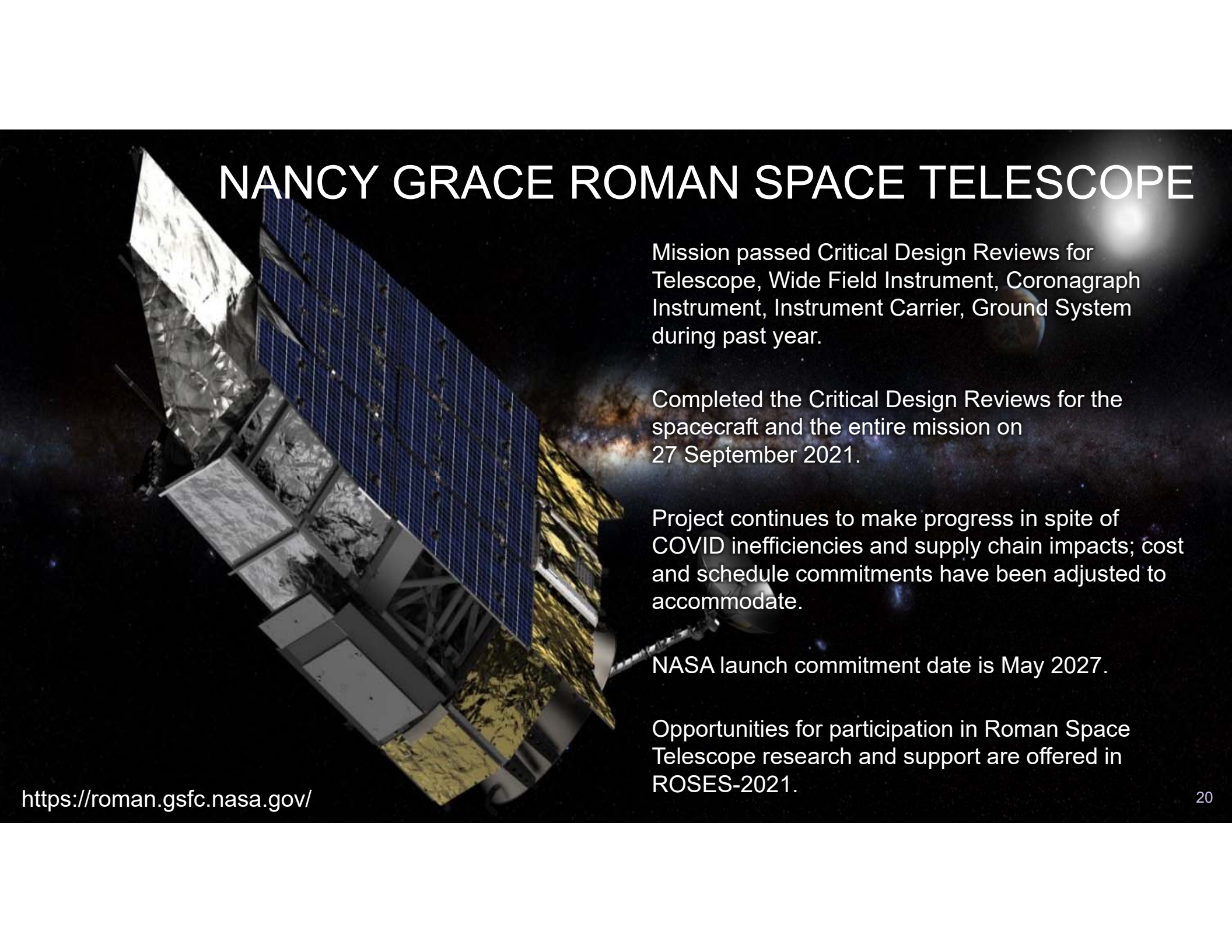
Program elements addressing CMB / Inflation technology development, including, in preparation for a possible mission beyond 2020	Budget (FY12-FY21)
Planck extension and support of data analysis for third archival release	\$29M
Suborbital missions: 3 investigations ¹	\$29M
APRA technology: 14 investigations	\$22M
SAT technology: 8 investigations	\$14M
LiteBIRD technology development	\$3.5M
PICO probe study	\$0.2M

1.
 - E and B Experiment (EBEX), PI: S. Hanany (U. Minnesota). Flew in Antarctica in 2012-2013
 - SPIDER, PI. W. Jones (Princeton). Flew in Antarctica in 2014-2015; waiting to re-fly (extensive delay due to cancellation of Antarctic campaigns due to COVID)
 - Primordial Inflation Polarization Explorer (PIPER), PI: A. Kogut (GSFC). Flew in Ft. Sumner in Fall 2016; waiting for a new launch opportunity in 2022

TABLE ES.5

Space: Recommended Activities—Large Scale (Priority Order)

Recommendation	Budget	Response	Budget
1. WFIRST – NASA/DOE Collaboration	\$1.6B	Roman Space Telescope is in Phase C; launch NLT May 2027	Post-COVID Replan budget NTE \$4.3B; \$1.7B spent through FY21
2. Augmentation to Explorer Program	\$463M	AOs in 2011 (TESS, NICER), 2014 (IXPE, GUSTO), 2016 (SPHEREx, ARIEL), 2019 (COSI), 2021 (MIDEX, MO)	Budget rose from ~\$100M in FY10 to ~\$250M/yr in FY21
3. LISA – Requires ESA Partnership	\$852M (U.S. share)	Partner on ESA-led mission; NASA contributing payload components and ground system	\$400M for hardware + US data center and grants
4. IXO – Partnership with ESA and JAXA	\$200M (U.S. share)	Partner on ESA-led Athena mission; NASA contributing payload components and telescope testing facility	\$150M for hardware + US data center and grants



NANCY GRACE ROMAN SPACE TELESCOPE

Mission passed Critical Design Reviews for Telescope, Wide Field Instrument, Coronagraph Instrument, Instrument Carrier, Ground System during past year.

Completed the Critical Design Reviews for the spacecraft and the entire mission on 27 September 2021.

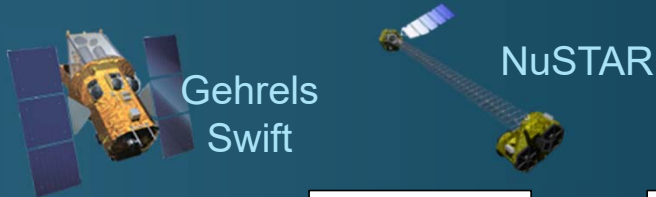
Project continues to make progress in spite of COVID inefficiencies and supply chain impacts; cost and schedule commitments have been adjusted to accommodate.

NASA launch commitment date is May 2027.

Opportunities for participation in Roman Space Telescope research and support are offered in ROSES-2021.

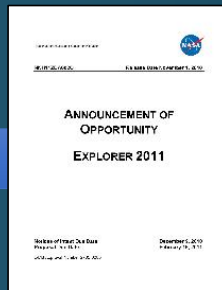
<https://roman.gsfc.nasa.gov/>

Astrophysics Explorers Program

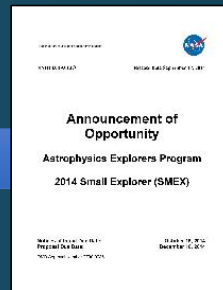


MIDEX 2021
Comm Ann release Sep 29, 2020
Draft AO release Jan 6, 2021
Comments due Feb 25, 2021
Final AO released Aug 24, 2021
NOIs due Nov 4, 2021
Proposals due Dec 9, 2021

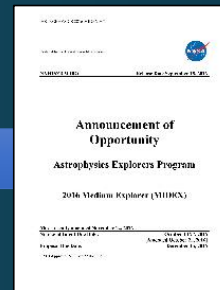
4 AOs per decade



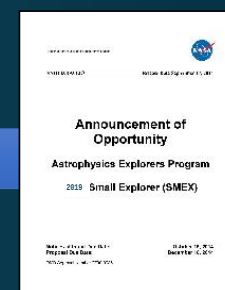
MIDEX
2011



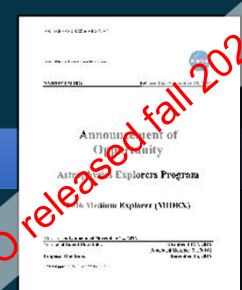
SMEX
2014



MIDEX
2016

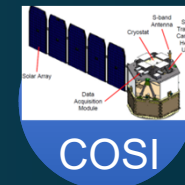
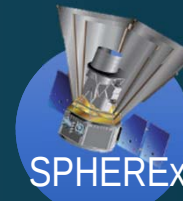
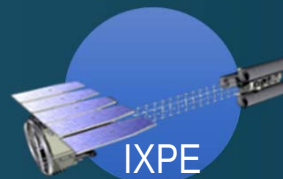


SMEX
2019



MIDEX
2021

Small and
Mid-Size
Missions



Directed
2013



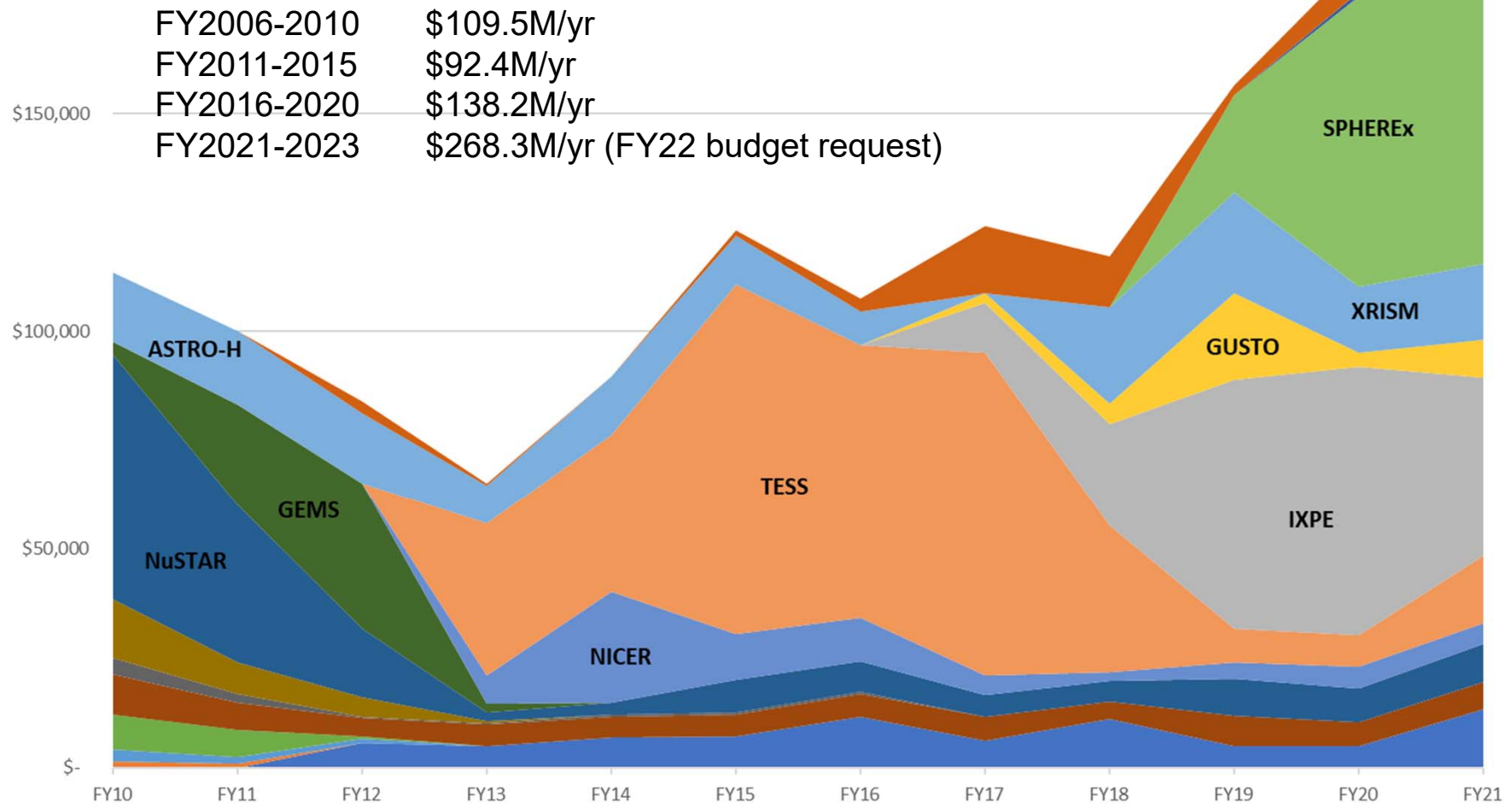
Missions of
Opportunity



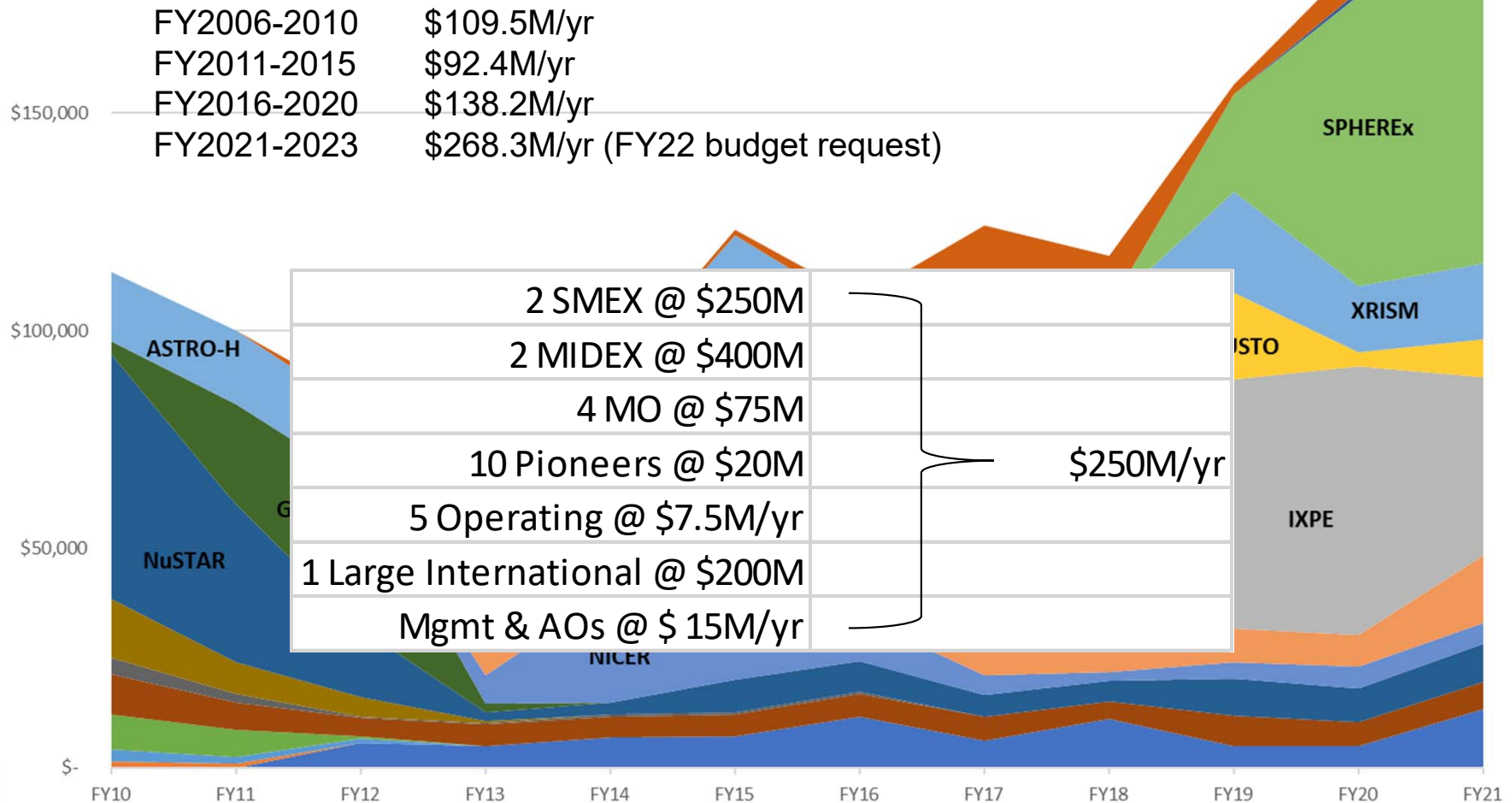
Directed
2017



Astrophysics Explorers Program



Astrophysics Explorers Program



ATHENA

Advanced Telescope for High Energy Astrophysics

ESA and NASA partnership

- ATHENA will map hot gas structures and determining their physical properties, search for supermassive black holes in the Hot and Energetic Universe

NASA contributions:

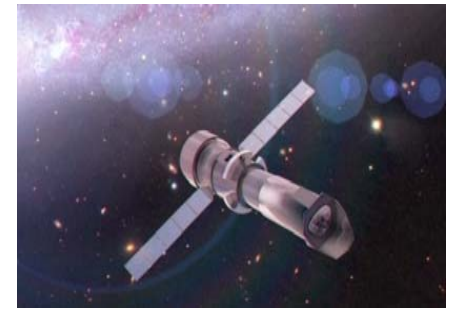
- X-IFU Focal Plane Array (GSFC, NIST-Boulder, LLNL, Stanford, UMBC, UC-Boulder)
- Use of NASA Testing Facilities MSFC XRCF facility for mirror calibration
- Vibration Isolation System
- WFI VERITAS ASIC Design for detector readout and WFI Background Analysis Model
- U.S. Science Data Center
- Grant Program for US Co-Is and Guest Observers

STATUS:

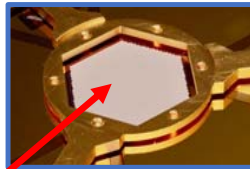
- NASA transitioned from ATHENA study phase to ATHENA project on October 1, 2021. GSFC is the implementing Center.

All dates approximate.

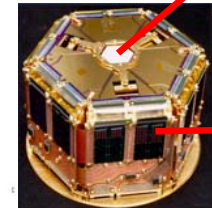
- August 2022 – NASA KDP-A/B
- February 2023 – ESA Mission Adoption
- September 2023 – NASA KDP-C
- 2034 – ESA Launch



Vibration Isolation System



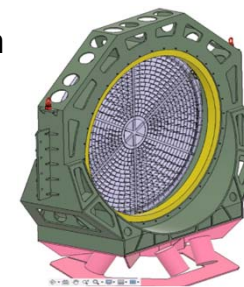
Focal Plane Array



Sensor Assembly



Readout



XRCF Mirror Assembly

X-IFU Focal Plane Array

LISA

Laser Interferometer Space Antenna

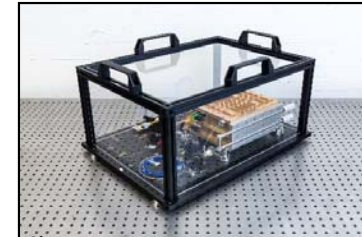


ESA and NASA partnership

- LISA will observe the universe in the millihertz gravitational wave band, detecting tens of thousands of sources ranging from white dwarf binaries in the Milky Way to massive black hole mergers at high redshift.

NASA contributions

- Interferometric Telescopes (GSFC, L3 Harris)
- Laser Systems (GSFC)
- Charge Management System (U. Florida, Fibertek)
- TBD contributions to data analysis & science (concept study initiated)
- Contributions to European-led mission and instrument systems engineering



TRL4 laser
brassboard



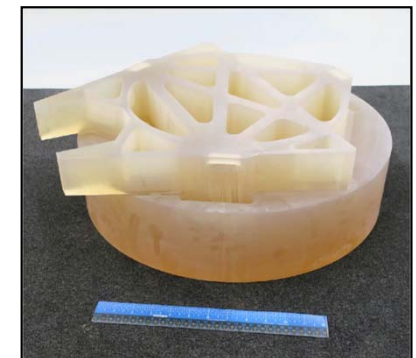
TRL5 Charge
Management Unit

STATUS

- NASA in pre-Phase A Study managed by Physics of the Cosmos Program Office at GSFC. Systems engineering & science support from JPL & MSFC.
- ESA nearing end of Phase A (Mission Formulation Review ongoing)

All dates approximate

- September 2023 – NASA KDP A
- February 2024 – ESA Mission Adoption
- 2026 NASA KDP C
- 2035 – ESA Launch



Primary mirror blank
for EDU telescope

Astro2010 Scorecard

(NASA Self-Assessment)

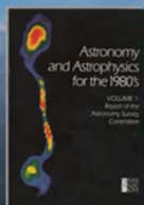
Recommendation		Response / Status	
L	WFIRST	Roman Space Telescope in Phase C, launch by 2027	✓
L	Explorers: 4 AOs / decade	AOs in 2011, 2014, 2016, 2019, 2021, 2024	✓
L	LISA	Partnered with ESA on LISA, launch in mid-2030s	✓
L	IXO	Partnered with ESA on Athena, launch in early 2030s	✓
M	New worlds technology	Matured coronagraphs & starshades, CGI tech demo on Roman, precursor science (LBTI, NEID, EPRV, etc.)	✓
M	Inflation probe technology	Matured detectors in labs and on balloons	✓
S	R&A augmentations	R&A up 60% from FY10 to FY24; added RTF, TCAN, evolved XRP	☐
S	Mid-TRL technology	Initiated SAT, competed and directed technologies	✓
S	Suborbital-class missions	Added New Zealand, developed super-pressure balloon, added CubeSats, added Pioneers	✓
S	SPICA	Elected not to participate	✗

Astrophysics

Decadal Survey Missions



1972
Decadal
Survey
Hubble



1982
Decadal
Survey
Chandra



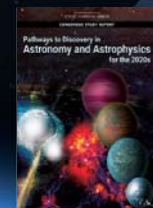
1991
Decadal
Survey
Spitzer



2001
Decadal
Survey
Webb



2010
Decadal
Survey
Roman



2021
Decadal
Survey

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