Astrophysics Projects Division

PCOS
Physics of the Cosmos Program

COR
Cosmic Origins Program

PCOS and COR Programs
Technology Gaps, Prioritization, and Development

SBIR/STTR Mirror Tech Days
November 14, 2017

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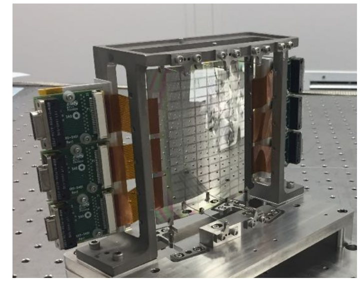
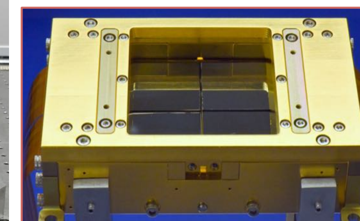
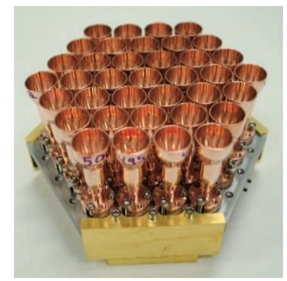
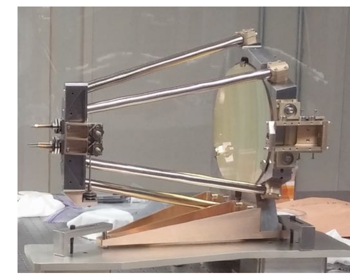
PCOS and COR Programs Technology Focus

- **PCOS Technology Focus**
  - Technologies for X-ray astrophysics
  - Technologies for gravitational wave astrophysics
  - Technologies for Cosmic Microwave Background (CMB) polarization measurement

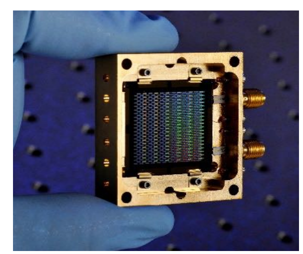


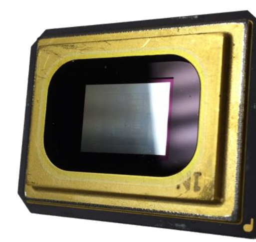


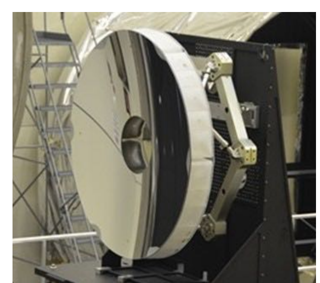


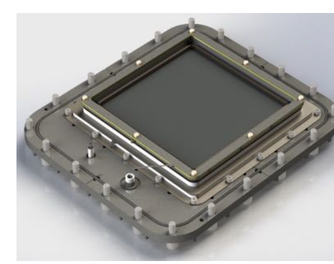


- **COR Technology Focus**
  - Next-generation detectors
  - Optical devices and coatings
  - Precision large mirror systems





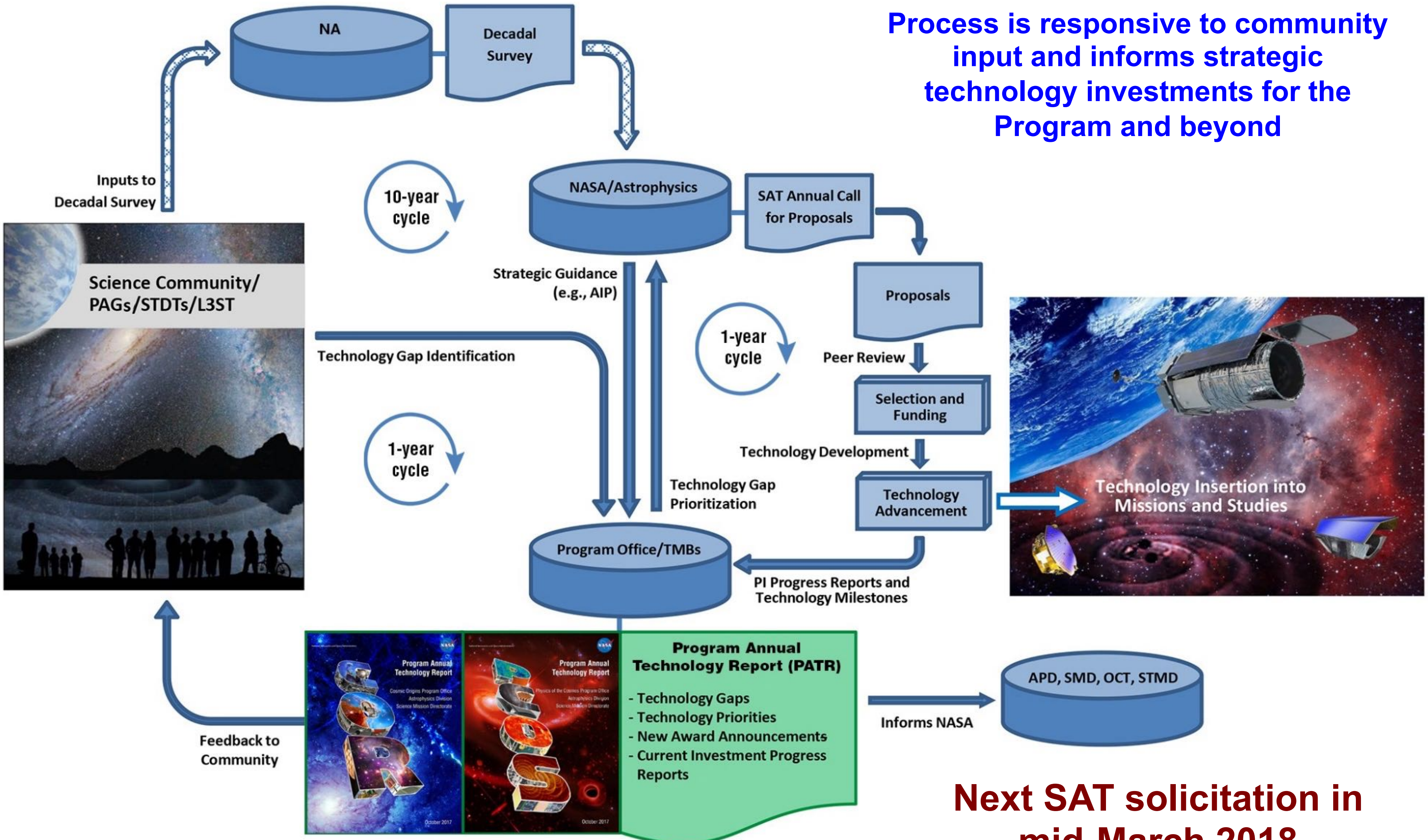




Technology Gap Prioritization Objectives

- **Identify technology gaps** applicable and relevant to Program strategic objectives as described in the Astrophysics Implementation Plan (AIP), the Roadmap, and the Decadal Survey
- **Rank technology gaps** to inform Program strategic technology development planning and investments (Strategic Astrophysics Technology (SAT) and directed-funding)
- **Inform SAT solicitation** and other NASA technology development programs (APRA, SBIR, and other OCT and STMD activities) of our technology gaps
- Results inform technology developers of Program needs to help **focus technology development efforts and leverage existing technologies** when possible and not duplicate development efforts
- Process **improves transparency and relevance** of Program technology investments
- Process **informs and engage the community** to optimize Program technology development process
- **Leverage technology investments** of other organizations by defining Program strategic technology gaps and identifying NASA as a potential customer

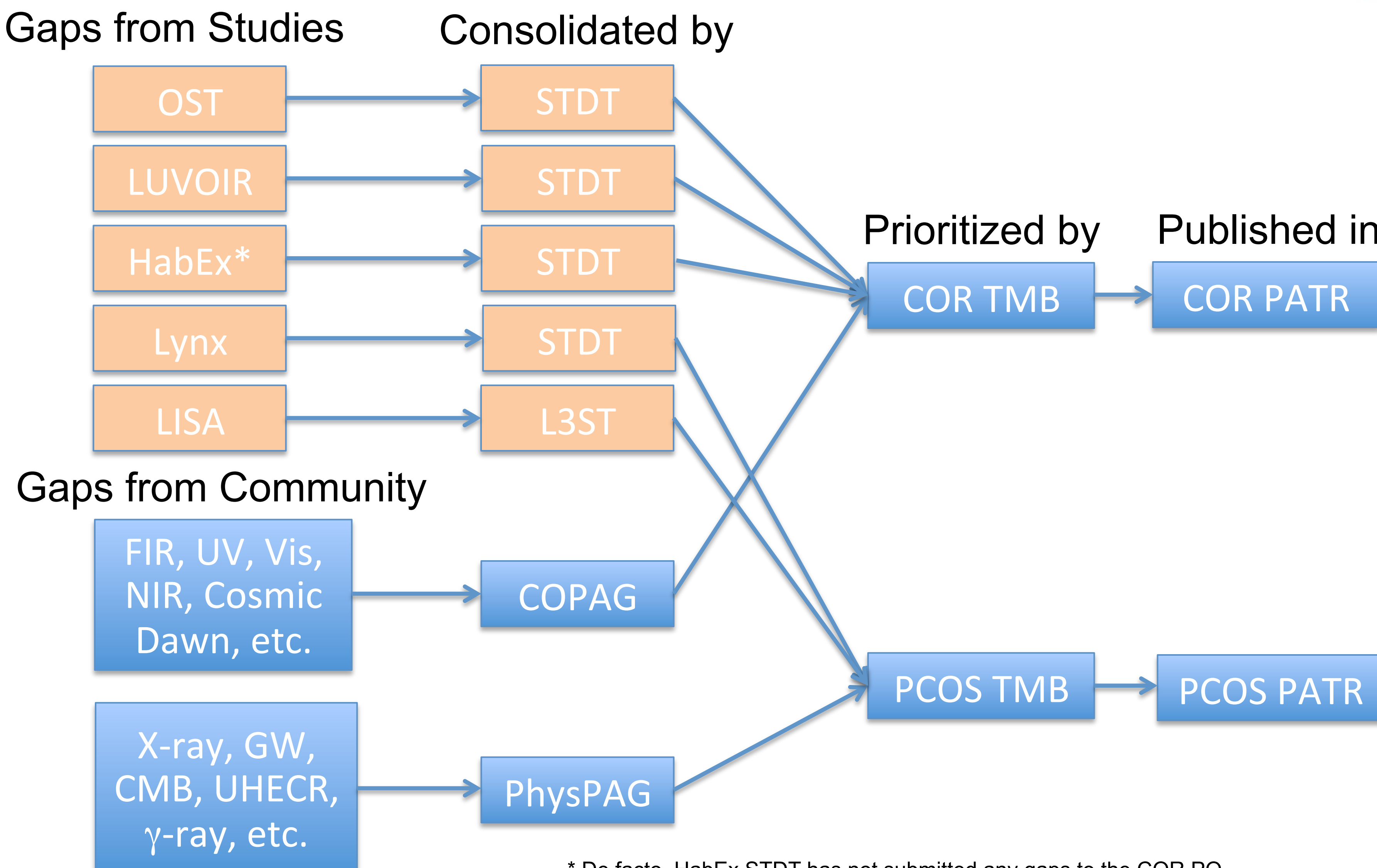
Strategic Technology Development Process



Process is responsive to community input and informs strategic technology investments for the Program and beyond

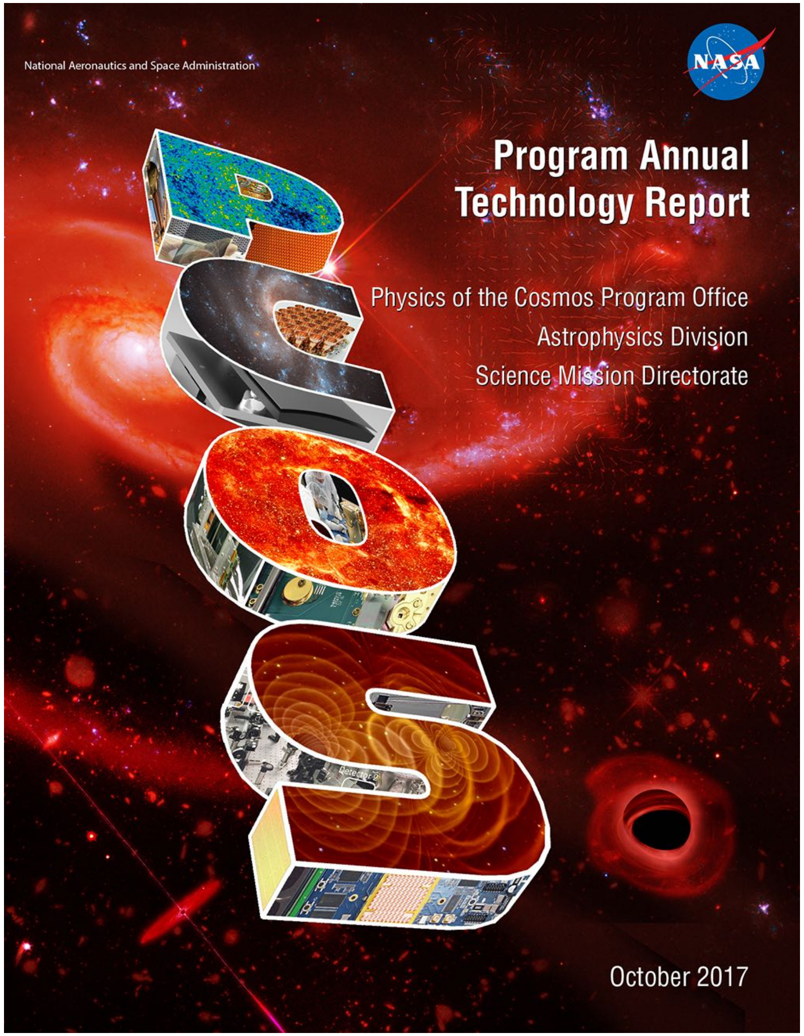
Next SAT solicitation in mid-March 2018

Origin of Gaps



* De facto, HabEx STDT has not submitted any gaps to the COR PO

2017 PCOS and COR PATRs



Available at Program websites (pcos.gsfc.nasa.gov and cor.gsfc.nasa.gov)

Prioritization and Coordination Among Program Offices

- Technology gap **prioritization is Program science-centric** (*not* mission-centric)
- We prioritize technology gaps according to community inputs based on **strategic alignment with the Program science goals, benefits and impacts to Program objectives, scope of applicability, and urgency**
- PCOS/COR/ExEP technologists coordinate during the prioritization cycle by participating in each other's prioritization process
- The POs work together to determine for each gap whether it addresses a science goal within their Program
  - If a gap provides benefits for science to more than one Program, it would be prioritized by each of the Programs, but would likely end up with different priorities due to differences in impacts, urgency, etc. for the different Programs.

2017 PCOS Technology Gaps Prioritization

	2017 PCOS Technology Capability Gaps	Science	Tech	SAT or Directed
1	**Highly stable low-stray-light telescope**	GW	Telescope	✓
	Low-mass, long-term-stability optical bench	GW	Optical Bench	
	Precision Microthrusters	GW	Propulsion	✓
	High-power, narrow-line-width laser sources	GW	Laser	✓
	Phase measurement subsystem (PMS)	GW	Electronics	✓
	Large-format, high-spectral-resolution, small-pixel X-ray focal plane arrays	X ray	Detector	✓
	Fast, low-noise, megapixel X-ray imaging arrays with moderate spectral resolution	X ray	Detector	✓
	High-efficiency X-ray grating arrays for high-resolution spectroscopy	X ray	Optics	✓
	High-resolution, large-area, lightweight X-ray optics	X ray	Optics	✓
	Non-deforming X-ray reflective coatings	X ray	Coating	New gap
	Long-wavelength-blocking filters for X-ray micro-calorimeters	X ray	Optics	New gap
2	Non-contact charge control for Gravitational Reference Sensors (GRS)	GW	Electronics	✓
	Advanced millimeter-wave focal plane arrays for CMB polarimetry	IP	Detector	✓
	Polarization-preserving millimeter-wave optical elements	IP	Optics	
	High-efficiency, low cost cooling systems for temperatures near 100 mK	IP, X ray	Cooler	✓
	Rapid readout electronics for X-ray detectors	X ray	Electronics	✓
	Optical-blocking filters (OBF)	X ray	Optics	✓
3	Gravitational reference sensor (GRS)	GW	Detector	
	Very-wide-field focusing instrument for time-domain X-ray astronomy	X ray	Optics	
	Ultra-high-resolution focusing X-ray observatory telescope	X ray	Telescope	
	Advancement of X-ray polarimeter sensitivity using negative ion gas	X ray	Detector	
4	Low-power, low-resolution continuous GSa/s direct RF digitizer	CR	Detector	
	Tileable, 2-D Proportional Counter Arrays	Gamma ray	Detector	
	High-performance gamma-ray telescope	Gamma ray	Telescope	
	Lattice optical clock for Solar Time Delay mission and other applications	STD	Electronics	
	Fast, few-photon UV detectors	UHECR	Detector	
	Lightweight, large-area reflective optics	UHECR	Optics	
	Low-power time-sampling readout	UHECR	Electronics	
	Low-power comparators and logic arrays	UHECR	Detector	

Gaps within a specific tier have equal priority. ✓ is PCOS funding. ✓ is COR funding.

2017 COR Technology Gaps Prioritization

	2017 COR Technology Capability Gaps	Science	Tech	SAT or Directed
1	Heterodyne FIR detector arrays and related technologies	Far IR	Detector	✓
	Cryogenic readouts for large-format Far-IR detectors	Far IR	Electronics	**New gap**
	Warm readout electronics for large-format Far-IR detectors	Far IR	Electronics	**New gap**
	Large Cryogenic Optics for the Far IR	Far IR	Optics	✓
	Large-format, low-noise and ultralow noise far-infrared (FIR) direct detectors	Far IR	Detector	✓
	High-performance, sub-Kelvin coolers	Far IR, X-ray	Cooler	✓
	Large-format, High-Dynamic-Range UV Detectors	UV, FUV	Detector	✓
	High-Reflectivity Broadband FUV-to-NIR Mirror Coatings	UVOIR	Coating	✓
2	**Lightweight, large-aperture, high-performance telescope mirror systems for Far-IR**	Far IR	Optics	✓
	Compact, Integrated Spectrometers for 100 to 1000 μm	Far IR	Detector	
	Advanced Cryocoolers	Far IR, X-ray	Cooler	
	Mid-IR detectors	Mid IR	Detector	**New gap**
	Cryogenic deformable mirror	Mid IR	Optics	**New gap**
	High-efficiency UV multi-object spectrometers	UV	Detector	✓
	Lightweight, large-aperture, high-performance telescope mirror systems for UVOIR	UVOIR	Optics	✓
	High-performance spectral dispersion component/device	UVOIR, Far IR	Optics	
	Advanced Adaptive Optics	UVOIR, HabEx	Optics	✓ (orange)
	Band-shaping and dichroic filters for the UV/Vis	UV, VIS	Optics	
3	Wide-bandwidth, high-spectral-dynamic-range receiving system	Cosmic Dawn	Detector	
	High-precision low-frequency radio spectrometers and interferometers	Cosmic Dawn	Detector	
	FIR interferometry	Far IR	Detector	
	Mid-IR coronagraph optics and architecture	Mid IR	Optics	
	UV/Opt/NIR Tunable Narrow-Band Filters	UVOIR	Optics	
	Ultra-Stable Opto-Mechanical Systems Architecture	UVOIR, HabEx	Telescope	✓
	Segment Phasing and Control	UVOIR, HabEx	Telescope	✓ (orange)
	Dynamic Isolation Systems	UVOIR, HabEx	Telescope	✓ (orange)
	Segmented-Aperture Coronagraph Architecture	UVOIR, HabEx	Optics	✓ (orange)
	High-contrast Imaging Post-Processing	UVOIR, HabEx	Electronics	✓ (orange)
	Mirror Segments Systems	UVOIR, HabEx	Optics	✓ (orange)

Gaps within a specific tier have equal priority. ✓ is COR funding. ✓ (orange) is Exoplanet funding.

Current PCOS Strategic Technology Investments

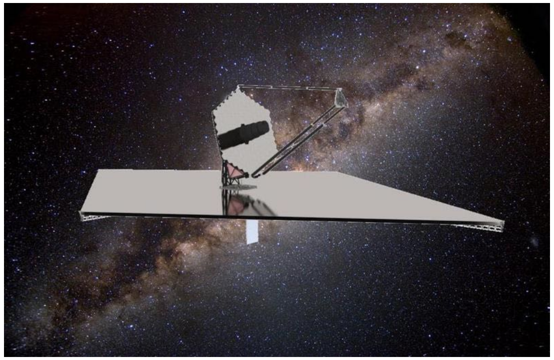
Funding Source	Technology Development Title	Principal Investigator	Org	Science Area	Tech Area
SAT2010	Directly-Deposited Blocking Filters for Imaging X-ray Detectors: Technology Development for the International X-ray Observatory	Mark Bautz	MIT	X Ray	Detector
SAT2013 APRA2011	**Development of 0.5 Arc-second Adjustable Grazing Incidence X-ray Mirrors for the SMART-X Mission Concept**	Paul Reid	SAO	X Ray	Optics
SAT2013	Fast Event Recognition for the ATHENA Wide Field Imager	David Burrows	PSU	X Ray	Electronics
SAT2014	High Efficiency Feedhorn-Coupled TES-based Detectors for CMB Polarization Measurements	Edward Wollack	GSFC	CMB	Detector
SAT2015, 2013, 2010	Development of a Critical Angle Transmission Grating Spectrometer	Mark Schattenburg	MIT	X Ray	Optics
SAT2015, 2013, 2011	**High-Resolution and Lightweight X-ray Optics for the X-Ray Surveyor**	William Zhang	GSFC	X Ray	Optics
SAT2015	**Hybrid lightweight X-ray optics for half arcsecond imaging**	Paul Reid	SAO	X Ray	Optics
Directed2016 Directed2012 SAT2011	Providing Enabling and Enhancing Technologies for a Demonstration Model of the Athena X-IFU	Caroline Kilbourne	GSFC	X Ray	Detector
SAT2016	High-Speed, Low-Noise, Radiation-Tolerant CCD Image Sensors for Strategic High-Energy Astrophysics Missions	Mark Bautz	MIT	X Ray	Detector
SAT2016, 2014, 2012, 2010	Superconducting Antenna-Coupled Detectors for CMB Polarimetry with the Inflation Probe	James Bock	JPL	CMB	Detector
Directed2017 SAT2014, 2011	**Telescope Dimensional Stability Study for a Space-based Gravitational Wave Mission**	Jeffrey Livas	GSFC	GW	Telescope
Directed2017 SAT2015, 2012	Phase Measurement System for Gravitational Wave Detection	Bill Klipstein	JPL	GW	Electronics
Directed2017 SAT2011	Colloid Microthruster Propellant Feed System for Gravity Wave Astrophysics Missions	John Ziemer	JPL	GW	Micro-propulsion
Directed2017 SAT2012	Demonstration of a TRL 5 Laser System for eLISA	Tony Yu	GSFC	GW	Laser
Directed2017	UV LED-based Charge Management System	John Conklin	UF	GW	Electronics

Current COR Strategic Technology Investment

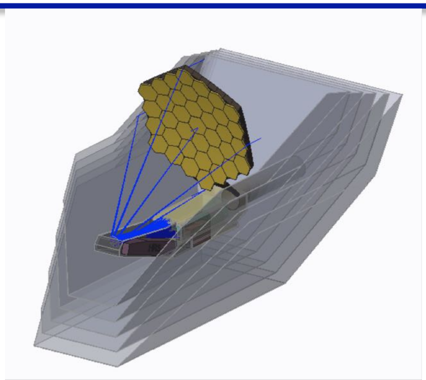
Funding Source	Technology Development Title	Principal Investigator	Org	Science Area	Tech Area
SAT2012 SAT2010	**Advanced UVOIR Mirror Technology Development for Very Large Space Telescopes**	Phil Stahl	MSFC	UVOIR	Optics
SAT2014	**Ultra-Stable Structures: Development and Characterization Using Spatial Dynamic Metrology**	Babak Saif	GSFC	UVOIR	Metrology/ Structure
SAT2014	Raising the Technology Readiness Level of 4.7-THz local oscillators	Qing Hu	MIT	Far IR	Detector
SAT2014 SAT2010	Cross-Strip Micro-Channel-Plate Detector Systems for Spaceflight	John Vallerga	UCB	UV	Detector
SAT2014	**Improving UV Coatings and Filters using Innovative Materials Deposited by ALD**	Paul Scowen	ASU	UV	Optical Coating
SAT2014 SAT2011	Advanced FUVUV/Visible Photon Counting and Ultralow Noise Detectors	Shouleh Nikzad	JPL	UVOIR	Detector
SAT2015	High-Efficiency Continuous Cooling for Cryogenic Instruments and sub-Kelvin Detectors	James Tuttle	GSFC	Far IR, Sub-mm, X Ray	Cooling System
SAT2015	**Predictive Thermal Control Technology for Stable Telescope**	Phil Stahl	MSFC	UVOIR	Optics
SAT2016	Ultrasensitive Bolometers for Far-IR Spectroscopy at the Background Limit	Charles Bradford	JPL	Far IR	Detector
SAT2016	High Performance Sealed Tube Cross Strip Photon Counting Sensors for UV-Vis Astrophysics Instruments	Oswald Siegmund	UCB	UV	Detector
SAT2016 SAT2012	**Development of Digital Micromirror Devices for Far-UV Applications**	Zoran Ninkov	RIT	UV	Optics
SAT2016	Development of a Robust, Efficient Process to Produce Scalable, Superconducting kilopixel Far-IR Detector Arrays	Johannes Staguhn	JHU	Far IR	Detector

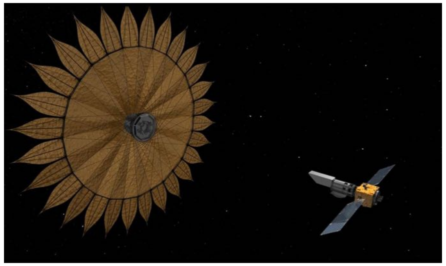
HQ SMD APD Planning for the Future

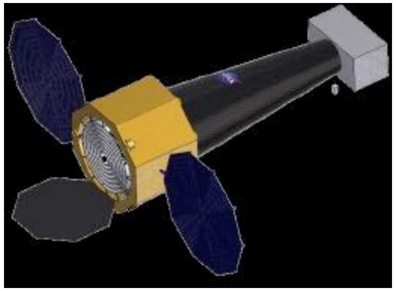
- **Strategic Mission Concept Studies**



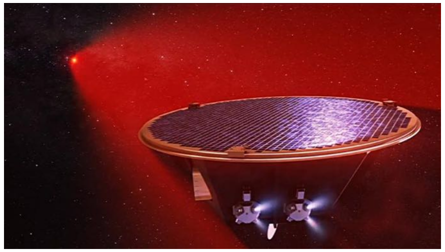
HabEx
LUVOIR
Lynx
OST
ATHENA
LISA
SOFIA

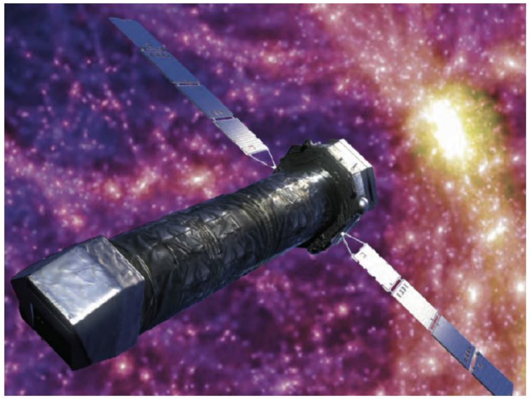






- **Medium (Probe) Concept Studies**
  - Cosmic Dawn Intensity Mapper (A. Cooray)
  - Cosmic Evolution through UV Spectroscopy Probe (W. Danchi)
  - Galaxy Evolution Probe (J. Glenn)
  - High Spatial Resolution X-ray Probe (R. Mushotzky)
  - Inflation Probe (S. Hanany)
  - Multi-Messenger Astrophysics Probe (A. Olinto)
  - Precise Radial Velocity Observatory (P. Plavchan)
  - Starshade Rendezvous Mission (S. Seager)
  - Transient Astrophysics Probe (J. Camp)
  - X-ray Timing and Spectroscopy Probe (P. Ray)





Impediments to Closing Gaps

- **Limited technology development funding**
  - Multiple compelling mission concept studies dilute available funding
  - Uncertainty as to which large mission concepts will be recommended by the Decadal Survey and its schedule
  - Directed funding will likely take effect after Decadal Survey to focus and expedite developments
- **Limited time before 2020 Decadal Survey begins**
  - Final STDT reports due spring CY19, desire is to demonstrate credibility by then
- **Limited technology solutions**
  - Can always use more new and viable ideas
    - **Some high ranking gaps did not receive SAT proposals to close**
    - Some current solution ideas are incremental instead of game changing or revolutionary
    - Developing only one solution path or only an aspect of a gap is risky

Backup

The Program Annual Technology Report (PATR)

The Program Annual Technology Report is an annual report, released in early October, that summarizes the Program's technology development activities for the prior year and supports Program planning for the following year. The PATRs:

- Provide an overview of Program objectives
- Summarize activities, progress, and status of Program strategic technology investments for prior year
- Announce new SAT award selections
- Summarize technology gaps submitted by the community and study teams
- Provide a prioritized list of technology gaps to inform SAT proposal call and selection decisions
- Inform the community and NASA programs of Program technology development activities and gaps in support of planning and advocacy activities
- Identify Program PIs to customers and collaborators beyond NASA, encouraging industry and other players to invest in enabling technologies for future missions, and promoting productive collaborations

Key Participants

- **Community**
  - Input from community through current Decadal Survey and mid-decade update
  - Technology gap submitters (general community and mission concept study teams)
  - PCOS and COR Program Analysis Groups (PhysPAG and COPAG) help consolidate technology gaps and enhance their descriptions
- **Program Office (PO)**
  - Solicits and integrates technology gaps and coordinates prioritization process
  - Participates in Technology Management Board (TMB) to prioritize gaps
  - Monitors progress of technology developments
  - Publishes PCOS and COR PATRs
- **Technology Management Board (TMB)**
  - Comprised of senior staff from HQ, PO, and SMEs
  - Prioritizes technology gaps according to established criteria
- **NASA Astrophysics Division at HQ**
  - Provides strategic guidance for PO
  - Participates in TMB to prioritize gaps
  - Solicits, selects, and funds SATs
  - Has final approval to release the PATR

Technology Gap and Prioritization Timeline

ID	Activity	Timeframe
1	Technology gap submission window is open all year	Continuous
2	General community submission deadline for current year prioritization	June 1
3	PO compiles new community inputs and prior year's gaps and forwards to PhysPAG and COPAG for consolidation, and to Study Teams for consideration in their gaps update	June 3
4	PhysPAG, COPAG, and Study Teams submission deadline for current year prioritization	June 30
5	PO integrates gap lists from PhysPAG, COPAG, and Study Teams	Mid-June
6	TMB meets to prioritize integrated gap list	Late July
7	Prioritization may be used to inform current year SAT selection	Aug
8	Current year SAT award selection is announced	Aug-Sep
9	Prioritization is published in PCOS and COR PATRs	Early Oct
10	Prioritization informs SAT Program which may choose to amend current solicitation	Nov-Dec
11	SAT proposals due	Following Mar
12	Following-year SAT award selection is announced	Following Aug

Prioritization Criteria Address…

- **Strategic alignment:** How well does the technology align with Program science and programmatic priorities of current Astrophysics programmatic guidance (i.e., Astrophysics Implementation Plan, Astrophysics Roadmap, and the Decadal Survey)?
- **Benefits and impacts:** How much impact does the technology have on Program-relevant science in applicable mission(s)? To what degree does the technology enable and/or enhance achievable science objectives, reduce cost, and/or reduce mission risks?
- **Scope of applicability:** How crosscutting is the technology? How many Astrophysics programs and/or mission concepts would it benefit?
- **Urgency:** When are launches and/or other schedule drivers of missions enhanced or enabled by this technology anticipated?

COR Prioritization Criteria 2017

#	Criterion	Weight	Max Score	Max Weighted Score	General Description/ Question	4	3	2	1	0
1	Strategic Alignment	10	4	40	How well does the technology align with COR science and programmatic priorities of current programmatic guidance (i.e., AIP, Roadmap, NWNH)?	Technology enables COR-relevant science within mission concept receiving highest current programmatic consideration	Technology enables COR-relevant science within mission concept receiving mid to high current programmatic consideration in AIP or Roadmap	Technology enables COR-relevant science within mission concept receiving low current programmatic consideration in AIP or Roadmap	Technology enables COR-relevant science within mission concept not considered in AIP or Roadmap, but positively addressed in NWNH	Technology does not enable COR-relevant science within any mission concept considered by current programmatic guidance
2	Benefits and Impacts	8	4	32	How much impact does the technology have on COR-relevant science in applicable mission(s)? To what degree does the technology enable and/or enhance achievable science objectives, reduce cost, and/or reduce mission risks?	Critical and key enabling technology; required to meet COR-science-relevant mission concept objectives; without this technology mission would not launch or COR science return would be significantly impaired	Highly desirable; not mission-critical to COR-science-relevant objectives, but significantly enhances COR science capability, reduces critical resources needed, and/or reduces mission risks; without it, missions may launch, but COR science return would be compromised	Desirable - not required for COR-relevant mission success, but offers moderate COR-relevant science or implementation benefits; if technology is available, would almost certainly be implemented in missions for COR purposes	Minor COR-relevant science impact or implementation improvements; if technology is available would be considered for implementation in missions for COR purposes	No COR-relevant science impact or implementation improvement; even if available, technology would not be implemented in missions for COR purposes
3	Scope of Applicability	3	4	12	How cross-cutting is the technology? How many Astrophysics programs and/or mission concepts (including Explorers and Probes) could it benefit?	Applies widely to COR mission concepts and both PCOS <u>and</u> ExoPlanet mission concepts	Applies widely to COR mission concepts and either PCOS <u>or</u> ExoPlanet mission concepts	Applies widely to COR mission concepts	Applies to a single COR mission concept	No known applicable COR mission concept
4	Urgency	4	4	16	When are launches and/or other schedule drivers of missions enhanced or enabled by this technology anticipated?	Launch anticipated in next 4-8 years (2021-2025) or other schedule driver requires progress in 2-3 years (2019-2020)	Launch anticipated in next 9-13 years (2026-2030) or other schedule driver requires progress in 4-8 years (2021-2025)	Launch anticipated in next 14-18 years (2031-2035)	Launch anticipated in next 19-23 years (2036-2040)	Launch anticipated in 24 or more years (2041 or later)

Strategic Astrophysics Technology (SAT)

The SAT Program was established in 2009 to support maturation of mid-range TRL technologies. It is organized into 3 elements, one for each of the Division's three science themes. PCOS and COR first SAT solicitations were in 2010.

Solicitation year	PCOS SAT Proposals		Selection Rate
	Submitted	Awarded	
2010	21	5	24%
2011	26	5	19%
2012	10	3	30%
2013	8	6	75%
2014	6	3	50%
2015	10	4	40%
2016	5	2	40%
Total to Date	86	28	33%

Solicitation year	COR SAT Proposals		Selection Rate
	Submitted	Awarded	
2010	14	3	21%
2011	24	5	21%
2012	13	3	23%
2013	Not Solicited	N/A	N/A
2014	14	5	36%
2015	12	2	17%
2016	19	4	21%
Total to Date	96	22	23%

"Sunset Clause" Consideration for Gaps with No Strategic Alignment: The 4th Tier

- **The Concern:** Over time, as we keep on our list all gaps from the previous year and add new ones, our gap lists become longer and longer. This will inevitably make the TMB's prioritization work more and more time-consuming. This suggested the need for a "sunset clause" to remove gaps from the list.

- **Context:** Where gaps are actually relevant to strategic missions, gaps must be retained. However, there are many gaps (and more each year) that are not aligned with any strategic mission. We could require that new gaps be relevant to one or more strategic missions, but this runs the risk of chilling community participation, and disengaging important segments of the community who at this time have no strategic mission on HQ's list.

- **The Solution:** Rather than require new gaps be relevant for strategic missions, we instituted a new fourth tier of gap priority. This holds all gaps (new or from a prior year) that are deemed by the TMB as having no strategic alignment. Such gaps would appear in that year's PATR, but would not be automatically included in the following year's gap list. Further, resubmission of these gaps would not be accepted unless a new strategic mission is added by HQ to which such a gap is relevant, or the entry is significantly revised in a way that makes it relevant for a strategic mission. The Program Office contacts submitters of gaps falling into this tier to explain what happened, why, and under what circumstances those gaps might be resubmitted.

Prioritization Tiers

- **Priority Tier 1**
  - Technologies the TMB determined to be of the highest interest to the Program
  - Advancing these key enabling technologies is judged to be most critical to making substantive near-term Program-science-relevant progress on the highest-priority strategic astrophysics missions
  - The TMB recommends SAT calls and award decisions address these technology gaps first
- **Priority Tier 2**
  - Technologies the TMB believes would be highly desirable or desirable for a variety of strategic missions
  - The TMB recommends that, should sufficient funding be available, SAT calls and award decisions address closing these technology gaps as well
- **Priority Tier 3**
  - Technologies the TMB deemed supportive of Program objectives, but scoring lower than Priority 1 and 2 technology gaps
- **Priority Tier 4**
  - Technologies the TMB deemed legitimate Program technology gaps, but not currently aligned with any strategic mission
  - Will not be automatically reprioritized in following year unless attains strategic alignment

Sample Technology Gaps List Excerpt

1. "Tracking number" is simply for reference during gap collection, consolidation, and prioritization purposes only; number in parentheses (if any) shows prior year tracking

3. "Description" and "Applications and Potential Relevant Missions" inform about its **strategic alignment** and **scope of applicability**

Tracking No. 2016 (2015)	Gap Name	Description	Current State-of-the-Art	TRL		Performance Goals and Objectives	Scientific, Engineering, and/or Programmatic Benefits	COR Applications and Potential Relevant Missions	Time to Anticipated Need
				SOTA	Solution				
17 (13)	**High-reflectivity mirror coatings for UV/Vis/NIR** Submitted by LUVOIR STDT	High-reflectivity, highly uniform mirror coatings with low polarization are required to deliver high throughput UV observations and support high-contrast imaging via starlight suppression. High-reflectivity coatings would allow multiple reflections with minimal throughput penalty in the UV, while still providing broadband performance out to NIR wavelengths. For a UVOIR flagship telescope, a single reflective coating that has excellent reflectivity and precise	The best current coatings provide > 90% reflectivity for wavelengths 300-2500 nm and longer, ~85% reflectivity for 120-300 nm (HST), and < 50% for 90-120 nm (FUSE). Current physical vapor deposition coatings can provide 2% uniformity at wavelengths greater than 120 nm and require coating thicknesses greater than 15 nm in order to maintain performance. Conventional technologies such as chemical vapor deposition with precision controls have been developed for producing high-performance mirror coatings on large-diameter substrates.	3		1. Coatings with excellent UV and FUV efficiency, particularly in the 90 to 2500 nm range (> 90% for as much as possible of this spectral range). 1a. Also coatings with excellent UV and acceptable IR efficiency. 2. High-uniformity coatings (< 1%), over a large spectral range (90-2500 nm), with low polarization (< 1%) for wavelengths 200-1800 nm, for high-contrast imaging.	High coating reflectivity in UV makes possible high-performance optical systems that can be highly multi-passed, significantly increasing potential impact of future missions. Wideband coatings could enable a combined UV to IR mission with very broad scientific potential from general astrophysics to exoplanet imaging and spectroscopy.	NWNH noted the importance of technology development for a future ≥ 4-m class UV/visible mission for spectroscopy and imaging. This technology would also support the next generation of UV missions, including Explorers, medium-size Probe missions, and large (> 4-m apertures) future UV/Vis/IR telescopes, and is key for NASA's next large UVOIR mission.	Need to demonstrate credibility before the 2020 Decadal Survey, and would require TRL 6 by mission PDR anticipated in the mid-2020s. Mirror cleaning would be immediately useful for missions already

2. Gap submitter identified here. Study teams indicate here whether gap is enabling or enhancing

5. "Time to Anticipated Need" describes its **urgency**

4. "Current SOTA", "TRL", and "Performance Goals…" describe the gap quantitatively and in more detail and help identify its **benefits and impacts** along with the "Scientific/Eng/Prog Benefits" column

Cosmic Origins Program Analysis Group (COPAG)

- The COPAG serves as a community-based, interdisciplinary forum for soliciting and coordinating community analysis and input in support of Cosmic Origin objectives and of their implications for architecture planning and activity prioritization and for future exploration. It provides findings of analyses to the NASA Astrophysics Division Director.
- The COPAG is constituted by the NASA Astrophysics Subcommittee (ApS) to support community coordination and analysis of scientific and technological issues impacting NASA's Cosmic Origins (COR) Program.
- All COPAG substantive activities—meetings, workshops, Science Analysis Groups, Science Interest Groups, telecons, or other core work—are open to participation by the community.
- The COPAG is coordinated by an Executive Committee, which meets biweekly by telecon.

PCOS Technology Gap Inputs This Year

- Passed on to PhysPAG EC 9 new inputs and 25 gaps prioritized last year to consolidate
  - Combine similar or overlapping gaps
  - Refine/update gap descriptions
  - Add missing gap(s)
  - Identify gaps to be considered for removal from being prioritized if they are at TRL 6 or higher already, are not technology gaps, are not sufficiently described or defined, or are not relevant to Program strategic objectives
- PhysPAG EC returned gap list with notes indicating concurrences of strategically relevant gaps (or not) and suggestions to merge similar/overlapping gaps or drop duplicating gaps
- Lynx STDT submitted 6 gaps
- LISA submitted 7 gaps
- TMB reviewed, consolidated, and prioritized 29 gaps

COR Technology Gap Inputs This Year

- Passed on to COPAG Technology Interest Group (TIG) 16 new inputs and 18 gaps prioritized last year to consolidate
  - Combine similar or overlapping gaps
  - Refine/update gap descriptions
  - Add missing gap(s)
  - Identify gaps to be considered for removal from being prioritized if they are at TRL 6 or higher already, are not technology gaps, are not sufficiently described or defined, or are not relevant to Program strategic objectives
- TIG updated and enhanced gap descriptions and recommended some merging, splitting, and dismissal of gaps not aligned with Program objective
- LUVOIR STDT submitted 13 gaps
- OST STDT submitted 11 gaps
- TMB reviewed, consolidated, and prioritized 29 gaps
  - Technology gaps driven by exoplanet science were discussed with Exoplanet Exploration Program (ExEP) technologists who concurred that those gaps would be prioritized by ExEP