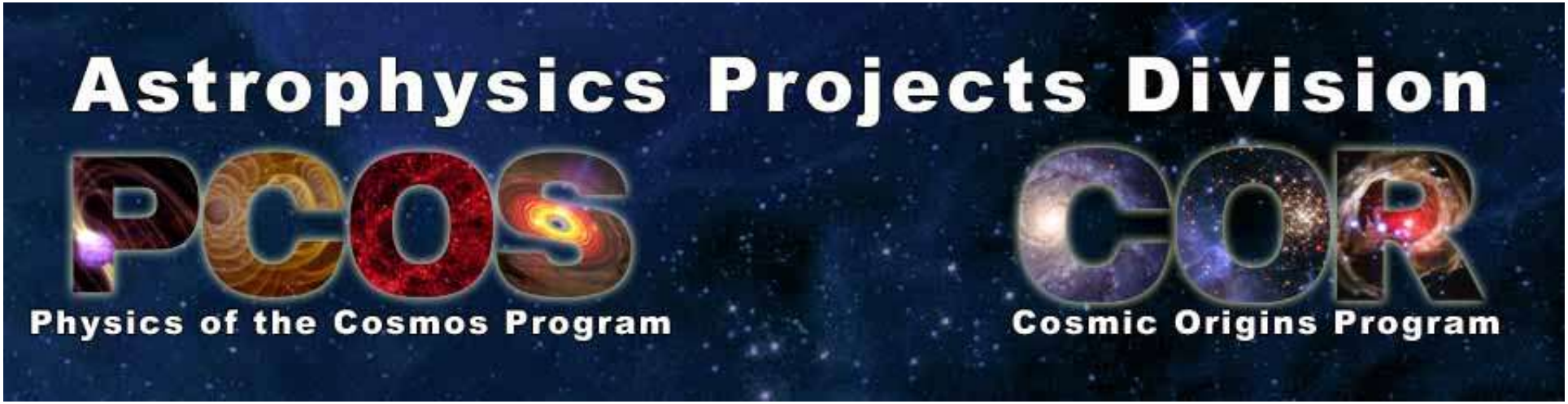


# NASA Astrophysics Technology Gaps, Prioritization, and Development

18th Annual Mirror Technology Workshop; November 5, 2018

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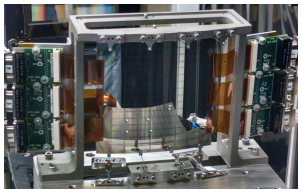
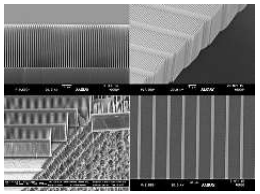
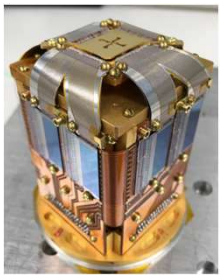
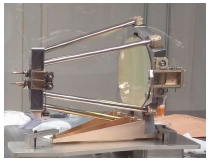
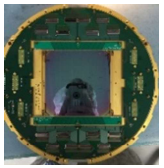
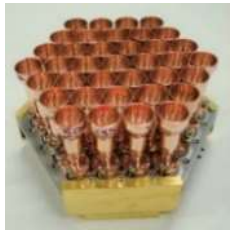
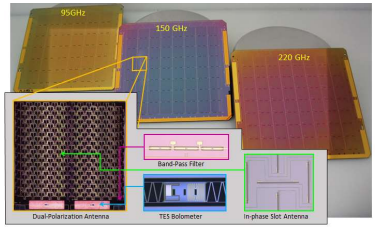
# PCOS and COR Programs Technology Interests

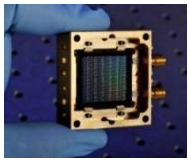
## Physics of the Cosmos (PCOS)

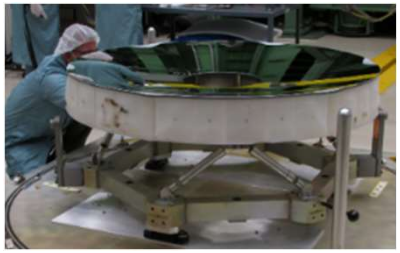
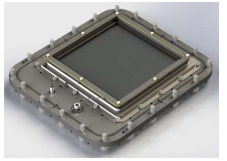
- **X-ray astrophysics:** grazing-angle mirrors, optical blocking filters, fast event ID, gratings, micro-calorimeters, radiation-tolerant detectors
- **Gravitational-wave astrophysics:** phase measurement system, micro-Newton thrusters, non-contact charge-management system, stable laser system, low-stray-light telescope
- **Cosmic Microwave Background (CMB)**: superconducting FPAs and optical elements (cryo filters and coatings)


## Cosmic Origins (COR)

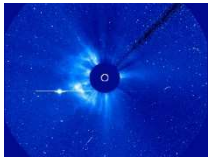
- **UV/Optical/IR:** Next-gen detectors, ultra-stable high-precision telescope systems (including mirrors, thermal control, structures, metrology, etc.), and advanced UV coatings
- **Far-IR:** Heterodyne detectors, advanced cooling systems, ultra-sensitive detectors and large arrays

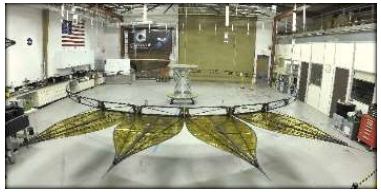



## Exoplanet Exploration Program (ExEP)

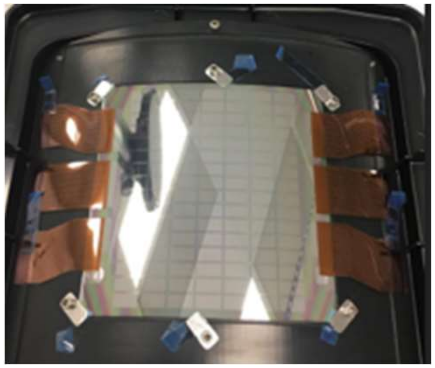
- **Exoplanet direct imaging:** Coronagraph masks, deformable mirrors, starshades, ultra-stable optomechanical systems, ultra low-noise detectors

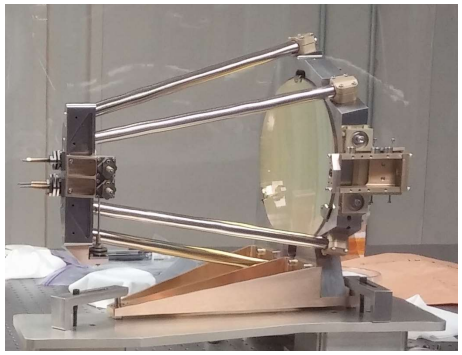


# Focusing on Optics Technologies

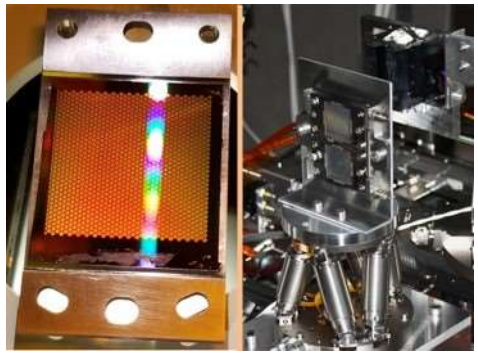
Thin grazing-incidence X-ray mirrors (intrinsic high precision, left; adjustable, right)



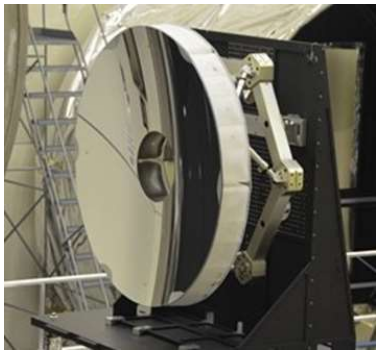


Ultra-stable, low-scattered-light telescope for grav-wave observatory

Nano-fabbed, high-resolution X-ray grating

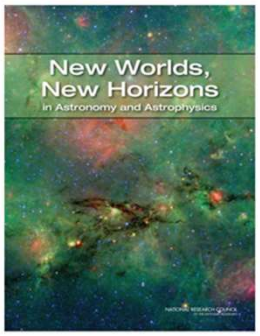


Large high-quality optical mirrors and coatings



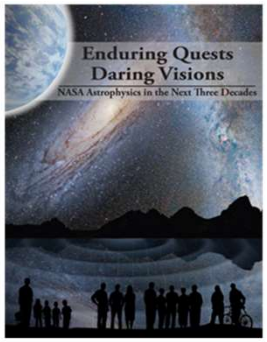
# Technology Gap Prioritization Objectives

- **Identify technology gaps** applicable and relevant to Astrophysics strategic objectives as described (in order of initial publication) in the Astronomy & Astrophysics Decadal Survey, the Astrophysics Implementation Plan (AIP), and the Astrophysics Roadmap




2010 Decadal Survey

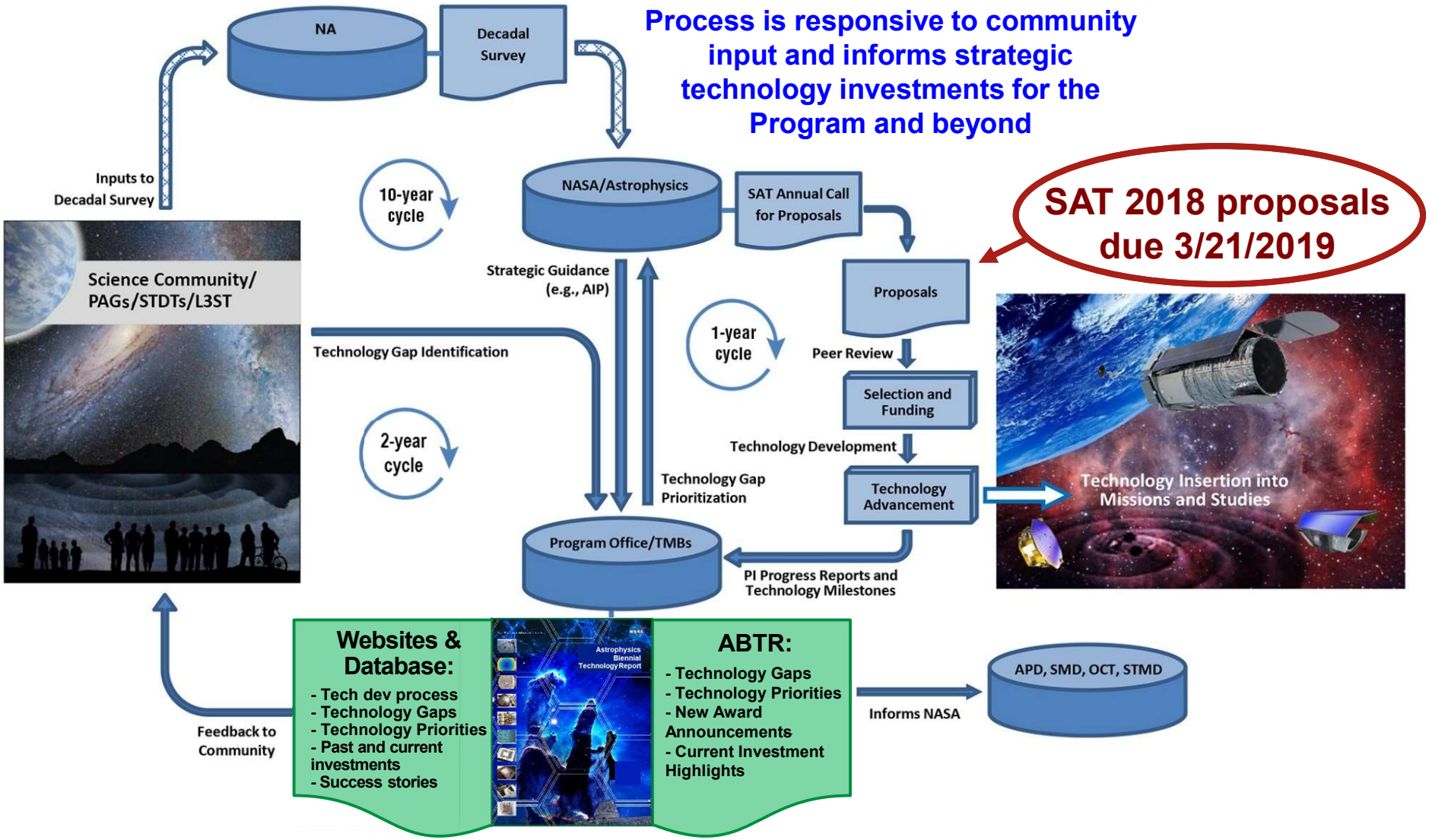

APD Implementation Plan (2012, 2014, 2016)




NASA APD 30 year vision (2013)

- **Rank technology gaps** to inform Astrophysics 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 SMD, 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 avoid duplicating development efforts
- Process **improves transparency and relevance** of Astrophysics technology investments
- Process **informs and engage the community** to optimize Astrophysics technology development process
- **Leverage technology investments** of other organizations by defining Astrophysics strategic technology gaps and identifying NASA as a potential customer

# Strategic Technology Development Process



# Program Annual Technology Reports (PCOS & COR) and Program Plan Appendix (ExEP) Contents Moved into ABTR and Websites

## Was three reports annually
(with websites in support role)


## Will be:

**One report biennially starting 2019**
(*cover mockup shown*)


## Websites & Database playing major role


PCOS/COR technology

apd440.gsfc.nasa.gov/technology


AstroTech searchable database for PCOS, COR, and ExEP

www.astrostrategictech.us/


ExEP technology

exoplanets.nasa.gov/exep/technology

# Prioritization and Coordination Among Astrophysics Program Offices


- Technology gap **prioritization is changing from Program science-centric** to **Astrophysics-wide**
- Technologists from PCOS/COR/ExEP work together:
  - Determine for each gap which Program would benefit most from closing it, after which it is prioritized by that Program (if more than one Program, split into unique gaps)
  - Technologists from the three POs jointly prioritize gaps for each of the Programs
  - After the three POs complete their prioritization, the technologists merge the three priority lists into a single prioritized Astrophysics technology gaps list
- We prioritize technology gaps according to community inputs based on a uniform set of criteria:
  - **Strategic alignment with Program science goals**
  - **Benefits and impacts to Program objectives**
  - **Urgency**
  - **Scope of applicability across Astrophysics**

# Current PCOS Technology Gaps Prioritization

| | PCOS Technology Capability Gaps | Science | Tech | Funded |
|---|---|---|---|---|
| 1 | Highly stable low-stray-light telescope | GW | Telescope | ✓ |
| | Low-mass, long-term-stability optical bench | GW | Optical | |
| | 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 | X ray | Detector | ✓ |
| | Fast, low-noise, megapixel X-ray imaging arrays with moderate spectral | 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 | |
| | Long-wavelength-blocking filters (free standing) for X-ray micro- | X ray | Optics | |
| 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.

# Current COR Technology Gaps Prioritization

| | COR Technology Capability Gaps | Science | Tech | Funded |
|---|---|---|---|---|
| 1 | Heterodyne FIR detector arrays and related technologies | Far IR | Detector | ✓ |
| | Cryogenic readouts for large-format Far-IR detectors | Far IR | Electronics | |
| | Warm readout electronics for large-format Far-IR detectors | Far IR | Electronics | |
| | 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 | 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 | |
| | Cryogenic deformable mirror | Mid IR | Optics | |
| | High-efficiency UV multi-object spectrometers | UV | Detector | ✓ |
| | Lightweight, large-aperture, high-performance telescope mirror systems for | UVOIR | Optics | ✓ |
| | High-performance spectral dispersion component/device | UVOIR, Far IR | Optics | |
| | Advanced Adaptive Optics | UVOIR, | Optics | ✓ |
| | 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, | Telescope | ✓ |
| | Segment Phasing and Control | UVOIR, | Telescope | ✓ |
| | Dynamic Isolation Systems | UVOIR, | Telescope | ✓ |
| | Segmented-Aperture Coronagraph Architecture | UVOIR, | Optics | ✓ |
| | High-contrast Imaging Post-Processing | UVOIR, | Electronics | ✓ |
| | Mirror Segments Systems | UVOIR, | Optics | ✓ |

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

# Current PCOS Strategic Technology Investment

| Funding Program | Project Title | PI Name | PI Org | Tech Area | Signal Type |
|---|---|---|---|---|---|
| SAT2016 | High-Speed, Low-Noise, Radiation-Tolerant CCD Image Sensors for Strategic High-Energy Astrophysics Missions | Bautz, Mark | MIT | Detector | X Ray |
| SAT2016 | Superconducting Antenna-Coupled Detectors for CMB Polarimetry with the Inflation Probe | Bock, James | JPL | Detector | Sub-mm |
| SAT2017 | Development of Adjustable X-ray Optics with 0.5 Arcsecond Resolution for the Lynx Mission Concept | Reid, Paul | SAO | Optics | X Ray |
| SAT2017 | Microwave SQUID readout technology to enable Lynx and other future Great | Bennett, Douglas | NIST | Detector | X Ray |
| SAT2017 | High Resolution and High Efficiency X-ray Transmission Grating Spectrometer | Schattenburg, Mark | MIT | Optics | X Ray |
| Directed2018 | Advancing the Focal Plane TRL for LiteBIRD and Other Next Generation CMB Space Missions | Lee, Adrian | UCB | Detector | Sub-mm |
| Directed2018 | Next Generation X-ray Optics | Zhang, William | GSFC | Optics | X Ray |
| Directed2018 | Advanced X-ray Optics ISFM Sub-package #1: Differential Deposition for Figure Correction in X-ray Optics | Kilaru, Kiran | MSFC | Optics | X Ray |
| Directed2018 | Advanced X-ray Optics ISFM Sub-package #2: Direct Fabrication of Full Shells | Bongiorno, Stephen | MSFC | Optics | X Ray |
| Directed2018 | Advanced X-ray Optics ISFM Sub-package #3: Computer-Controlled Polishing of High-Quality Mandrels | Davis, Jacqueline | MSFC | Optics | X Ray |
| Directed2018 | Advanced X-ray Optics ISFM Sub-package #4: Low Stress Mirror Coatings | Broadway, David | MSFC | Optics | X Ray |
| Directed2018 | Advanced X-ray Optics ISFM Sub-package #5: X-ray Testing and Calibration | Ramsey, Brian | MSFC | Optics | X Ray |
| Directed2018 | Advanced X-ray Optics ISFM Sub-package #6: Hybrid X-ray Optics by Additive Manufacturing | Broadway, David | MSFC | Optics | X Ray |
| Directed2018 | Advanced X-ray Microcalorimeters ISFM Sub-package #1:TES Microcalorimeters | Kilbourne, Caroline | GSFC | Detector | X Ray |
| Directed2018 | Advanced X-ray Microcalorimeters ISFM Sub-package #2: Lab Spectroscopy for Space Atomic Physics | Porter, Scott | GSFC | Detector | X Ray |
| Directed2018 | Advanced X-ray Microcalorimeters ISFM Sub-package #3: Magnetically Coupled Calorimeters | Bandler, Simon | GSFC | Detector | X Ray |
| Directed2018 | Providing Enabling and Enhancing Technologies for a Demonstration Model of the Athena X-IFU | Kilbourne, Caroline | GSFC | Detector | X Ray |
| Directed2018 | US Contribution to the Athena Wide Field Imager | Burrows, David | PSU | Electronics | X Ray |

# Current COR Strategic Technology Investment

| Funding Program | Project Title | PI Name | PI Org | Tech Area | Signal Type |
|---|---|---|---|---|---|
| SAT2014 | Raising the Technology Readiness Level of 4.7-THz local oscillators | Hu, Qing | MIT | Detector | Far IR |
| SAT2014 | Development of Large Area (100x100 mm) photon counting UV detectors | Vallerga, John | UCB | Detector | UV |
| SAT2014 | Improving UV Coatings and Filters using Innovative Materials Deposited by ALD | Scowen, Paul | ASU | Optical Coating | UV |
| SAT2014 | Advanced FUVUV/Visible Photon Counting and Ultralow Noise Detectors | Nikzad, Shouleh | JPL | Detector | UVOIR |
| SAT2015 | High-Efficiency Continuous Cooling for Cryogenic Instruments and sub-Kelvin Detectors | Tuttle, James | GSFC | Cooling System | X Ray Far IR, Sub-mm |
| SAT2016 | Ultrasensitive Bolometers for Far-IR Spectroscopy at the Background Limit | Bradford, Charles | JPL | Detector | Far IR |
| SAT2016 | High Performance Sealed Tube Cross Strip Photon Counting Sensors for UV-Vis Astrophysics Instruments | Siegmund, Oswald | UCB | Detector | UV |
| SAT2016 | Development of Digital Micromirror Devices for Far-UV Applications | Ninkov, Zoran | RIT | Optics | UV |
| SAT2016 | Development of a Robust, Efficient Process to Produce Scalable, Superconducting kilopixel Far-IR Detector Arrays | Staguhn, Johannes | JHU | Detector | Far IR |
| SAT2017 | Ultra-Stable Structures Development and Characterization Using Spatial Dynamic | Saif, Babak | GSFC | Metrology/ Structure | UVOIR |
| SAT2017 | Scalable micro-shutter systems for UV, visible, and infrared spectroscopy | Greenhouse, Matthew | GSFC | Optics | UVOIR |
| SAT2017 | Electron-beam Generated Plasma to Enhance Performance of Protected Aluminum | Quijada, Manuel | GSFC | Optical Coating | UVOIR |
| SAT2017 | Development of High-Resolution Far-Infrared Array Receivers | Mehdi, Imran | JPL | Detector | Far IR |
| Directed2018 | Predictive Thermal Control (PTC) Performance Tests | Stahl, H. Philip | MSFC | Optics | UVOIR |
| SMTP2018 | System-Level Segmented Telescope Design (SLSTD) | Dewell, Larry | LM | Telescope | UVOIR |
| SMTP2018 | Ultrastable Large Telescope Research & Analysis (ULTRA) | Knight, Scott | Ball | Telescope | UVOIR |

# Segmented Mirror Technology Program (SMTP) Phase I


- One-year program to mature integrated system architectures to enable next generation ≥ 10m segmented space telescopes with integrated coronagraphs (e.g., Large UV/Optical/IR Surveyor, LUVOIR; Habitable Exoplanet Observatory, HabEx; and Origins Space Telescope, OST)
- Two industry-based efforts funded, one led by Lockheed Martin and the other by Ball Aerospace
- Teams presented interim status to NASA in September 2018
- Final reports are expected in spring 2019

# Segmented Mirror Technology Program (SMTP) Phase II


- **Two-year technology program to advance key technologies identified by the large-mission-concept study teams; this development and maturation effort is intended to build on architectures and findings developed in Phase I for LUVOIR, HabEx, and OST, specifically:**
  - Move individual technologies identified in Phase I to Technology Readiness Level (TRL) 4
  - Move toward system-level TRL 3
  - Through the above, mitigate risk, shorten fabrication time, and reduce overall mission costs
- **Approximately $8M total expected to be provided for 2-3 efforts**
- **RFP is currently being drafted, expected to be released in 2019 (exact timing TBD)**

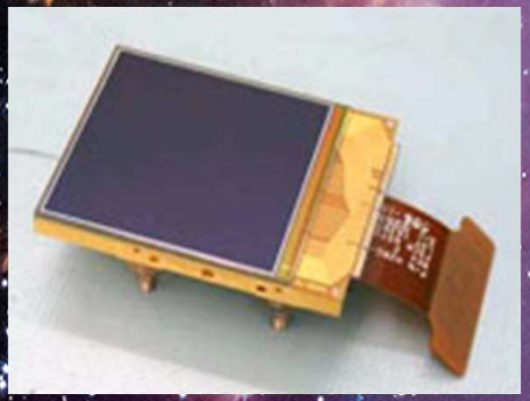
# Astrophysics Technology Website and AstroTech Database

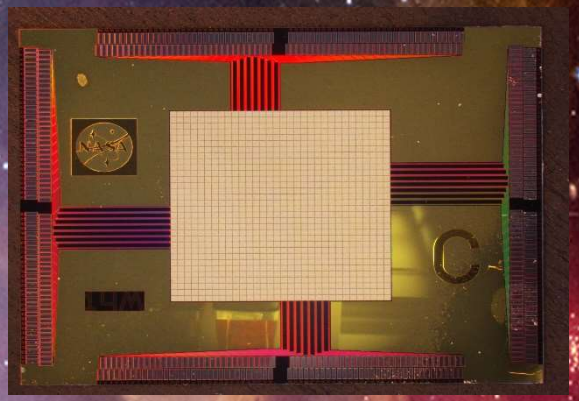

**PCOS/COR technology development website**
**(https://apd440.gsfc.nasa.gov/Technology/Index.html)**

- **Description of tech development process**
- **Full details of gaps and their priority ranking**
- **Access to abstracts, annual PI status reports, one-page project summaries (quad charts), etc. of past and current strategic tech dev investments across PCOS, COR, and ExEP through searchable AstroTech database (http://www.AstroStrategicTech.us/)**
- **Benefits and success stories**
- **Archive of Program Office documents (including e.g. PATRs) and conference posters**

# Integrated Strategic Astrophysics Technology Solicitation


- Strategic Astrophysics Technology (SAT, element D8 of Research Opportunity in Earth and Space Sciences, ROSES) will continue its current annual solicitation cycle
- The SAT solicitation will no longer be split into three separate programs, Technology development for PCOS (TPCOS), Technology Development for COR (TCOR) and Technology Development for Exoplanet Missions (TDEM); instead, a single SAT solicitation will address a range of technology gaps across Astrophysics
- **SAT mandatory NOIs due 1/24/2019; proposals due 3/21/2019**
- **We continue to solicit technology gaps ongoingly, with cutoff dates on the 1st of June every other year (next cutoff scheduled for 6/1/2019)**





# PCOS/COR/ExEP Program Offices technology development enables future Astrophysics missions