NASA Astrophysics Technology Gaps, Prioritization, and Development

19th Annual Mirror Technology Workshop
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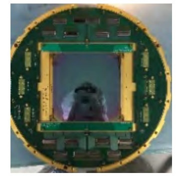
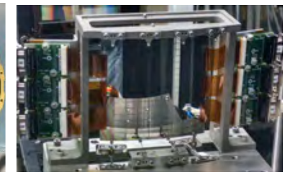
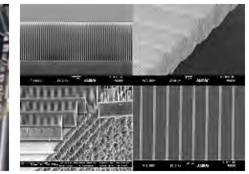
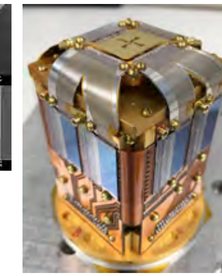
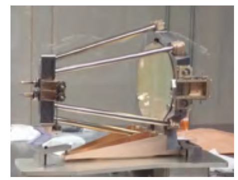
NASA Astrophysics Division's PCOS and COR Program Technology Interests

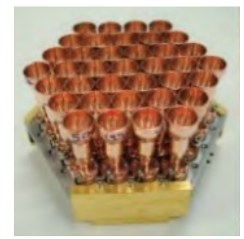
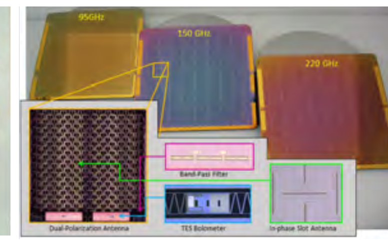
Physics of the Cosmos (PCOS)

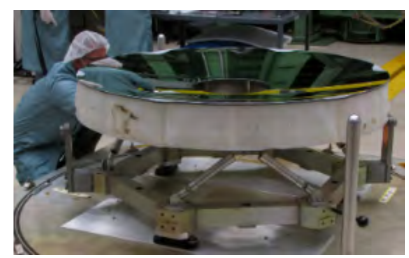
- **X-ray astrophysics:** grazing-angle mirrors, optical blocking filters, fast event ID, gratings, micro-calorimeters, radiation-tolerant detectors
- **Gravitational-wave astrophysics:** phase measurement system, micro-Newton thrusters, non-contact charge-management system, stable laser system, low-stray-light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

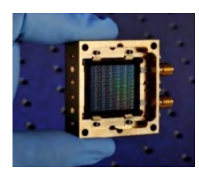
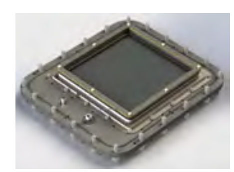
Cosmic Origins (COR)

- **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
- **Large Space Optics:** As discussed earlier by Mario Perez, the Program Office supports HQ in monitoring/tracking the Segmented Mirror Technology Program (SMTP) and other technology development projects targeting large space telescopes

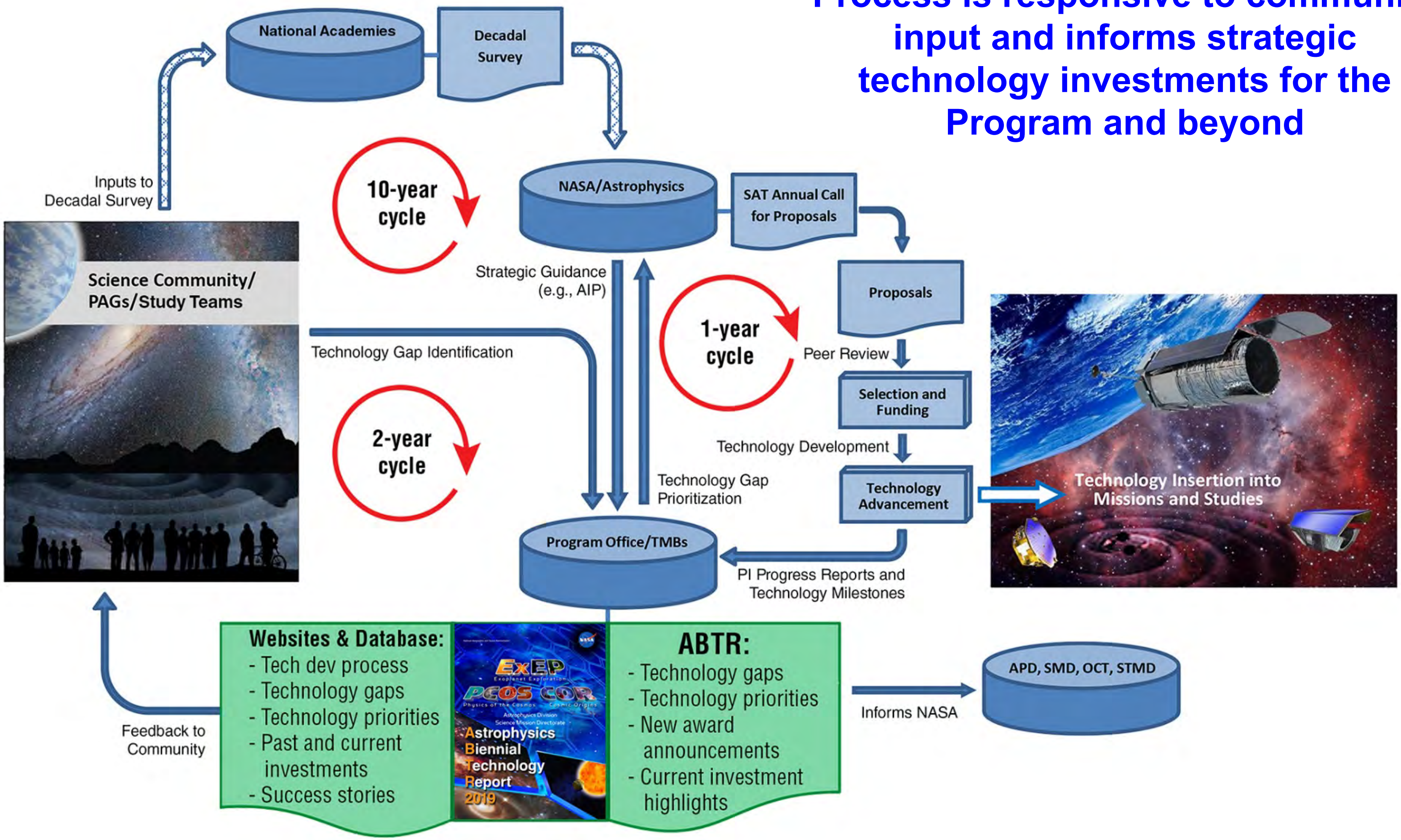



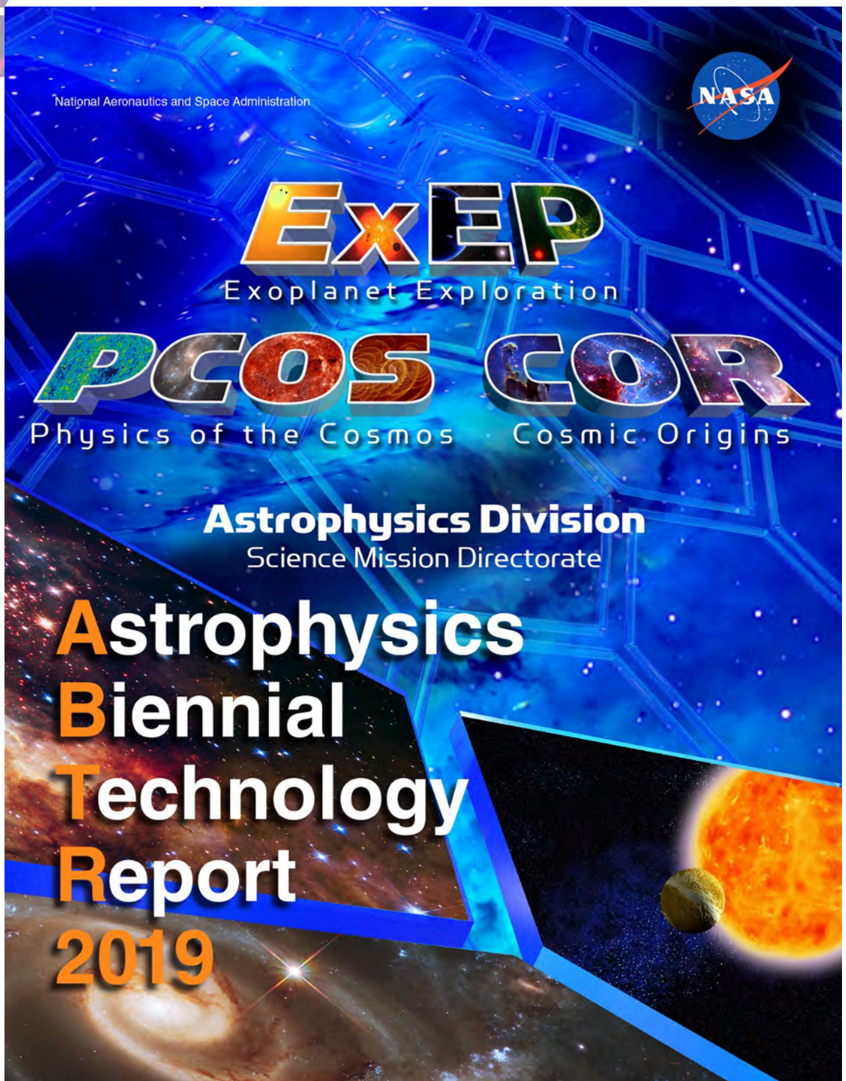



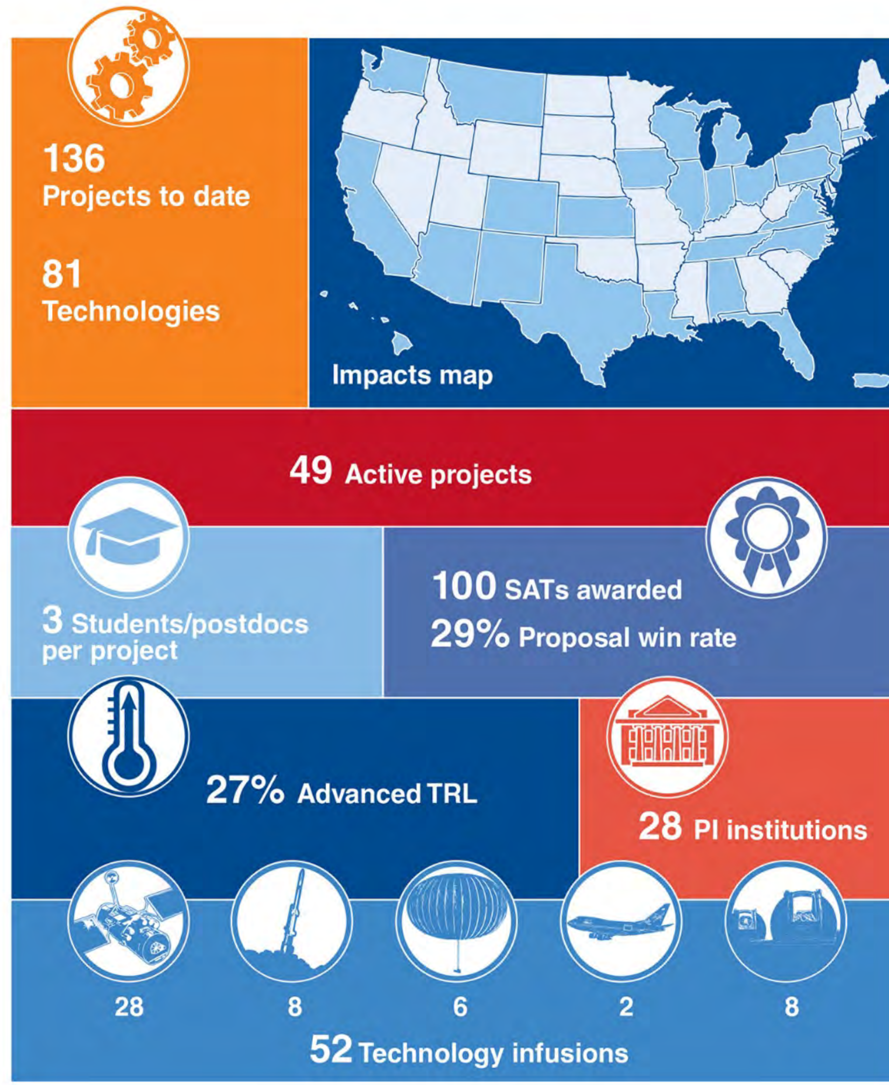
Strategic Technology Development Process

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



First ABTR Just Published





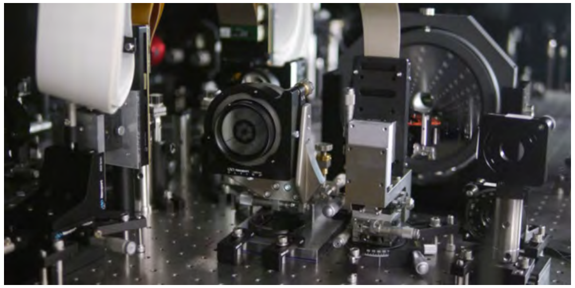
Technology Infusion Achievements

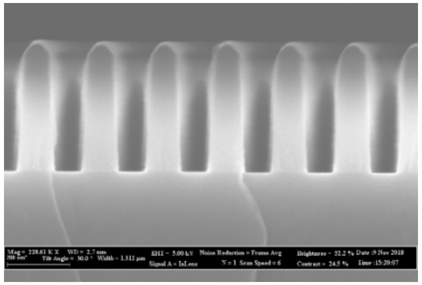
Tier 1 Priority Technology Gaps

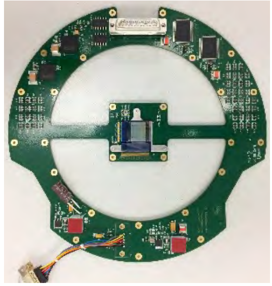
Gaps within a specific tier have equal priority

Tier 1 Technology Gaps

- Angular Resolution (UV/Vis/NIR)
- Coronagraph Contrast
- Coronagraph Contrast Stability
- Cryogenic Readouts for Large-Format Far-IR Detectors
- Fast, Low-Noise, Megapixel X-Ray Imaging Arrays with Moderate Spectral Resolution
- High-Efficiency X-Ray Grating Arrays for High-Resolution Spectroscopy
- High-Resolution, Large-Area, Lightweight X-Ray Optics
- Large-Format, High-Resolution, UV/Vis Focal Plane Arrays
- Large-Format, High-Spectral-Resolution, Small-Pixel X-Ray Focal-Plane Arrays
- Large-Format, Low-Noise and Ultralow-Noise Far-IR Direct Detectors
- Large-Format, Low-Noise, High-QE Far-UV Detectors
- Next-Generation, Large-Format, Object Selection Technology for Multi-Object Spectrometers for LUVOIR
- Vis/NIR Detection Sensitivity





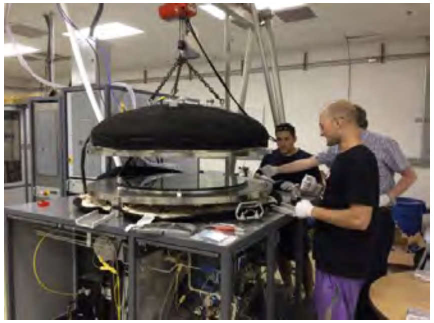


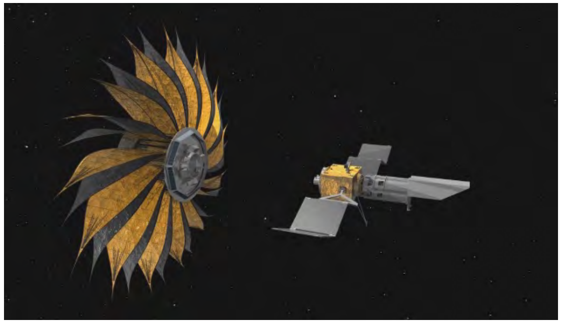
Tier 2 Priority Technology Gaps

Gaps within a specific tier have equal priority

Tier 2 Technology Gaps

- Advanced Millimeter-Wave Focal-Plane Arrays for CMB Polarimetry
- Detection Stability in Mid-IR
- Heterodyne FIR Detector Arrays and Related Technologies
- High-Efficiency Object Selection Technology for UV Multi-Object Spectrometers
- High-Performance Spectral Dispersion Component/Device
- High-Reflectivity Broadband FUV-to-NIR Mirror Coatings
- High-Throughput Bandpass Selection for UV/VIS
- Large-Format Object Selection Technology for Multi-Object Spectrometers for HabEx
- Starshade Deployment and Shape Stability
- Starshade Starlight Suppression and Model Validation
- Stellar Reflex Motion Sensitivity – Astrometry
- Stellar Reflex Motion Sensitivity – Extreme Precision Radial Velocity



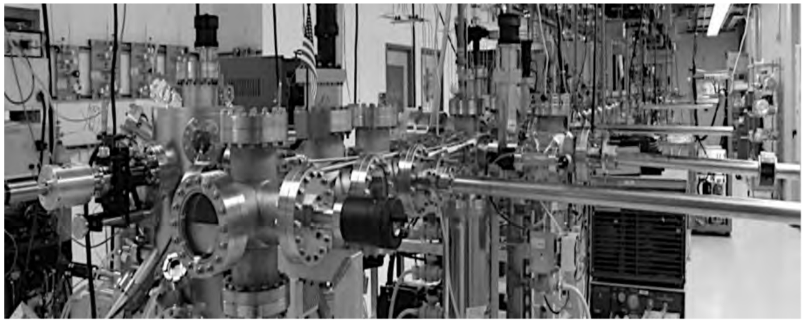


Tier 3 Priority Technology Gaps

Gaps within a specific tier have equal priority

Tier 3 Technology Gaps

- Advanced Cryocoolers
- High-Performance, Sub-Kelvin Coolers
- Large Cryogenic Optics for the Mid-IR to Far-IR
- Long-Wavelength-Blocking Filters for X-Ray Micro-Calorimeters
- Low-Noise, High-QE UV Detectors
- Low-Stress, Highly Stable X-Ray Reflective Coatings
- Photon-Counting, Large-Format UV Detectors
- Polarization-Preserving Millimeter-Wave Optical Elements
- UV Coatings
- UV Detection Sensitivity
- UV/Vis/NIR Tunable Narrow-Band Imaging Capability
- Warm Readout Electronics for Large-Format Far-IR Detectors



Tiers 4 & 5 Priority Technology Gaps

Gaps within a specific tier have equal priority

Tier 4 Technology Gaps

- Compact, Integrated Spectrometers for 100 to 1000 μm
- Optical-Blocking Filters
- Rapid Readout Electronics for X-Ray Detectors
- Short-Wave UV Coatings

Gaps within a specific tier have equal priority

Tier 5 Technology Gaps

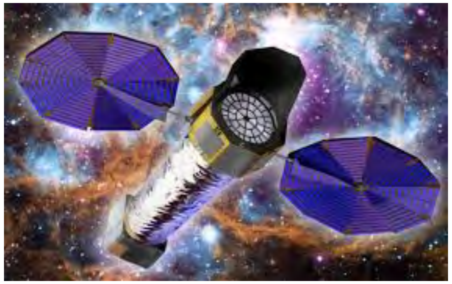
- Advancement of X-Ray Polarimeter Sensitivity
- Far-IR Spatio-Spectral Interferometry
- High-Precision Low-Frequency Radio Spectrometers and Interferometers
- Mid-IR Coronagraph Contrast
- Ultra-High-Resolution Focusing X-Ray Observatory Telescope
- Very-Wide-Field Focusing Instrument for Time-Domain X-Ray Astronomy
- Wide-Bandwidth, High-Spectral-Dynamic-Range Receiving System for Low-Radio-Frequency Observations on the Lunar Far Side

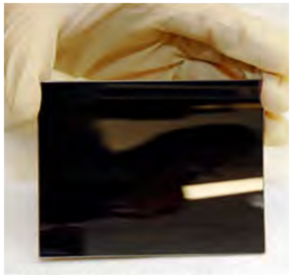
Current Optics-Related Strategic Technology Investments

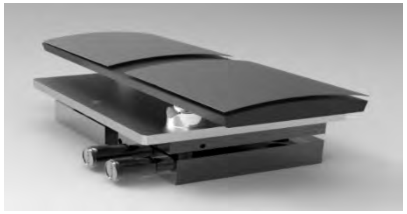
Technology Development Title	PI Name	Institution	Tech Area
Development of Adjustable X-Ray Optics with 0.5 Arcsec Resolution for the Lynx Mission Concept	Reid, Paul	SAO	Optics
High-Resolution and High-Efficiency X-Ray Transmission Grating Spectrometer	Schattenburg, Mark	MIT	Optics
Telescopes for Space-Based Grav-Wave Observatories	Livas, Jeffrey	GSFC	Telescope
Next-Generation X-Ray Optics	Zhang, William	GSFC	Optics
Differential Deposition for Figure Correction in X-Ray Optics	Kilaru, Kiran	MSFC	Optics
Direct Fabrication of Full-Shell X-Ray Optics	Bongiorno, Stephen	MSFC	Optics
Computer-Controlled Polishing of High-Quality X-Ray Optics Mandrels	Davis, Jacqueline	MSFC	Optics
Low-Stress Mirror Coatings for X-Ray Optics	Broadway, David	MSFC	Coatings
X-Ray Testing and Calibration	Ramsey, Brian	MSFC	Optics
Hybrid X-Ray Optics by Additive Manufacturing	Broadway, David	MSFC	Optics
Improving UV Coatings & Filters using Innovative Materials Deposited by ALD	Scowen, Paul	ASU	Optical Coating
Development of DMDs for Far-UV Applications	Ninkov, Zoran	RIT	Optics
Ultra-Stable Structures Development and Characterization Using Spatial Dynamic Metrology	Saif, Babak	GSFC	Metrology/ Structure
e-Beam Lithography Ruled Gratings for Future UV/Optical Missions: High-Efficiency and Low-Scatter in the Vacuum UV	Fleming, Brian	CU Boulder	Optics
Scalable Micro-Shutter Systems for UV, Visible, and Infrared Spectroscopy	Greenhouse, Matthew	GSFC	Optics
e-Beam-Generated Plasma to Enhance Performance of Protected Aluminum Mirrors for Large Space Telescopes	Quijada, Manuel	GSFC	Optical Coating
Predictive Thermal Control (PTC) Performance Tests	Stahl, H. Philip	MSFC	Optics
High-Performance, Stable, and Scalable UV Aluminum Mirror Coatings Using ALD	Hennessy, John	JPL	Optical Coating
Technology Maturation for Astrophysics Space Telescopes (TechMAST)	Nordt, Alison	LM	Telescope
Ultra-Stable Telescope Research and Analysis -Technology Maturation (ULTRA-TM)	Coyle, Laura	Ball	Telescope

Strategic Technology Highlights: X-Ray Optics

- A technology maturation project, funded by the Physics of the Cosmos (PCOS) Program, led by William Zhang of GSFC, has successfully tested a pair of mono-crystalline-silicon mirrors, achieving an image quality equivalent to 0.57 arcsec half-power diameter (HPD) after accounting for gravity distortion
  - *This represents the best image quality ever achieved with extremely lightweight X-ray optics, as good as Chandra's image quality, but with mirrors that are 50 times lighter*
  - *This technology is the baseline mirror architecture of the reference design developed by the Lynx X-ray Surveyor study team (one of the four decadal flagship concepts)*

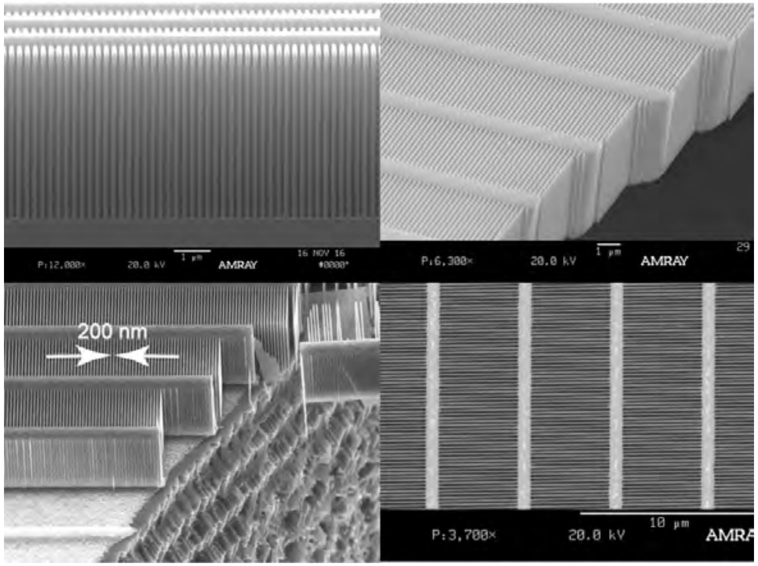

The Lynx X-ray Surveyor mission concept


Single 10 × 10 cm^2 X-ray mirror segment

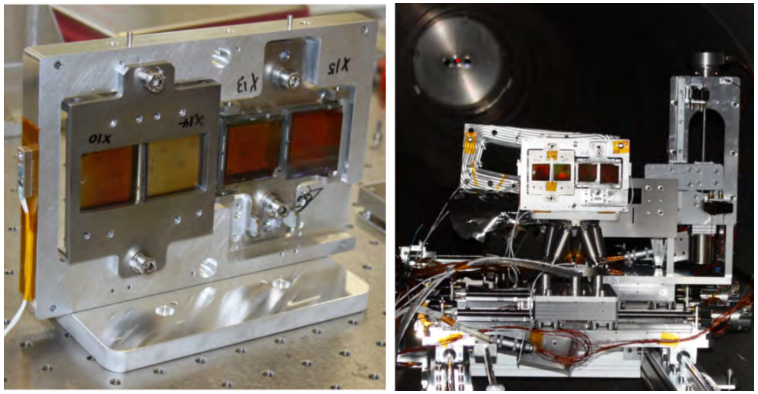

A Technology Development Module (TDM) with a pair of mono-crystalline-silicon mirrors

Strategic Technology Highlights: X-Ray Transmission Gratings

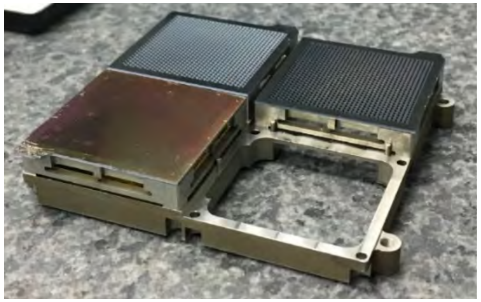
- A technology maturation project, funded by the PCOS Program, led by Mark Schattenburg of MIT, developed critical-angle transmission (CAT) gratings demonstrating single-grating resolution of >10,000 at TRL 4, then successfully fabricated larger (32×32 mm^2) gratings, frame-mounted, and aligned them to each other. The gratings were tested in an X-ray beam line, obtaining ray-trace-predicted performance
  - *This technology will help enable Lynx, as well as Explorer missions (e.g., Arcus)*



SEM images of CAT gratings



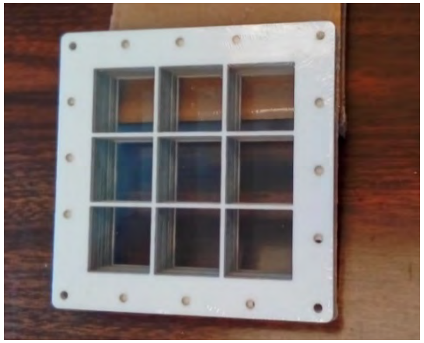
Grating petal holding four co-aligned 32x32-mm^2 CAT gratings tested at the PANTER X-ray facility



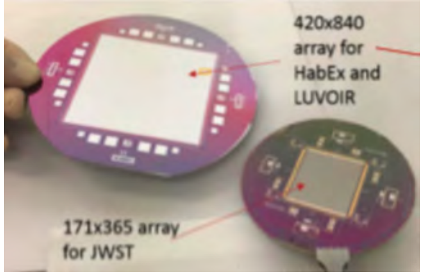
Arcus flight-like grating window w/flight-like CAT grating facet on left

Strategic Technology Highlights:
Scalable Microshutter System for UVOIR Spectroscopy

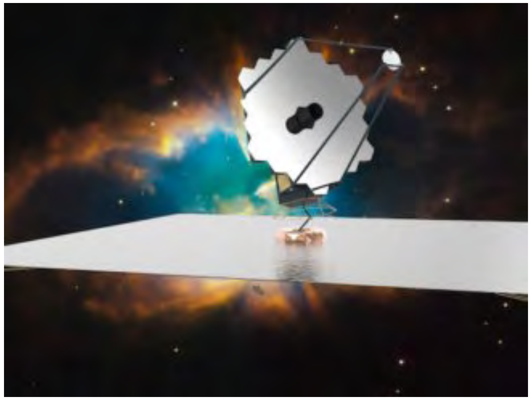
- A technology maturation project, funded by the Cosmic Origins (COR) Program, led by Matt Greenhouse of GSFC, fabricated and assembled pilot microshutter arrays, and delivered suborbital flight assemblies to FORTIS sounding rocket mission
  - *Mission reference designs including HabEx, LUVOIR, and CETUS (Probe mission), will be enabled by advanced, electrostatically actuated microshutter arrays for large-field-of-view multi-object spectroscopy. These eliminate the macro-mechanisms required by JWST's magnetic actuation technology. The large-format design includes three-side-buttable packaging and incorporates 3D printing. Pixel operability is improved by incorporating anti-stiction techniques*



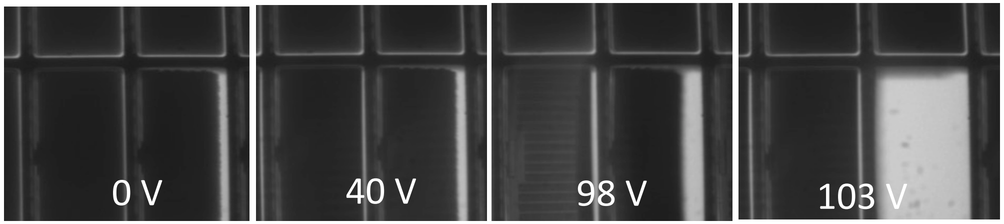
Ceramic frames with support beams



Large-format arrays on 6"-wafer



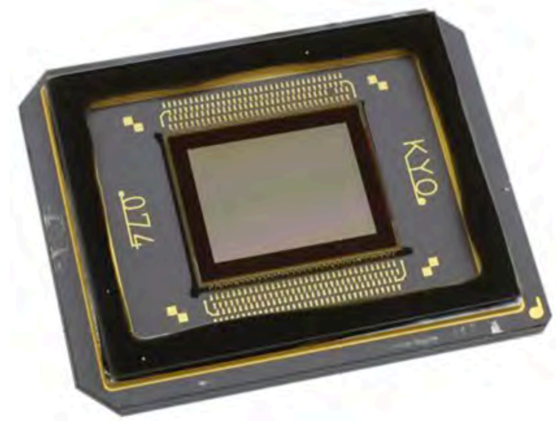
Mission concept design of the Large UltraViolet, Optical, InfraRed surveyor (LUVOIR)



0V DC voltage was applied on two shutters, the one on the right was laser trimmed into a keystone shape; 40V applied, the shutter on the right slightly open; with 98V, the shutter opened further; and with 103V, the shutter fully opened and latched. As a comparison, the shutter on the left without size change kept closed for all voltages.

Strategic Technology Highlights: Development of DMDs for Far-UV Applications

- A technology maturation project, funded by the COR Program, led by Zoran Ninkov of RIT, modifies commercial off-the-shelf digital micromirror devices (DMDs), recoating their mirrors (e.g., with Al/AlF_3) and replacing their windows with UV-transparent ones, or operating in an open mode. The recoated devices were successfully tested and are functional
  - *A technology allowing target selection in a field of view to be input to an imaging spectrometer will enable multi-object spectroscopy. One option for this technology is a modified DMD*



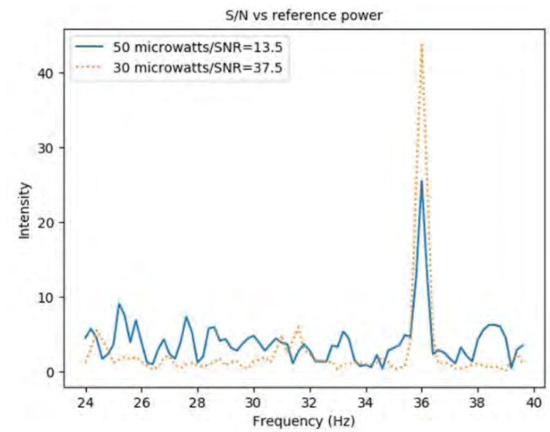
A TI DMD with HEM Sapphire UVT window

RIT team led by Zoran Ninkov

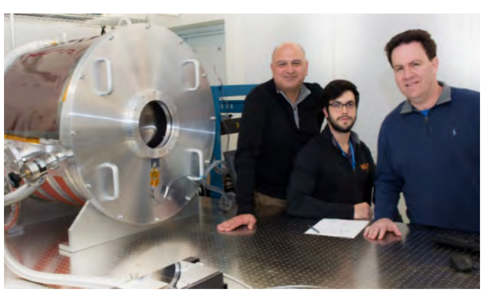
PCOS COR

Strategic Technology Highlights: Ultra-Stable Structures

- A technology maturation project, funded by the COR Program, led by Babak Saif of GSFC, designed and built a high-speed speckle interferometer for measuring motions and distortions in solid materials at the pm scale and sub-pm precision; the system successfully measured distance to a ULE® target at nm-level accuracy
  - *This technology will help enable missions such as LISA, LUVOIR, and HabEx through precise wavefront sensing and control, and system-alignment stability to pm scale*
  - *A paper by Babak Saif, titled "Sub-picometer Dynamic Measurements of a Diffuse Surface" was published in the April edition of Applied Optics, and nominated by the publisher's Editorial Office as "Editor's Pick" for excellent content*

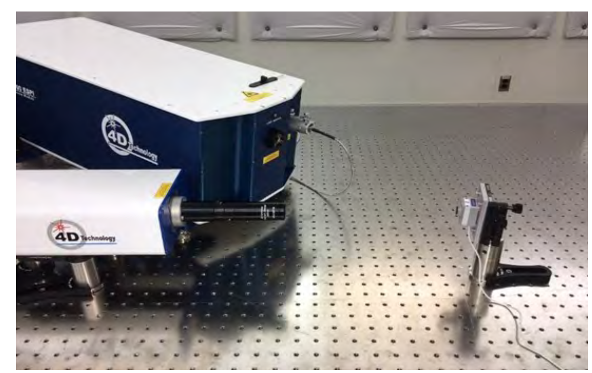


Optimal reference power improves measurement S/N



Babak Saif (left) with his team members next to an ultra-stable thermal-vac test chamber

Ultra-Stable pm-scale mirror assembly functional testing with surrogate fused-Si substrate



High-speed interferometer configuration for operating in speckle mode with a composite target mounted to a precision actuator

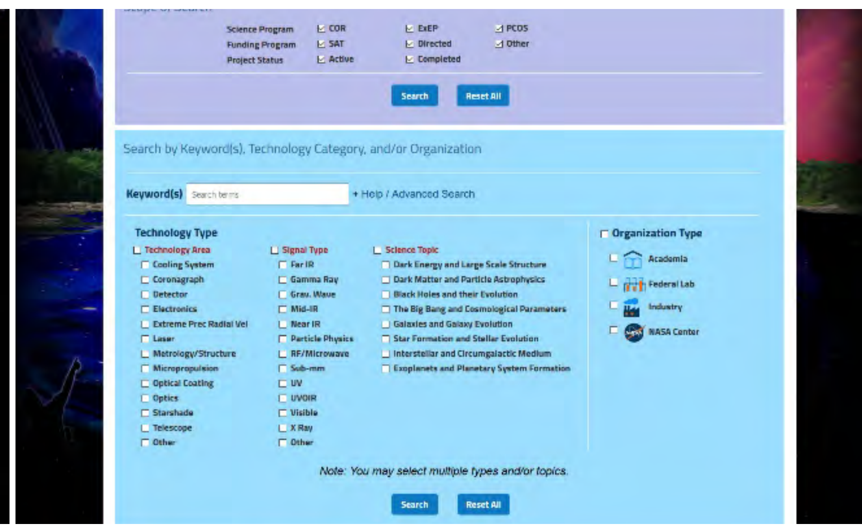
APRA and SAT Solicitations and Technology Gap Submissions

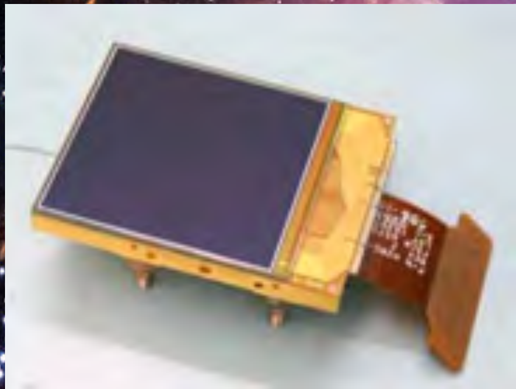
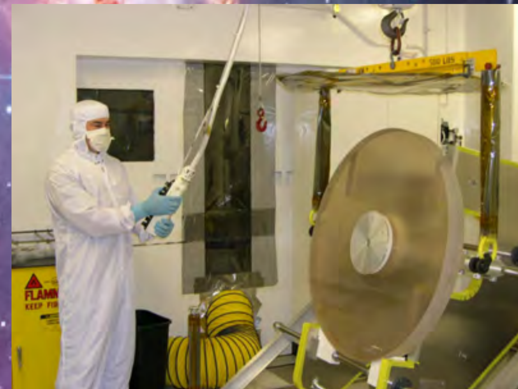
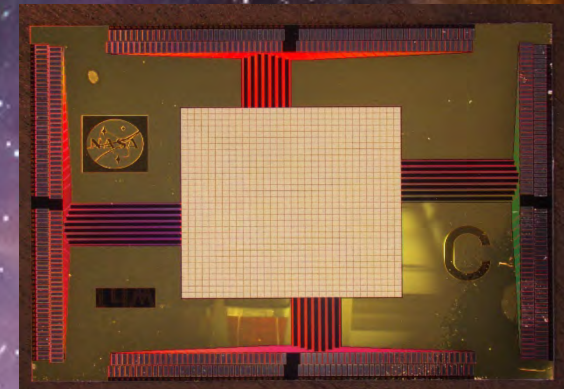
- The APRA and SAT program elements for calendar year 2020 have been shifted to ROSES-2020; the deadlines will be announced in ROSES-2020, to be released in February 2020
  - *APRA selects on average 45 new projects per cycle (about 3 in 10 submitted proposals)*
  - *SAT selects on average 10 new projects per cycle (also about 3 in 10 submitted proposals); for FY 2020 (ROSES 2018), 40% were selected*
- We solicit technology gaps continuously
  - *Cutoff dates on the 1st of June of alternate years (next cutoff 6/1/2021)*
  - *In this recent cycle, 22 of 48 gaps are optics-related (12 of 25 are in top two priority tiers)*

Astrophysics Technology Website and AstroTech Database

PCOS/COR technology website (https://apd440.gsfc.nasa.gov/technology.html):

- **Description of tech development process**
- **Full details of gaps and their priority ranking**
- **AstroTech database (http://www.AstroStrategicTech.us/) with abstracts, PI reports, quad charts, etc. of PCOS, COR, and ExEP past and current strategic tech investments**
- **Program benefits and success stories**
- **Archive of PATRs, ABTR(s), conference posters**



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