Astrophysics Technology Development PhysCOS/COR Programs

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Astrophysics Technology Enables (and Limits) Science

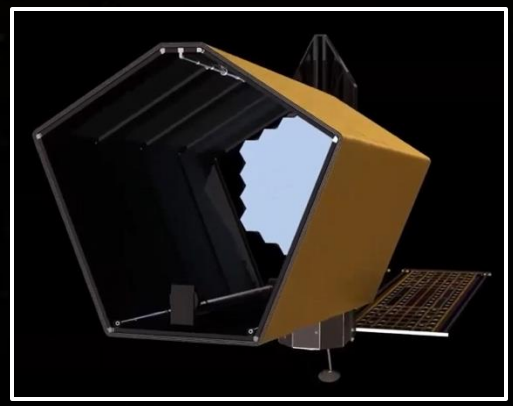
- Current technologies enable great science (e.g., Hubble, Webb, etc.)
- However, our SOTA technologies also limit us – science we can do with existing technologies has already been done (or will be "soon");
- Next-level science requires us to push the technological envelope
- To have a chance of going *beyond* that next level will require new ways of thinking, new approaches, and new synergies

Let's start with a look at our current plans…

Strategic Astrophysics Missions: Habitable Worlds Observatory (HWO)

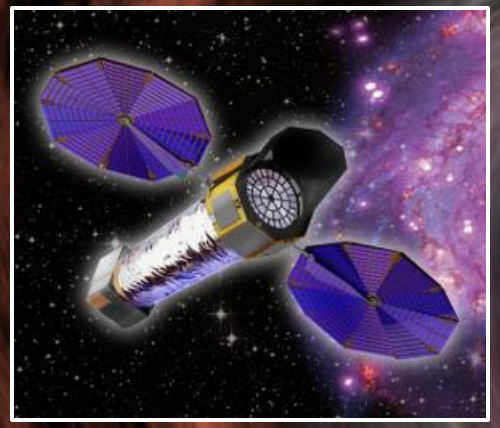
Capabilities needed

- Large telescope optics
- Broadband coatings (down to Lyman α)
- Large-format detector arrays
- High-contrast imaging (for exoplanet science)
- Extreme stability (for exoplanet science)



An initial HWO architecture under study

Strategic Astrophysics Missions: X-Ray Flagship



Capabilities needed

- Low-density, high-precision X-ray optics
- Cryogenics
- Large-format, low-noise X-ray detector arrays

An X-ray Probe may fly in the coming decade that could also benefit from these capabilities

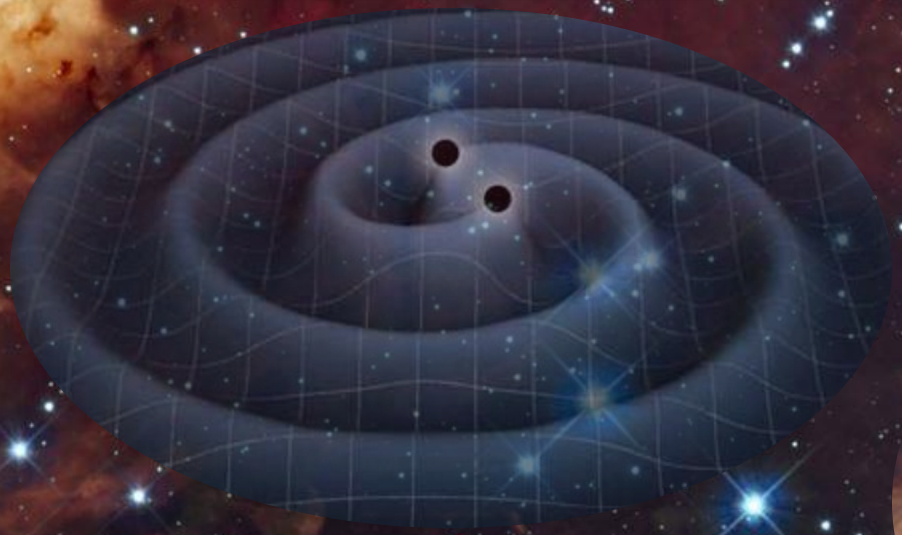
Strategic Astrophysics Missions: Far-IR Flagship

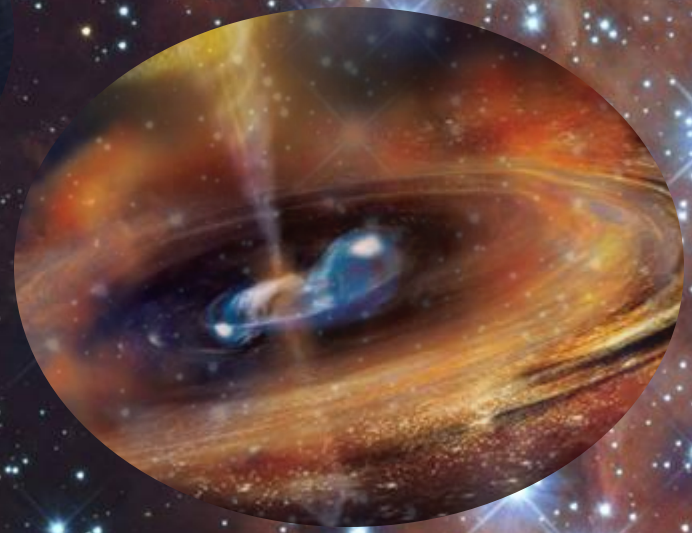
Capabilities needed

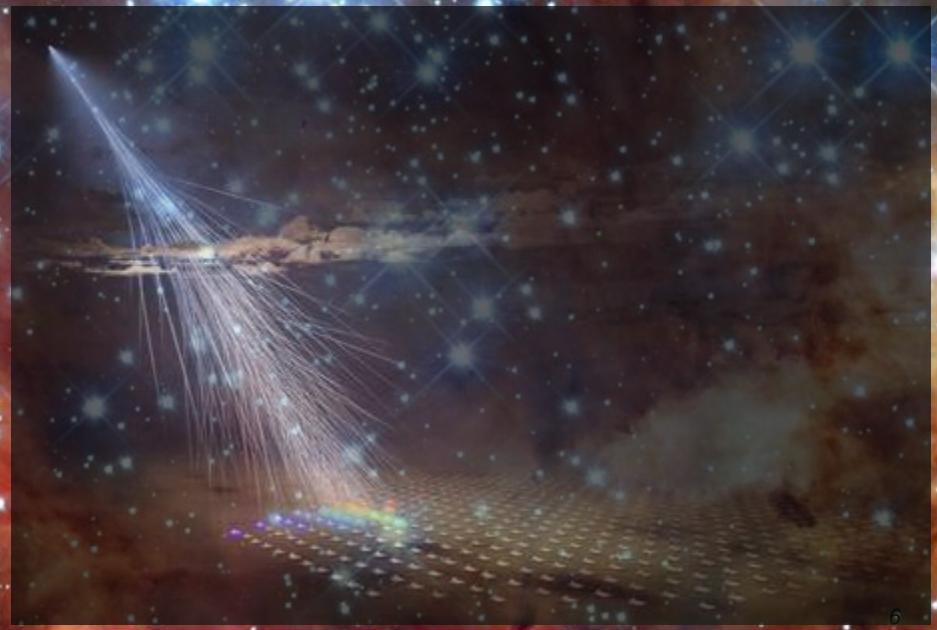
- Cryogenic optics
- Large-format cryogenic detector arrays
- Cryogenic coolers

A far-IR Probe may fly in the coming decade and a CMB Probe may fly in the following decade; each could also benefit from some of these capabilities

Strategic Astrophysics Activities: Time-Domain and Multi-Messenger (TDAMM) Science







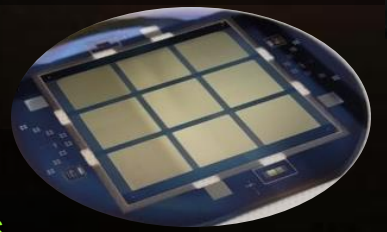
Capabilities needed

- Precision timing and advanced onboard computing
- Gamma-ray optics
- Low-noise high-energy detector arrays & electronics
- Cryogenics
- AI/ML for coordinating observations and reviewing existing datasets

From Capabilities to Gaps: HWO General Astrophysics

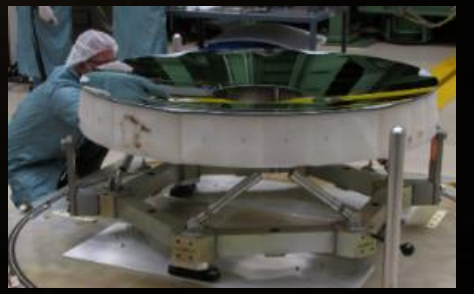
Large telescope optics

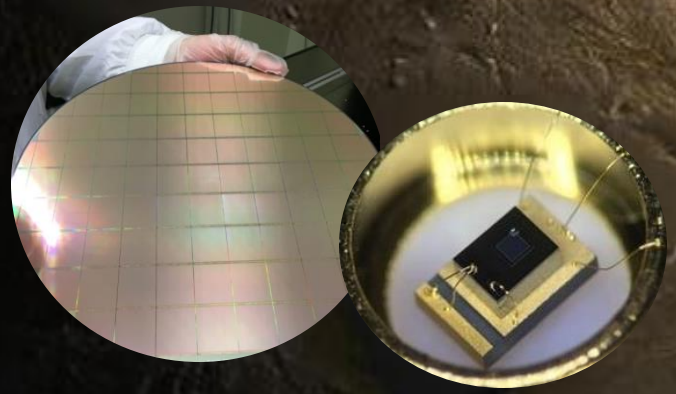
- High-Efficiency, Low-Scatter, High- and Low-Ruling-Density, High- and Low-Blazed-Angle UV Gratings
- High-Throughput, Large-Format Object-Selection Tech for Multi-Object and Integral-Field Spectroscopy
- Mirror Technologies for High Angular Resolution (UV/Visible/Near IR)
- High-Throughput UV Bandpass Standalone and Detector-Integrated Filters and Bandpass Selection



Broadband coatings (down to Lyman α)

- High-Reflectivity Broadband Far-UV-to-Near-IR Mirror Coatings
- Scaling and Metrology for Advanced Broadband Mirror Coatings for HWO





Large-format detector arrays

- Large-Format, High-Resolution Far-UV (100 - 200 nm) Detectors
- Large-Format, High-Resolution Near-UV (200 - 400 nm) Detectors
- UV Multi-Object Spectrograph Calibration Technologies
- UV Single-Photon Detection Sensitivity
- Visible/Near-IR Single-Photon Detection Sensitivity
- UV/Optical/Near-IR Tunable Narrowband Imaging Capability

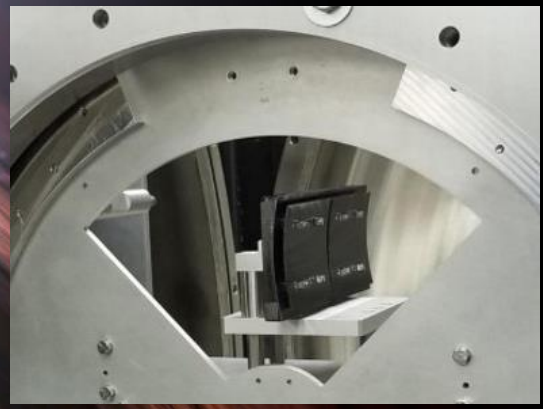
Key: Strategic Technology Gaps

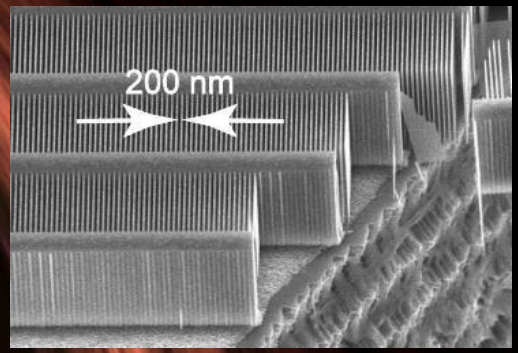
- Priority Tier 1 gaps
- Priority Tier 2 gaps
- Priority Tier 3 gaps

From Capabilities to Gaps: X-Ray Flagship*

Low-density, high-precision X-ray optics

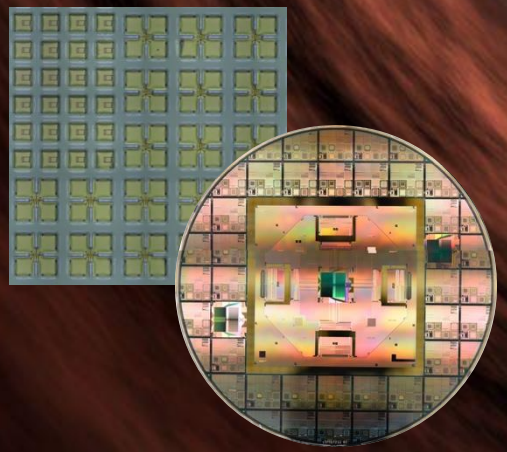
- High-Resolution, Lightweight X-ray Optics
- High-Efficiency X-ray Grating Arrays for High-Resolution Spectroscopy
- Low-Stress, Low-Roughness, High-Stability X-ray Reflective Coatings
- Optical Blocking Filters for X-ray Instruments





Cryogenics

- Advanced Cryocoolers



Large-format, low-noise X-ray detector arrays

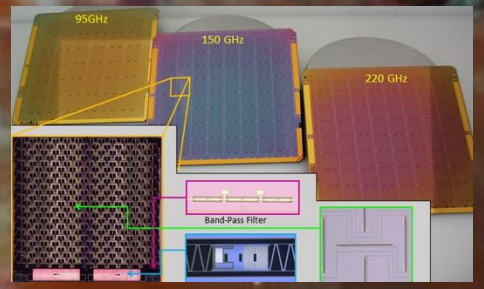
- Fast, Low-Noise, Megapixel X-ray Imaging Arrays with Moderate Spectral Resolution
- High-Bandwidth Cryogenic Readout Technologies for Compact and Large-Format Calorimeter Arrays
- Broadband X-ray Detectors
- Imaging Capability Broadband X-ray Polarimeter

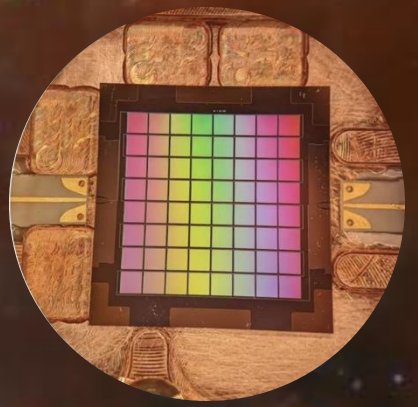
* Flagship: NASA Astrophysics term for a multi-billion-dollar space observatory such as Hubble or James Webb

From Capabilities to Gaps: Far-IR Flagship

Large-format cryogenic detector arrays

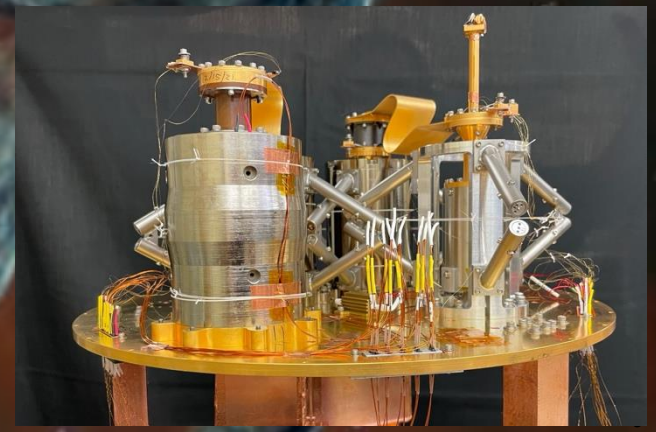
- Compact, Integrated Spectrometers for 100 to 1000 μm
- Cryogenic Far-IR to mm-Wave Focal-Plane Detectors
- Cryogenic Readouts for Large-Format Far-IR Detectors
- Far-IR Imaging Interferometer for High-Resolution Spectroscopy
- Far-IR Spatio-Spectral Interferometry
- Heterodyne Far-IR Detector Systems
- High-Resolution, Direct-Detection Spectrometers for Far-IR Wavelengths
- Improving the Calibration of Far-IR Heterodyne Measurements
- Large-Format, Low-Noise and Ultralow-Noise, Far-IR Direct Detectors
- Low-Power Readout and Multiplexing for CMB Detectors
- Millimeter-Wave Focal-Plane Arrays for CMB Polarimetry
- Warm Readout Electronics for Large-Format Far-IR Detectors
- Sensitive Spectrometer for CMB Spectrum Measurement





Cryogenic optics

- Optical Elements for a CMB Space Mission
- Large-Aperture Deployable Antennas for Far-IR/THz/sub-mm Astronomy for Frequencies Above 100 GHz
- Large Cryogenic Optics for the Mid IR to Far IR



Cryogenic coolers

- High-Performance Sub-Kelvin Coolers
- Advanced Cryocoolers

From Capabilities to Gaps: TDAMM

Precision timing and advanced onboard computing

- High-Performance Computing for Event Reconstruction
- Precision Timing Measurement Technology

Gamma-ray optics

- High-Throughput Focusing Optics for 0.1-1 MeV Photons

Low-noise high-energy detector arrays & electronics

- Charged-Particle-Discriminating X-ray/Gamma-Ray Detectors
- High-Energy-Resolution Gamma-Ray Detectors
- Large Field-of-View and Effective-Area Gamma-Ray Detectors
- Low-Power, Low-Cost Semiconductor Detectors
- Radiation-Tolerant, Photon-Counting Light Detectors
- Low-Power Readout for Silicon Photomultipliers
- Photometric and Spectro-Photometric Precision of Time-Domain and Time-Series Measurements
- Dynamic Switching for Ultra-Low-Power, High-Resolution Charge Readout

Cryogenics

- Advanced Cryocoolers

From Gaps to Investments: Current Tech Project Portfolio

Project Title	Tech Area	Signal Type
Development of a 30 mK ultra-low temperature Continuous ADR with a continuous 700 mK intermediate stage for heat intercept	Cooling	X Ray, Far IR, Sub-mm
Ultrasensitive Far-IR Kinetic Inductance Detector Arrays: Maturation for Flight	Detector	Far IR
Demonstrating Large Low Noise Transition Edge Sensor Arrays for Future FIR Space Missions	Detector	Far IR
Ultra-stable Telescope Metrology Development for High-contrast Exoplanet Detection	Metrology	UVOIR
Ultraviolet Spectroscopy for the Next Decade Enable		
Scalable Microshutter Systems for Multi-object Spec		
Advanced Al mirrors with passivated LiF for environ		
UV/Optical to Far-IR Mirror & Telescope Technology		
Four megapixel sensor for ultra-low-background sho		
High Performance FUV, NUV, and UV/Optical CMOS I		
Large Format, High Efficiency, UV/Optical/NIR Photo		
Advancing Readout of Large-Format Far-IR Transitio		
Characterizing Single-photon Sensing CMOS Image		
NASA Ames Laboratory Astrophysics Directed Work		
Ultrasensitive Far-IR Kinetic Inductance Detector Ar		

Project Title	Tech Area	Signal Type
Far-IR Detector Solutions for Low Noise, Large Format, Direct Absorption Kinetic Inductance Detector Arrays	Detector	Far IR
A High-Performance Ultraviolet Photon Counting Detector for Strategic Astrophysics Missions	Detector	UV
The Advanced Astrophysics Spectroscopy Lab at LASP	Facilities & Optics	UV
Advancing & Qualifying UV Space Technology & Instrumentation	Lab Characterization	UV
Single-photon counting with SiSeRO to search for Earth-like planets	Electronics	UVOIR
Large-area ALD-protected aluminum mirror coatings for HWO	Coatings	UV
Development of space-qualified signal-processing		
New techniques toward the nanofabrication of		
PHANTOM: Precision High-strain composites (H		
Building the Foundations for Huge-N Lunar Rad		
Development of a Low EMI and Acoustic Backgrou		
Supporting technologies for large-scale kinetic		
Build and Commission a new Space Optics Lab		
STABLE: Systems Technologies for Architectu		
TechMAST: Technology Maturation for Astroph		
ULTRA-CT: Ultra-stable Telescope Research an		

Project Title	Tech Area	Signal Type
Advanced X-ray Microcalorimeters Sub-package #3: Magnetically Coupled Calorimeters	Detector	X Ray
Extremely Low-noise, High Frame-rate X-ray Image Sensors for Strategic Astrophysics Missions	Detector	X-ray
Microwave SQUID readout technology development for future X-ray astrophysics missions	Electronics	X Ray
Flex Modules for manufacturable high-resolution X-ray telescope optics	Opto-mechanical Processes	X Ray
Rapid EBL Patterning for Customized Reflection Gratings	Optics	X Ray, UV
MSFC Advanced X-Ray Optics: Formulation to Flight	Optics, coatings, metrology, facilities	X-ray
Optimized Soft X-ray Sensors for Strategic X-ray Astrophysics Missions: Achieving TRL 5	Detector	X-ray
Advanced X-ray Microcalorimeters Sub-package #2: Laboratory Spectroscopy	Laboratory Astrophysics	X Ray
General Coordinates Network	Software	TDAMM
Technology development for a high-resolving-power X-ray spectrometer	Optics	X-ray
Advanced X-Ray Microcalorimeters Sub-package #1: Transition-Edge Sensor (TES)	Detector	X Ray
MSFC Relativistic Astrophysics – Multi-messenger Astrophysics Community Tools and Support	Software	TDAMM
Next-Generation X-ray Optics: High Resolution, Light Weight, and Low Cost	Optics	X Ray

Additional Material

The Physics of the Cosmos (PhysCOS)/Cosmic Origins (COR) technology website (https://apd440.gsfc.nasa.gov/technology.html) provides more details, including:

- Description of our technology development process
- Full details of the current technology gaps and their priority ranking
- AstroTech database (in process of move to NASA URL) with abstracts, PI reports, quad charts, etc. of PhysCOS, COR, and Exoplanet Exploration Program (ExEP) past and current strategic tech investments

Final Words (for Now…)

- We've seen our currently planned path to enable breakthrough science
- The challenges are extreme, as in "Miracles we provide immediately; the impossible takes a little longer"
- Sometimes, impossible-seeming problems become easy when you look at them differently
- Our invitation to you: Where you can, disrupt our assumptions, approaches, and plans, if it enables even more inspiring science – in short, help us find better paths…

Contact information for questions and comments:
- Jason Derleth, PhysCOS/COR Chief Technologist: jason.e.derleth@nasa.gov
- Opher Ganel, PhysCOS/COR Technologist: opher.ganel@nasa.gov

Backup

From Missions to Gaps (Tier 1 Gaps)

TIER	TECHNOLOGY GAP	HWO	X-RAY GO/PROBE	FAR-IR GO/ PROBE	CMB PROBE	TDAMM
1	Coronagraph Contrast and Efficiency in the Near IR	×				
	Coronagraph Contrast and Efficiency in the Near UV	×				
	Coronagraph Stability	×				
	Cryogenic Readouts for Large-format Far-IR Detectors			×	×	
	Fast, Low-noise, Megapixel X-ray Imaging Arrays with Moderate Spectral Resolution		×			
	High-Bandwidth Cryogenic Readout Technologies for Compact and Large-Format Calorimeter Arrays			×		
	High-Efficiency, Low-Scatter, High- and Low-Ruling-Density, High- and Low-Blazed-Angle UV Gratings (from HWO START/TAG)	×				
	High-Efficiency X-ray Grating Arrays for High-Resolution Spectroscopy		×			
	High-Performance, Sub-Kelvin Coolers		×	×	×	
	High-Reflectivity Broadband Far-UV-to-Near-IR Mirror Coatings (from HWO START/TAG)	×				
	High-Resolution, Lightweight X-ray Optics		×			
	High-Throughput, Large-Format Object-Selection Technologies for Multi-Object and Integral Field Spectroscopy (from HWO START/TAG)	×				
	Integrated Modeling for HWO: Multi-Physics Systems Modeling, Uncertainty Quantification, and Model Validation	×				
	Large-Format, High-Resolution Far-UV (100-200 nm) Detectors (from HWO START/TAG)	×				
	Large-Format, High-Resolution Near-UV (200 - 400 nm) Detectors (from HWO START/TAG)	×				
	Low-Stress, Low-Roughness, High-Stability X-ray Reflective Coatings		×			
	Mirror Technologies for High Angular Resolution (UV/Visible/Near IR)	×				
	Optical Blocking Filters for X-ray Instruments		×			
	Scaling and Metrology for Advanced Broadband Mirror Coatings for HWO (from HWO START/TAG)	×				
	Segmented-Pupil Coronagraph Contrast and Efficiency in the Visible Band	×				
	UV Multi-Object Spectrograph Calibration Technologies (from HWO START/TAG)	×				
	UV Single-Photon Detection Sensitivity	×				
	Visible/Near-IR Single-Photon Detection Sensitivity	×				

From Missions to Gaps (Tier 2 Gaps)

TIER	TECHNOLOGY GAP	HWO	X-RAY GO/PROBE	FAR-IR GO/PROBE	CMB PROBE	TDAMM
2	Advanced Cryocoolers		×	×		
	Broadband X-Ray Detectors		×			
	Compact, Integrated Spectrometers for 100 to 1000 μm			×		
	Cryogenic Far-IR to Millimeter-Wave Focal Plane Detectors			×	×	
	Far-IR Imaging Interferometer for High-Resolution Spectroscopy			×		
	Far-IR Spatio-Spectral Interferometry			×		
	Heterodyne Far-IR Detector Systems			×		
	High-Performance Computing for Event Reconstruction					×
	High-Resolution, Direct-Detection Spectrometers for Far-IR Wavelengths			×		
	High-Throughput Focusing Optics for 0.1-1 MeV Photons					×
	High-Throughput UV Bandpass Standalone and Detector-Integrated Filters and Bandpass Selection (from HWO START/TAG)	×				
	Improving the Calibration of Far-IR Heterodyne Measurements			×		
	Large-Format, High-Spectral-Resolution, Small-Pixel X-ray Focal Plane Arrays		×			
	Large-Format, Low-Noise and Ultralow-Noise Far-IR Direct Detectors			×		
	Low-Power Readout and Multiplexing for CMB Detectors				×	
	Millimeter-Wave Focal-Plane Arrays for CMB Polarimetry				×	
	Optical Elements for a CMB Space Mission			×	×	
	Starshade Deployment and Shape Stability	×				
	Starshade Starlight Suppression and Model Validation	×				
	Stellar Reflex Motion Sensitivity: Astrometry	×				
	Stellar Reflex Motion Sensitivity: Extreme Precision Radial Velocity	×				
	Warm Readout Electronics for Large-Format Far-IR Detectors			×		

From Missions to Gaps (Tier 3 Gaps etc.)

TIER	TECHNOLOGY GAP	HWO	X-RAY GO/PROBE	FAR-IR GO/ PROBE	CMB PROBE	TDAMM
3	Broadband X-ray Polarimeter		×			
	Charged-Particle-Discriminating X-ray/Gamma-Ray Detectors					×
	Dynamic Switching for Ultra-Low-Power, High-Resolution Charge Readout					×
	High-Energy-Resolution Gamma-Ray Detectors					×
	Large-Aperture Deployable Antennas for Far-IR/THz/sub-mm Astronomy for Frequencies Above 100 GHz			×		
	Large Cryogenic Optics for the Mid IR to Far IR			×		
	Large Field-of-View and Effective Area Gamma-Ray Detectors					×
	Low-Power, Low-Cost Semiconductor Detectors					×
	Low-Power Readout for Silicon Photomultipliers					×
	Photometric and Spectro-Photometric Precision of Time-Domain and Time-Series Measurements					×
	Precision Timing Measurement Technology			×		
	Radiation-Tolerant, Photon-Counting Light Detectors		×			
	Sensitive Spectrometer for CMB Spectrum Measurement				×	
	UV/Optical/Near-IR Tunable Narrowband Imaging Capability	×				
4	Advancement of X-ray Polarimeter Sensitivity	None				
	Detection Stability in Mid-IR	None				

Current COR Technology Portfolio

Program	Project Title	PI Name	PI Inst	Technology Area	Signal Type
SAT2021	Development of a 30 mK ultra-low temperature Continuous ADR with a continuous 700 mK intermediate stage for heat intercept	Kimball, M	GSFC	Cooling System	X Ray, Far IR, Sub-mm
SAT2021	Ultrasensitive Far-IR Kinetic Inductance Detector Arrays: Maturation for Flight	Bradford, C	JPL	Detector	Far IR
SAT2021	Demonstrating Large Low Noise Transition Edge Sensor Arrays for Future FIR Space Missions	Staguhn, J	JHU	Detector	Far IR
SAT2021	Ultra-stable Telescope Metrology Development for High-contrast Exoplanet Detection	Saif, B	GSFC	Metrology	UVOIR
SAT2021	Ultraviolet Spectroscopy for the Next Decade Enabled Through Nanofabrication Techniques	McEntaffer, R	PSU	Optics	UVOIR
SAT2022	Scalable Microshutter Systems for Multi-object Spectroscopy	Scowen, P	GSFC	Optics	UVOIR
SAT2021	Advanced Al mirrors with passivated LiF for environmentally stable 1-meter class UV space telescopes	Quijada, M	GSFC	Optical Coating	UVOIR
ISFM22	UV/Optical to Far-IR Mirror & Telescope Technology Development	Stahl, H P	MSFC	Optics	UVOIR
SAT2022	Four megapixel sensor for ultra-low-background shortwave infrared astronomy	Bottom, M	UH	Detector	Near-IR
SAT2021	High Performance FUV, NUV, and UV/Optical CMOS Imagers	Hoenk, M	JPL	Detector	UV
SAT2021	Large Format, High Efficiency, UV/Optical/NIR Photon Counting Detectors	Nikzad, S	JPL	Detector	UVOIR
SAT2021	Advancing Readout of Large-Format Far-IR Transition-Edge Sensor Arrays	Rostem, K	GSFC	Electronics	Far IR
SAT22	Characterizing Single-photon Sensing CMOS Image Sensors for NASA Missions	Figer, D	RIT	Detector	VIS
ISFM22	NASA Ames Laboratory Astrophysics Directed Work Package (LADWP) Round 2 ISFM	Sciamma-O'Brien, E	Ames	Lab Astrophysics	UV, IR, VIS
SAT22	Ultrasensitive Far-IR Kinetic Inductance Detector Arrays for Space	Hailey-Dunsheath, S	Caltech	Detector	Far IR
SAT22	Far-IR Detector Solutions for Low Noise, Large Format, Direct Absorption Kinetic Inductance Detector Arrays	Austermann, J	NIST	Detector	Far IR
SAT22	A High-Performance Ultraviolet Photon Counting Detector for Strategic Astrophysics Missions	Nikzad, S	JPL	Detector	UV
RTF23	The Advanced Astrophysics Spectroscopy Lab at LASP	Vorobiev, D	LASP	Facilities & Optics	UV
RTF23	Advancing & Qualifying UV Space Technology & Instrumentation	Hoadley, K	Univ of Iowa	Lab Characterization	UV
SAT23	Single-photon counting with SiSeRO to search for Earth-like planets	Estrada, J	U. of Chicago	Electronics	UVOIR
SAT23	Large-area ALD-protected aluminum mirror coatings for HWO	Hennessy, J	JPL	Coatings	UV
SAT23	Development of space-qualified signal-processing readout electronics for HWO and Origins Space Telescope detector arrays	Jamison-Hooks, T	ASU	Electronics	UVOIR and Far-IR
SAT23	New techniques toward the nanofabrication of custom, blazed UV gratings to enable next-generation spectroscopy	Miles, D	Caltech	Optics	UV
SAT23	PHANTOM: Precision High-strain composites (HSCs) for AstroNomical Telescope OptoMechanics	Silver, M	MIT/LL	Structures	UVOIR
RTF24	Building the Foundations for Huge-N Lunar Radio Interferometry	Pober, J	Brown	Software	CMB
RTF24	Development of a Low EMI and Acoustic Background Characterization Testbed for Ultra-low Noise Transition Edge Sensor Bolometers	Connors, J	GSFC	Detectors	Far-IR
RTF24	Supporting technologies for large-scale kinetic inductance current sensor readouts	Szypryt, P	Colorado	Electronics	Visible, Near IR
RTF24	Build and Commission a new Space Optics Laboratory (SOL) at UMass Lowell	Mendillo, C	Umass Lowell	Facilities	UVOIR
CT4LT	STABLE: Systems Technologies for Architecture Baseline	Glassman, T	NG	Structures	UVOIR
CT4LT	TechMAST: Technology Maturation for Astrophysics Space Telescopes	Carrier, A	LM	Modeling	UVOIR

Current PhysCOS Technology Portfolio

Funding Program	Project Title	PI Name	PI Inst	Technology Area	Signal Type
ISFM22	Advanced X-ray Microcalorimeters Sub-package #3: Magnetically Coupled Calorimeters	Bandler, Simon	GSFC	Detector	X Ray
SAT2021	Extremely Low-noise, High Frame-rate X-ray Image Sensors for Strategic Astrophysics Missions	Bautz, Mark	MIT	Detector	X-ray
SAT2021	Microwave SQUID readout technology development for future X-ray astrophysics missions	Bennett, Douglas	NIST	Electronics	X Ray
RTF24	Flex Modules for manufacturable high-resolution X-ray telescope optics	Chalifoux, Brandon	ASU	Opto-mechanical Processes	X Ray
RTF23	Rapid EBL Patterning for Customized Reflection Gratings	DeRoo, Casey	Univ of Iowa	Optics	X Ray, UV
ISFM22	MSFC Advanced X-Ray Optics: Formulation to Flight	Gaskins, Jessica	MSFC	Optics, coatings, metrology, facilities	X-ray
SAT22	Optimized Soft X-ray Sensors for Strategic X-ray Astrophysics Missions: Achieving TRL 5	Leitz, Christopher	MIT/LL	Detector	X-ray
ISFM22	Advanced X-ray Microcalorimeters Sub-package #2: Laboratory Spectroscopy	Porter, Scott	GSFC	Laboratory Astrophysics	X Ray
ISFM22	General Coordinates Network	Racusin, Judith	GSFC	Software	TDAMM
SAT23	Technology development for a high-resolving-power X-ray spectrometer	Schattenburg, Mark	MIT	Optics	X-ray
ISFM22	Advanced X-Ray Microcalorimeters Sub-package #1: Transition-Edge Sensor (TES)	Smith, Stephen	GSFC	Detector	X Ray
ISFM22	MSFC Relativistic Astrophysics – Multi-messenger Astrophysics Community Tools and Support	Wilson-Hodge, Colleen	MSFC	Software	TDAMM
ISFM22	Next-Generation X-ray Optics: High Resolution, Light Weight, and Low Cost	Zhang, William	GSFC	Optics	X Ray