Linking Strategic Astrophysics Missions, Technology Gaps, and Technology Maturation Investments

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What We'll Cover Today

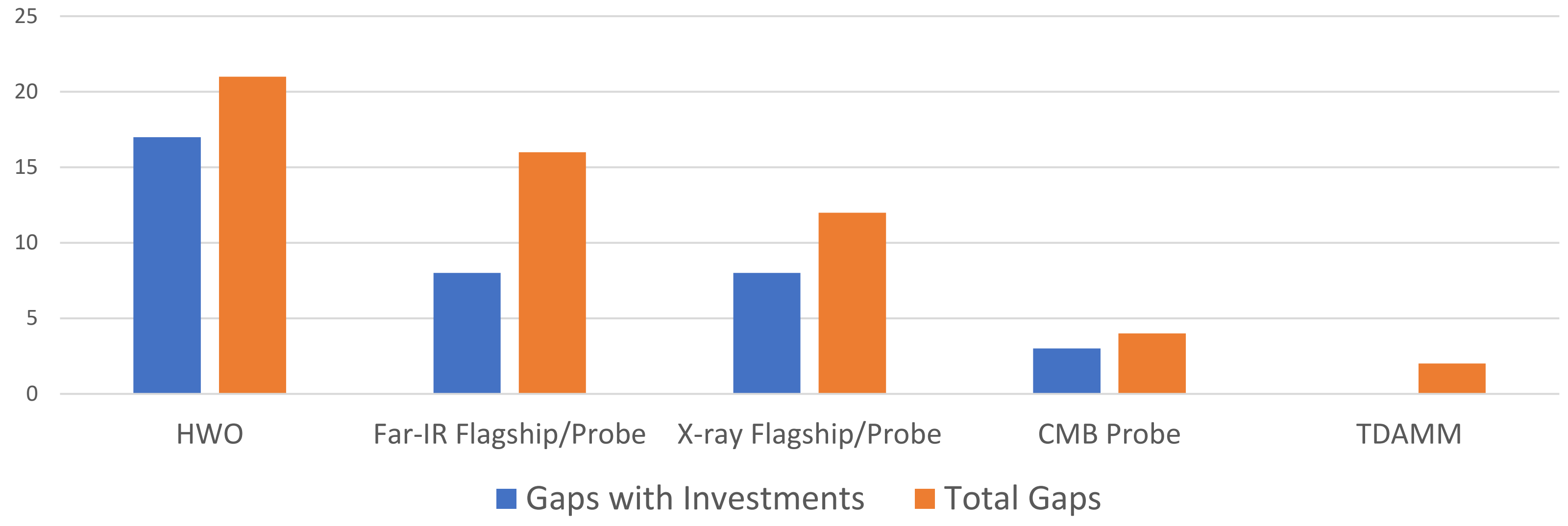
- Strategic Astrophysics missions/activities vs. technology gaps vs. APD technology maturation investments (over 12 months since funding start)
- Technology maturation project stats
- Investments by technology type and mission/activity affected
- Technology Readiness Level (TRL) advances
- Technology infusions

Strategic Missions/Activities vs. 2022 Tech Gaps vs. Technology Maturation Investments

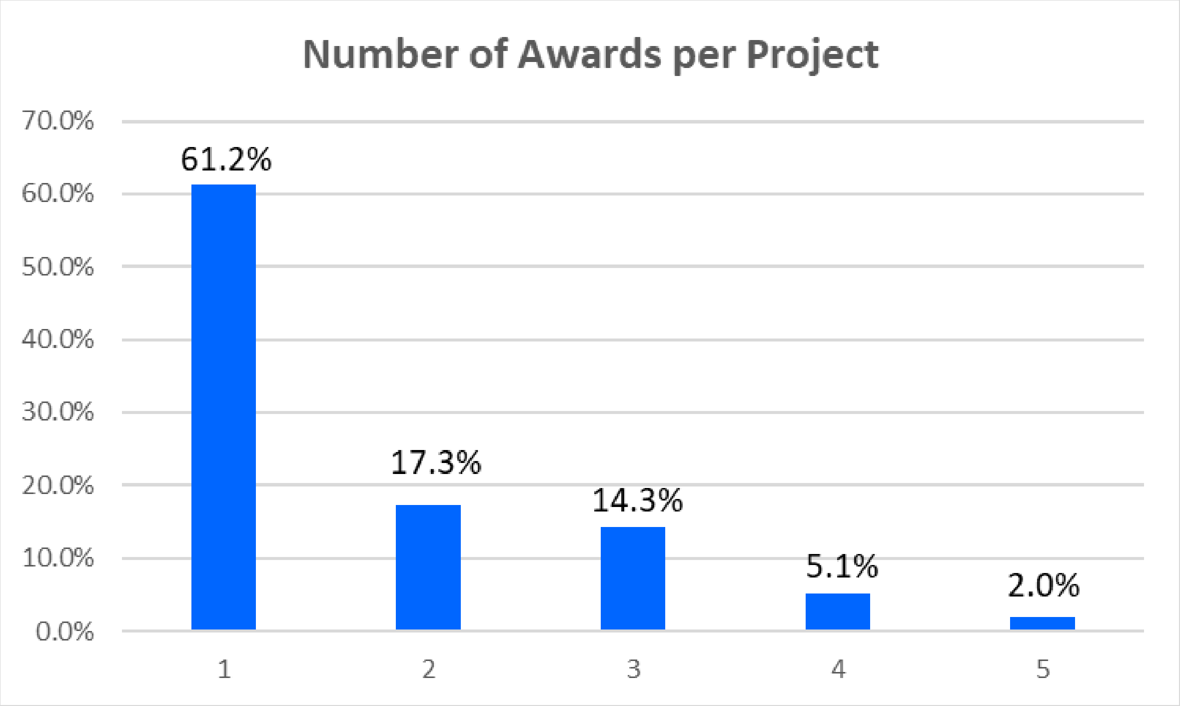
Strategic Mission/Activity	Gaps w/Investments (all Tiers)	Tier 1	Tier 2	Tier 3	Tier 4
Habitable Worlds Observatory (HWO)	17 of 21	9 of 11	3 of 3	5 of 6	0 of 1
Far-IR Flagship/Probe	8 of 16	5 of 6	1 of 8	2 of 2	No gaps
X-ray Flagship/Probe	8 of 12	3 of 5	5 of 5	0 of 1	0 of 1
Cosmic Microwave Background (CMB) Probe	3 of 4	2 of 2	0 of 1	No gaps	1 of 1
Time Domain and Multi-Messenger Astrophysics (TDAMM)	0 of 2	No gaps	No gaps	No gaps	0 of 2
Total (excl. mission overlaps)	**33 of 49**	**16 of 20**	**9 of 16**	**7 of 9**	**1 of 4**
	67%	**80%**	**56%**	**78%**	**25%**

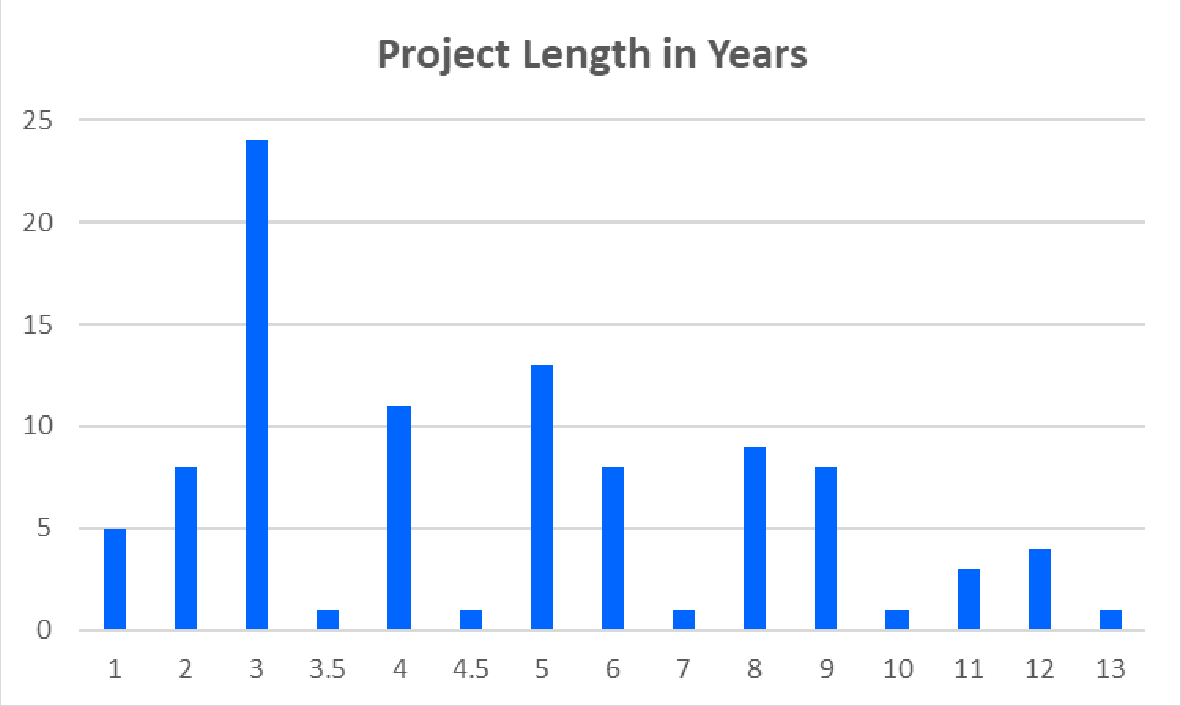
In 2022

Tech gaps assessed: 57
Tier 1: 20
Tier 2: 16
Tier 3: 9
Tier 4: 4
Tier 5 (non-strategic): 8



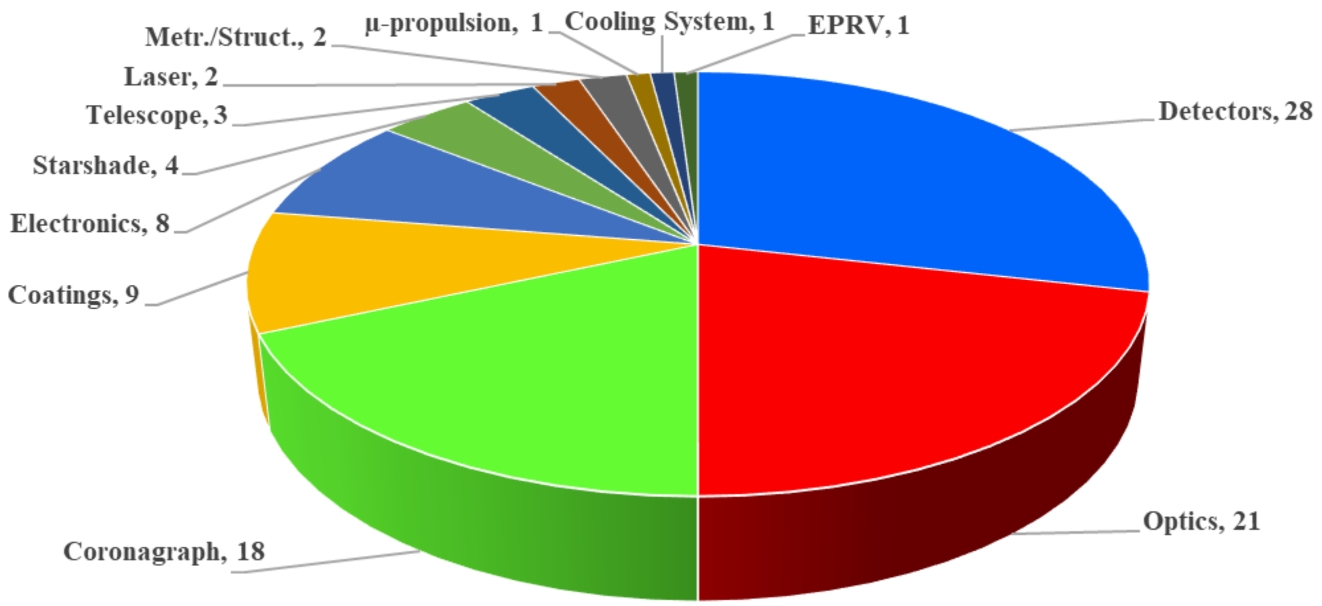
Technology Maturation Project Stats





- Most technology projects received one funding cycle while others received up to five (average was 1.7 awards)
- Project durations varied from one year to 13 (mode was three years, median five years, and average 5.2 years)

Technology Types and Missions Affected



Project distribution by technology type

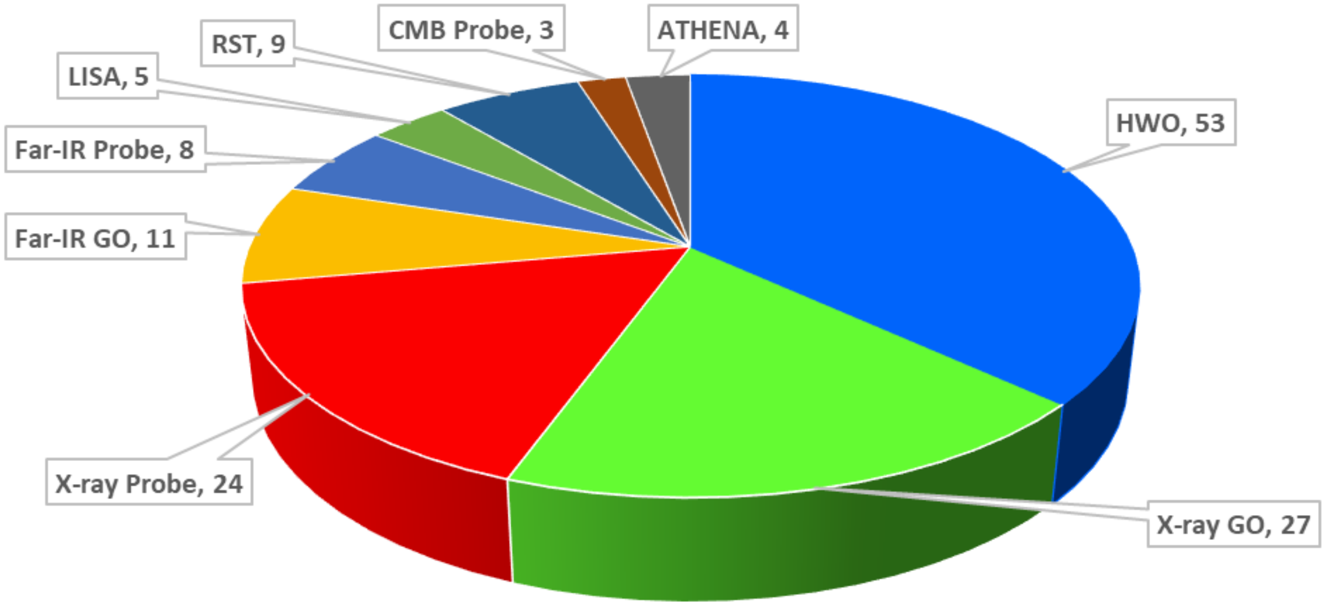
Detectors:	28	(29%)
Optics:	21	(21%)
Coronagraphs:	18	(18%)
Coatings:	9	(9%)
Electronics:	8	(8%)
Starshade:	4	(4%)
Telescopes:	3	(3%)
Lasers:	2	(2%)
Metr./Strct.:	2	(2%)
µ-Propulsion:	1	(1%)
Cooling Sys.:	1	(1%)
EPRV:	1	(1%)

68% (Detectors, Optics, Coronagraphs)

86% (Detectors through Electronics)

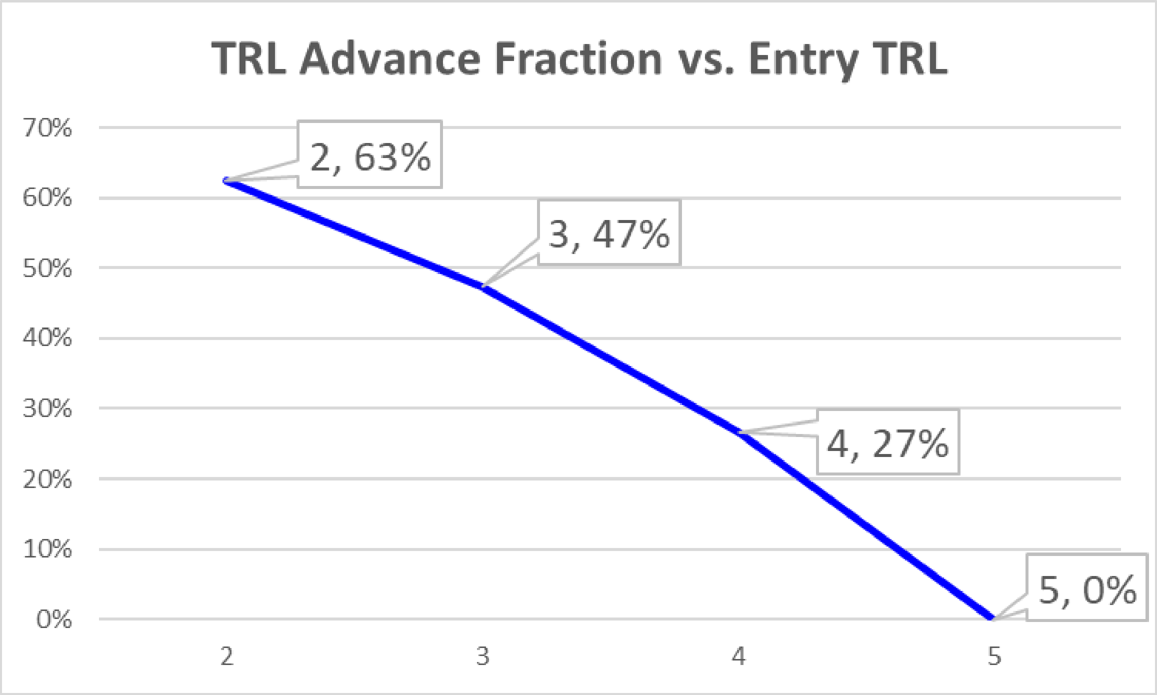
9	Roman Space Telescope (RST)
4	Advanced Telescope for High-ENergy Astrophysics (ATHENA)
24	X-ray Probe
8	Far-IR Probe
5	Laser Interferometer Space Antenna (LISA)
3	CMB Probe
53	HWO
27	X-ray Great Observatory (GO)
11	Far-IR GO

Distribution of strategic missions affected (including duplicates)



Technology Readiness Level (TRL) Advances

Entry TRL	Number of Projects	Number Advancing	Fraction Advancing
2	8	5	63%
3	74	35	47 %
4	15	4	27 %
5	1	0	0 %
Total	**98**	**44**	**45%**



Note: Projects without TRL advances still made significant progress, but missed at least one criterion for the next TRL

Technology Infusions

		Space	Rocket	Balloon	Airborne	Ground	Total	
Infused	Implemented	19	15	11	3	45	**93**	Flown, deployed, or implemented
	Upcoming	31	19	8	1	6	**65**	Baselined or in progress
Infused Subtotal		50	34	19	4	51	158	

		Space	Rocket	Balloon	Airborne	Ground	Total	
Potential	Concepts	60	-	-	-	-	**60**	Baselined by APD-funded studies
	Ready	3	-	-	-	-	**3**	At TRL 5 but not infused yet
Potential Subtotal		63	-	-	-	-	63	
Infused/Infusable Total		113	34	19	4	51	221	

- 42 of 98 projects (43%) accounted for 99 unique technologies being infused into 106 unique missions/projects
- An Aerospace Corporation study found that 62% of APD-funded technology projects (including all APRA technology projects) led to infusions

Summary

- NASA APD invested hundreds of millions of dollars to date toward maturing strategic technologies:
  - Investments toward closing 33 of 49 technology gaps (67%), mostly Tier 1-3
  - Investments toward closing 17 of 21 HWO-relevant gaps (81%), 8 of 16 Far-IR GO/Probe gaps (50%), 8 of 12 X-ray GO/Probe gaps (67%), and 3 of 4 CMB Probe gaps (75%)
- These investments have led to:
  - 166 awards grouped into 98 unique technology maturation projects (5.2-year average project duration)
  - 44 of 98 projects (45%) advanced technologies by at least one TRL (12 advanced by two levels)
  - 42 of 98 projects (43%) led to infusion of 99 unique technologies into 106 unique missions/projects
- Investments addressed detectors (28 projects), optics (21), coronagraphs (18), coatings (9), electronics (8), starshade (4), and other technologies (10)
- Investments impact RST (9 projects), ATHENA (4), X-ray Probe (24), Far-IR Probe (8), LISA (5), CMB Probe (3), HWO (53), X-ray GO (27), and Far-IR GO (11) (w/overlap by approximate launch order)
- Ongoing investments will continue maturing and infusing technologies, enabling and enhancing strategic (and other) Astrophysics missions, as well as other missions and projects
- APD also funds technology development and testing facility development and upgrades

Backup

2022 Tech Gaps vs. Strategic Missions/Activities Tier 1

Tier	Technology Gap	HWO	X-ray GO/Probe	Far-IR GO/Probe	CMB Probe	TDAMM
1	Advanced Cryocoolers		×	×		
	Coronagraph Contrast and Efficiency	×				
	Coronagraph Stability	×				
	Cryogenic Readouts for Large-Format Far-IR Detectors			×	×	
	Heterodyne Far-IR Detector Systems			×		
	High-Throughput Large-Format Object Sel. Tech for Multi-Object & Integ. Field Spectroscopy	×				
	High-Performance, Sub-Kelvin Coolers		×	×	×	
	High-Reflectivity Broadband FUV-to-NIR Mirror Coatings	×				
	High-Resolution, Large-Area, Lightweight X-Ray Optics		×			
	High-Throughput Bandpass Selection for UV/VIS	×				
	Large Cryogenic Optics for the Mid IR to Far IR			×		
	Large-Format, High-Resolution Focal Plane Arrays	×				
	Large-Format, Low-Darkrate, High Eff., Photon-Counting, Solar-blind, Far- & Near-UV Detectors	×				
	Large-Format, Low-Noise and Ultralow-Noise Far-IR Direct Detectors			×		
	Low-stress, High-Stability, X-Ray Reflective Coatings		×			
	Mirror Technologies for High Angular Resolution in the UV/Vis/NIR	×				
	Optical Blocking Filters for X-ray Instruments		×			
	Stellar Reflex Motion Sensitivity: Extreme Precision Radial Velocity (EPRV)	×				
	Stellar Reflex Motion Sensitivity: Astrometry	×				
	Vis/NIR Detection Sensitivity	×				

2022 Tech Gaps vs. Strategic Missions/Activities Tier 2

Tier	Technology Gap	HWO	X-ray GO/Probe	Far-IR GO/Probe	CMB Probe	TDAMM
2	Broadband X-Ray Detectors		×			
	Compact, Integrated Spectrometers for 100 to 1000 μm			×		
	Far-IR Imaging Interferometer for High-Resolution Spectroscopy			×		
	Far-IR Spatio-Spectral Interferometry			×		
	Fast, Low-Noise, Megapixel X-Ray Imaging Arrays with Moderate Spectral Resolution		×			
	High-Efficiency X-Ray Grating Arrays for High-Resolution Spectroscopy		×			
	High-resolution Direct-Detection Spectrometers for Far-IR Wavelengths			×		
	Improving the Calibration of Far-IR Heterodyne Measurements			×		
	Large-Aperture Deployable Antennas for FIR/THz/Sub-mm Astr. for Freq's >100 GHz			×		
	Large-Format, High-Spectral-Resolution, Small-Pixel X-Ray Focal-Plane Arrays		×			
	Polarization-Preserving Millimeter-Wave Optical Elements			×	×	
	Precision Timing for Space-Based Astrophysics			×		
	Rapid Readout Electronics for X-Ray Detectors		×			
	Starshade Deployment and Shape Stability	×				
	Starshade Starlight Suppression and Model Validation	×				
	UV Detection Sensitivity	×				

2022 Tech Gaps vs. Strategic Missions/Activities Tiers 3 – 5

Tier	Technology Gap	HWO	X-ray GO/Probe	Far-IR GO/Probe	CMB Probe	TDAMM
3	Advancement of X-Ray Polarimeter Sensitivity		×			
3	Detection Stability in the Mid-IR			×		
3	Far-UV Imaging Bandpass Filters	×				
3	High Efficiency Far-UV Mirror	×				
3	High-Eff. Low-Scatter, High- & Low-Ruling-Density, High- & Low-Blaze-Angle UV Gratings	×				
3	High-QE, Solar-Blind, Broadband NUV Detector	×				
3	Photon-Counting, Large-Format UV Detectors	×				
3	Short-Wave UV Coatings	×				
3	Warm Readout Electronics for Large-Format Far-IR Detectors			×		
4	Advanced Millimeter-Wave Focal-Plane Arrays for CMB Polarimetry				×	
4	Improving Photometric/Spectrophotometric Precision of Time-Domain & Time-Series Measur.					×
4	UV/Optical/NIR Tunable Narrow-Band Imaging Capability	×				
4	Very-Wide-Field Focusing Instrument for Time-Domain X-Ray Astronomy		×			×
5	Complex ultra-stable structures for future GW missions	None				
5	Disturbance Reduction for GW Missions	None				
5	Gravitational Reference Sensor (GRS)	None				
5	High-Performance Spectral Dispersion Component/Device	None				
5	High-Power, High-Stability Laser for GW Missions	None				
5	Laser Phase Measurement Chain for a Decihertz GW Mission	None				
5	Micro-Newton Thrusters for GW Missions	None				
5	Stable Telescopes for GW Missions	None				

Current COR Strategic Technology Portfolio

Project Title	PI	PI Org	Tech Type
Low-Noise, Large-Format, Direct-Absorption Far-IR KID Arrays	Austermann, J	NIST	Detector
Four Megapixel Sensor for Ultra-Low-Background Shortwave IR Astronomy	Bottom, M	U Hawaii	Detector
Ultrasensitive Far-IR KID Arrays: Maturation for Flight	Bradford, CM	JPL	Detector
Characterizing Single-Photon Sensing CMOS Image Sensors for NASA Missions	Figer, D	RIT	Detector
Ultrasensitive Far-IR KID Arrays for Space	Hailey-Dunsheath, S	Caltech	Detector
High Performance, Stable, and Scalable UV Al Mirror Coatings Using ALD	Hennessy, J	JPL	Coating
High-Performance FUV, NUV, and UV/Optical CMOS Imagers	Hoenk, M	JPL	Detector
High-Eff. Continuous Cooling for Cryogenic Instruments and sub-Kelvin Detectors	Kimball, M	GSFC	Cooling Sys.
UV Spectroscopy for the Next Decade Through Nanofabrication Techniques	McEntaffer, R	PSU	Optics
High-Perf. UV Photon Counting Detector for Strategic Astrophysics Missions	Nikzad, S	JPL	Detector
Large Format, High Efficiency, UV/Optical/NIR Photon Counting Detectors	Nikzad, S	JPL	Detector
Adv. Al Mirrors w/Passivated LiF for Env. Stable Meter-Class UV Space Telescopes	Quijada, M	GSFC	Coating
Advancing Readout of Large-Format Far-IR TES Arrays	Rostem, K	GSFC	Electronics
Scalable Microshutter Systems for Multi-object Spectroscopy	Scowen, P	GSFC	Optics
Large Low Noise Transition Edge Sensor Arrays for Future FIR Space Missions	Staguhn, J	JHU	Detector
Ultra-Stable Structures Dev. & Characterization Using Spatial Dynamic Metrology	Saif, B	GSFC	Metr./Struct.
UV/Optical to Far-IR Mirror & Telescope Technology Development	Stahl, HP	MSFC	Optics
Large-Format, High-Dyn.-Range UV Detector Using MCPs & Timepix4 Readouts	Vallerga, J	UCB	Detector

Detectors:	9
Optics:	3
Coatings:	2
Electronics:	1
Cooling Sys.:	1
Metr./Strct.:	1

Acronyms: PI, Principal Investigator; KID, Kinetic Inductance Detector; NIST, National Institute of Standards and Technology; IR, Infrared; NIR, Near Infrared; LmAPD, Linear-mode Avalanche Photodiode; JPL, Jet Propulsion Lab; CMOS, Complementary Metal-Oxide Semiconductor; RIT, Rochester Institute of Technology; Caltech, California Institute of Technology; ALD, Atomic Layer Deposition; FUV, Far UV; NUV, Near UV; GSFC, Goddard Spaceflight Center; TES, Transition-Edge Sensor; JHU, Johns Hopkins University; MSFC, Marshall Spaceflight Center; MCP, Multi-Channel Plate; UCB, University of California Berkeley.

Current ExEP Strategic Technology Portfolio

Title	PI	PI Org	Tech Type
Development of a Method for Exoplanet Imaging in Multi-Star Systems	Belikov, R	ARC	Coronagraph
High Contrast w/Phase-Induced Amplitude Apodization Complex Mask Coronagraph on a Segmented Aperture	Belikov, R	ARC	Coronagraph
Laboratory Demonstration of Multi-Star Wavefront Control in Vacuum	Belikov, R	ARC	Coronagraph
Starshade Large-Structure Precision Deployment and Stability	Aaron, K	JPL	Starshade
Starshade Starlight Suppression	Aaron, K	JPL	Starshade
Adaptive High-Order Wavefront Control Algorithms for High-Contrast Imaging on the Decadal Survey Testbed	Cahoy, K	MIT	Coronagraph
Segmented Coronagraph Design and Analysis study	Chen, P	JPL	Coronagraph
Linear Wavefront Control for High-Contrast Imaging	Guyon, O	U Arizona	Coronagraph
Robust Deep-Contrast Imaging with Self-Calibrating Coronagraph Systems	Guyon, O	U Arizona	Coronagraph
Colloid Thruster Life Testing and Modeling	Marrese-Reading, C	JPL	µ-Propulsion
Optimal Spectrograph and Wavefront Control Architectures for High-Contrast Exoplanet Characterization	Mawet, D	Caltech	Coronagraph
Radiation-Tolerant, Photon-Counting, Vis/Near-IR Detectors for Coronagraphs and Starshades	Rauscher, B	GSFC	Detector
Laboratory Demonstrations of High Contrast with Black Si Coronagraph Masks	Riggs, AJ	JPL	Coronagraph
Vortex Coronagraph High-Contrast Demonstrations	Serabyn, E	JPL	Coronagraph
System-level Demonstration of High Contrast for Segmented Space Telescopes	Soummer, R	STScI	Coronagraph
Ultra-Stable Mid-IR Detector Array for Space-Based Exoplanet Transit Spectroscopy	Staguhn, J	JHU	Detector
Demonstration of Adv. Wavefront Control for Segmented Aperture Telescopes	Tesch, J	JPL	Coronagraph
Super Lyot ExoEarth Coronagraph	Trauger, J	JPL	Coronagraph
Low-Order HW Implementation for Sensing and Control in Exoplanet Imaging	Trauger, J	JPL	Coronagraph
A Novel Optical Etalon for Precision Radial Velocity Measurements	Vasisht, G	JPL	EPRV
Dual-Purpose Coronagraph Masks for Enabling High-Contrast Imaging with an IR/Optical/UV Flagship Mission	Wallace, K	JPL	Coronagraph

Coronagraphs:	15
Starshade:	2
Detectors:	2
µ-Propulsion:	1
EPRV:	1

Acronyms: ARC, Ames Research Center; MIT, Massachusetts Institute of Technology; STScI, Space Telescope Science Institute; HW, Hardware).

Current PhysCOS Strategic Technology Portfolio

Title	PI	PI Org	Tech Type
Magnetically Coupled Calorimeters	Bandler, S	GSFC	Detector
Extremely Low-noise, High Frame-rate X-ray Image Sensors	Bautz, M	MIT	Detector
Microwave SQUID Readout Technology to Enable Lynx and Other GOs	Bennett, D	NIST	Electronics
Mounting and Alignment of Full-Shell X-Ray Mirrors	Bongiorno, S	MSFC	Optics
Metrology Development for Full-Shell X-Ray Mirrors	Davis, J	MSFC	Metr./Struct.
Rapid Electron-Beam Lithography Patterning for Customized Reflection Gratings	DeRoo, C	U Iowa	Optics
Thin Film Coatings for Full-Shell X-Ray Mirrors	Gurgew, D	MSFC	Coating
Advanced Pixelated Si Sensors for the Next Generation of X-ray Observatories	Kenter, A.	SAO	Detector
Polishing Mandrels and Optics for Full-Shell X-Ray Mirrors	Kolodziejczak, J	MSFC	Optics
Optimized Soft X-ray Sensors for Strategic X-ray Astrophysics Missions	Leitz, C	MIT/LL	Detector
High-Sensitivity and High-Resolving-Power X-ray Spectrometer	Schattenburg, M	MIT	Optics
Replication Studies for Full-Shell X-ray Mirrors	Singam, P	MSFC	Optics
Advanced X-Ray Microcalorimeters	Smith, S	GSFC	Detector
Next-Generation X-ray Optics: High Resolution, Light Weight, and Low Cost	Zhang, W	GSFC	Optics

Optics:	6
Detectors:	5
Coating:	1
Electronics:	1
Metr./Strct.:	1

Acronyms: SQUID, Superconducting Quantum Interference Device; SAO, Smithsonian Astrophysical Observatory; LL, Lincoln Laboratory