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

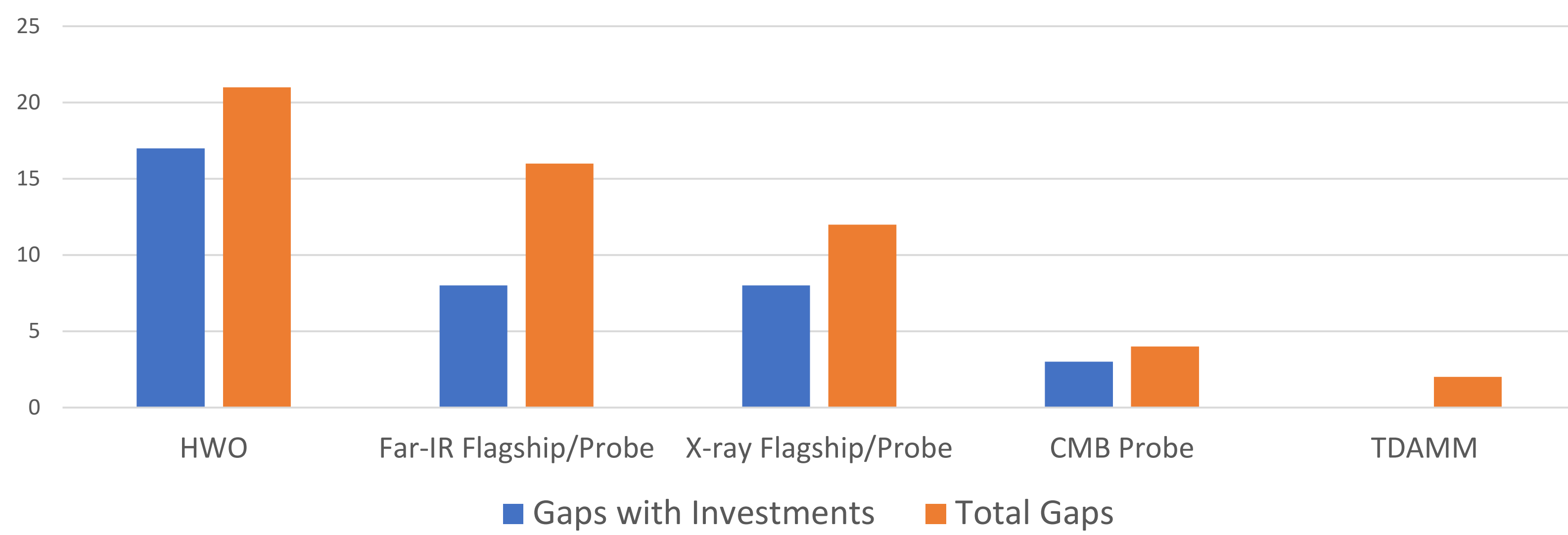
For more information on these and related topics, including a searchable database of APD technology investments, visit https://apd440.gsfc.nasa.gov/tech

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

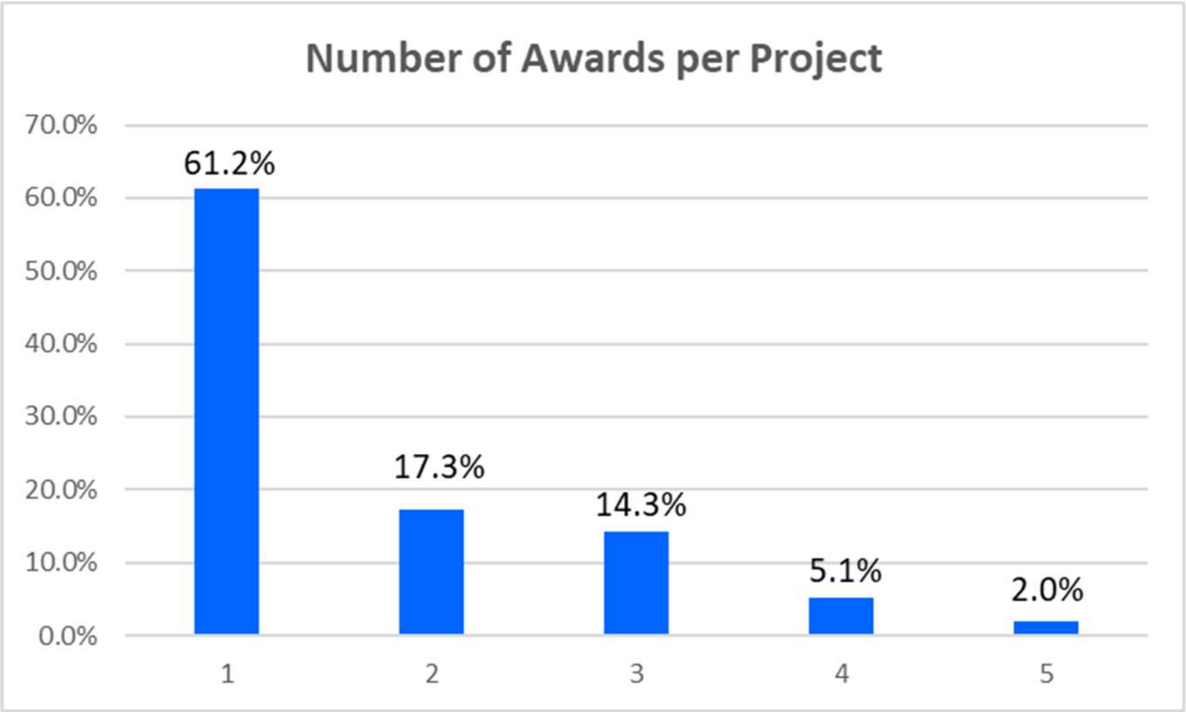
Strategic Mission/Activity	Gaps w/Investments (Tiers 1-4)	Tier 1	Tier 2	Tier 3	Tier 4
Habitable Worlds Observatory (HWO)	17 of 21	9 of 11	3 of 3	5 of 6	0 of 1
Far-IR Flagship/Probe	8 of 16	5 of 6	1 of 8	2 of 2	No gaps
X-ray Flagship/Probe	8 of 12	3 of 5	5 of 5	0 of 1	0 of 1
Cosmic Microwave Background (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%**

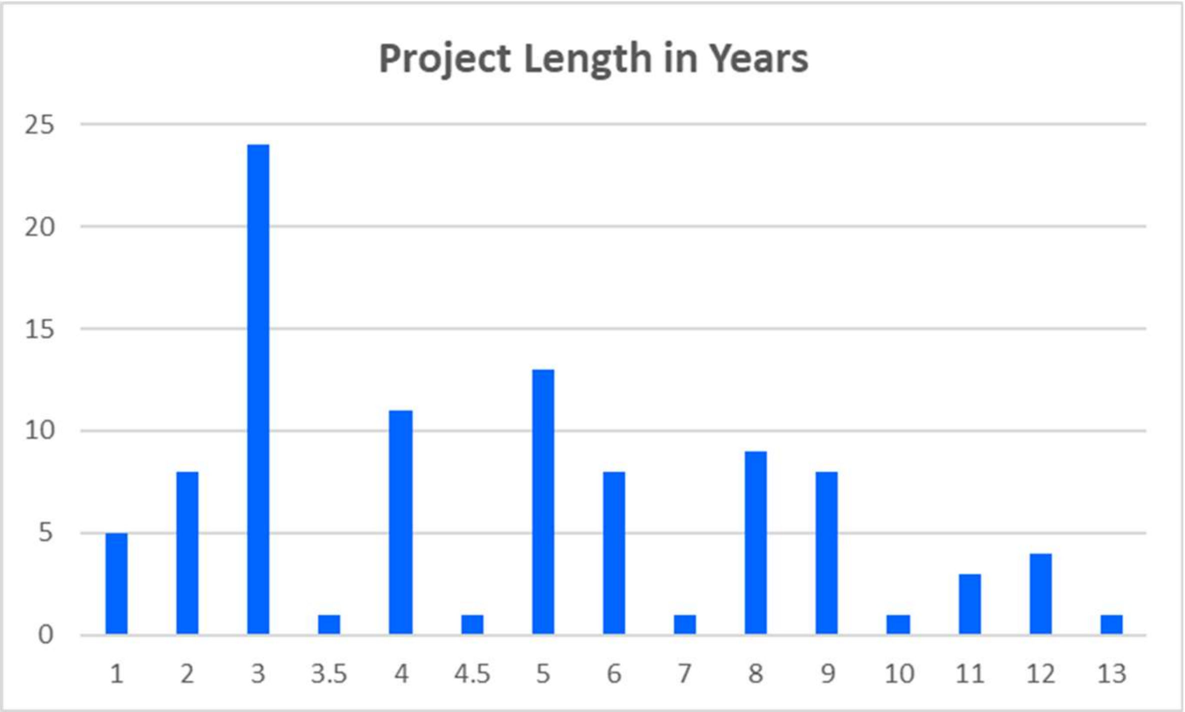
In 2022

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



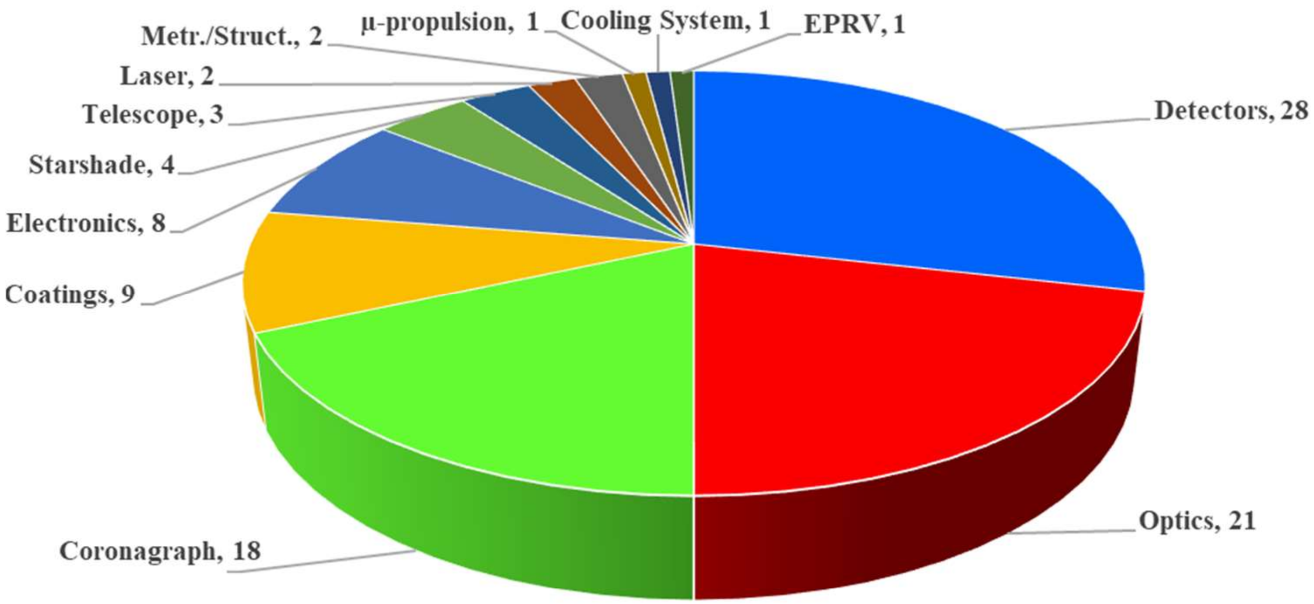
Technology Maturation Project Stats





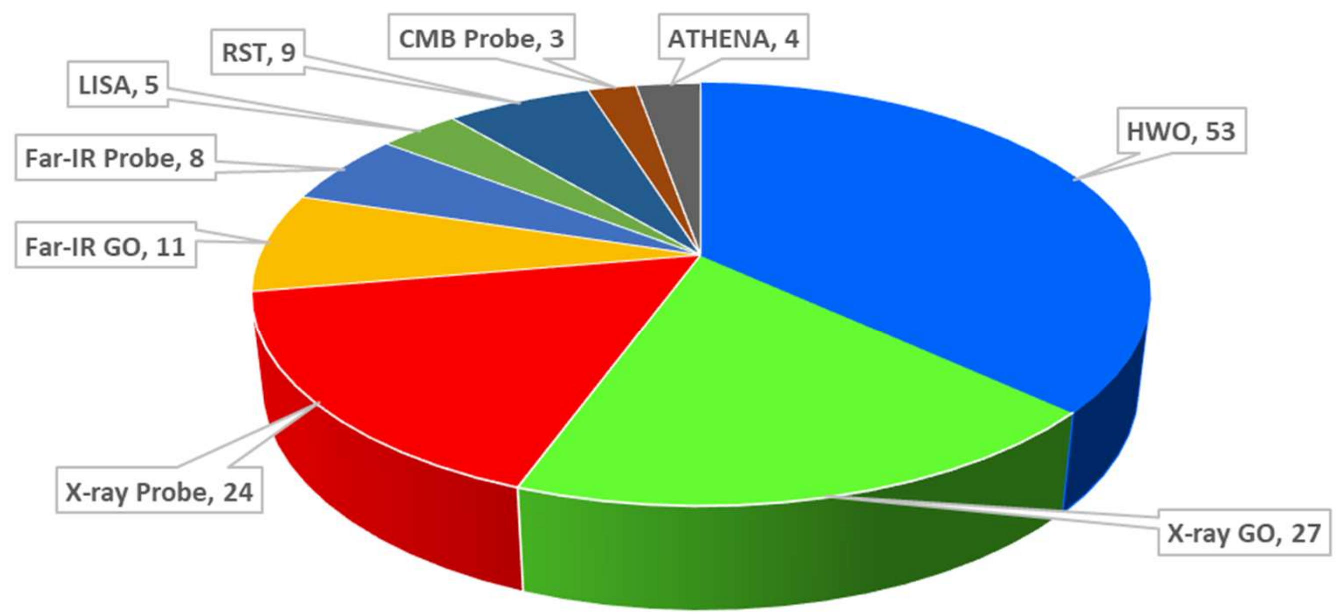
- Most technology projects received one funding cycle while others received up to five (average was 1.7 awards)
- Project durations varied from one year to 13 (mode was three years, median five years, and average 5.2 years)

Technology Types and Missions Affected



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)

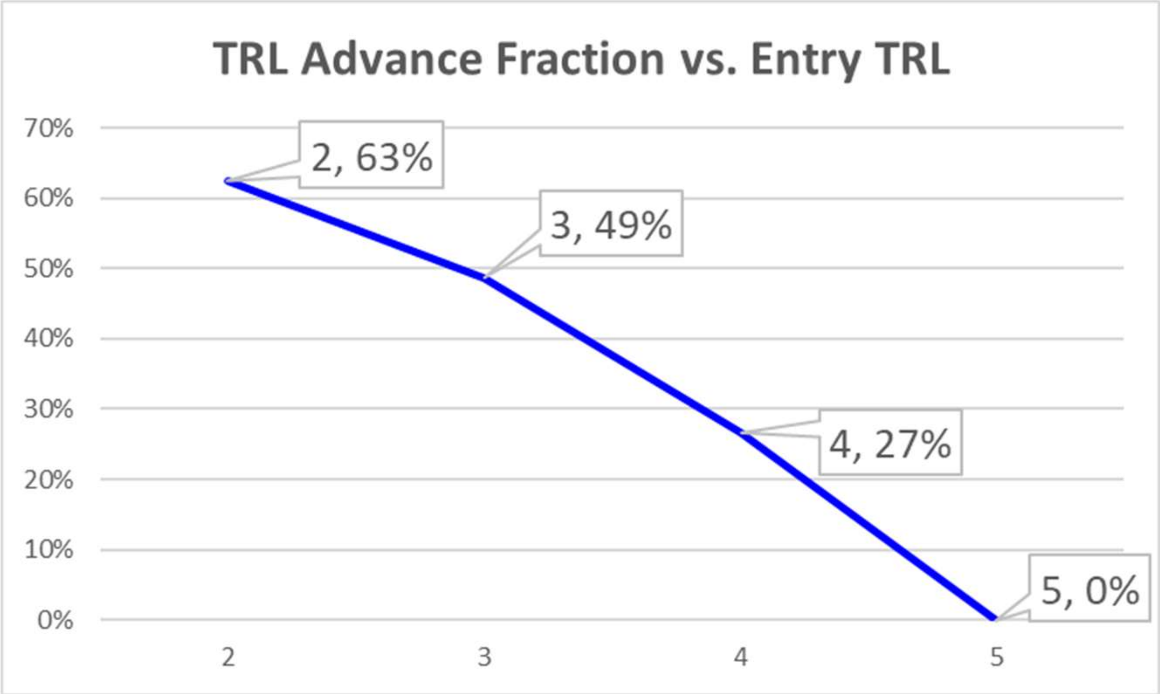


Project distribution by technology type

Detectors:	28	(29%)	68%	86%
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%)		

Technology Readiness Level (TRL) Advances

Entry TRL	Number of Projects	Number Advancing	Fraction Advancing
2	8	5	63%
3	74	36	49 %
4	15	4	27 %
5	1	0	0 %
Total	98	45	46%



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[1]	19	15	11	3	43	**91**	Flown, deployed, or implemented
	Upcoming[2]	31	19	8	1	6	**65**	Baselined or in progress
Infused Subtotal		50	34	19	4	49	156	

Potential	Concepts[3]	62	-	-	-	-	**62**	Baselined by APD-funded studies
	Ready[4]	3	-	-	-	-	**3**	At TRL 5 but not infused yet
Potential Subtotal		65	-	-	-	-	65	
Infused/Infusable Total		115	34	19	4	49	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 over the past 15 years to mature strategic technologies:
  - Investments toward closing 33 of 49 strategic 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%)
  - Later this year, we will publish an update to the Astrophysics Prioritized Technology Gaps List online and in the 2024 Astrophysics Biennial Technology Report (ABTR)
- These investments have led to:
  - 166 awards grouped into 98 unique technology maturation projects (5.2-year average project duration)
  - 45 of 98 projects (46%) 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		×			
	Detection Stability in the Mid-IR			×		
	Far-UV Imaging Bandpass Filters	×				
	High Efficiency Far-UV Mirror	×				
	High-Eff. Low-Scatter, High- & Low-Ruling-Density, High- & Low-Blaze-Angle UV Gratings	×				
	High-QE, Solar-Blind, Broadband NUV Detector	×				
	Photon-Counting, Large-Format UV Detectors	×				
	Short-Wave UV Coatings	×				
	Warm Readout Electronics for Large-Format Far-IR Detectors			×		
4	Advanced Millimeter-Wave Focal-Plane Arrays for CMB Polarimetry				×	
	Improving Photometric/Spectrophotometric Precision of Time-Domain & Time-Series Measur.					×
	UV/Optical/NIR Tunable Narrow-Band Imaging Capability	×				
	Very-Wide-Field Focusing Instrument for Time-Domain X-Ray Astronomy		×			×
5	Complex ultra-stable structures for future GW missions	None				
	Disturbance Reduction for GW Missions					
	Gravitational Reference Sensor (GRS)					
	High-Performance Spectral Dispersion Component/Device					
	High-Power, High-Stability Laser for GW Missions					
	Laser Phase Measurement Chain for a Decihertz GW Mission					
	Micro-Newton Thrusters for GW Missions					
	Stable Telescopes for GW Missions					

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