NASA Strategic Astrophysics Technology Investments: A Decade of Benefits, Outlook Informed by the 2020 Decadal Survey

Opher Ganel*, Rachel Rivera, and Jay Falker (NASA/GSFC)
Nicholas Siegler and Brendan Crill (NASA/JPL)
Mario R. Perez (NASA/HQ)

July 17, 2022

Strategic Astrophysics Missions

- **Strategic Astrophysics missions as recommended by the 2020 Decadal Survey on Astronomy and Astrophysics**
  - IR/O/UV Flagship to be launched in the first half of the 2040s
  - X-ray Flagship to be launched in a later decade than IR/O/UV Flagship
  - Far-IR Flagship to be launched in a later decade than IR/O/UV Flagship
  - X-ray Probe to compete for 2030s launch
  - Far-IR Probe to compete for 2030s launch
  - CMB Probe to compete for 2040s launch vs. above Probe that hasn't launched
  - TDAMM (program recommendation at this point, but missions may be added)

Strategic Astrophysics Technology Development

- **The three Program Offices serve the critical function of developing concepts and technologies for strategic missions and facilitating science investigations derived from them, specifically:**
  - Assess and prioritize technology gaps, collecting inputs from the community and technology activities.
  - Manage projects maturing technologies for strategic missions from TRLs of 3, 4, or 5.
  - Promote infusion of technologies into missions and projects.
  - Conduct mission studies and develop mission concepts enabling future scientific discoveries.
  - Communicate progress to and coordinate with the scientific community.
  - Inform the general public about progress achieved by the Programs.
- **Astrophysics Program Office technology maturation process comprises three cycles**
  - A 10-year Decadal Survey cycle to recommend the highest-priority missions and activities for the coming decade.
  - A biennial technology gap prioritization and Program Office reporting cycle.
  - An annual process of soliciting, reviewing, and funding SAT proposals.

Astrophysics Strategic Technology Portfolio

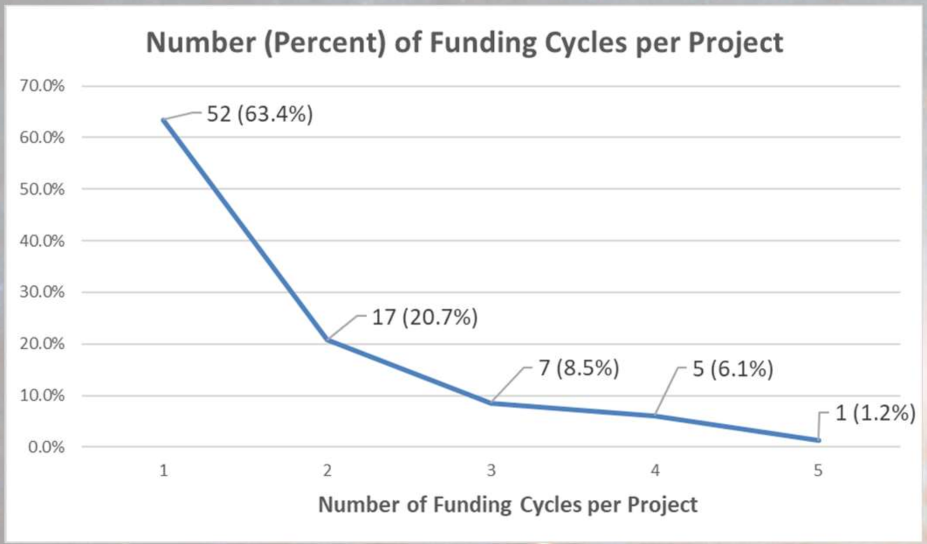
Current COR Technology Development Projects	PI Name	Org.	Tech Area
Photon-Counting NIR LmAPD Arr			
Ultrasensitive Bolometers for Far			
Ultrastable Large Telescope Rese			
A Single-Photon-Sensing and Pho			
Electron Beam Lithography Ruled			
Scalable Micro-Shutter Systems f			
High-Performance, Stable, and Sc			
Development of High-Resolution			
Development of Digital Micromir			
Technology Maturation for Astro			
Electron-Beam Generated Plasma			
Ultra-Stable Structures Developm			
High Performance Sealed Tube C			
Process to Produce Scalable, Sup			
Precision Thermal Control (PTC)			
High-Efficiency Continuous Cooli			
Large-Format, High-Dynamic-Ran			

Current ExEP Technology Development Projects	PI Name	Org.	Tech Area
Development of a Method for Exop			
Laboratory Demonstration of High			
Laboratory Demonstration of Multi			
MEMS Deformable Mirror Technolo			
Segmented Coronagraph Design an			
Linear Wavefront Control for High-			
Optimal Spectrograph and Wavefro			
Radiation-Tolerant, Photon-Countin			
Broadband Light Rejection with the			
Vortex Coronagraph High-Contrast			
First System-level Demonstration o			
Ultra-Stable Mid-Infrared Detector			
Super Lyot ExoEarth Coronagraph			
A Novel Optical Etalon for Precision			
Starshade Large-Structure Precision			
Starshade Starlight Suppression			

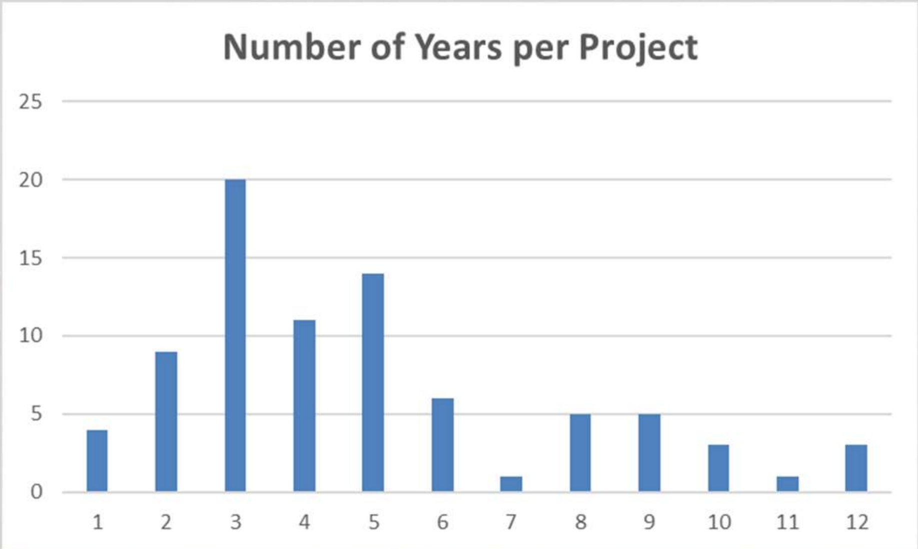
Current PCOS Technology Development Projects	PI Name	Org.	Tech Area
Advanced X-ray Microcalorimeters: Magnetically Coupled Calorimeters	Bandler, Simon	GSFC	Detector
High-Speed, Low-Noise, Radiation-Tolerant CCD Image Sensors	Bautz, Mark	MIT	Detector
Microwave SQUID Readout to Enable Lynx and Other Future Observatories	Bennett, Douglas	NIST	Electronics
Direct Fabrication of Full-Shell X-ray Optics	Bongiorno, Stephen	MSFC	Optics
Hybrid X-ray Optics by Additive Manufacturing	Broadway, David	MSFC	Optics
Low-Stress Mirror Coatings for X-ray Optics	Broadway, David	MSFC	Opt. Coatings
UV-LED-Based Charge Management System	Conklin, John	UF	Electronics
Computer-Controlled Polishing of High-Quality X-ray Optics Mandrels	Davis, Jacqueline	MSFC	Optics
High-Density Readout Technology for Superconducting Sensor Arrays for Spaceflight	Frisch, Josef	SLAC	Electronics
Differential Deposition for Figure Correction in X-ray Optics	Kilaru, Kiran	MSFC	Optics
Advanced TES Microcalorimeters	Kilbourne, Caroline	GSFC	Detector
Enabling and Enhancing Technologies for ATHENA X-IFU Demonstration Model	Kilbourne, Caroline	GSFC	Detector
Advancing the Focal Plane TRL for LiteBIRD and Other Next-Generation CMB Missions	Lee, Adrian	UCB	Detector
Telescopes for Space-Based Gravitational-Wave Observatories	Livas, Jeffrey	GSFC	Telescope
Development of RFSoC-Based Readout Electronics	Mauskopf, Philip	ASU	Electronics
Superconducting Antenna-Coupled Detectors for CMB Polarimetry	O'Brient, Roger	JPL	Detector
Advanced X-ray Microcalorimeters: Lab Spectroscopy for Space Atomic Physics	Porter, Scott	GSFC	Detector
X-ray Testing and Calibration	Ramsey, Brian	MSFC	Optics
Development of Adjustable X-ray Optics with 0.5 Arcsecond Resolution	Reid, Paul	SAO	Optics
High Resolution High Efficiency X-ray Transmission Grating Spectrometer	Schattenburg, Mark	MIT	Optics
Manufacturability & Alignment of X-ray Gratings and Optics for Space Applications	Smith, Randall	SAO	Optics
Phase Measurement System for Interferometric Gravitational Wave Detectors	Ware, Brent	JPL	Electronics
Space-based Gravitational Wave Laser Technology Development for the LISA Mission	Yu, Anthony	GSFC	Laser
Next Generation X-ray Optics	Zhang, William	GSFC	Optics
LISA Colloid Microthruster Technology	Ziemer, John	JPL	Micropropulsion

Note that this does not include APRA and RTF projects, which are not strategic.

Technology Development Projects' Length

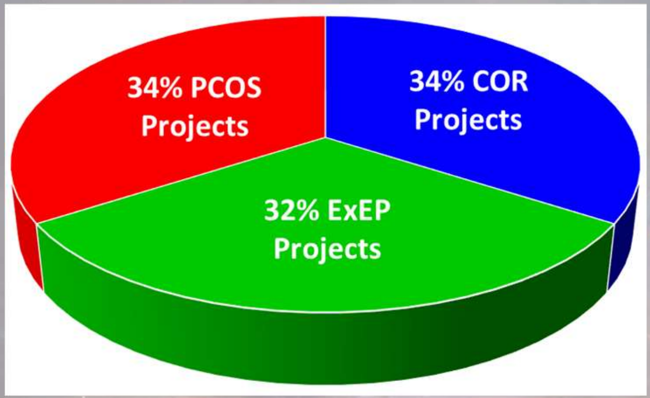


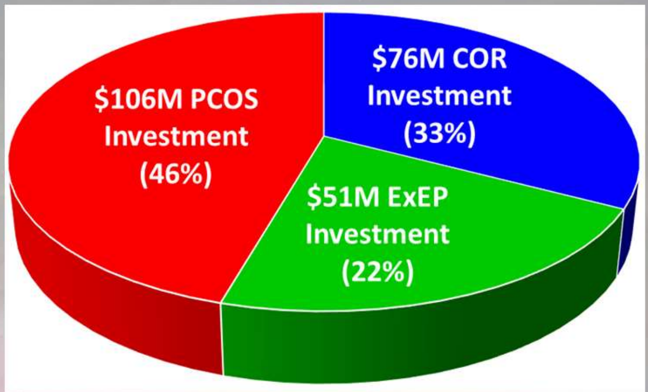
Number of funding cycles per project, with 30 projects extending 1–4 additional cycles.



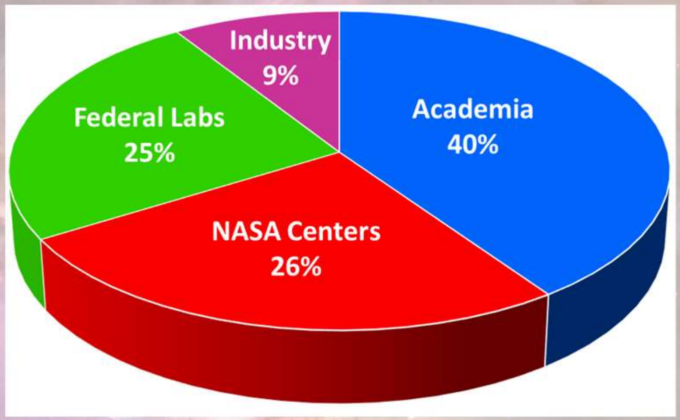
Distribution of projects by total length in years, including any follow-on cycles.

Technology Development Projects by Program and Org Type



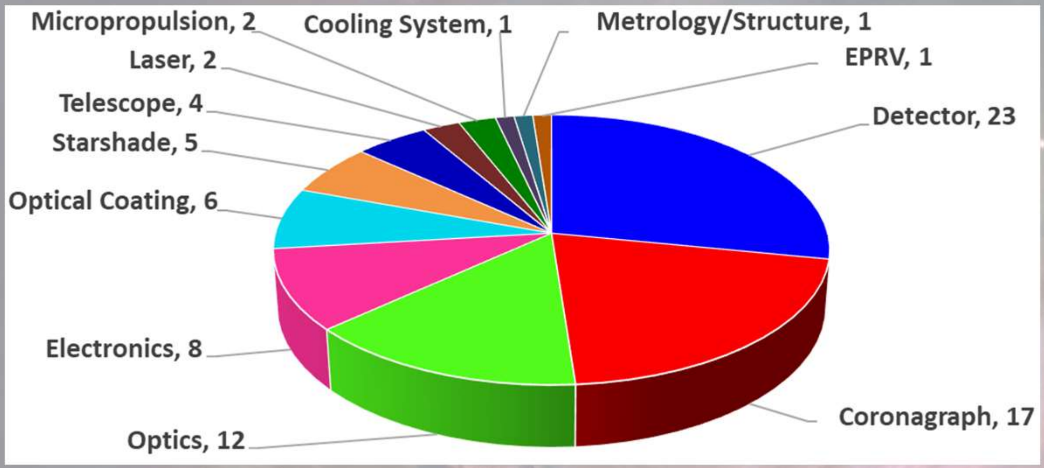


Technology development by Program since 2009: number of projects (left), and total investment (right).



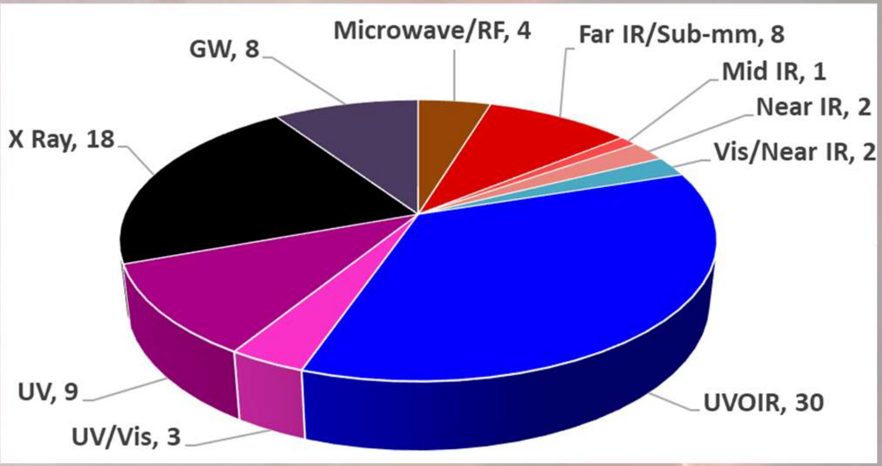
Distribution institutional types receiving awards for strategic technology developments.

Technology Development Projects by Technology Area and Signal Type

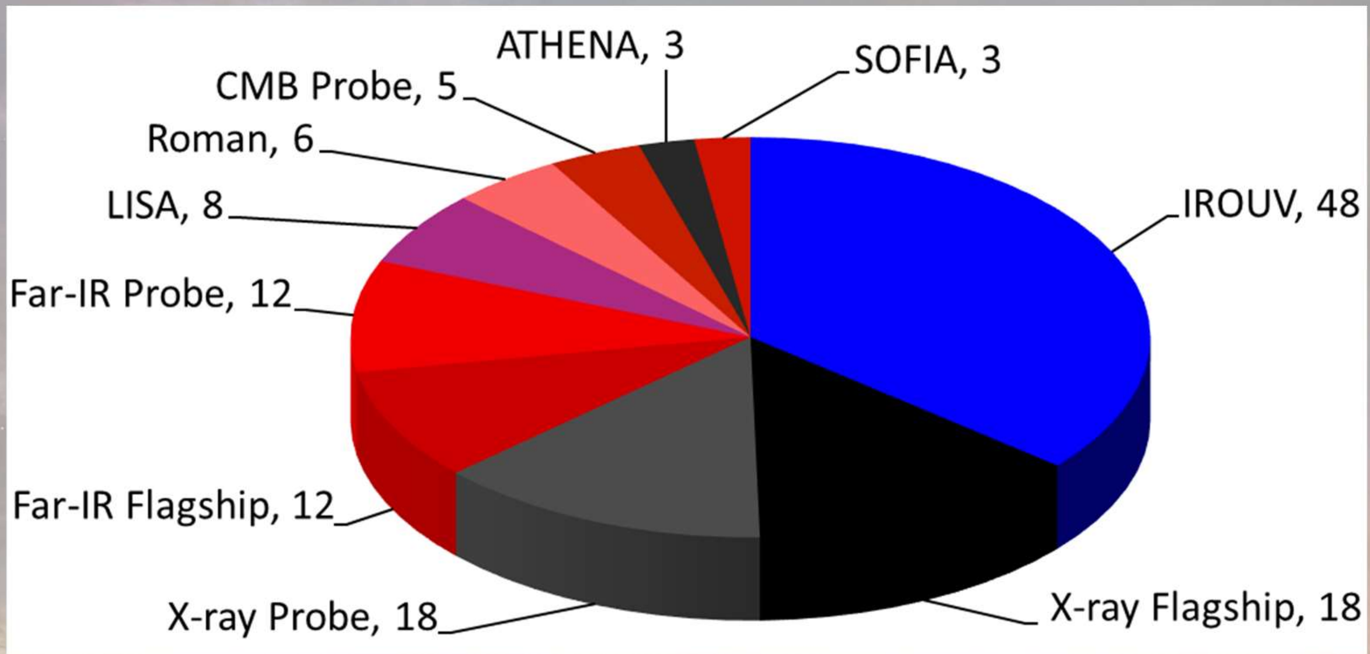


Distribution of the 82 projects in the strategic technology portfolio by topic.

Distribution of the 82 projects in the strategic technology portfolio by signal type

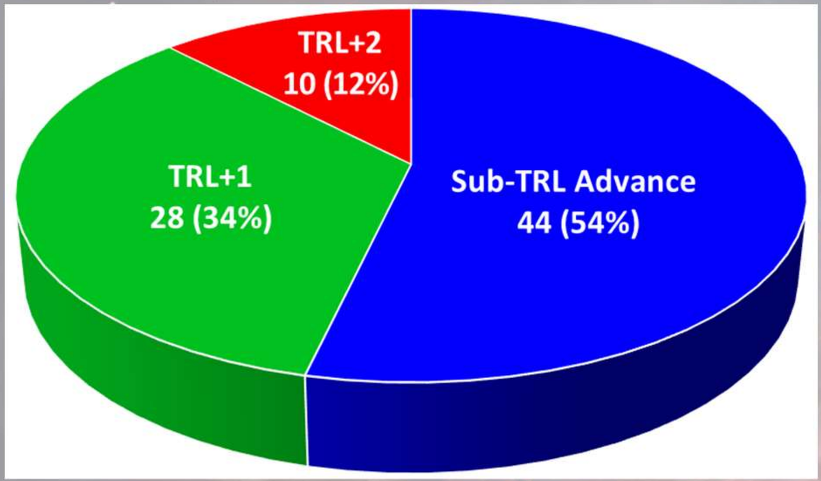


Technology Development Projects by Strategic Mission Supported

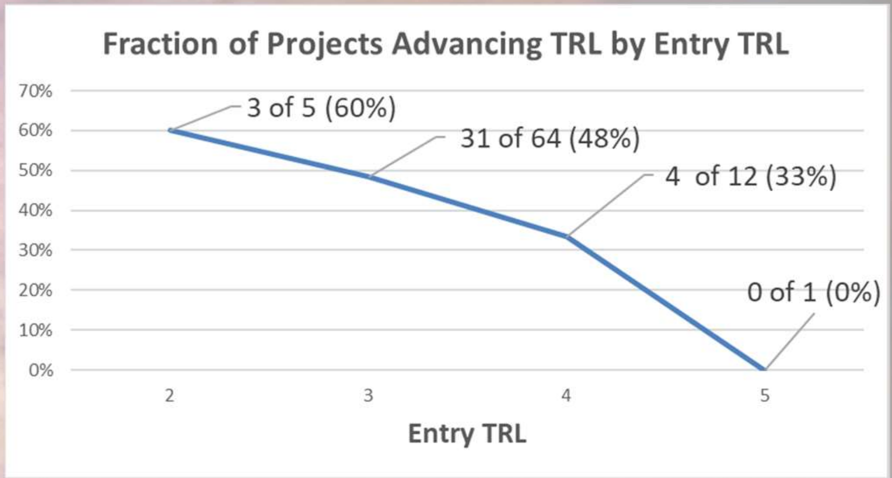


Distribution of the 82 projects in the strategic technology portfolio by strategic mission(s) supported. Note that many projects support multiple missions, so the total is greater than 82.

Technology Readiness Level (TRL) Advancements



Distribution of TRL advancement (while in the program) for strategic technology development projects. Some continue advancing in TRL after project completion, especially those infused into spaceflight projects.



Percentage of technology development projects achieving TRL advancement vs. TRL_{in}. Not shown in the graph, nine of 31 projects advancing from TRL_{in} of 3 advanced by two levels, to 5.

Technology Infusions

	Space	Rocket	Balloon	Airborne	Ground	Total
Implemented	8	14	8	2	25	**57**
Upcoming	21	14	5	1	15	**56**
Concepts	61	-	-	-	-	**61**
Total	**90**	**28**	**13**	**3**	**40**	**174**

Summary of infusions, already implemented/upcoming/conceptual by mission/project type.
(Implemented = in existing/past mission/project; Upcoming = selected by mission/project in development; Concepts = baselined by reference design of strategic mission)

Discipline	Space	Rocket	Balloon	Airborne	Ground	Total
Astrophysics	22	15	10	1	23	**71**
Planetary	4	1	-	-	-	**5**
Heliophysics	4	3	-	-	-	**7**
Earth Science	3	-	-	-	-	**3**
Other	-	-	-	1	1	**2**
Total	**33**	**19**	**10**	**2**	**24**	**88**

Summary of missions/projects infused into, by discipline and type.

Astrophysics Technology Gaps

- **Technology gaps are what separates the current state of the art (SOTA) from what's needed to enable and/or enhance future strategic missions**
- **Technology gap entries need to:**
  - Focus on strategic Astrophysics missions
  - Be directly applicable to Program objectives
  - Require technology development (i.e., TRL < 6 for stated requirements)
  - Describe gap between SOTA and what's required for targeted science objective
- **Technology gaps entries should not:**
  - Be outside our purview (e.g., for launch vehicles, spacecraft systems, etc.)
  - Be a specific solution, or advocate for one

Strategic Technology Gap Priorities – Tier 1

1. Advanced Cryocoolers
2. Coronagraph Contrast and Efficiency
3. Coronagraph Stability
4. Cryogenic Readouts for Large-Format Far-IR Detectors
5. Heterodyne Far-IR Detector Systems
6. High-Performance, Sub-Kelvin Coolers
7. High-Reflectivity Broadband Far-UV-to-Near-IR Mirror Coatings
8. High-Resolution, Large-Area, Lightweight X-ray Optics
9. High-Throughput Bandpass Selection for UV/VIS
10. High-Throughput, Large-Format Object Selection Technologies for Multi-Object and Integral Field Spectroscopy
11. Large Cryogenic Optics for the Mid IR to Far IR
12. Large-Format, High-Resolution Focal Plane Arrays
13. Large-Format, Low-Darkrate, High-Efficiency, Photon-Counting, Solar-blind, Far- and Near-UV Detectors
14. Large-Format, Low-Noise and Ultralow-Noise Far-IR Direct Detectors
15. Long-Wavelength-Blocking Filters for X-ray Micro-Calorimeters
16. Low-Stress, High-Stability, X-ray Reflective Coatings
17. Mirror Technologies for High Angular Resolution (UV/Vis/Near IR)
18. Stellar Reflex Motion Sensitivity – Astrometry
19. Stellar Reflex Motion Sensitivity – Extreme Precision Radial Velocity
20. Vis/Near-IR Detection Sensitivity

Strategic Technology Gap Priorities – Tier 2

1. Broadband X-ray Detectors
2. Compact, Integrated Spectrometers for 100 to 1000 µm
3. Far-IR Imaging Interferometer for High-Resolution Spectroscopy
4. Far-IR Spatio-Spectral Interferometry
5. Fast, Low-Noise, Megapixel X-ray Imaging Arrays with Moderate Spectral Resolution
6. High-Efficiency X-ray Grating Arrays for High-Resolution Spectroscopy
7. High-Resolution, Direct-Detection Spectrometers for Far-IR Wavelengths
8. Improving the Calibration of Far-IR Heterodyne Measurements
9. Large-Aperture Deployable Antennas for Far-IR/THz/sub-mm Astronomy for Frequencies over 100 GHz
10. Large-Format, High-Spectral-Resolution, Small-Pixel X-ray Focal-Plane Arrays
11. Polarization-Preserving Millimeter-Wave Optical Elements
12. Precision Timing for Space-Based Astrophysics
13. Rapid Readout Electronics for X-ray Detectors
14. Starshade Deployment and Shape Stability
15. Starshade Starlight Suppression and Model Validation
16. UV Detection Sensitivity

Strategic Technology Gap Priorities – Tiers 3 to 5

Tier 3:
1. Advancement of X-ray Polarimeter Sensitivity
2. Detection Stability in Mid-IR
3. Far-UV Imaging Bandpass Filters
4. High-Efficiency Far-UV Mirror
5. High-Efficiency, Low-Scatter, High- and Low-Ruling-Density, High- and Low-Blazed-Angle UV Gratings
6. High-Quantum-Efficiency, Solar-Blind, Broadband Near-UV Detector
7. Photon-Counting, Large-Format UV Detectors
8. Short-Wave UV Coatings
9. Warm Readout Electronics for Large-Format Far-IR Detectors

Tier 4:
1. Advanced Millimeter-Wave Focal-Plane Arrays for CMB Polarimetry
2. Improving Photometric and Spectro-Photometric Precision of Time-Domain and Time-Series Measurements
3. UV/Opt/Near-IR Tunable Narrow-Band Imaging Capability
4. Very-Wide-Field Focusing Instrument for Time-Domain X-ray Astronomy

Tier 5:
1. Complex Ultra-Stable Structures for Future Gravitational-Wave Missions
2. Disturbance Reduction for Gravitational-Wave Missions
3. Gravitational Reference Sensor
4. High-Performance Spectral Dispersion Component/Device
5. High-Power, High-Stability Laser for Gravitational-Wave Missions
6. Laser Phase Measurement Chain for a Decihertz Gravitational-Wave Mission
7. Micro-Newton Thrusters for Gravitational Wave-Missions
8. Stable Telescopes for Gravitational Wave-Missions

What do These Priorities Mean?

- **The technology gap list informs SAT solicitation and selections; historically the focus has been on the first two priority tiers**
- **However, gaps in lower tiers are not ignored**
  - Technologies that address any gap, whether solicited in SAT or not, may fit in APRA
  - Gaps in lower tiers have at times moved to higher tiers in later cycles (a new Astrophysics Implementation Plan, AIP, is expected to be released by the end of 2022, and will inform the next cycle)
  - Astrophysics Division may decide to direct-fund technologies they deem important enough after considering programmatic aspects and technology strategy for the future great observatories

Gaps by Program & Mission Supported

Program	Tier 1	Tier 2	Tier 3	Tier 4	Tier 5	Total	2019
COR	11	7	7	2	1	**28**	23
ExEP	6	3	1	0	0	**10**	12
PCOS	3	6	1	2	7	**19**	13
Total	**20**	**16**	**9**	**4**	**8**	**57**	**48**

Mission	Tier 1	Tier 2	Tier 3	Tier 4	Tier 5	Total
IROUV	11	3	6	1		**21**
Far-IR Flagship	6	8	2			**16**
X-ray Flagship	3	5	1			**9**
Far-IR Probe	6	8	2			**16**
X-ray Probe	3	5	1	1		**10**
CMB Probe				1		**2**
TDAMM				2		**2**
None					8	**8**
Total	**29**	**30**	**12**	**5**	**8**	**84**

Many gaps affect multiple missions, so the total is greater than 57.

How Can You Participate?

- **If you're from a US institution, you can propose to any of the following opportunities:**
  - APRA (https://nspires.nasaprs.com/external/solicitations/summary.do?solId={8378F31B-1E87-B357-98A2-9E4237B0F1FB}&path=&method=init)
  - SAT (https://nspires.nasaprs.com/external/solicitations/summary.do?solId={14958525-AA09-111E-59C2-5BBF6585F7AA}&path=&method=init)
  - RTF (https://nspires.nasaprs.com/external/solicitations/summary.do?solId={1EF0CA93-73C0-F40B-CE95-96647D403CA6}&path=&method=init)
  - FINESST (https://nspires.nasaprs.com/external/solicitations/summary!init.do?solId=%7b87947100-56AE-C4DC-C511-0349862D658A%7d&path=open)
- **Important Due Dates for APRA and SAT**
  - Mandatory Notice of Intent (NOI) is due by October 21, 2022
  - Proposals are due by December 15, 2022

Resources

- Decadal Survey: https://www.nationalacademies.org/our-work/decadal-survey-on-astronomy-and-astrophysics-2020-astro2020
- ABTR: https://apd440.gsfc.nasa.gov/images/tech/2022_ABTR.pdf
- Tech gap list: https://apd440.gsfc.nasa.gov/tech_gap_priorities.html
- Tech gaps details: https://apd440.gsfc.nasa.gov/tech_gap-descriptions.html