

Name of technology	High QE, low noise, large-format UV photon counting detectors	UV coatings	Large, low-cost, light-weight precision mirrors for Ultra-Stable Large Aperture UV/Optical Telescopes	Large format, low noise Far-IR direct detectors	Large, cryogenic far-IR telescopes	Sub-Kelvin Coolers
Brief description (1024)	Future NASA UV missions, particularly those devoted to spectroscopy, require high quantum efficiency (>50%), low noise (<1e-7 ct/pixel/s), large-format (>2k x 2k) photon-counting detectors	High reflectivity, highly uniform UV coatings are required to support the next generation of UV missions, including explorers, medium missions, and a UV/optical large mission. High reflectivity coatings allow multiple reflections, extended bandpasses, and accommodate combined UV and high-contrast exoplanet imaging objectives.	Future UV/Optical telescopes will require increasingly large apertures to answer the questions raised by HST, JWST, Planck and Herschel, and to complement the ≥ 30 -m ground-based telescopes that will be coming on line in the next decade. For diffraction limited performance, the pointing budget gets tighter as aperture grows and wavelengths shrink, requiring $\theta \sim 0.1 \lambda/D$ pointing accuracy. Technologies are therefore required that provide a high degree of thermal and dynamic stability, and wave front sensing and control	Future NASA Far-IR missions require large format detectors optimized for the very low photon backgrounds present in space. Arrays containing up to tens of thousands of pixels are needed to take full advantage of the focal plane available on a large, cryogenic telescope. Detector sensitivity is required to achieve background-limited performance, using direct (incoherent) detectors to avoid quantum-limited sensitivity.	Large telescopes provide both light gathering power, to see the faintest targets, and spatial resolution, to see the most detail and reduce source confusion. To achieve the ultimate sensitivity, their emission must be minimized, which requires that these telescopes be operated at temperatures that, depending on the application, have to be as low as 4K. Collecting areas on the order of 10m are needed.	Optics and detectors for far-IR and certain X-ray missions require very low temperatures of operation, typically well below 1K. Compact, low-power, lightweight coolers suitable for space flight are needed to provide this cooling..
TABS category	8.1.1	8.1.3	8.1.3	8.1.1	8.1.3	8.1.3
Goals and Objectives	The goal is to produce large-format, high QE, low-noise UV-sensitive detectors routinely that can be employed in a variety of explorer, medium, and strategic missions.	Development of UV coatings with high reflectivity (>90-95%), high uniformity (<1-0.1%), and wide bandpasses (~100 nm to 300-1000 nm). New coating technologies such as Atomic Layer Deposition are particularly promising. Some will be required for large optics (0.5-4m), many for smaller instrument optical elements.	Develop lightweight UV and optical mirrors with Areal density <20kg/m ² , surface roughness 5 to 10 nm rms, cost <\$2M/m ² , for telescopes with > 50 m ² aperture, <1 mas pointing accuracy, and < 15 nm rms stability	Detector sensitivities with noise equivalent powers of 10 ⁻¹⁹ W/√Hz are needed for photometry, and $\approx 3 \cdot 10^{-21}$ W/√Hz are needed for spectroscopy.	The goal is to develop a feasible and affordable approach to producing a 10m-class telescope with sufficiently high specific stiffness, strength, and low areal density to be launched, while maintaining compatibility with cryogenic cooling and far-IR surface quality/figure of $\sim 1 \mu\text{m}$ RMS.	A cryocooler operating from a base temperature of $\sim 4\text{K}$ and cooling to <0.1K with a continuous heat lift of 10 μW is required for several mission concepts. Features such as compactness, low power, low vibration, intermediate cooling and other impact-reducing design aspects are desired.
TRL	Silicon-CCD detectors are TRL4-5. Other technologies are TRL2-4.	Depending on the coating and approach these range from TRL3-5.	Lightweight 1.3-m Be and SiC mirrors are TRL 6. Borosilicate glass mirrors are TRL 5. Larger mirrors are TRL 2-3	Single detectors are approaching TRL4, but demonstrated array architectures are lagging at TRL2.	JWST Be mirror segments may meet requirements now, so TRL5 with an extremely expensive technology; TRL3 exists for other materials.	Existing magnetic refrigeration demonstrations have achieved TRL3-4.
Tipping point (100 words or less)	TRL6 with Si-CCD detectors can be achieved in 2-3 years with modest funding investment.	Relatively modest investment can determine the best approaches and scalability of various coatings and coating techniques.	One or more mirror technologies can be matured to meet requirements with reasonable investments in 3-5 years.	TRL4-5 with transition edge sensors could be achieved within 3 years with moderate investment; with MKIDs within 4-5 years.	TRL4 could be achieved within 3 years with modest investments using existing materials.	TRL5 could be achieved within 3 years with modest investments based on existing demonstrating.
NASA capability (100 words or less)	NASA is partnering with industry to produce these detectors.	NASA has capabilities for UV coatings at GSFC and JPL to ~ 10 cm for ALD coating development. Large optics will require more significant investments. NASA-private industry partnerships are possible and likely particular for matured coating techniques.	NASA has the necessary capabilities at GSFC, MSFC and JPL to develop these UV/Optical mirror technologies in partnership with industry	NASA has laboratory fabrication facilities at GSFC and JPL currently working at a low level on these technologies.	NASA has cryogenic mirror testing capabilities at GSFC, MSFC, and JPL; mirror production would likely rely on industry partnerships.	NASA has cryogenic refrigerator fabrication and testing capabilities at GSFC, with some relevant experience at JPL.
Benefit	High performance detectors can increase the science impact of missions by 10-1000.	High coating reflectivity in UV make possible high-performance optical systems that can be highly-multiplexed, significantly increasing the potential impact of future missions. High uniformity will allow a combined general UV/optical and exoplanet imaging mission, which could provide a natural follow-on to JWST.	Low-cost, light-weight optics are required to enable the development of large aperture UV / Optical telescopes in the 2020 decade. Large apertures telescopes are required to provide the spatial resolution and sensitivity needed to follow up on discoveries with the current generation of space telescopes.	Sensitivity reduces observing times from many hours to a few minutes ($\approx 100\times$ improvement), while array format increases areal coverage by a 10x-100x. Overall mapping speed can increase by factors of thousands.	Low-cost, light-weight cryogenic optics are required to enable the development of large aperture far-IR telescopes in the 2020 decade. Large apertures are required to provide the spatial resolution and sensitivity needed to follow up on discoveries with the current generation of space telescopes.	Sub-Kelvin cryocoolers are required to enable the use of far-IR telescopes in the next decade, and are similarly necessary for certain X-ray detectors.
NASA Needs	Current UV detectors obtain ~ 5 -20% QE, require high voltage, and can be difficult to fabricate. The science impact of cost-constrained, aperture-constrained future missions is dramatically improved by reaching near-perfect detector performance. 2010 Astro Decadal survey noted importance of technology development for a future 4-m class UV/optical mission for spectroscopy and imaging. Benefits will also accrue to Planetary, Heliospheric, and Earth missions in the UV band.	2010 Astro Decadal survey noted importance of technology development for a future 4-m class UV/optical mission for spectroscopy and imaging. Benefits will accrue to Planetary, Heliospheric, and Earth missions utilizing the UV band.	This technology is a key enabling technology for NASA's next large UV/Optical mission.	Far-IR detector technology is an enabling aspect of all future far-IR mission concepts, and is essential for future progress. This technology can improve science capability at a fixed cost much more rapidly than larger telescope sizes. However, the development serves Astrophysics almost exclusively (with some impact to Planetary and Earth studies).	This technology is a key enabling technology for any future NASA-built far-IR mission.	This technology is a key enabling technology for any future NASA-built far-IR mission.
Non-NASA but aerospace needs	High performance UV detectors can have numerous aerospace applications, remote-sensing, situational awareness, etc.	UV sensors require high-performance optical systems that benefit greatly from UV coating improvements.	This technology is critically important for many remote sensing missions sponsored by other government agencies	This technology is primarily needed and supported by NASA.	Lightweight telescopes are critically important for remote sensing applications.	This technology is primarily needed and supported by NASA.
Non-aerospace needs	High performance UV detectors may have applications in bio and medical imaging.	Unknown but could be important.	Ground based, airborne, balloon and sounding rocket telescopes could all benefit from this technology	Large format arrays are needed by suborbital astrophysics missions, and similar technologies find application in airport screening devices for DHS.	Ground based, airborne, balloon and sounding rocket telescopes could all benefit from this technology	Ground based, airborne, balloon and sounding rocket telescopes could all benefit from this technology; other laboratory needs could be fulfilled with commercialization.
Technical risk	Technical risk of Si-CCD detectors is low-moderate because of prior investments in Si detector and CCD processing.	Technical risk is low-moderate. Facilities and techniques exist for small optical elements. Moderate risk in scaling to large optics.	Technical risk is moderate because the development effort is an extension of activities currently planned or underway at several government, academic and industrial facilities	Technical risk for individual detectors is low, as the approach is relatively mature. Large format array technologies include integrated readout devices, which have moderate development risk.	Technical risk is low, as development of many other mirror materials leverages large existing investments in industry; NASA needs in the near term can be demonstrated by testing existing technologies.	Technical risk is low, as development leverages previous investments at NASA.
Sequencing/timing	Should come as early as possible since mission definition and capabilities are built around detector performance. There is a clear plan to achieve this technology. Users identified.	Should come as early as possible since mission definition and capabilities are built around coating performance. There is a clear plan to achieve this technology. Users identified.	Should come as early as possible since technology is applicable to small, medium and large missions. By 2020 for the next large UV astrophysics mission.	Should come as early as possible since mission definition and capabilities are built around detector performance. There is a clear plan to achieve this technology. Users identified.	Should come as early as possible since technology is applicable to small, medium and large missions. By 2020 for the next large far-IR astrophysics mission.	Would be beneficial to undertake soon since technology is applicable to small, medium and large missions. By 2020 for the next large far-IR astrophysics mission.
Time and effort	5 year collaboration between NASA, university groups, and industry.	5 year collaboration between NASA, university groups, and industry.	5 year collaboration between NASA, university groups, and industry.	5 year collaboration between NASA, university groups, and other government agencies.	3 year collaboration between NASA and industry.	3 year effort at NASA.