# 2022 Technology Gap List

Extracted from <https://apd440.gsfc.nasa.gov/tech_gap_priorities.html>

## Vis/NIR Detection Sensitivity

### Description

The capability to detect single photons in the Vis and NIR to enable imaging and spectroscopy of Earth-like exoplanets.

### Current State of the Art

Vis: 1k×1k silicon EMCCD detectors provide dark current of 7×10-4 e-/px/sec; CIC of 0.01 e-/px/frame; zero effective read noise (in photon counting mode) after irradiation when cooled to 165.15 K (Roman); 4k×4k EMCCD fabricated but still under development

NIR: HgCdTe photodiode arrays have read noise ≾ 2 e- rms with multiple nondestructive reads; 2k×2k format; dark current < 0.001 e-/s/pix; very radiation tolerant (JWST), high QE down to 750nm;HgCdTe APDs demonstrated dark current ~10–20 e-/s/pix, RN << 1 e- rms and 1k×1k format

Cryogenic superconducting photon-counting, energy-resolving detectors (MKID,TES): 0 read noise/dark current; space radiation tolerance not systematically studied; <1k×1k format

### Performance Goals and Objectives

Near IR (900 nm to 2.5 μm) and visible-band (400-900nm) extremely low noise detectors for exo-Earth spectral characterization with spectrographs or intrinsic energy resolution. NIR Read noise << 1 e- rms, dark current noise < 0.001 e-/pix/s, Vis band read noise < 0.1 e- rms; CIC < 3×1e-3 e-/px/frame; dark current < 1e-4 e-/px/sec , functioning in a space radiation environment over mission lifetime (5-10 years); may need large ≥ 2k×2k format

Sub-gaps that could partially or fully close this gap:

- NIR Low-noise Detector

- UV/VIS Low-noise Detector

- Rad-Hard, High-QE, Energy Resolving, Noiseless Single Photon Detector Arrays for the NIR, VIS, and UV

# Exoplanet Exploration Program Sub-gaps

## NIR Low-Noise Detector

### Description

Low-noise, large-format detectors with high quantum efficiency between 1000 —2000 nm enable high-contrast exoplanet spectroscopy in the NIR. For LUVOIR, operating temperatures above ~70 K are necessary to be consistent with currently anticipated thermal architecture.

### Current State of the Art

HgCdTe photodiode arrays are high-TRL, high performance NIR detectors. Teledyne H4RG-10 detectors have direct heritage to the H4RG detectors baselined on Roman, and H2RG detectors used in JWST. However, for use in a high-contrast coronagraph, it is desirable to reduce read noise and dark current further, if possible.   
  
Roman: H4RG detectors developed for Roman already exhibit exceptionally good noise

performance (single-digit read noise, 1e-3 dark current), as well as large-format tileable arrays. SAPHIRA linear mode avalanche HgCdTe photodiode sensors have demonstrated 0.1 e- rms read noise, 0.02 e-/pix/s dark current, 320 × 255 pixel format. Reference A. Roman Space Telescope WFI: project status reports and review documentation

### Performance Goals and Objectives

Array Format: 4k×4k

Read Noise: < 3 e-

Dark Current: <   1e-3 e-/pix/s

Quantum Efficiency: > 90% over band

Operating Temperature: >70 K

Explore two engineering paths that have been identified to potentially achieve H4RG noise reduction goals: reducing the pixel size (to smaller than 10 mm), and optimizing the readout electronics for lower-noise performance.

Invest in the development of a 1k × 1k HgCdTe APD array and evaluate its noise and sensitivity performance relative to the H4RG. Select a single candidate technology for continued development. Following selection of a NIR detector candidate, continue investment in optimizing detector performance for use with a high-contrast imaging

system. Specific attention should be made to the operational thermal environment that is required to achieve the best performance, and how that thermal environment might be enabled in the context of the overall LUVOIR system.

## UV/Vis Low-Noise Detector

### Description

Low-noise, large-format detectors with high quantum efficiency between the bands 200-525 nm and 500–1030 nm enable high-contrast imaging and spectroscopy. For the LUVOIR visible band (500–1030 nm), emphasis on improved quantum efficiency between 800 and 1000 nm is desired to maximize exoEarth yields.

### Current State of the Art

EMCCDs are being developed for Roman Coronagraph, and can achieve the low read- and dark noise requirements for high-contrast imaging (Nemati 2014). However, radiation exposure reduces the long-term performance of these devices (Nemati et al. 2016). An improvement in quantum efficiency at the red end of the visible spectrum ( 800 —1000 nm) may be needed to enhance exoEarth detection yields. HMCCD should also be developed as a potential alternative. HMCCDs are inherently radiation hard, and do not suffer long-term degradation under continuous exposure. Furthermore, this radiation hardness allows thicker substrates to be used in the devices, improving long-wavelength quantum efficiency.

### Performance Goals and Objectives

Array Format: 4k × 4k (or buttable 1k × 1k )

Read Noise:  << 1 e-

Dark Current: < 3e-5 e-/pix/s

Quantum Efficiency: >80% at all detection wavelengths EMCCD development should be continued in the context of a LUVOIR coronagraph system. Focus on improving radiation tolerance through shielding design and readout electronics optimization,

and on improved red-end quantum efficiency via substrate thickness and optical coatings. Building off current development activities that are already funded, design and fabricate a 1k ×1k pixel HMCCD device and evaluate its noise and sensitivity performance relative to the existing EMCCDs.

Select a single candidate technology for continued development. Incorporate this 1k × 1k candidate into coronagraph testbeds for validation at the system level. Following the candidate down-select, design and fabricate a 4k × 4k device, including all necessary readout electronics. Complete functional, performance, radiation, and environmental qualification testing to achieve a component-level TRL 6.

## Rad-Hard, High-QE, Energy Resolving, Noiseless Single Photon Detector Arrays for the NIR, VIS, and UV

### Description

The search for life on exoplanets via direct imaging is fundamentally photon starved. For context, the median observation time to collect a single exoEarth twin spectra shown in Astro2020 Fig 7.5, (for Signal-to-Noise Ratio (SNR)=8.5, 6.5 m aperture LUVOIR-B) from the biased catalog of exoEarth candidates is  12 years. Collecting the lowest hanging fruit, the bottom 25% (2.5%) of biased catalog distribution still takes 2.5 (0.26) years.Additionally,

most of the mission is spent finding planets and not collecting spectra (2–2.5 years vs 0.5 year). An efficient spectroscopy detection solution is needed to collect spectra during all phases of the mission without penalty and increased spectra collection rate. This calls for rad-hard, ultra-high QE, energyresolving, noiseless single photon detector arrays to provide the increased throughput to find and spectrally characterize rocky Earth-like exoplanets.

Such an approach dramatically increases science yield and the chance of finding, recognizing, and quantifying life—enabling the required statistical significance with a smaller aperture.

### Current State of the Art

Photoconducting detectors are not noiseless (falsely report photons: dark counts, read noise, spurious charge, charge transfer inefficiency, charge trapping, after pulsing), not energy resolving thus requiring dispersive optics to provide spectroscopy.

EMCCDs needs improved radiation hardness, reduced susceptiblity to cosmic ray events. TESs, MKIDs, and Superconducting Tunnel Junction (STJ) detectors are cryogenic energy resolving detectors (up to the Fano noise limit). STJs are difficult to read-out larger arrays whereas TESs and MKIDs use similar multiplexing techniques. TESs have achieved >99% QE narrowband and averaging 97% broadband for VIS and NIR. MKID efficiencies of 70%/40% at 0.4/1 mm.

### Performance Goals and Objectives

Need arrayable rad-hard (no performance degradation in 5+ year mission with margin), high-QE detectors (QE >90% across the whole bandpass), operating in the NIR, VIS, and UV that spectrally resolve targeted life-identifying biosignatures for the specific mission bandpass(es).

NIR (1000–2000 nm), R>200 or fundamental limits,

VIS (515–1030 nm), R>140,

UV (200–500 nm), R>10.