S12.06 Detector Technologies for Ultraviolet (UV), X-Ray, and Gamma-Ray Instruments

Lead Center: JPL

Participating Center(s): GSFC, MSFC

Scope Title: Detectors

Scope Description:

This subtopic covers detector requirements for a broad range of wavelengths from ultraviolet (UV) through to gamma ray for applications in Astrophysics, Earth Science, Heliophysics, and Planetary Science. Requirements across the board are for greater numbers of readout pixels, lower power, faster readout rates, greater quantum efficiency, single photon counting, and enhanced energy resolution. The proposed efforts must be directly linked to a requirement for a NASA mission. These include Explorers, Discovery, Cosmic Origins, Physics of the Cosmos, Solar-Terrestrial Probes, Vision Missions, and Decadal Survey missions. Proposals should reference current NASA missions and mission concepts where relevant. Specific technology areas are:

- Large-format, solid-state single-photon-counting radiation-tolerant detectors in charge-coupled device (CCD) or complementary metal-oxide-semiconductor (CMOS) architecture—including 3D stacked architecture—for astrophysics, planetary, and UV heliophysics missions. Detectors with fast readout that can support high count rates and large incident flux from the extreme UV (EUV) and x-rays for heliophysics applications, especially solar-flare measurements.
- Solid-state detectors with polarization sensitivity relevant to astrophysics as well as planetary and Earth science applications; for example, in spectropolarimetry as well as air quality and aerosol monitoring.
- Solid-state detector arrays (2x128) with high sensitivity from 120 to 350 nm in one semiconductor chip; in particular, higher quantum efficiency (QE) and lower dark current than currently available silicon devices for this wavelength range. The active area of the photodiode should not exceed 40 µm in the 128-element direction, but it can be larger in the cross-array direction. To minimize noise from stray capacitance, the first stage of amplification shall be integrated on the same chip directly adjacent to the photodiode area, in an active pixel sensor configuration with at least three transistors to enable multiplexing between individual pixels. The design shall be amenable to scaling to smaller pixel sizes and larger format two-dimensional arrays in the future.
- UV detectors for O$_3$, NO$_2$, SO$_2$, H$_2$S, and ash detection. Refer to National Research Council’s Earth Science Decadal Survey (2018).
- Supporting technologies that would enable the next-generation x-ray Observatory (Flagship- and Probe-class) that may require the development of x-ray microcalorimeter arrays with much larger field of view, ~10$^5$ to 10$^6$ pixels, of pitch ~25 to 100 µm, and ways to read out the signals. For example, modular
superconducting magnetic shielding is sought that can be extended to enclose a full-scale focal plane array. All joints between segments of the shielding enclosure must also be superconducting. Improved long-wavelength blocking filters are needed for large-area, x-ray microcalorimeters.

- Significant improvement in wide-band-gap semiconductor materials (such as AlGaN, ZnMgO, and SiC), individual detectors, and detector arrays for astrophysics missions and planetary science composition measurements. For example, SiC avalanche photodiodes (APDs) must show:
  - EUV photon counting, a linear mode gain \( >10 \times 10^6 \) at a breakdown reverse voltage between 80 and 100 V.
  - Detection capability of better than 6 photons/pixel/sec down to 135 nm wavelength.

- Solar-blind (visible-blind) UV, far-UV (80 to 200 nm), and EUV sensor technology with high pixel resolution, large format, high sensitivity and high dynamic range, and low voltage and power requirements—with or without photon counting.

- UV detectors suitable for upcoming ultra-high-energy cosmic ray (UHECR) mission concepts.

- Solar x-ray detectors with small independent pixels (10,000 count/sec/pixel) over an energy range from <5 to 300 keV.

- Filters with supporting grids are sought that, in addition to increasing filter strength, also enhance electromagnetic interference (EMI) shielding (1 to 10 GHz) and thermal uniformity for decontamination heating. X-ray transmission of greater than 80% at 600 eV per filter is sought, with infrared transmissions less than 0.01% and UV transmission of less than 5% per filter. A means of producing filter diameters as large as 10 cm should be considered.

**Expected TRL or TRL Range at completion of the Project:**

3 to 5

**Primary Technology Taxonomy:**
Level 1: TX 08 Sensors and Instruments
Level 2: TX 08.1 Remote Sensing Instruments/Sensors

**Desired Deliverables of Phase I and Phase II:**

- Research
- Analysis
- Prototype
- Hardware

**Desired Deliverables Description:**

Phase I deliverables: results of tests and analysis of designs, as described in a final report.

Phase II deliverables: prototype hardware or hardware for further testing and evaluation is desired.

**State of the Art and Critical Gaps:**

This subtopic aims to develop, and advance detector technologies focused on UV, x-ray, and gamma-ray spectral ranges. The science needs in this range span a number of fields, focusing on astrophysics, planetary science, and UV heliophysics. A number of solid-state detector technologies promise to surpass the traditional image-tube-based detectors. Silicon-based detectors leverage enormous investments and promise high-performance detectors, and more complex materials such as gallium nitride and silicon carbide offer intrinsic solar blind response. This subtopic supports efforts to advance technologies that significantly improve the efficiency, dynamic range, noise, radiation tolerance, spectral selectivity, reliability, and manufacturability in detectors.
Relevance / Science Traceability:

NASA Science Mission Directorate (SMD) applications:

- NASA Astrophysics: https://science.nasa.gov/astrophysics/
- The Explorers Program: https://explorers.gsfc.nasa.gov/
- Planetary Missions Program Office: https://www.nasa.gov/planetarymissions/index.html
- Heliophysics: https://science.nasa.gov/heliophysics

Missions under study (Large Ultraviolet Optical Infrared Surveyor (LUVOIR), Habitable Exoplanet Observatory (HabEx), Lynx, and New Frontiers-Io Observer):

- LUVOIR—Large UV/Optical/IR Surveyor: https://asd.gsfc.nasa.gov/luvoir/
- Habitable Exoplanet Observatory (HabEx): https://www.jpl.nasa.gov/habex/
- The LYNX Mission Concept: https://wwwastro.msfc.nasa.gov/lynx/
- Lunar Science/Missions: UV spectroscopy to understand Lunar water cycle and minerology (water detection using edge at 165 nm, H₂ at 121.6 nm, and OH⁻ at 308 nm); LRO-LAMP (Lyman Alpha Mapping Project).
- Gravitational Wave Science: Swift detection of X-ray and UV counterparts of gravitation wave sources; Dorado mission to detect early UV counterpart.
- Planetary Science: Europa Clipper (water/plume detection); Enceladus; Venus (sulfur lines in the 140 to 300 nm range).
- Earth Science: ozone mapping, pollution studies.

References:

2. Explorers and Heliophysics Projects Division (EHPD): https://ehpd.gsfc.nasa.gov/