NASA SBIR 2019 Phase I Solicitation

S1.04 Sensor and Detector Technologies for Visible, IR, Far-IR, and Submillimeter

Lead Center: JPL

Participating Center(s): ARC, GSFC, JPL, LaRC

Technology Area: TA15 Aeronautics

Sensor and Detector Technologies for Visible, IR, Far-IR, and Submillimeter

NASA is seeking new technologies or improvements to existing technologies to meet the detector needs of future missions, as described in the most recent decadal surveys:

- *Earth science* - (http://www.nap.edu/catalog/11820.html)
- *Planetary science* - (http://www.nap.edu/catalog/10432.html)
- *Astronomy and astrophysics* - (http://www.nap.edu/books/0309070317/html/)

Sensor and detector technologies operating in the visible range are not being solicited this year.
Low-power and low-cost digital readout integrated circuits (DROICs):

- In pixel digital readout integrated circuit (DROIC) for high dynamic range infrared imaging and spectral imaging (10-60 Hz operation) focal plane arrays to circumvent the limitations in charge well capacity, by using in-pixel digital counters that can provide orders of magnitude larger effective well depth, thereby affording longer integration times. Longer integration times provide improved signal-to-noise ratio and/or higher operating temperature, which reduces cooler capacity, resulting in savings in size, weight, power and cost.
- High speed (> 1 KHz full frame) shallow well (LSB between 32 – 128 electrons), integrate-while-read mode, with global shutter, 2-color bias-switchable focal planes with DROIC are required for high speed applications such as Fourier transform spectrometers. One color must be responsive to the solar spectrum and the other color must be responsive to thermal emission spectrum, with linear e-APD in both colors.

Low Size, Weight, and Power (SWaP) novel spectrometers:

- Compact low size, weight, and power (SWaP) novel spectrometers for space applications. This could include the conventional high-performance spectrometers based on dispersive elements, Fourier transform spectrometers, tilted grating concepts, etc. Furthermore, an integrated optics based low SWaP spectrometer also applicable to CubeSat and SmallSat applications.

MKID/TES Readout:

- Compact, low power, ASICs for readout of Kinetic Inductance Detector (KID) arrays each with a low operating power and capable of operation at both room temperature and cryogenic temperatures to perform one of the following functions: 8192 point FFT processor with 5 bits of depth using a polyphase oversampling or a Hanning window. Input format would be SERDES (2-4Gsamples/sec) and output format USB2.0 or similar and Power <=2W. >10bit ADC at >1GHz sampling rate with >2000 bands, ~5kHz bandwidth, power <0.3W. Of particular interest are SQUID based systems with a first stage operating at sub-Kelvin temperatures and compatible with 32X40 detector array format.
- Low power, low noise, cryogenic multiplexed readout for large format two-dimensional bolometer arrays with 1000 or more pixels, operating at 65-350 mK. We require a superconducting readout capable of reading two Transition Edge Sensors (TESs) per pixel within a 1 mm-square spacing. The wafer-scale readout of interest will be capable of being indium-bump bonded directly to two dimensional arrays of membrane bolometers, after the application of indium-bumps possibly at another facility. We require row and column readout with very low crosstalk, low read noise, and low detector Noise Equivalent Power degradation.

Lidar Detectors:

- Single photon (Geiger-mode) avalanche photodiode detector array technology for high-speed, imaging or non-imaging lidar applications. Detector array should be 32x32 or larger, demonstrating scalability to 256x256 or larger to cover 2×10^{12} photon/s dynamic range, with crosstalk and after pulsing probability < 2%, photon detection probability > 50% @ 532nm, and dark count rate < 10Hz per pixel at non-cryogenic temperatures, and radiation tolerance for 5 year low earth orbit mission. Detector should be compatible with hybridization techniques allowing connection to readout integrated circuit. Future missions and applications include the Aerosols Lidar Mission called for by the 2017 Decadal Survey for Earth Science, planetary surface mapping, vegetation, and trace gas lidar.
- Space qualify a commercial 2k x 2k polarization camera for a solar coronograph for low Earth orbit and Earth-Sun Lagrange point environments.

IR and Far-IR/Submillimeter-wave Detector Technologies:

- Tunable IR Detector: Development of an un-cooled broadband photon detector with average QE>50% over the spectral range from 3um to 50um. The Detectivity D* must be greater than 5x109. The detector may have electrically tunable spectral range.

Novel Materials and Devices: New or improved technologies leading to measurement of trace atmospheric species (e.g., CO, CH_4, N_2O) or broadband energy balance in the IR and far-IR from geostationary and low-Earth orbital platforms. Of particular interest are new direct detectors or heterodyne detectors technologies made using high temperature superconducting films (YBCO, MgB_2) or engineered semiconductor materials, especially 2Dimensional Electron Gas (2DEG) and Quantum Wells (QW). Candidate missions are thermal imaging, LANDSAT Thermal InfraRed Sensor (TIRS), Climate Absolute Radiance and Refractivity Observatory (CLARREO), BOReal Ecosystem Atmosphere Study (BOREAS), Methane Trace Gas Sounder or other infrared earth observing missions.

Array Receivers: Development of a robust wafer level packaging/integration technology that will allow high-frequency capable interconnects and allow two dissimilar substrates (i.e., Silicon and GaAs) to be aligned and mechanically 'welded' together. Specially develop ball grid and/or Through Silicon Via (TSV) technology that can support submillimeter-wave (frequency above 300 GHz) arrays.

Receiver Components: Local Oscillators capable of spectral coverage 2-5 THz; Output power up to >2 mW; Frequency agility with > 1GHz near chosen THz frequency; Continuous phase-locking ability over the THz tunable range with <100 kHz line width. Both solid-state (low parasitic Schottky diodes) as well as Quantum Cascade Lasers (for f>2 THz) will be needed. Components and devices such as mixers, isolators, and orthomode transducers, working in the THz range, that enable future heterodyne array receivers are also desired. GaN based power amplifiers at frequencies above 100 GHz and with PAE> 25% are also needed. ASIC based SoC solutions are needed for heterodyne receiver backends. ASICs capable of binning >6GHz intermediate frequency bandwidth into 0.1-0.5 MHz channels with low power dissipation <0.5W would be needed for array receivers. Low-power Low Noise Amplifiers (LNA) with 15-20 dB Gain and <5 Kelvin Noise over the 4-8 GHz bandwidth must be demonstrated while operating linearly and biasing at 200uW or less. The P1dB and OIP3 data should be collected at different biases to recommend gain and gain stages at temperatures from 4 Kelvin to 300K. An intermediate set point of particular interest is 20 Kelvin.

Relevance to NASA

- Future short-wave, mid-wave, and long-wave infrared Earth science and planetary science missions all require detectors that are sensitive, broadband, and require low-power for operation.
- Future Astrophysics instruments require cryogenic detectors that are super sensitive, broadband, and provide imaging capability (multi-pixel).
- Aerosol spaceborne lidar as identified by 2017 decadal survey. Reduces uncertainty about climate forcing in aerosol-cloud interactions and ocean ecosystem carbon dioxide uptake. Additional applications in planetary surface mapping, vegetation, and trace gas lidar.
- Earth Radiation Budget measurement per 2007 decadal survey Clouds and Earth's Radiant Energy System (CERES) Tier-1 designation. To maintain the continuous radiation budget measurement for climate modeling and better understand radiative forcings.
- Astrophysical missions such as Origins Space Telescope (OST) will need IR and Far-IR detector and related technologies.
- LANDSAT Thermal InfraRed Sensor (TIRS), Climate Absolute Radiance and Refractivity Observatory (CLARREO), BOReal Ecosystem Atmosphere Study (BOREAS), Methane Trace Gas Sounder or other infrared earth observing missions

Current Science missions utilizing two-dimensional, large-format cryogenic readout circuits:

- HAWC + (High Resolution Airborne Wideband Camera Upgrade) for SOFIA (Stratospheric Observatory for Infrared Astronomy)
- PIPER (Primordial Inflation Polarization Experiment), Balloon-borne

The expected Technology Readiness Level (TRL) range at completion of the project is 2-4.

Two-Dimensional Cryogenic Readout for Far IR Bolometers

Low power, low noise, cryogenic multiplexed readout for large format two-dimensional bolometer arrays with 1000 or more pixels, operating at 65-350 mK. We require a superconducting readout capable of reading two Transition Edge Sensors (TESs) per pixel within a 1 mm-square spacing. The wafer-scale readout of interest will be capable of being indium-bump bonded directly to two dimensional arrays of membrane bolometers, after the application of indium-bumps possibly at another facility. We require row and column readout with very low crosstalk, low read noise, and low detector Noise Equivalent Power degradation.

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Future missions requiring two-TES per pixel readout with two-dimensional cryogenic circuits:

- PIPER Dual Polarization Upgrade
- PICO (Probe of Inflation and Cosmic Origins, a Probe-class Cosmic Microwave Background mission concept

The expected Technology Readiness Level (TRL) range at completion of the project is 4-5.

Sub-milliWatt amplifiers enabling multiplexed readout systems (MRS)

Sub-milliWatt amplifiers enabling multiplexed readout systems (MRS) in the 4-8 GHz bandwidth are needed to maintain the thermal stability of Focal Plane Array and Origins Space Telescope(OST) instruments Origins Survey Spectrometer (OSS) microwave kinetic inductance detectors (MKIDs) and Far-infrared Imager and Polarimeter (FIP) and Lynx Telescope X-ray Microcalorimeter using microwave SQUID multiplexers.

Another bandwidth 0.5-8.5 GHz, would also be useful for Heterodyne Receiver for OST (HERO). Other NASA systems in the Space Geodesy Project (SGP) would be interested in bandwidths up to 2-14 GHz. All these systems include a comb generator coupled in periodically to calibrate out system drifts. A 30 dB coupler is being baselined.

Regardless of bandwidth or thermal dissipation requirements (both OST and Lynx instruments have tight self-heating requirements), the linearity of these amplifiers over the bandwidth is critical. With 200 microWatt power dissipation up to optimal biasing, we seek devices' P1dB and OIP3 data characterized at these low biases and packaging that provides matching circuits and calibration coupling at set temperatures from 4 Kelvin (~200uW biases) up to 300 Kelvin (nominal biases). We need to trade off Gain Flatness and Gain stages, with Noise Temperature that's achievable without upsetting the thermal stability and isolation of the overall telescope.

The dual objectives of controlling self-heating and optimizing linearity and noise temperature maintenance, trading off gain and gain stages is not unique (e.g., SGP), but NASA's OST and Lynx missions drive the state-of-the-art technology to new levels that other NASA programs and industry can benefit from.

15-20 dB Gain and <5 Kelvin Noise over the 4-8 GHz bandwidth must be demonstrated while operating linearly, biasing at 200uW (e.g., Vd=0.09V, Id=2.2mA) or less. The P1dB and OIP3 data should be collected at different biases to recommend gain and gain stages at temperatures from 4 Kelvin to 300K. An intermediate set point of particular interest is 20 Kelvin.

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The expected Technology Readiness Level (TRL) range at completion of the project is 3-4.

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Sub-milliWatt amplifiers enabling multiplexed readout systems (MRS)

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