



NASA SBIR 2016 Phase I Solicitation

S1 Sensors, Detectors and Instruments

NASA's Science Mission Directorate (SMD) (<http://nasascience.nasa.gov/>) encompasses research in the areas of Astrophysics, Earth Science, Heliophysics and Planetary Science. The National Academy of Science has provided NASA with recently updated Decadal surveys that are useful to identify technologies that are of interest to the above science divisions. Those documents are available at the following locations:

- Astrophysics – (http://sites.nationalacademies.org/bpa/BPA_049810).
- Planetary – (<http://solarsystem.nasa.gov/2013decadal/index.cfm>).
- Earth Science – (<http://science.nasa.gov/earth-science/decadal-surveys/>).
- Heliophysics the 2009 technology roadmap can be downloaded here (<http://science.nasa.gov/heliophysics/>).

A major objective of SMD instrument development programs is to implement science measurement capabilities with smaller or more affordable spacecraft so development programs can meet multiple mission needs and therefore make the best use of limited resources. The rapid development of small, low-cost remote sensing and in-situ instruments is essential to achieving this objective. For Earth Science needs, in particular, the subtopics reflect a focus on instrument development for airborne and Unmanned Aerial Vehicle (UAV) platforms. Astrophysics has a critical need for sensitive detector arrays with imaging, spectroscopy, and polarimetric capabilities, which can be demonstrated on ground, airborne, balloon, or suborbital rocket instruments. Heliophysics, which focuses on measurements of the sun and its interaction with the Earth and the other planets in the solar system, needs a significant reduction in the size, mass, power, and cost for instruments to fly on smaller spacecraft. Planetary Science has a critical need for miniaturized instruments with in-situ sensors that can be deployed on surface landers, rovers, and airborne platforms. The following subtopics are concomitant with these objectives and are organized by technology.

Subtopics

S1.01 Lidar Remote Sensing Technologies

Lead Center: LaRC

Participating Center(s): GSFC, JPL

NASA recognizes the potential of lidar technology in meeting many of its science objectives by providing new capabilities or offering enhancements over current measurements of atmospheric and topographic parameters from ground, airborne, and space-based platforms. To meet NASA's requirements for remote sensing from space, advances are needed in state-of-the-art lidar technology with an emphasis on compactness, efficiency, reliability, lifetime, and high performance. Innovative lidar subsystem and component technologies that directly address the

measurement of atmospheric constituents and surface topography of the Earth, Mars, the Moon, and other planetary bodies will be considered under this subtopic. Compact, high-efficiency lidar instruments for deployment on unconventional platforms, such as balloon, small sat, and CubeSat are also considered and encouraged.

Proposals must show relevance to the development of lidar instruments that can be used for NASA science-focused measurements or to support current technology programs. Meeting science needs leads to four primary instrument types:

- *Backscatter* - Measures beam reflection from aerosols to retrieve the opacity of a gas.
- *Ranging* - Measures the return beam's time-of-flight to retrieve distance.
- *Doppler* - Measures wavelength changes in the return beam to retrieve relative velocity.
- *Differential absorption* - Measures attenuation of two different return beams (one centered on a spectral line of interest) to retrieve concentration of a trace gas.

Phase I research should demonstrate technical feasibility and show a path toward a Phase II prototype unit. Phase II prototypes should be capable of laboratory demonstration and preferably suitable for operation in the field from a ground-based station, an aircraft platform, or any science platform amply defended by the proposer. For the 2016 SBIR Program, NASA is soliciting the component and subsystem technologies described below.

- Compact and rugged single-frequency continuous-wave and pulsed lasers operating between 0.28- μm and 2.05- μm wavelengths suitable for lidar. Specific wavelengths are of interest to match absorption lines or atmospheric transmission: 0.28 to 0.32- μm (ozone absorption), 0.45 to 0.49- μm (transmission through ocean water), 0.532- μm , 0.817 to 0.830- μm (water lines), 1.0- μm , 1.57- μm (CO_2 line), 1.65- μm (methane line), and 2.05- μm (CO_2 line). For wavelengths associated with an absorption line, tunability on the order tens of nanometers is desired. Architectures involving new developments in diode laser, quantum cascade laser, and fiber laser technology are especially encouraged. For pulsed lasers two different regimes of repetition rate and pulse energies are desired: from 8-kHz to 10-kHz with pulse energy greater than 1-mJ and from 20-Hz to 100-Hz with pulse energy greater than 100-mJ.
- Optical amplifiers for increasing the energy of pulsed lasers in the wavelength range of 0.28- μm to 2.05- μm . Specific wavelengths of interest are listed above in the bullet above. Also, amplifier and modulator combinations for converting continuous-wave lasers to a pulsed format are encouraged. Amplifier designs must preserve the wavelength stability and spectral purity of the input laser.
- Ultra-low noise photoreceiver modules, operating at 1.6- μm wavelength, consisting of the detection device, complete Dewar/cooling systems, and associated amplifiers. General requirements are: large single-element active detection diameter (>200 micron), high quantum efficiency (>85%), noise equivalent power of the order of 10-14 W/sqrt(Hz), and bandwidth greater than 10 MHz.
- Novel, highly efficient approaches for High Spectral Resolution Lidar (HSRL) receivers. New approaches for high-efficiency measurement of HSRL aerosol properties at 1064, 532 and/or 355-nm. New or improved approaches are sought that substantially increase detection efficiency over current state of the art. Ideally, complete receiver subsystems will be proposed that can be evaluated and/or implemented in instrument concept designs.
- New space lidar technologies that use small and high-efficiency diode or fiber lasers to measure range and surface reflectance of asteroids and comets from >100 km altitude during mapping to <1 m during landing and sample return at a fraction of the power, mass, and cost of the Mercury Laser Altimeter (i.e., less than 7.4kg, 17W, and 28x28x26cm). The technologies can significantly extend the receiver dynamic range of the current space lidar without movable attenuators, providing sufficient link margin for the longest range but not saturating during landing. The output power of the laser transmitters should be continuously adjusted according to the spacecraft altitude. The receiver should have single photon sensitivity to achieve a near-quantum limited performance for long distance measurement. The receiver integration time can be continuously adjusted to allow trade-off between the maximum range and measurement rate. The lidar should have multiple beams so that it can measure not only the range but also surface slope and orientation.
- Narrow linewidth and frequency stable laser transmitter at 780-nm wavelength for development of low-cost, compact, and eye-safe high spectral resolution lidar (HSRL) for ground-based profile measurements of aerosol and cloud intensive and extensive properties. Desired specifications include pulse energy of 5 to 20-mJ, pulse repetition rate of 1 to 10-kHz, wavelength near 780-nm coincident with rubidium vapor line, linewidth < 10-MHz, spectral purity > 99.9%, and wavelength tunability of at least 0.5-nm around central

wavelength.

S1.02 Microwave Technologies for Remote Sensing

Lead Center: JPL

Participating Center(s): GSFC

NASA employs active (radar) and passive (radiometer) microwave sensors for a wide range of remote sensing applications (for example, see (<http://www.nap.edu/catalog/11820.html>)). These sensors include low frequency (less than 10 MHz) sounders to G-band (160 GHz) radars for measuring precipitation and clouds, for planetary landing, upper atmospheric monitoring, and global snow coverage, topography measurement and other Earth and planetary science applications. We are seeking proposals for the development of innovative technologies to support these future radar and radiometer missions and applications. The areas of interest for this call are listed below.

Single Pole Double Throw Switch with the following specifications:

- Frequency: 183 GHz, 325 GHz, or 380 GHz.
- Bandwidth: > 15 GHz.
- Insertion Loss: < 2 dB.
- Isolation: > 15 dB.

Calibration of sub-mm wave radiometers is limited in large part to external sources due to the lack of suitable switches for internal calibration. This increases the mass and cost of these instruments. A SPDT switch at 180 or 340 GHz will significantly reduce the cost and complexity of radiometers at these frequencies.

NEW: GaN Schottky diode technology for ultra-high power local oscillator power sources

This includes the development of GaN epi-structures on Si or SiC substrates suitable for millimeter-wave operations (SOA electron mobility >1000 cm²/V·s for 5E16 to 1E17 cm⁻³ epi doping levels, and discrete GaN Schottky diodes (power handling capabilities > 200 mW/diode).

Technology for compact Dual Frequency (Ka and W-band) quasi-optical radar front end

W-band (94 GHz +/- 50 MHz):

- Single Polarization Tx, Dual Polarization Rx using a quasioptical duplexer such as a faraday rotator.

Ka-band (35.5 GHz +/- 100 MHz):

- Dual Polarization Tx and Rx.
- Shared beam waist with W-band.
- Waveguide duplexer and OMT okay.

The Decadal Survey ACE mission calls for a dual-frequency (Ka/W-band) radar for observation of clouds and light precipitation from space. Recently a similar but more compact and low cost radar is considered for operation on the International Space Station (ISS). Compared to traditional ferrite material based radar Tx/Rx front-end, quasi-optical front-end offers significantly low loss and high power handling capability, which have direct impact on radar performance. A compact dual-frequency and dual-polarization quasi-optical radar front-end has not been developed and is in critical need for ISS, ACE and suborbital airborne radars.

Interconnection technologies to enable highly integrated, low loss distribution networks that integrate power splitters, couplers, filters, and/or isolators in a compact package

Technologies are sought that integrate X, Ku, and Ka-bands transmit/receive modules with antenna arrays and/or LO distribution networks for F- and/or G-band receiver arrays.

Dual-frequency (Ka/W-band), dual polarization compact quasi-optical front-end for cloud radars.

- Freq: 35.5 GHz \pm 100MHz.
- 94 GHz \pm 100MHz.
- Loss: < 0.5 dB.
- Polarization Isolation: > 30 dB.
- Polarization: V and H.

640 GHz Heterodyne Polarimeter with I, Q, U Channels

Current 640 GHz polarimetric radiometers are either unsuitably large for space in terms of Mass/Volume/Power, or are direct-detection instruments that lack the ability to reject ozone emission contamination by selectively filtering the signal in the IF stages. This technology would help enable polarimetric measurements to provide microphysical parameterization of ice clouds applicable to ACE.

Low power RFI mitigating receiver back ends for broad band microwave radiometers

NASA requires a low power, low mass, low volume, and low data rate RFI mitigating receiver back end that can be incorporated into existing and future radiometer designs. The system should be able to channelize up to 1 GHz with 16 sub bands and be able to identify RFI contamination using tools such as kurtosis.

Compact 10+ Watt W-band transceiver including:

- SSPA, LNA, Circulator, and receiver protection switches.
- Mixer and 2 GHz Band-Pass Filter.
- 10-Watt SSPA, <1 dB transmit loss, 7 dB Rx Noise Figure.
- Approximately 3.5" x 3.5" x 4" dimensions.

NEW: Compact, highly integrated technologies enabling Altimetry/Velocimetry for space qualified radars

- Frequency: C-band to K-band.
- 0.2% range and 1% velocity accuracies.
- Operating range 6000m to 0 m.
- Compact antenna development.
- Integrated digital backend.
- Highly integrated MMIC for radar systems/subsystems.
- < 3kg and 1U (10 x 10 x 3 cm³) for electronics.

Deployable 1-D Parabolic Antenna

- At least 2 m x 2 m in dimensions.
- Operable up to Ka-band (35.5 GHz).

Deployable 1-D parabolic antenna technology at Ka-band will allow higher gain and better spatial resolution for future flight precipitation measurement missions.

Technology for low-power, rad-tolerant broad band spectrometer back ends for microwave radiometers

Includes - digitizers with 20 Gsps, 20 GHz bandwidth, 4 or more bit and simple interface to FPGA; ASIC implementations of polyphase spectrometer digital signal processing with ~1 watt/GHz. Current FPGA based

spectrometers require ~10 W/GHz and are not flight qualifiable. High speed digitizers exist but have poorly designed output interfaces. Specifically designed ASICs could reduce this power by a factor of 10.

A compact, broadband (6-12 GHz or 10-30 GHz), low insertion loss isolator

- < 0.3 insertion loss.
- 20 dB input and output return loss.

The isolator should be compatible with either microstrip or CPW for ease of transition with the rest of the system.

Ka-band Power Amplifier for CubeSats

- F = 35.7 GHz +/- 200MHz.
- Volume: <1U (10 x10 x10 cm³).
- Psat >32W.
- Gain > 35 dB.
- PAE > 20%.
- Pulsed, 12% duty cycle.
- Current state of the art amplifiers are limited to 7W at < 15% efficiencies.

Development of on-wafer high frequency probes above 300 GHz for cryogenic temperatures

Passive or active cooled space missions will benefit from early performance characterization and selection at operating temperatures. The conventional test on individual packaged components is expensive and time consuming.

Advanced Deployable Antennas for CubeSats

- F = 35.7 GHz +/- 200MHz capable of 1D scanning.
- F = 94.05 GHz ± 50MHz.
- Aperture size = 2 m.
- Gain > 48dB @36GHz.
- Sidelobe ratio > 20dB.
- Stowed volume: <2.5U (25 x 10 x 10 cm³).
- Polarization: Linear.

Components for addressing gain instability in LNA based radiometers from 100 and 600 GHz

NASA requires low insertion loss solutions to the challenges of developing stable radiometers and spectrometers operating above 100 GHz that employ LNA based receiver front ends. This includes noise diodes with ENR>10dBm and with better than ? 0.01 dB/°C thermal stability when integrated with a proper electrical circuit, Dicke switches with better than 30 dB isolation, phase modulators, and low loss isolators along with fully integrated state-of-art receiver systems operating at room and cryogenic temperatures.

NEW: Wideband Antenna Technologies for GPRs

- Conformal / planar.
- 0.1 - 3 GHz bandwidth.
- Separate tx/rx with high isolation (> 30 dB).

S1.03 Sensor and Detector Technology for Visible, IR, Far IR and Submillimeter

Lead Center: JPL

Participating Center(s): ARC, GSFC, LaRC

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/>).

Development of un-cooled or cooled infrared detectors (hybridized or designed to be hybridized to an appropriate read-out integrated circuit) with $NEP < 20 \text{ mK}$, $QE > 30\%$ and dark currents $< 1.5 \times 10^{-6} \text{ A/cm}^2$ in the 5-14 μm infrared wavelength region. Array formats may be variable, 640 x 512 typical, with a goal to meet or exceed 2k X 2k pixel arrays. Evolve new technologies such as InAs/GaSb type-II strained layer super-lattices to meet these specifications.

New or improved technologies leading to measurement of trace atmospheric species (e.g., CO, CH₄, N₂O) or broadband energy balance in the IR and far-IR from geostationary and low-Earth orbital platforms. Of particular interest are new direct, nanowire or heterodyne detector technologies made using high temperature superconducting films (YBCO, MgB₂) or engineered semiconductor materials, especially 2-Dimensional Electron Gas (2-DEG) and Quantum Wells (QW) that operate at temperatures achieved by standard 1 or 2 stage flight qualified cryocoolers and do not require cooling to liquid helium temperatures. 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.

1k x 1k or larger format MCT detector arrays with cutoff wavelength extended to 12 microns for use in missions to NEOs, comets and the outer planets.

Compact, low power, readout electronics for Kinetic Inductance Detector arrays with $> 8 \text{ bit}$ ADC at $> 500 \text{ MHz}$ sampling rate that channelizes into 1000 readout tones each with $> 5 \text{ kHz}$ of bandwidth. This type of readout would be used for photometers and spectrometers for astrophysics focal planes, and earth or planetary remote sensing instruments.

Development of new or improved large-format focal plane array Readout Integrated Circuit (ROIC) architectures to provide advanced detection features for overcoming existing limitations for low background astronomical applications. The main limitations of existing source-follower unit cells include potential image persistence and interpixel capacitance induced crosstalk. These limitations have complicated the use of these ROICs in a number of past missions, and will likely be even more constraining as detector performance improves. An improvement of a factor of 2 or more over current state-of-the-art would be of interest. Ideally, this would be done without compromising any good characteristics, but even in the case of a modest degradation in some parameters (like noise), the new features may prove to be superior for some applications.

Development of a robust wafer-level integration technology that will allow high-frequency capable interconnects and allow two dis-similar 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 arrays. Initially the technology can be demonstrated at the '1-inch' die level but should be do-able at the 4-inch wafer level.

New or improved, lightweight spectrometer operating over the spectral range 350 – 2300 nm with 4 nm spectral sampling and that is capable of making irradiance measurements of both the sun and the moon.

S1.04 Detector Technologies for UV, X-Ray, Gamma-Ray and Cosmic-Ray Instruments

Lead Center: GSFC

Participating Center(s): JPL, MSFC

This subtopic covers detector requirements for a broad range of wavelengths from 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, 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, Vision Missions, and Earth Science Decadal Survey missions. Details of these can be found at the following URLs:

- General Information on Future NASA Missions - (<http://www.nasa.gov/missions>).
- Specific mission pages:
 - Future planetary programs - (http://nasascience.nasa.gov/planetary-science/mission_list).
 - Earth Science Decadal missions - (<http://www.nas.nasa.gov/public/11820.html>).
 - Helio Probes - (http://nasascience.nasa.gov/heliophysics/mission_list).
 - X-ray Astrophysics - (http://sites.nationalacademies.org/bpa/BPA_049810).

Specific technology areas are:

- Significant improvement in wide band gap semiconductor materials, such as AlGaIn, ZnMgO and SiC, individual detectors, and detector arrays for operation at room temperature or higher for missions such as Geo-CAPE, NWO, ATALAST and planetary science composition measurements.
- Highly integrated, low noise (< 300 electrons rms with interconnects), low power (< 100 uW/channel) mixed signal ASIC readout electronics as well as charge amplifier ASIC readouts with tunable capacitive inputs to match detector pixel capacitance. See needs of National Research Council's Earth Science Decadal Survey (NRC, 2007): Future Missions include GEOCAPE, HyspIRI, GACM, future GOES and SOHO programs and planetary science composition measurements.
- Visible-blind SiC Avalanche Photodiodes (APDs) for EUV photon counting are required. The APDs must show a linear mode gain >10E6 at a breakdown reverse voltage between 80 and 100V. The APD's must demonstrate detection capability of better than 6 photons/pixel/s down to 135nm wavelength. See needs of National Research Council's Earth Science Decadal Survey (NRC, 2007): Tropospheric ozone.
- Large area (3 m²) photon counting near-UV detectors with 3 mm pixels and able to count at 10 MHz. Array with high active area fraction (>85%), 0.5 megapixels and readout less than 1 mW/channel. Future instruments are focal planes for JEM-EUSO and OWL ultra-high energy cosmic ray instruments and ground Cherenkov telescope arrays such as CTA, and ring-imaging Cherenkov detectors for cosmic ray instruments such as BESS-ISO. As an example (JEM-EUSO and OWL), imaging from low-Earth orbit of air fluorescence, UV light generated by giant air showers by ultra-high energy (E >10E19 eV) cosmic rays require the development of high sensitivity and efficiency detection of 300-400 nm UV photons to measure signals at the few photon (single photo-electron) level. A secondary goal minimizes the sensitivity to photons with a wavelength greater than 400 nm. High electronic gain (10E4 to 10E6), low noise, fast time response (<10 ns), minimal dead time (<5% dead time at 10 ns response time), high segmentation with low dead area (<20% nominal, <5% goal), and the ability to tailor pixel size to match that dictated by the imaging optics. Optical designs under consideration dictate a pixel size ranging from approximately 2 x 2 mm² to 10 x 10 mm². Focal plane mass must be minimized (2g/cm² goal). Individual pixel readout is required. The entire focal plane detector can be formed from smaller, individual sub-arrays.

S1.05 Particles and Field Sensors and Instrument Enabling Technologies

Lead Center: GSFC

Participating Center(s): ARC, JPL, JSC, MSFC

Advanced sensors for the detection of elementary particles (atoms, molecules and their ions) and electric and magnetic fields in space and associated instrument technologies are often critical for enabling transformational science from the study of the sun's outer corona, to the solar wind, to the trapped radiation in Earth's and other planetary magnetic fields, and to the atmospheric composition of the planets and their moons. Improvements in particles and fields sensors and associated instrument technologies enable further scientific advancement for

upcoming NASA missions such as CubeSats, Explorers, STP, and planetary exploration missions. Technology developments that result in a reduction in size, mass, power, and cost will enable these missions to proceed. Of interest are advanced magnetometers, electric field booms, ion/atom/molecule detectors, and associated support electronics and materials. Specific areas of interest include:

- High efficiency conversion surfaces for the conversion of Energetic Neutral Atoms (ENAs) to ions for increasing the sensitivity of low energy ENA instruments.
 - Science Traceability: Decadal survey missions: IMAP, MEDICI, DRIVE Initiative, EXPLORERs DISCOVERY, CubeSats / Smallsats, Sounding Rockets.
 - Need Horizon: 1 to 3 years, 3 to 5 years.
 - State of the Art: The efficiency of present SOA conversion surfaces is 1-2%. This is quite low and results to low sensitivities. An efficiency increase to 10% will lead to increased sensitivity by a factor of x 5 to 10 and /or smaller instruments sizes / resources.
 - Importance: Very High – Critical need for next generation low energy ENA instruments.
- Very low energy threshold < 5eV particle detectors for direct neutral particle detection.
 - Science Traceability: Explorer missions, Decadal survey missions IMAP, MEDICI, DYNAMICS, DRIVE Initiative, DISCOVERY and CubeSat/Smallsat missions.
 - Need Horizon: 1 to 3 years.
 - State of the Art: SOA solid state detectors have an energy threshold for particle detection of ~1keV. Although this problem can be overcome in charged particle detection with pre acceleration, it poses a severe limitation in direct neutral particle. New detectors with low energy threshold will enable a whole new class of instruments and improve existing instruments.
 - Importance: Very High – Critical need for next generation direct neutral instruments.
- UV filters that greatly attenuate UV Ly radiation but let particles freely pass through. Enabling technology for direct particle detection.
 - Science Traceability: Decadal survey missions: IMAP, MEDICI, DRIVE Initiative, EXPLORERs DISCOVERY, CubeSats / Smallsats, Sounding Rockets.
 - Need Horizon: 1 to 3 years, 3 to 5 years.
 - State of the Art: Particle detectors are very sensitive to UV light. The commonly used technology for direct particle detection is very thin foil that attenuate UV light but at the same time pose an energy threshold / scatter particles. A possible micro porous type of detector that greatly attenuates UV but let particles pass through will greatly improve current instruments.
 - Importance: Very High – Critical need for next generation particle instruments.
- Strong, compactly stowed magnetically clean magnetic field booms possibly using composite materials that deploy mag sensors (including internal harness) to distances up to 10 meters, for Cubesats;
 - Science Traceability: Explorer missions, DRIVE Initiative, CubeSat/Smallsat missions.
 - Need Horizon: 1 to 3 years.
 - State of the Art: Such a boom up to 10 meters long will high quality electric field measurements from small platforms.
 - Importance: Very High for future Cubesat and SmallSat stand alone and constellation missions.
- Strong, lightweight, thin, rigid, compactly stowed electric field booms possibly using composite materials that deploy sensors (including internal harness) to distances of 10 m or more
 - Explorer missions, DRIVE Initiative, CubeSat/Smallsat missions.
 - Need Horizon: 1 to 3 years, 3 to 5 years.
 - Particle detectors are very sensitive to UV light. The commonly used technology for direct particle detection is very thin foil that attenuate UV light but at the same time pose an energy threshold / scatter particles. A possible micro porous type of detector that greatly attenuates UV but let particles pass through will greatly improve current instruments.
 - Importance: Very High for future Cubesat and SmallSat stand alone and constellation missions.

S1.06 In Situ Sensors and Sensor Systems for Lunar and Planetary Science

Lead Center: JPL

Participating Center(s): ARC, GRC, GSFC, JSC, MSFC

This subtopic solicits development of advanced instrument technologies and components suitable for deployment

on planetary and lunar missions. These technologies must be capable of withstanding operation in space and planetary environments, including the expected pressures, radiation levels, launch and impact stresses, and range of survival and operational temperatures. Technologies that reduce mass, power, volume, and data rates for instruments and instrument components without loss of scientific capability are of particular importance. In addition, technologies that can increase instrument resolution and sensitivity or achieve new & innovative scientific measurements are solicited. For example missions, see (<http://science.hq.nasa.gov/missions>). For details of the specific requirements see the National Research Councils, Vision and Voyages for Planetary Science in the Decade 2013-2022 (<http://solarsystem.nasa.gov/2013decadal/>). Technologies that support NASAs New Frontiers and Discovery missions to various planetary bodies are of top priority.

In-situ technologies are being sought to achieve much higher resolution and sensitivity with significant improvements over existing technologies. Orbital sensors and technologies that can provide significant improvements over previous orbital missions are also sought. Specifically, this subtopic solicits instrument development that provides significant advances in the following areas, broken out by planetary body:

- *Mars* - Sub-systems relevant to current in-situ instrument needs (e.g., lasers and other light sources from UV to microwave, X-ray and ion sources, detectors, mixers, mass analyzers, etc.) or electronics technologies (e.g., FPGA and ASIC implementations, advanced array readouts, miniature high voltage power supplies). Technologies that support high precision in-situ measurements of elemental, mineralogical, and organic composition of planetary materials are sought. Conceptually simple, low risk technologies for in-situ sample extraction and/or manipulation including fluid and gas storage, pumping, and chemical labeling to support analytical instrumentation. Seismometers, mass analyzers, technologies for heat flow probes, and atmospheric trace gas detectors. Improved robustness and g-force survivability for instrument components, especially for geophysical network sensors, seismometers, and advanced detectors (iCCDs, PMT arrays, etc.). Instruments geared towards rock/sample interrogation prior to sample return are desired.
- *Europa & Io* - Technologies for high radiation environments, e.g., radiation mitigation strategies, radiation tolerant detectors, and readout electronic components, which enable orbiting instruments to be both radiation-hard and undergo the planetary protection requirements of sterilization (or equivalent) for candidate instruments on proposed missions such as Europa Clipper and Io Volcano.
- *Titan* - Low mass and power sensors, mechanisms and concepts for converting terrestrial instruments such as turbidimeters and echo sounders for lake measurements, weather stations, surface (lake and solid) properties packages, etc. to cryogenic environments (95K). Mechanical and electrical components and subsystems that work in cryogenic (95K) environments; sample extraction from liquid methane/ethane, sampling from organic 'dunes' at 95K and robust sample preparation and handling mechanisms that feed into mass analyzers are sought. Balloon instruments, such as IR spectrometers, imagers, meteorological instruments, radar sounders, air sampling mechanisms for mass analyzers, and aerosol detectors are also solicited.
- *Venus* - Sensors, mechanisms, and environmental chamber technologies for operation in Venus's high temperature, high-pressure environment with its unique atmospheric composition. Approaches that can enable precision measurements of surface mineralogy and elemental composition and precision measurements of trace species, noble gases and isotopes in the atmosphere are particularly desired.
- *Small Bodies* - Technologies that can enable sampling from asteroids and from depth in a comet nucleus, improved in-situ analysis of comets. Also, imagers and spectrometers that provide high performance in low light environments dust environment measurements & particle analysis, small body resource identification, and/or quantification of potential small body resources (e.g., oxygen, water and other volatiles, hydrated minerals, carbon compounds, fuels, metals, etc.). Specifically, advancements geared towards instruments that enable elemental or mineralogy analysis (such as high-sensitivity X-ray and UV-fluorescence spectrometers, UV/fluorescence flash lamp/camera systems, scanning electron microscopy with chemical analysis capability, time-of-flight mass spectrometry, gas chromatography and tunable diode laser sensors, calorimetry, laser-Raman spectroscopy, imaging spectroscopy, and LIBS) are sought. These developments should be geared towards sample interrogation, prior to possible sample return.
- *Saturn, Uranus and Neptune* - Technologies are sought for components, sample acquisition and instrument systems that can enhance mission science return and withstand the low-temperatures/high-pressures of the atmospheric probes during entry.
- *The Moon* - This solicitation seeks advancements in the areas of compact, light-weight, low power instruments geared towards in-situ lunar surface measurements, geophysical measurements, lunar atmosphere and dust environment measurements & regolith particle analysis, lunar resource identification,

and/or quantification of potential lunar resources (e.g., oxygen, nitrogen, and other volatiles, fuels, metals, etc.). Specifically, advancements geared towards instruments that enable elemental or mineralogy analysis (such as high-sensitivity X-ray and UV-fluorescence spectrometers, UV/fluorescence flash lamp/camera systems, scanning electron microscopy with chemical analysis capability, time-of-flight mass spectrometry, gas chromatography and tunable diode laser sensors, calorimetry, laser-Raman spectroscopy, imaging spectroscopy, and LIBS) are sought. These developments should be geared towards sample interrogation, prior to possible sample return. Systems and subsystems for seismometers and heat flow sensors capable of long-term continuous operation over multiple lunar day/night cycles with improved sensitivity at lower mass and reduced power consumption are sought. Also of interest are portable surface ground penetrating radars to characterize the thickness of the lunar regolith, as well as, low mass, thermally stable hollow cubes and retro-reflector array assemblies for lunar surface laser ranging. Of secondary importance are instruments that measure the micrometeoroid and lunar secondary ejecta environment, plasma environment, surface electric field, secondary radiation at the lunar surface, and dust concentrations and its diurnal dynamics are sought. Further, lunar regolith particle analysis techniques are desired (e.g., optical interrogation or software development that would automate integration of suites of multiple back scatter electron images acquired at different operating conditions, as well as permit integration of other data such as cathodoluminescence and energy-dispersive x-ray analysis.)

Proposers are strongly encouraged to relate their proposed development to:

- NASA's future planetary exploration goals.
- Existing flight instrument capability, to provide a comparison metric for assessing proposed improvements.

Proposed instrument architectures should be as simple, reliable, and low risk as possible while enabling compelling science. Novel instrument concepts are encouraged particularly if they enable a new class of scientific discovery. Technology developments relevant to multiple environments and platforms are also desired.

Proposers should show an understanding of relevant space science needs, and present a feasible plan to fully develop a technology and infuse it into a NASA program.

S1.07 Airborne Measurement Systems

Lead Center: GSFC

Participating Center(s): ARC, GRC, JPL, KSC, LaRC, MSFC, SSC

Measurement system miniaturization and/or increased performance is needed to support for NASA's airborne science missions, particularly those utilizing the Global Hawk, SIERRA-class, Dragon Eye or other unmanned aircraft. The subject airborne instruments are intended as calibration/validation systems for space-based measurements, or to provide local measurements not available from space-based instruments. Linkages to other subtopics such as S3.04 Unmanned Aircraft and Sounding Rocket Technologies are encouraged. Complete instrument systems are desired, including features such as remote/unattended operation and data acquisition, low power consumption, and minimum size and weight. Desired sensors include:

- High accuracy and precision atmospheric measurements of Nitrous Oxide, Ammonia, Sulfur Dioxide, Dimethyl Sulfide, Carbonyl Sulfide and Formaldehyde, with significant improvements over the current state-of-the-art, such as measurement speed, resolution, or system weight/volume.
- Preconcentration instruments for the measurement of the isotopic composition of atmospherically relevant trace gases (CO₂, CH₄, O₃, Ozone depleting substances and isotopomer, etc.) in are using optical, mass-spectrometric, and other types of detection. Proposals are invited for the development of versatile preconcentration instrumentation that initially can be used with a range of measurement instrumentation as well as for field and laboratory applications.
- Spectrally resolved absorption and extinction of atmospheric aerosols (0.1 to 10 micron).
- Multiphase Precipitation (0.1 mm to 20 mm with 5 % accuracy in three dimensions).
- Size distribution, phase, and asymmetry of atmospheric aerosols and cloud particles (0.1 micron to 200 micron with 10% accuracy).

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- Three-dimensional wind measurement (1 mps accuracy/resolution at 10 Hz sampling).

S1.08 Surface & Sub-surface Measurement Systems

Lead Center: ARC

Participating Center(s): GSFC, JPL, LaRC, MSFC, SSC

Surface & Sub-surface Measurement Systems are sought with relevance to future space missions such as Active Sensing of CO₂ Emissions over Nights, Days, and Seasons (ASCENDS), Orbiting Carbon Observatory – 2 (OCO-2), Global Precipitation Measurement (GPM), Geostationary Coastal and Air Pollution Events (GEO-CAPE), Hyperspectral InfraRed Imager (HyspIRI), Aerosol, Cloud, and Ecosystems (ACE, including Pre-ACE/PACE). Early adoption for alternative uses by NASA, other agencies, or industry is desirable and recognized as a viable path towards full maturity. Sensor system innovations with significant near-term commercial potential that may be suitable for NASA's research after full development are of interest:

- Precipitation (e.g., motion stabilized disdrometer for shipboard deployments).
- Aquatic suspended particle concentrations and spectra of mineral and biogenic (phytoplankton and detritus) components.
- Miniaturized, stable, pH sensors for ocean applications to support validation of OCO-2 that can be used in the ARGO network.
- Miniaturized gas sensors or small instruments for carbon dioxide, methane, etc., only where the sensing technology solution will clearly exceed current state of the art for its targeted application.
- Miniaturized air-dropped sensors, for ocean surface and subsurface measurements such as conductivity, temperature, and depth.
- Multi-wavelength, LIDAR-based, atmospheric ozone and aerosol profilers for continuous, simultaneous observations from multiple locations. Examples include three-band ozone measurement systems operating in the UV spectrum (e.g., 280-316 nm, possibly tunable), or visible/infrared systems with depolarization sensitivity for aerosols and clouds.
- Portable, robust, ground based LIDAR system for 3D scanning of winds, temperature, density, and humidity with ability to scan horizontally and vertically with a range of up to 10 km
- Miniaturized, novel instrumentation for measuring inherent and apparent optical properties (specifically to support vicarious calibration and validation of ocean color satellites, i.e., reflectance, absorption, scattering), in-situ biogeochemical measurements of marine and aquatic components and rates including but not limited to nutrients, phytoplankton and their functional groups, and floating and submerged aquatic plants.
- Novel geophysical and diagnostic instruments suitable for ecosystem monitoring. Fielding for NASA's Applications and Earth Science Research activities is a primary goal.

S1.09 Cryogenic Systems for Sensors and Detectors

Lead Center: GSFC

Participating Center(s): ARC, JPL, MSFC

Cryogenic cooling systems often serve as enabling technologies for detectors and sensors flown on scientific instruments as well as advanced telescopes and observatories. As such, technological improvements to cryogenic systems further advance the mission goals of NASA through enabling performance (and ultimately science gathering) capabilities of flight detectors and sensors. There are four potential investment areas that NASA is seeking to expand state of the art capabilities for possible use on future programs such as WFirst (<http://wfirst.gsfc.nasa.gov/>), the Europa Jupiter System Science missions (<http://www.nasa.gov/multimedia/podcasting/jpl-europa20090218.html>) and PIXIE (Primordial Inflation Explorer). The topic areas are as follows:

Cryocooler Systems and Components

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- *Miniaturized/Efficient Cryocooler Systems* - Cryocooler systems viable for application on SmallSat space platforms are sought. Present state of the art capabilities demonstrate approximately 0.4W of cooling capacity at 77K provided an input power of 5W. Contemporary system mass is on the order of 400 grams. Desired performance specifications for cryocoolers sought include a cooling capability on the order of 0.2W at temperatures spanning 30K - 80K. Desired masses and input powers will be < 400 grams and < 5W respectively. Component level improvements are also desirable.
 - *Low Temperature/Input Power Cooling Systems* - Low temperature/Input Power Cooling systems are sought for application on future Planetary missions that require performance in space environments that have limited access to power. Contemporary cooling systems are incapable of providing cooling loads as high as 0.2W at 30K while rejecting heat to an ambient environment of approximately 150K. Cooling systems providing cooling capacities of approximately 0.3W at 35K with heat rejection capability to temperature sinks at 150 K or lower are of interest. Component level improvements are also desirable.
 - *High Capacity/Efficiency Cryocooler Systems* - High Capacity/Efficiency cryocoolers are of interest for use on future science missions. State of the art high capacity cryocooler systems have demonstrated cooling capabilities spanning 0.3W - 1W with a load temperature of 20K and < 0.3 W at 10K. High Capacity cryocoolers are available at low to mid TRL levels for both Pulse Tube (e.g., 5W cooling capacity at 20K) and Turbo Brayton (e.g., cooling capacity of 20W at 20K) configurations. Desired cryocooler systems will provide cold tip operational temperatures spanning 10K to 20K with a cooling capacity of > 4W at 20K or more than 0.3 W at 10 K. Very low vibration systems with these capabilities are desirable. Component level improvements that increase overall efficiency are also desirable.

Sub-Kelvin Cooling Systems

- *Magnetic Cooling Systems* - State of the art sub-Kelvin temperature control architectures that use magnetic cooling consist of ADR (Adiabatic Demagnetization Refrigeration) systems. The Astro-H FM (Flight Model) ADR represents the state of the art in ADR system and component level technologies for space application. Future missions requiring cooling to sub-Kelvin levels will look to use new and improved ADR systems. AMRR (Active Magnetic Regenerative Refrigeration) systems are a related magnetic cooling technology that requires system and component level development in order to attain sub-Kelvin cooling levels. Improvements at the component level may lead to better overall system performance and increased hold times at target temperatures. Both of these are highly advantageous and desirable to future science missions. Specific components sought include:
 - Low current superconducting magnets (3-4 Tesla at temperatures > 15K).
 - Heat Switches (including optimization of current designs, such as low thermal conductivity heat switch shells)
 - High cooling power density magnetocaloric materials, especially single crystals with volume > 20 cm³.
 - Active/Passive magnetic shielding (for use with 3-4 Tesla magnets).
 - Superconducting leads (10K - 90K) capable of 10 A operation with 1 mW conduction.
 - 10 mK- 300 mK high resolution thermometry.

Proposals considered viable for Phase I award will seek to validate hypotheses through proof of concept testing at relevant temperatures.