



NASA SBIR 2011 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 (<http://nasascience.nasa.gov/astrophysics>), Earth Science (<http://nasascience.nasa.gov/earth-science>), Heliophysics (<http://nasascience.nasa.gov/heliophysics>), and Planetary Science (<http://nasascience.nasa.gov/planetary-science>). 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. For planetary missions, planetary protection requirements vary by planetary destination, and additional backward contamination requirements apply to hardware with the potential to return to Earth (e.g., as part of a sample return mission). Technologies intended for use at/around Mars, Europa (Jupiter), and Enceladus (Saturn) must be developed so as to ensure compliance with relevant planetary protection requirements. Constraints could include surface cleaning with alcohol or water, and/or sterilization treatments such as dry heat (approved specification in NPR 8020.12; exposure of hours at 115C or higher, non-functioning); penetrating radiation (requirements not yet established); or vapor-phase hydrogen peroxide (specification pending). For the 2011 program year, we are encouraging proposals for two new subtopics, S1.10 for technologies in support of atomic interferometry to enable precise targeting, pointing, and tracking and S1.11 for technologies in support of the specific needs of planetary orbital remote sensing instruments. A key objective of this SBIR topic is to develop and demonstrate instrument component and subsystem technologies that reduce the risk, cost, size, and development time of SMD observing instruments and to enable new measurements. Proposals are sought for development components that can be used in planned missions or a current technology program. Research should be conducted to demonstrate feasibility during Phase I and show a path towards a Phase II prototype demonstration. The following subtopics are concomitant with these objectives and are organized by technology.

Subtopics

S1.01 Lidar and Laser System Components

Lead Center: LaRC

Participating Center(s): GSFC, JPL

Accurate measurements of atmospheric parameters with high spatial resolution from ground, airborne, and space-based platforms require advances in the state-of-the-art lidar technology with emphasis on compactness, efficiency, reliability, lifetime, and high performance. Innovative lidar component technologies that directly address the measurements of the atmosphere and surface topography of the Earth, Mars, the Moon, and other planetary bodies will be considered under this subtopic. Frequency-stabilized lasers for a number of lidar applications such as CO₂ concentration measurements as well as for highly accurate measurements of the distance between spacecraft for gravitational wave astronomy and gravitational field planetary science are among technologies of interest. Single longitudinal mode lasers and optical filter technologies for high spectral resolution lidars are also of interest. Proposals relevant to the development of components that can be used in planned missions or current technology programs are highly encouraged. Examples of planned missions and technology programs are: Laser Interferometer Space Antenna (LISA), Doppler Wind Lidar, Lidar for Surface Topography (LIST), Active Sensing of CO₂ Emissions over Nights, Days, and Seasons (ASCENDS), and Aerosols-Clouds-Ecosystems (ACE). In addition, innovative technologies relevant to the NASA sub-orbital programs, such as Unmanned Aircraft Systems (UAS) and Venture-class focusing on the studies of the Earth climate, carbon cycle, weather, and atmospheric composition, are being sought.

Research should be conducted to demonstrate technical feasibility during Phase I and show a path toward a Phase II prototype demonstration. For the PY11 SBIR Program, we are soliciting only the specific component technologies described below:

- Highly efficient solid state laser transmitter operating in the 1.0 μm - 1.7 μm range with wall-plug efficiency of greater than 25%. The proposed laser must show path in maturing to space applications. The laser transmitter must be capable of single frequency with narrow spectral width capable of generating transform-limited pulses, and M2 beam quality 70% are of interest. Although amplifiers such as planar waveguide or grazing incidence have been shown to generate optical efficiencies >50%, much higher efficiency is needed for space applications. Proposed solutions should incorporate electronics packages suitable for use in aircraft demonstration (i.e., small, well packaged, low power).
- Narrow linewidth laser transmitters and receiver components (seeds, fiber amplifiers, modulators, drivers, etc.) supporting laser absorption spectroscopy applications in the 1.3, 1.5 and 2.0 micron wavelength regimes. The lasers and components should be tunable by several nm, support amplitude modulation at frequencies from 50 KHz to 10 MHz, have frequency stability of less than 3 MHz, and be capable of mixing and simultaneous transmission of multiple lines for differential absorption measurements without introducing non-linear mixing effects. Techniques for cloud and aerosol discrimination are also sought.
- Efficient and compact single mode solid state or fiber lasers operating at 1.5 and 2.0 micron wavelength regimes suitable for direct detection differential absorption lidar (DIAL) and coherent lidar applications. These lasers must meet the following general requirements: pulse energy 0.5 mJ to 50 mJ, repetition rate 10 Hz to 10 kHz, and pulse duration of either 10 nsec or 200 nsec regimes.
- Low noise detectors operating in 1.5 to 2.0 micron wavelength for use in differential absorption lidar (DIAL) instruments measuring CO₂ concentration. Large area (>250 micron dia.) detectors with high quantum efficiency (>75%), noise equivalent power of less than 2×10^{-14} W/Hz^{1/2}, and bandwidth greater than 50 MHz are being sought. Additionally, arrays of 4x4 PIN detectors for coherent detection and avalanche photodiodes with a minimum gain of 10 are of interest. Other detectors relevant to NASA programs are low-noise, high quantum efficiency devices operating at 355 nm, 532 nm, and 1064 nm with gain greater than or equal to 100. These detectors must be linear or correctable for incident power levels ranging from 0.1 pW to 50 nW and have bandwidths exceeding 200 MHz with excellent transient recovery.
- Novel compact solid-state UV laser for Ozone DIAL measurements from surface and airborne UAS science platforms that also enables technology demonstrations for future spaceborne measurements are needed. New and novel technology developments that enable solid-state UV lasers operating within the 280 nm -

320 nm wavelength range (305-320 nm for the spaceborne lasers) generating laser pulses of up to 1 KHz rate and average output power greater than 1 Watt. Operation at two distinct wavelengths separated by 10 nm to 15 nm is required for the Ozone measurements. Scalability of the laser design to power levels greater than 10 W for space deployment is important.

- Novel scanning telescope capable of scanning over 360 degrees in azimuth with nadir angle fixed in the range of 30 to 45 degrees. Clear apertures scalable to 1 m, good optical performance (although diffraction limited performance is not necessary), and high optical efficiency are desired, as is ability to operate at multiple wavelengths from 1064 nm to 355 nm. Optical materials (e.g., substrates and coatings) and components should be space qualifiable. Phase II should result in a prototype unit capable of demonstration in a high-altitude aircraft environment, with aperture on the order 8 inches. Due to issues with spacecraft momentum compensation and previous investments, concepts for large articulating telescopes will not be considered responsive to this request, nor will holographic substrates.
- Flash Lidar Receiver for planetary landing application with at least 128X128 pixels capable of generating 3-dimensional images and detection of hazardous terrain features, such as rocks, craters and steep slopes from at least 1 km distance. The receiver must include real-time image processing capability with 30 Hz frame rate. Embedded image enhancement and classification algorithms are highly desirable. Proposals for low noise Avalanche Photodiode (APD) arrays with 256x256 pixels format suitable for use in Flash Lidar receiver will be also considered. The detector array must operate in the 1.06 to 1.57 micron region and be able to detect laser pulses with 6 nsec in duration. The array needs to achieve greater than 90% fill factor with a pitch size of 50 to 100 microns with provisions for hybridization with an Integrated Readout Circuit (ROIC).

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

S1.02 Active Microwave Technologies

Lead Center: JPL

Participating Center(s): GSFC, LaRC

NASA employs active sensors (radars) 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 and for planetary landing. We are seeking proposals for the development of innovative technologies to support future radar missions and applications. The areas of interest for this call are listed below:

Low-Loss, Dual-Polarized W-band Radiator Array With MMIC Integration

- Frequency: 94 GHz.
- Radiation Efficiency: >70%.
- Polarization isolation = 25 dB.
- Interconnect loss:

-
- No dielectric materials.

These radiator and interconnect technologies are critical to achieving the density and RF signal performance required for scanning millimeter-wave array radars.

High Performance W-band Millimeter-wave Transmit/Receive MMICs

- Frequency: 94 GHz.
- Transmit Power: >1W, TX PAE: >25%.
- TX Gain >20 dB.
- RX NF:
- RX Gain: > 20 dB.
- RX input power tolerance >250mW
- Monolithic integration of TR function is required to meet space constraints for high-density arrays and to reduce assembly costs.

Low-Cost mm-wave Beamforming MMIC Receiver

- Frequencies: 35.6, 94 GHz.
- Input Channels: 16.
- Phase shifter: 360 deg.
- 5-bits, Output IF: 1 channel @
- Bandwidth: >100 MHz.
- Serial phase update rate: >10kHz for all channels.

Millimeter-wave phased arrays require integration of a large number of phase shifters in a small space, leading to impossible interconnect requirements. Integrating many channels vastly reduces the number of interconnects required, achieving the needed array density.

High-Speed Radar Distributed Target Simulator

Given model inputs of radar parameters, radar/target geometries and distributed target properties, generates simulated radar echo signals. For some missions, a single scene would take approximately a year to simulate on a single processor and global simulations are not feasible. It is critical to reduce simulation time for global validation of on-board processor. The simulator should be able to produce and store simulated returns for a product of 40 billion targets and pulses per second.

Low-Jitter Programmable Delay/Divide Clock Distribution IC

- Total Jitter:
- Fanout: ≥ 10 .
- Prog. Delay: up to 192 ns.
- Delay Resolution: 2 ps.
- Divide by: 2 or 3.
- Temp. range: -40 to +80C.
- Implemented in radiation-hard technology.

This part is critical to high-speed real-time digital beamforming and processing required for next generation of Earth and space based high-resolution sensors.

L-band Array Antennas

- Compact, lightweight arrays (
- Dual-polarization.
- High polarization isolation (> 25 dB) for airborne and spaceborne radar applications.
- W-band (94 GHz).
- Ka-band (35GHz).
- Low loss (
- High speed (transition time
- Peak power ≥ 1.5 kW.
- Average power ≥ 75 W.
- Isolation ≥ 25 dB.

Fast Turn on and Turn Off Power Amplifiers

To increase solid state radar sensitivity NASA requires compact and high efficiency ($> 50\%$) power amplifiers (> 25 W peak.) in P, L, and X-bands that can be switched off during the receive period to prevent noise leakage.

• Switch on and switch off times under 1 μ s, stable amplitude (

Small Radar Packaging Concepts for Unmanned Aerial Systems (UAV)

Miniaturization of radar and radiometer components while maintaining power and performance is a requirement for UAV science. Seeking high isolation switched filters and phase shifters for interleaved radar/radiometer operation at multiple channels, LNAs, stable noise sources, circulators, and solid-state power amplifiers for operation at L-, C-, X-, and Ku-Bands.

Real Time Adaptive Waveform-Agile Radars for Very Weak Targets Detection in Strong Clutter/Noise Environment for Remote Sensing

NASA seeks novel ideas in advancing software and hardware technology of real time adaptive waveform-agile radars for detection and exploration of weak targets hidden behind strong targets (such as sub-surface planetary surfaces). -25 dB signal-to-clutter, range resolution

S1.03 Passive Microwave Technologies

Lead Center: GSFC

Participating Center(s): JPL

NASA employs passive microwave and millimeter-wave instruments for a wide range of remote sensing applications from measurements of the Earth's surface and atmosphere (http://www.nap.edu/catalog.php?record_id=11820) to cosmic background emission. Proposals are sought for the development of innovative technology to support future science and exploration missions employing 450 MHz to 5 THz sensors. Technology innovations should either enhance measurement capabilities (e.g., improve spatial, temporal, or spectral resolution, or improve calibration accuracy) or ease implementation in spaceborne missions (e.g., reduce size, weight, or power, improve reliability, or lower cost). While other concepts will be entertained, specific technology innovations of interest are listed below for missions including decadal survey missions (<http://www.nap.edu/catalog/11820.html>) such as PATH, SCLP, and GACM and the Beyond Einstein Inflation Probe (Inflation Probe - cosmic microwave background, <http://science.gsfc.nasa.gov/660/research/>):

- High emissivity (>40 dB return loss) surfaces/structures for use as onboard calibration targets that will reduce the weight of aluminum core targets, while reliably improving the uniformity and knowledge of the calibration target temperature. Earth Science Decadal survey missions which apply: SCLP and PATH.
- Room temperature LNAs for 165 to 193 GHz with low 1/f noise, and a noise figure of 6.0 dB or better; and cryogenic LNAs for 180 to 270 GHz with noise temperatures of less than 150K. Earth Science Decadal Survey missions that apply: PATH, GACM and future Earth Venture Class low cost millimeter wave instruments.
- Low noise amplifiers, MMIC or discrete transistor, at frequencies below 2 GHz, operating at room temperature or thermoelectrically cooled, and giving noise figures below 0.25 dB (17K noise temperature). Amplifier should have S11 25 dB, over an octave band, and be stable for any generator impedance at any frequency. For highly red shifted hydrogen spectroscopy for early universe cosmology.
- Local Oscillator technologies for 2nd generation instruments for SOFIA, next generation HIFI, and suborbital instruments (GUSSTO). This can include: GaN based frequency multipliers that can work in the 200-400 GHz range (output frequency) with input powers up to 1 W. Graphene based devices that can work as frequency multipliers in the frequency range of 1-3 THz.
- Enabling technology for ultra-stable microwave noise references (three or more) embedded in switched network with reference stability (after temperature correction) to within 0.01K/year. Applies to: PATH, SCLP, GACM, SWOT.
- RFI mitigation approaches employing channelizers for broadband (>100MHz) radiometers at frequencies

between 1 and 40 GHz. These systems should demonstrate both detection and removal approaches for mitigating RFI. Earth Science Decadal Survey missions that apply: SCLP, SWOT.

- Multi-Frequency and/or multi-Beam Focal Plane Arrays (FPA) as a primary feed for reflector antennas. Earth Science Decadal Survey missions that apply: PATH, SCLP, SWOT.
- In addition to the technologies listed above, proposals for innovative passive microwave instruments for a wide range of remote sensing applications from measurements of the Earth's surface and atmosphere to cosmic background emission would also be welcome.

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

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

Lead Center: JPL

Participating Center(s): ARC, GSFC, KSC, 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 for Earth science (<http://www.nap.edu/catalog/11820.html>), planetary science (<http://www.nap.edu/catalog/10432.html>), and astronomy and astrophysics (<http://www.nap.edu/books/0309070317/html/>).

The following technologies are of interest for the Scanning Microwave Limb Sounder (<http://mls.jpl.nasa.gov/index-cameo.php>) on the Global Atmospheric Composition Mission, Single Aperture Far Infrared (SAFIR) Observatory (<http://safir.jpl.nasa.gov/technologies.shtml>), the SOFIA (Stratospheric Observatory for Infrared Astronomy) airborne observatory (<http://www.sofia.usra.edu/>), and Inflation Probe (cosmic microwave background, <http://science.gsfc.nasa.gov/660/research/>):

- Radiation tolerant digital polyphase filterbank back ends for sideband separating microwave spectrometers. Requirements are >5GHz instantaneous bandwidth per sideband, 2 MHz resolution, low power (
- Improved submillimeter mixers for frequencies >2 THz are needed for heterodyne receivers to fly on SOFIA. Minimum noise temperatures for cryogenic operation and instantaneous bandwidths >5 GHz are key parameters.
- Large format (megapixel) broadband detector arrays in the 30 to 300 micron wavelength range are needed for SAFIR. These should offer background limited operation with cooled (5 K) telescope optics, and have minimal power dissipation at low temperatures. Low power frequency multiplexers are also of interest for readout of submm bolometer arrays for SAFIR and Inflation Probe.

High performance sensors and detectors that can operate with low noise under the severe radiation environment (high-energy electrons, =1 megarad total dose) anticipated during the Europa Jupiter System Mission (EJSM) are of interest (see the Jupiter Europa Orbiter Mission Study 2008: Final Report, <http://opfm.jpl.nasa.gov/library/>).

Notional instruments include visible and infrared cameras and spectrometers, a thermal imager and laser altimeter. Devices can be radiation hardened by design and/or process:

- Hardened visible imaging arrays with low dark currents even in harsh radiation environments, line or framing arrays suitable for use in pushbroom and framing cameras. Detectors include CCDs (n or p-channel), CMOS imagers, PIN photodiode hybrids, etc.
- Hardened infrared imaging arrays with a spectral range of 400 to 5000 nm with high quantum efficiency and low dark current, as well as compatible radiation hardened CMOS readouts. These devices could include substrate removed HgCdTe hybrid focal plane arrays responsive from 400 to 2500 nm and IR only focal plane arrays responsive from 2500 nm to 5000 nm.
- High-speed radiation hardened avalanche photodiodes that respond to a 1.06 micron laser beam suitable for use in time of flight laser rangefinders. Devices should have high and stable gain with lower dark current in harsh radiation environments.
- Radiation hardened detectors suitable for use in uncooled thermal imagers that respond to spectral bands ranging from 8 to 100 microns. Detectors could include thermopile or microbolometer small line arrays.

Technologies are needed for active and passive wave front and amplitude control, and relevant missions include Extra solar Planetary Imaging Coronagraph (EPIC), and other coronagraphic missions such as Terrestrial Planet Finder (http://planetquest.jpl.nasa.gov/TPF/tpf_index.cfm) and Stellar Imager (<http://hires.gsfc.nasa.gov/si/>):

- Spatial Filter Array (SFA) consisting of a monolithic array of up to 1200 coherent, polarization preserving, single mode fibers, or custom waveguides, that operate with minimal coupling losses over a large fraction of the spectral range from 0.4 - 1.0 microns. The SFA should have input and output lenslet with each pair mapped to a single fiber or waveguide and such that the lenslets maintain path length uniformity to
- MEMS based segmented deformable mirrors consisting of arrays of up to 1200 hexagonal packed segments with strokes over the range of 0 to 1.0 microns, quantized with 16-bit electronics with segment level stabilities of 0.015 nm rms (1-bit) over 1 hour intervals. Segments should be flat to 2 nm rms or better and the substrate flat to 125 nm or better and high uniformity of coatings (1% rms).

Thermal imaging, LANDSAT, all IR Earth observing missions:

- Development of uncooled or passively cooled detectors with NE $\hat{\#}$ 148;T30% in the 6-14 $\hat{\#}$ 148;T30 μ m infrared wavelength region. Formats ~ 640 x 512 with a goal to exceed 3,000 pixel linear dimension. Also, work in promising new technologies such as InAs/GaSb type-II strain layer superlattices.

The Geo-CAPE Mission

Wide Field 0.26-15 $\hat{\#}$ 148;T30 μ m and Narrow Field 0.35-2.1 $\hat{\#}$ 148;T30 μ m. PanFTS 60 $\hat{\#}$ 148;T30 μ m pixel pitch, 256 X 256 format with in-pixel ADC digitization ROIC, 16-bit precision, 16kHz frame rate.

S1.05 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: IXO: <http://htxs.gsfc.nasa.gov/index.html>, future planetary programs: http://nasascience.nasa.gov/planetary-science/mission_list, Earth Science Decadal missions: <http://www.nap.edu/catalog/11820.html>.
- Helio Probes: http://nasascience.nasa.gov/heliophysics/mission_list.

Specific technology areas are listed below:

- 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 (
- Large format UV and X-ray focal plane detector arrays: micro-channel plates, CCDs, and active pixel sensors (>50% QE, 100 Megapixels,
- Advanced Charged Couple Device (CCD) detectors, including improvements in UV quantum efficiency and read noise, to increase the limiting sensitivity in long exposures and improved radiation tolerance. Electron-bombarded CCD and CMOS detectors, including improvements in efficiency, resolution, and global and local count rate capability. In the X-ray, we seek to extend the response to lower energies in some CCDs, and to higher, perhaps up to 50 keV, in others. Possible missions are future GOES missions and International X-ray Observatory.
- Wide band gap semiconductor, radiation hard, visible and solar blind large format imagers for next generation hyperspectral Earth remote sensing experiments. Need larger formats (>1Kx1K), much higher

resolution (

- Solar blind, compact, low-noise, radiation hard, EUV and soft X-ray detectors are required. Both single pixels (up to 1cm x 1cm) and large format 1D and 2D arrays are required to span the 0.05nm to 150nm spectral wavelength range. Future GOES missions post-GOES R and T.
- Visible-blind SiC Avalanche Photodiodes (APDs) for EUV photon counting are required. The APDs must show a linear mode gain $>1E6$ at a breakdown reverse voltage between 80 and 100V. The APD's must demonstrate detection capability of better than 6 photons/pixel/s at near 135nm spectral wavelength. See needs of National Research Council's Earth Science Decadal Survey (NRC, 2007): Tropospheric ozone.
- 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 ($\sim 10^6$), low noise, fast time response (2 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.
- 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 JEM-EUSO and OWL.
- Large area (m²) X-ray detectors with 85%.
- Improve beyond CdZnTe detectors using micro-calorimeter arrays at hard X-ray, low gamma-ray bands (above 10 keV and Below 80 keV).
- Improvement of spatial resolution for the hard x-ray band up to 10 and ultimately to 5 arcsecond resolution.

Future instrument is a Phased-Fresnel X-ray Imager.

S1.06 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 Solar Orbiter, Solar Probe Plus, ONEP, SEPAT, INCA, CISR, DGC, HMag 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:

- Self-calibrating scalar-vector magnetometer for future Earth and space science missions. Performance

goals: dynamic range: $\hat{\Delta}\pm 100,000$ nT, accuracy with self-calibration: 1 nT, sensitivity: 5 pT $\hat{\Delta}\#149$; Hz $\hat{\Delta}\#150$; $1/2$ (max), max sensor unit size: 6 x 6 x 12 cm, max sensor mass: 0.6 kg, max electronics unit size: 8 x 13 x 5 cm, max electronics mass: 1 kg, and max power: 5 W operation, 0.5 W standby, including, but not limited to $\hat{\Delta}\#147$; sensors on a chip $\hat{\Delta}\#148$;

- High-magnetic-field sensor that measures magnetic field magnitudes to 16 Gauss with an accuracy of 1 part in 10⁵.
- Strong, lightweight, thin, compactly-stowed electric field booms possibly using composite materials that deploy sensors to distances of 10-m or more.
- Cooled (-60 $\hat{\Delta}$ C) solid state ion detector capable of operating at a floating potential of -15 kV relative to ground.
- Low noise magnetic materials for advanced magnetometer sensors with performance equal to or better than those in the 6-81.3 Mo-Permalloy family.
- Radiation hardened ASIC spectrum analyzer module that determines mass spectra using fast algorithm deconvolution to produce ion counts for specific ion species.
- Low-cost, low-power, fast-stepping (= 50- $\hat{\Delta}$ μ s), high-voltage power supplies 5-15 kV.
- Low-cost, efficient low-power power supplies (5-10 V).
- Low-power charge sensitive preamplifiers on a chip.
- High efficiency (5% or greater) conversion surfaces for low energy neutral atom conversion to ions possibly based on nanotechnology.
- Miniature low-power, high efficiency, thermionic cathodes, capable of 1-mA electron emission per 100-mW $\hat{\Delta}$ heater power with emission surface area of 1-mm² and expected lifetime of 20,000 hours.
- Long wire boom (= 50 m) deployment systems for the deployment of very lightweight tethers or antennae on spinning spacecraft.
- Systems to determine the orthogonality of a deployed electric/magnetic field boom system in flight (for use with three-axis rigid 10-m booms) accurate to 0.10 $\hat{\Delta}$ dynamic.
- Die-level optical interferometer, micro-sized, for measuring Fabry-Perot plate spacing with 0.1-nm accuracy.
- Diffractive optics (photon sieves) of 0.1-m aperture or larger with micron-sized outer Fresnel zones for high-resolution EUV imaging.

Developing near-real time data-assimilative models and tools, for both solar quiet and active times, which allow for precise specification and forecasts of the space environment, beginning with solar eruptions and propagation, and including ionospheric electron density specification.

S1.07 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 (as well as components) further advance the mission goals of NASA through enabling performance (and ultimately science gathering) capabilities of flight detectors and sensors. Presently, there are six potential investment areas that NASA is seeking to expand state of the art capabilities in for possible use on future programs such as GEOID, SPICA, WFIRST (<http://wfirst.gsfc.nasa.gov/>), Space Infrared Interferometric Telescope (SPIRIT), Submillimeter Probe of the Evolution of Cosmic Structure (SPECS), as well as, the Planetary and Europa Science missions (<http://www.nasa.gov/multimedia/podcasting/jpl-europa20090218.html>). The topic areas are as follows:

- Extremely Low Vibration Cooling Systems - Examples of such systems include Joule Thompson, pulse tube and turbo Brayton cycles. Desired cooling capabilities sought are on the order of 40 mW at 4K or 1 W at 50K. Present state of the art capabilities display
- Advanced Magnetic Cooler Components - An example of an advanced magnetic cooler might be Adiabatic Demagnetization Refrigeration systems. Specific components sought include:
 - Low current superconducting magnets.
 - Active/Passive magnetic shielding (3-4 Tesla magnets).
 - Single or Polycrystalline magnetocaloric materials (3).
 - Superconducting leads (10K - 90K) capable of 10 amp operation with 1 mW conduction.
 - 10 mK scale thermometry.
- Continuous Flow Distributed Cooling Systems - Distributed cooling provides increased lifetime of cryogen fluids for applications on both the ground and spaceborne platforms. This has impacts on payload mass and volume for flight systems which translate into costs (either on the ground, during launch or in flight). Cooling systems that provide continuous distributed flow are a cost effective alternative to present techniques/methodologies. Cooling systems that can be used with large loads and/or deployable structures are presently being sought after.
- Heat Switches - Heat switches for operating ranges of
- Highly Efficient Magnetic and Dilution Cooling Technologies - The desired temperature range for a proposed system is
- Low Input Power (

S1.08 In Situ Airborne, Surface, and Submersible Instruments for Earth Science

Lead Center: GSFC

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

New, innovative, high risk/high payoff approaches to miniaturized and low cost instrument systems are needed to enhance Earth science research capabilities. Sensor systems for a variety of platforms are desired, including those designed for remotely operated robotic aircraft, surface craft, submersible vehicles, balloon-based systems (tethered or free), and kites. Global deployment of numerous sensors is an important objective, therefore cost and

platform adaptability are key factors.

Novel methods to minimize the operational labor requirements and improve reliability are desired. Long endurance (days/weeks/months) autonomous/unattended instruments with self/remote diagnostics, self/remote maintenance, capable of maintaining calibration for long periods, and remote control are important. Use of data systems that collect geospatial, inertial, temporal information, and synchronize multiple sensor platforms are also of interest.

Priorities include:

- Atmospheric measurements in the troposphere and lower stratosphere: Aerosol Optical and Microphysical Properties, Cloud Properties and Particles, Water, Chemical Composition, i.e., Carbon Dioxide ($^{12}\text{CO}_2$ and $^{13}\text{CO}_2$), Carbon Monoxide, Methane, Nitrogen Dioxide, Hydrogen Peroxide, Formaldehyde, Bromine Oxides, Ozone, and Three-dimensional Winds and Turbulence.
- Oceanic, coastal, and fresh water measurements including inherent and apparent optical properties, temperature, salinity, currents, chemical and particle composition, sediment, and biological components such as nutrient distribution, phytoplankton, harmful algal blooms, fish or aquatic plants.
- Hyperspectral radiometers for above water (340 -1400 nm) and shallow water (340 - 900 nm) profiling: high frequency measurements of sky-radiance, sun irradiance, water leaving radiance, and bidirectional reflectance, with solar-tracking and autonomous operation.
- Instrument systems for hazardous environments such as volcanoes and severe storms, including measurements of Sulfur Dioxide, Particles, and Precipitation.
- Land Surface characterization geopotential field sensors, such as gravity, geomagnetic, electric, and electromagnetic.
- Urban air-quality profiler: ground based, compact, inexpensive, (laser based) systems suited for unattended measurement (e.g., ozone) profiles of the troposphere.

Instrument systems to support satellite measurement calibration and validation observations, as well as field studies of fundamental processes are of interest. A priority is applicability to NASA's research activities such as the Atmospheric Composition and Radiation Sciences programs, including Airborne Science support thereof, as well as the Applied Sciences, and Ocean Biology and Biogeochemistry programs. Support of algorithm development for the Geostationary Coastal and Air Pollution Events (Geo-CAPE) mission is also a priority. Development of instruments that will provide near-term benefit to the NASA science community is a priority - working prototypes delivered by the completion of Phase II are desired.

S1.09 In Situ Sensors and Sensor Systems for Lunar and Planetary Science

Lead Center: JPL

Participating Center(s): ARC, GRC, GSFC, JSC, KSC, LaRC, 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 Council's, Vision and Voyages for Planetary Science in the Decade 2013-2022 <http://solarsystem.nasa.gov/2013decadal/>. Technologies which support NASA's Planetary Flagship mission candidates (Mars 2018, JEO, & Uranus Orbiter & Probe Mission), New Frontiers Mission candidates (Comet Surface Sample Return, Lunar South Pole-Aitken Basin Sample Return, Saturn Probe, Trojan Tour & Rendezvous, Venus In-Situ Explorer, Io Observer, and the Lunar Geophysical Network) 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 the Europa-Jupiter System Mission (JEO) and Io Observer are sought.
- 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.

- 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.

S1.10 Atomic Interferometry

Lead Center: GSFC

Participating Center(s): JPL

"Atom/BEC (Bose Einstein Condensate) Interferometry for space applications"

Sensors based on Atom/BEC Interferometry are attractive because:

Atoms have internal and external degrees of freedom that are used to optimize detection of desired signal. These states are easily manipulated by external magnetic and electric fields. Different Atoms possess a wide range of different properties that offer the experimentalists an opportunity to address a wide range of problems. Laser Cooling and Atom trapping enable experimentalists long measurement times that translates to high precision Interferometry measurements. Generally these measurements are done in the inertial frame of the atoms, which is mostly isolated from the environment.

The Atom/BEC Interferometry based sensors of interest to NASA are:

- Accelerometers.
- Gyros.
- Inertial Measurement Units for navigation.
- Gravity Gradient sensors (Gravimeters and gradiometers).
- Optical metrology instrumentation.
- Large area matter wave interferometers.
- Precise clocks for space applications.
- Higher sensitivity space magnetometers.

These are subset of the possible sensors based on this technology that has direct applications to GRACE II, Gravity Wave Science Mission, and small explorer missions. In general, Atom/BEC Interferometry enables much higher precision of the phase than optical Interferometers.

This subtopic seeks concepts and prototypes of devices below:

- Compact Low Noise accelerometers are Vital to gravity mapping, gravity wave detections, and navigation. Noise of $5E-10$ (m/s^2 Hz^{-1/2}) over frequency range of $1E-05$ Hz to $1E+00$ Hz are required.
- Compact Low Noise gyroscopes based on Atom/BEC Interferometry with better than 0.01deg/hour accuracy and better than 0.001deg/sqrt(Hz) low drift.

The criteria for evaluations also include:

- Lowest temperature achieved.
- Number of Atoms in the gas.

Robustness of the design /prototype to Space environments.

S1.11 Planetary Orbital Sensors and Sensor Systems (POSSS)

Lead Center: JPL

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