NASA SBIR 2010 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 the 2010 program year, we are actively encouraging proposal submissions for subtopic S1.10 that solicits technology for geodetic instruments and instruments to enable global navigation and very long baseline interferometry. 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 CO$_2$ 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. Innovative technologies that can expand current measurement capabilities to spaceborne or Unmanned Aerial Vehicle (UAV) platforms are particularly desirable. Development of components that can be used in planned missions or current technology programs is highly encouraged. Examples of planned missions and technology programs are: Deformation, Ecosystem Structure and Dynamics of Ice (DESDynI), Laser Interferometer Space Antenna (LISA), Doppler Wind Lidar, Lidar for Surface Topography (LIST), or Active Sensing of CO$_2$ Emissions over Nights, Days, and Seasons (ASCENDS).

Research should be conducted to demonstrate technical feasibility during Phase I and show a path toward a Phase II prototype demonstration. For the PY10 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 M$^2$ 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).

- Efficient and compact single mode solid state or fiber lasers operating at 1.5 and 2.0 micron wavelength regimes suitable for direct detection 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 1 kHz, and pulse duration of either 10 nsec or 200 nsec regimes.

- Single frequency semiconductor or fiber laser generating CW power greater than 50 mW in 1.5 or 2.0 micron wavelength regions with less than 10 kHz linewidth tunable over several nanometers. Frequency modulation with about 5 GHz bandwidth over 1 msec period is highly desirable.

- Novel compact solid-state UV laser for Ozone DIAL measurements operating within the 300 nm - 320 nm wavelength range 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.

- High quantum efficiency, low-noise detectors operating at 355, 532, and 1064 nm suitable for space applications. Detectors must have an active area diameter greater than 0.5 mm and be capable of temporal resolutions less than 0.67 microsecond. Detectors must be linear over 4 orders of magnitude in dynamic range and suitable for analog detection schemes. Associated electronics including amplifiers and filters with matching impedance are desired.

- 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**

NASA employs active sensors (radars) for a wide range of remote sensing applications (for example, see: [http://www.nap.edu/catalog/11820.html](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:

- **High -density low- loss millimeter-wave packaging and interconnects** for Advanced Cloud and Precipitation Radars and Mars Landing Radars. These packing and interconnect technologies are critical to achieving the density and RF signal performance required for scanning millimeter-wave array radars.
  - Frequency: 35 - 160 GHz
  - Interconnect loss:
  - Line loss:

- **High -speed, low- power analog -to -digital converters (ADCs) and digital -to -analog Converters (DACs)** for Advanced SAR, Advanced Interferometer for Surface monitoring, ice topography, and hydrology. Digital beam forming (DBF) systems require an array of ADCs. The power consumption of current ADC chips prohibits implementation of large DBF arrays. Furthermore, large arrays require true time delays, which can be implemented using low- power high speed ADCs and DACs. Ideal ADCs are modeled with perfectly linear input-output transfer functions. In addition to seeking novel devices, we are seeking innovative methods to correct for both differential and integral nonlinearities (DNL and INL) in ADCs to increase ADC ENOB. Proposed methods should be adaptable to a wide range of sampling rates, input frequencies, and device types; furthermore, they should be amenable to realtime operation on an FPGA.
  - Bandwidth: 1.5 GHz
- Sampling rate: 500 MS/s
- ENOB: 12 bits
- Power consumption: 100 mW

- **Compact True-Time Delay Beamformers** for Advanced Cloud and Precipitation Radars, Mars Landing Radars, and Advanced SAR. Large, wideband scanned arrays require true-time-delay beamforming to avoid beam squint over operating frequency range.
  - Center Frequencies: 35, 94, 160 GHz
  - Inputs: 128
  - Loss:
  - Mass:

- **Dual frequency Millimeter-wave transmit/receive MMICs** for Advanced SAR, Advanced Interferometer for surface monitoring, ice topography, hydrology, Advanced Cloud and Precipitation Radars, and Mars Landing Radars. Monolithic integration of TR function is required to meet space constraints for high-density arrays and to reduce assembly costs.
  - Frequencies: 35/94 GHz
  - Transmit Power: 5W@35GHz, 1W@94 GHz
  - TX PAE: >25%
  - TX Gain >20 dB
  - TX/RX Switch Isolation: 40 dB
  - RX NF:
  - RX Gain: > 20 dB
  - Phase Shifter: 360 deg, 6-bits

- **Ultra - high efficiency P-band and L - band power amplifiers** for Advanced SAR / Interferometers, Geosynchronous SAR for earthquake monitoring, and Mars subsurface sounding. Using lower efficiency amplifiers in large arrays leads to much higher power system requirements and thermal management challenges.
  - Frequency: 400-500 MHz, 1.2-1.3 GHz
  - Efficiency: >85%

- **High Efficiency Ka-band and W-band Vacuum Device Amplifiers** for Advanced Cloud and Precipitation
Radars, Advanced SAR, Telecommunications. Using lower efficiency amplifiers leads to much higher power system requirements and thermal management challenges.

- Center Frequencies: 35, 94 GHz
- Power output: 1-5 kW (for pulsed operation); 25 W (for CW operation)
- Efficiency: >50%

- **Frequency selective surface at Ka and W-band** for Clouds and Precipitation, ACE Decadal Survey Mission. A Ka/W frequency selective surface will enable the development of compact dual frequency radar using a shared single aperture antenna, significantly reducing the dual radar beam pointing error, and radar development cost.
  
  - High reflection at Ka-band (35GHz) and high pass (low loss) at W-band (94 GHz).
  - Power handling requirement: 2 kW (peak), 100 W (average)

- **FPGA based Radar Pulse Compression Technology and techniques** for Clouds and Precipitation, and ACE Decadal Survey Mission. Cloud and precipitation radars require very high system sensitivity that can be achieved using pulse compression. However, conventional pulse compression techniques cannot be used in downward-looking spaceborne and airborne radar applications due to poor range sidelobe performance.
  
  - Achieves low range side lobe levels

- **Radar Receiver Protector** for Clouds and Precipitation and ACE Decadal Survey Mission. Spaceborne and airborne cloud/precipitation radars require medium to high peak power transmitters in order to achieve the desired system sensitivity. High speed, low loss receiver protector is necessary to prevent RF damage of the receiver components.
  
  - W-band (94 GHz), Ka-band (35GHz), low loss

- **Technologies and techniques for noise assisted data analysis of I-Q ensemble detection** for Clouds and Precipitation, ACE Decadal Survey. Radar receiver technologies that mix in-phase and quadrature components of radar returns with calibrated-correlated noise references and noise assisted data analysis algorithms are sought to reduce the effects of platform motion on Doppler measurement and retrieval of hydrometeor drop size distribution. Pulse pair and spectral processing drive the need for a large aperture to reduce the effect of platform motion on Doppler estimates.

- **Multi-frequency compact, light weight electronically tunable antennas and radar systems** for Ice sheet sounding, subsurface exploration of planetary and near-Earth objects. Low, multi-frequency active radars are often used for ice sounding and subsurface exploration of planets, moons and near-Earth objects/bodies. The large size and narrow bandwidth of HF/VHF antennas and radars make them unsuitable for many applications. Compact, light weight electronically tunable antennas and radar systems will enable a range of missions.
  
  - Compact, light weight, electronically tunable antennas, and radars units to make up basic building blocks of transmission-reflection tomography radars.
- Tunable Frequency Ranges:
  - 3-30 MHz, 25-100 MHz

- VSWR:
  - Gain: >0 dBi
  - Power handling: >200W

**S1.03 Passive Microwave Technologies**

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/)

- RF (GHz to THz) MEMS switches with low insertion loss (18 dB), capable of switching with speeds of >100 Hz at cryogenic temperatures (below 5 K) for 10^8 or more cycles. Technology applies to Beyond Einstein Probe.

- MEMs variable delay line up to 40 GHz with 180 degree of phase variation at room temperature. The delay line's phase increment should be linear or with at least 16 discrete steps. Applies to: Venture class airborne instruments, SCLP.

- MMIC Low Noise Amplifiers (LNA). 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 and GACM.

- 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.

- 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.

- Broad band 180 - 270 GHz radomes for aircraft borne submillimeter remote sensing instruments.

- Multi-Frequency and/or multi-Beam Focal Plane Arrays (FPA) as a primary feed for reflector antennas. PATH, SCLP, SWOT.
• Low power >200 Mb/s 1-bit A/D converters and cross-correlators for microwave interferometers. Earth Science Decadal survey missions which apply: PATH, SCLP.

• Automated assembly of 180 GHz direct conversion I-Q receiver modules. This technology applies to both the Beyond Einstein Inflation probe and the Decadal Survey PATH concept.

• Low DC power spectrometer (channelizer) covering >500 MHz with 125 kHz resolution for planetary radiometer missions and covering 4 GHz with 1 MHz resolution for Earth observing missions. Also RFI mitigation approaches employing channelizers for broad band radiometers. Earth Science Decadal Survey mission which applies: GACM

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**

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/).


• 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 cyrogenic 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).

S1.02 Active Microwave Technologies

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

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• **High -density low- loss millimeter-wave packaging and interconnects** for Advanced Cloud and Precipitation Radars and Mars Landing Radars. These packing and interconnect technologies are critical to achieving the density and RF signal performance required for scanning millimeter-wave array radars.
  - Frequency: 35 - 160 GHz
  - Interconnect loss: <0.05 dB @35 GHz
  - Line loss: <0.1 dB/cm @35 GHz

• **High -speed, low- power analog -to -digital converters (ADCs) and digital -to -analog Converters (DACs)** for Advanced SAR, Advanced Interferometer for Surface monitoring, ice topography, and hydrology. Digital beam forming (DBF) systems require an array of ADCs. The power consumption of current ADC chips prohibits implementation of large DBF arrays. Furthermore, large arrays require true time delays, which can be implemented using low- power high speed ADCs and DACs. Ideal ADCs are modeled with perfectly linear input-output transfer functions. In addition to seeking novel devices, we are seeking innovative methods to correct for both differential and integral nonlinearities (DNL and INL) in ADCs to increase ADC ENOB. Proposed methods should be adaptable to a wide range of sampling rates, input frequencies, and device types; furthermore, they should be amenable to realtime operation on an FPGA.
  - Bandwidth: 1.5 GHz
  - Sampling rate: 500 MS/s
  - ENOB: 12 bits
  - Power consumption: 100 mW

• **Compact True-Time Delay Beamformers** for Advanced Cloud and Precipitation Radars, Mars Landing Radars, and Advanced SAR. Large, wideband scanned arrays require true-time-delay beamforming to avoid beam squint over operating frequency range.
  - Center Frequencies: 35, 94, 160 GHz
  - Inputs: 128
  - Loss: <6dB
  - Mass: < 250g

• **Dual frequency Millimeter-wave transmit/receive MMICs** for Advanced SAR, Advanced Interferometer for surface monitoring, ice topography, hydrology, Advanced Cloud and Precipitation Radars, and Mars Landing Radars. Monolithic integration of TR function is required to meet space constraints for high-density arrays and to reduce assembly costs.
  - Frequencies: 35/94 GHz
  - Transmit Power: 5W@35GHz, 1W@94 GHz
  - TX PAE: >25%
  - TX Gain >20 dB
  - TX/RX Switch Isolation: 40 dB
  - RX NF: <3 dB
  - RX Gain: > 20 dB
  - Phase Shifter: 360 deg, 6-bits

• **Ultra - high efficiency P-band and L - band power amplifiers** for Advanced SAR / Interferometers, Geosynchronous SAR for earthquake monitoring, and Mars subsurface sounding. Using lower efficiency amplifiers in large arrays leads to much higher power system requirements and thermal management challenges.
  - Frequency: 400-500 MHz, 1.2-1.3 GHz
  - Efficiency: >85%
• **High Efficiency Ka-band and W-band Vacuum Device Amplifiers** for Advanced Cloud and Precipitation Radars, Advanced SAR, Telecommunications. Using lower efficiency amplifiers leads to much higher power system requirements and thermal management challenges.
  - Center Frequencies: 35, 94 GHz
  - Power output: 1-5 kW (for pulsed operation); 25 W (for CW operation)
  - Efficiency: >50%

• **Frequency selective surface at Ka and W-band** for Clouds and Precipitation, ACE Decadal Survey Mission. A Ka/W frequency selective surface will enable the development of compact dual frequency radar using a shared single aperture antenna, significantly reducing the dual radar beam pointing error, and radar development cost.
  - High reflection at Ka-band (35GHz) and high pass (low loss) at W-band (94 GHz).
  - Power handling requirement: 2 kW (peak), 100 W (average)

• **FPGA based Radar Pulse Compression Technology and techniques** for Clouds and Precipitation, and ACE Decadal Survey Mission. Cloud and precipitation radars require very high system sensitivity that can be achieved using pulse compression. However, conventional pulse compression techniques cannot be used in downward-looking spaceborne and airborne radar applications due to poor range sidelobe performance.
  - Achieves low range side lobe levels (<-70dB), and low SNR loss. Must include methods to compensate for all sources of noise, distortion and drift in radar transmitter and receiver.

• **Radar Receiver Protector** for Clouds and Precipitation and ACE Decadal Survey Mission. Spaceborne and airborne cloud/precipitation radars require medium to high peak power transmitters in order to achieve the desired system sensitivity. High speed, low loss receiver protector is necessary to prevent RF damage of the receiver components.
  - W-band (94 GHz), Ka-band (35GHz), low loss ( < 0.5 dB), high speed (transition time < 500 ns) switching radar receiver protector.

• **Technologies and techniques for noise assisted data analysis of I-Q ensemble detection** for Clouds and Precipitation, ACE Decadal Survey. Radar receiver technologies that mix in-phase and quadrature components of radar returns with calibrated-correlated noise references and noise assisted data analysis algorithms are sought to reduce the effects of platform motion on Doppler measurement and retrieval of hydrometeor drop size distribution. Pulse pair and spectral processing drive the need for a large aperture to reduce the effect of platform motion on Doppler estimates.

• **Multi-frequency compact, light weight electronically tunable antennas and radar systems** for Ice sheet sounding, subsurface exploration of planetary and near-Earth objects. Low, multi-frequency active radars are often used for ice sounding and subsurface exploration of planets, moons and near-Earth objects/bodies. The large size and narrow bandwidth of HF/VHF antennas and radars make them unsuitable for many applications. Compact, light weight electronically tunable antennas and radar systems
will enable a range of missions.
- Compact, light weight, electronically tunable antennas, and radars units to make up basic building blocks of transmission-reflection tomography radars.
- Tunable Frequency Ranges:
  - 3-30 MHz, 25-100 MHz
  - VSWR: <2:1
  - Length: <6m, conformable to aircraft or spacecraft
  - Gain: >0 dBi
  - Power handling: >200W

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 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 such as PATH, SCLP, and GACM and the Beyond Einstein Inflation Probe (Inflation Probe - cosmic microwave background).

- RF (GHz to THz) MEMS switches with low insertion loss (< 0.5 dB), high isolation (>18 dB), capable of switching with speeds of >100 Hz at cryogenic temperatures (below 5 K) for 10^8 or more cycles. Technology applies to Beyond Einstein Probe.
- MEMs variable delay line up to 40 GHz with 180 degree of phase variation at room temperature. The delay line’s phase increment should be linear or with at least 16 discrete steps. Applies to: Venture class airborne instruments, SCLP.
- MMIC Low Noise Amplifiers (LNA). 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 and GACM.
- 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.
- 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.
- Broad band 180 - 270 GHz radomes for aircraft borne submillimeter remote sensing instruments.
- Multi-Frequency and/or multi-Beam Focal Plane Arrays (FPA) as a primary feed for reflector antennas. PATH, SCLP, SWOT.
- Low power >200 Mb/s 1-bit A/D converters and cross-correlators for microwave interferometers. Earth Science Decadal survey missions which apply: PATH, SCLP.
- Automated assembly of 180 GHz direct conversion I-Q receiver modules. This technology applies to both the Beyond Einstein Inflation probe and the Decadal Survey PATH concept.
- Low DC power spectrometer (channelizer) covering >500 MHz with 125 kHz resolution for planetary radiometer missions and covering 4 GHz with 1 MHz resolution for Earth observing missions. Also RFI mitigation approaches employing channelizers for broad band radiometers. Earth Science Decadal Survey mission which applies: GACM

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.
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- Radiation tolerant digital polyphase filterbank back ends for sideband separating microwave spectrometers. Requirements are >5GHz instantaneous bandwidth per sideband, 2 MHz resolution, low power (<5 W/GHz), and 4 bits or higher digitization.
- 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/sil):
Uniformity of both output intensity and wave front phase, and high throughput is desired and fiber-to-fiber placement accuracies of < 1.0 microns are required with < 0.5 microns desired.

- 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).

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 Decadel Survey missions. Details of these can be found at the following URLs:

General Information on Future NASA Missions: [http://www.nasa.gov/missions](http://www.nasa.gov/missions)

Specific mission pages:


Future Planetary Programs: [http://nasascience.nasa.gov/planetary-science/mission_list](http://nasascience.nasa.gov/planetary-science/mission_list),

Earth Science Decadel Missions: [http://www.nap.edu/catalog/11820.html](http://www.nap.edu/catalog/11820.html),

Helio Probes: [http://nasascience.nasa.gov/heliophysics/mission_list](http://nasascience.nasa.gov/heliophysics/mission_list)

Specific technology areas are listed below:

- Significant improvement in wide band gap semiconductor materials, individual detectors, and detector arrays for operation at room temperature or higher for missions such as EXIST, Geo-CAPE 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 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 (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 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 Council Decadal Survey (NRC, 2007): Tropospheric ozone.

- Imaging from low-Earth orbit of air fluorescence, UV light generated by giant airshowers 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 (~106), low noise, fast time response (2 to 10 x 10 mm²). Focal plane mass must be minimized (< 5 g/cm² goal). Individual pixel readout is required. The entire focal plane detector can be formed from smaller, individual sub-arrays.

- Large area (3 m**2) 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 (m**2) X-ray detectors with 85%).

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 and instrument enabling technologies for the measurement of the physical properties of space plasmas and energetic charged particles, mesospheric - thermospheric neutral species, energetic neutral atoms created at high altitudes by charge exchange, and electric and magnetic fields in space are needed to achieve NASA’s transformational science advancements in Heliophysics. The Heliophysics discipline (http://nasascience.nasa.gov/heliophysics) has as its primary strategic goal the understanding of the physical coupling between the sun's outer corona, the solar wind, the trapped radiation in Earth's and other planetary magnetic fields, and the upper atmospheres of the planets and their moons. This understanding is of national importance not only because of its intrinsic scientific worth, but also because it is the necessary first step toward developing the ability to measure and forecast the "space weather" that affects all human crewed and robotic space assets. Improvements in particles and fields sensors and associated instrument technologies will enable further scientific advancement for upcoming NASA missions such as Solar Probe Plus (SPP) (http://nasascience.nasa.gov/missions/solar-probe), Origins of Near Earth Plasma (ONEP), Solar Energetic Particle...
Acceleration and Transport (SEPAT), Ion-Neutral Coupling in the Atmosphere (INCA), Climate Impacts of Space Radiation (CISR), Dynamic Geospace Coupling (DGC) (http://sec.gsfc.nasa.gov/sec_roadmap.htm) and planetary exploration missions. Technology developments that result in expanded measurement capabilities and a reduction in size, mass, power, and cost are necessary in order for some of these missions to proceed. Of special interest are fast high voltage stepping power supplies for charged particle analyzers, electric field booms, self calibrating vector magnetometers, and other supporting sensor electronics.

Specific areas of interest include:

- Low cost, low power, low current, high voltage power supplies which allow ultra-fast stepping (t
- Strong, lightweight, thin, compactly-stowed electric field booms possibly using composite materials that deploy sensors to distances of 10m or more and/or long wire boom (> 50 m) deployment systems for the deployment of very lightweight tethers or antennae on spinning spacecraft.
- Self-calibrating scalar-vector magnetometer for future Earth and space science missions. Performance goals are dynamic range: +/-100,000 nT, accuracy with self-calibration: 1 nT, sensitivity: 5 pT / sqrtHz, 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 “sensors on a chip”.
- Low-power cathode for detection of neutral atoms and molecules ionosphere-thermosphere and planetary investigations. Performance goals are thermionic cathodes capable of emitting 1 mA electron current with heater power less than 0.1 W. The largest dimension of the electron emitter surface should not exceed 1 mm; the entire cathode assembly should be small enough so it may be mounted in a shallow channel shaped to match the largest cathode dimension. The assembly should include robust connection leads for heater and cathode surface. Uniformity across the electron beam is not critical.

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 IXO (http://ixo.gsfc.nasa.gov/), Safir (http://safir.jpl.nasa.gov/), Spirit and Specs, Planetary and Europa science missions (Jupiter Europa Orbiter (JEO), Jupiter Ganymede Orbiter (JGO), Titan Saturn System mission (TSSM)). The topic areas are as follows:

**Extremely Low Vibration Cooling Systems**

Examples of such systems include joule thomson coolers, pulse tube coolers and turbo brayton cycles. Desired
cooling capabilities sought are on the order of 40 mW at 4K or 1W at 50K. Present state of the art capabilities display

**Advanced Magnetic Cooler Components**

Continuous ADRs can operate at 50 mK or lower, with heat sinks up to 5 K. Refrigerators with larger operating temperature range (lower cold temperature, higher heat sink temperature), having lower mass, lower (or zero) fringing magnetic fields, and/or more efficient operation are sought. In addition, technologies that improve system performance (e.g., HTS leads) are also sought. Examples of specific components 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**

More robust heat switches (e.g., operating ranges and conductance performance) are currently needed that are easy to operate and applicable to spaceflight activities. Performance capabilities include heat switches for operating ranges 5 or greater, low off conductance and simple manufacturing/operational capability.

**Highly Efficient Magnetic and Dilution Cooling Technologies**

These systems are currently limited to continuous ADR performance capabilities. Alternative technologies that provide sub-Kelvin cooling are sought.

**Low Input Power/Low Temperature Cooling Systems**

Cooling systems providing cooling capacities upwards of 0.3W at 35K with heat rejection capability to temperature sinks as low as 150K are of interest. Presently there are no cooling systems operating at this heat rejection temperature. Input powers should be limited to no greater than 20W.
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:


- 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.

- Instrument systems for hazardous environments such as volcanoes and severe storms, including measurements Sulfur Dioxide, Particles, and Precipitation.

- Land Surface characterization geopotential field sensors, such as gravity, geomagnetic, electric, and electromagnetic.

- Miniaturized instrument systems for submersible vehicles and tethered sub-surface observation systems for difficult to access water bodies associated with glaciers, including sub-glacial lakes, melt-water channels, and sub-ice shelf environments. Systems may be put down boreholes or placed on small submersibles and are required to map all aspects of cavity shape; determine sediment depth, composition, and spatial variability by acoustic or other methods; and measure water currents, temperature, thermal structure, and composition.

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 the Integrated Ocean
Observing System (IOOS) and regional coastal research is also desired.

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

Lead Center: JPL
Participating Center(s): ARC, GSFC, JSC, KSC, LaRC, MSFC

This subtopic solicits development of advanced instrument technologies and components suitable for deployment on planetary missions which access the widely diverse bodies in our solar system. These instruments 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 scientific measurements are solicited. For example missions, see http://science.hq.nasa.gov/missions/solar_system.html. For details of the specific requirements see the Planetary Science Decadal Survey white papers on NASA Assessment Groups websites (OPAG, MEPAG, VEXAG, SBAG) or the National Academy of Science site http://www8.nationalacademies.org/ssbsurvey/publicview.aspx.

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 in situ measurements of elemental, mineralogical, and organic composition of planetary materials. 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.).

- **Europa**: Technologies, 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 are sought.

- **Titan**: Methods and technologies to achieve much higher resolution and sensitivity orbital instruments with significant improvements over those flown on Cassini. 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) for use on Titan's surface. Mechanical and electrical components and subsystems that work in cryogenic (95K) environments are particularly sought after. 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 particularly solicited. Balloon instruments, such as IR spectrometers, imagers, meteorological instruments, radar sounders, air sampling mechanisms for mass
analyzers, and aerosol detectors are also required.

- **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, improved determination of atmospheric and isotopic composition, and external sample acquisition into a pressure vessel are particularly desired. Sample acquisition and processing system for multiple samples that could operate under Venus surface conditions are sought.

- **Small Bodies:** Technologies that can enable sampling from asteroids and from depth in a comet nucleus, improved in situ analysis of comets.

- **Planetary Probes:** Technologies are sought for components, sample acquisition and instrument systems that can withstand the high temperature/pressure of Saturn and Neptune atmospheric probes during entry.

Proposers are strongly encouraged to relate their proposed development to (a) NASA's future planetary exploration goals, and (b) 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.

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 Space Geodetic Observatory Components

**Lead Center:** GSFC  
**Participating Center(s):** JPL

NASA is working with the international community to develop the next generation of geodetic instruments and networks to determine the terrestrial reference frame with accuracy better than one part per billion. These instruments include Global Navigation Satellite System (GNSS) receivers, Very Long Baseline Interferometry (VLBI) systems, and Next Generation Satellite Laser Ranging (SLR) stations. The development of these instruments and the needed integrating technology will require contributions from a broad variety of optical, microwave, antenna and survey engineering suppliers. These needs include but are not limited to:

- Broadband feeds capable of receiving GNSS signals, Ka-band feeds integrated with broadband feeds, and matching antennas that meet or exceed the slewing and duty cycle requirements of the IVS VLBI2010 specifications.

- VLBI system components including > 4 Gbps recorders, phase/cable calibrators, frequency standards / distribution systems and cluster or GPU-enhanced correlators that meet or exceed the requirements of the IVS VLBI2010 specifications.
- Cost-effective data transmission for e-VLBI from a global network of 30 VLBI stations operating up to 8 Gbps.

- Compact, low mass, space-qualified for MEO, SLR retroreflector arrays with greater than 100 million square meter lidar cross section, with a design that assures the ability to determine the array center to the center of mass of the spacecraft to a millimeter.

- A very high quantum efficiency (>50% at 532nm), low instrument noise, multi-pixelated detector for SLR use in the automated tracking.

- Wide band GNSS antenna and RF front-end technologies accommodating all expected GNSS signals in the next decade, and offering at least an order of magnitude improvements over COTS devices in terms of multipath rejection, and stability of output relative to temperature.

- Continuous, reliable co-location monitoring and control system for the relative 3-D displacement of geodetic instruments within a geodetic observatory to better than 1 mm.

- Single chip RF processors with selectable bandpasses from 1.1GHz to 2.2GHz. Greater than 50dB of gain and IF bandwidths from 10 to 60 MHz. Space-capable technology covering -40C to +85C and greater than 50 kRad TID.

- Space qualified GNSS array covering 1.15 to 1.61 GHz. Deployable from a compact, stowed position to a collector area of 1 - 2 meters, >40% efficiency. Array elements independently fed or phase combined; multiple polarizations available.

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.

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**S1.11 Lunar Science Instruments and Technology**

**Lead Center:** MSFC

**Participating Center(s):** ARC, GSFC, JPL, JSC, KSC

NASA lunar robotic science missions support the high-priority goals identified in the 2007 National Research Council report, *The Scientific Context for Exploration of the Moon: Final Report* ([http://www.nap.edu/catalog.php?record_id=11954](http://www.nap.edu/catalog.php?record_id=11954)) Space-qualified instruments perform remote and in situ lunar science investigations, to include measurements of micrometeoroid and lunar secondary ejecta environment, lunar dust composition, reactivity and transport, searching for water ice, assessing the radiation environment, gathering long period measurements of the lunar exosphere, and conducting surface and subsurface geophysical measurements. Improving science return and/or reducing mass, power, volume, or data rates is desired.

In support of these requirements, this subtopic seeks advancements in the following areas:

**Geophysical Measurements**
Systems, subsystems, and components 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 compared to the Apollo Lunar Surface Experiments Package (ALSEP) instruments ([http://www.hq.nasa.gov/alsj/frame.html](http://www.hq.nasa.gov/alsj/frame.html)). Instrument deployment options include robotic deployment from soft Landers, as well as emplacement by hard landers or penetrators. Also of interest are portable surface ground penetrating radars with antenna frequencies of 250-MHz, 500-MHz, and 1000-MHz to characterize the thickness of the lunar regolith. Also of interest are accurate, low mass, thermally stable hollow cubes and retroreflector array assemblies for lunar surface laser ranging.

**In Situ Lunar Surface Measurements**

Light-weight and power efficient instruments that enable elemental and/or mineralogy analysis using techniques 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 (TDL) sensors for in situ isotopic and elemental analysis of evolved volatiles, calorimetry, Laser-Raman Spectroscopy, Imaging Spectroscopy, and Laser Induced Breakdown Spectroscopy (LIBS). Instruments shall have the potential to provide isotope ratio measurements and/or hydrogen distributions to ±10 ppm locally. Characterizing the meteoroid and subsequent eject flux environment and measurements of surface and deep dielectric charging on the lunar surface should be considered. Also, self-calibrating instruments to measure surface and deep dielectric charging on a variety of materials encompassing conductors, semi-conductors, and insulators are another area. Instrument deployment options include robotic deployment from soft Landers, as well as emplacement by hard Landers or penetrators.

**Lunar Atmosphere and Dust Environment Measurements**

Low-mass and low-power instruments that measure the local lunar surface environment which includes but is not limited to the characterization of: micrometeoroid and lunar secondary ejecta environment, the plasma environment, surface electric field, secondary radiation at the lunar surface, and dust concentrations and its diurnal dynamics. Instrument deployment options include robotic deployment from soft Landers, as well as emplacement by hard Landers or penetrators.

**Lunar Regolith Particle Analysis**

A substantial portion of the particles in the Lunar Regolith are smaller than the integration volume of e-beam analytical equipment, making automated quantitative analysis extremely difficult using available approaches. Other techniques for obtaining particle analysis are desired. Example techniques include 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. The said software would then use standard image processing tools to resample to common scales, perform appropriate discriminant analysis using the high resolution data, mixed pixel inversion, image segmentation to extract particles, and correlate chemistry with products of the discriminant analysis.

Research should be conducted to demonstrate technical feasibility during Phase I and show a path toward a Phase II hardware and software demonstration, and when possible, deliver a demonstration unit or software package for NASA testing at the completion of the Phase II contract.