NASA SBIR 2010 Phase I Solicitation

Science

Sensors, Detectors and Instruments Topic S1

NASA's Science Mission Directorate (SMD) [http://nasascience.nasa.gov/ [1]) encompasses research in the areas of Astrophysics [http://nasascience.nasa.gov/astrophysics [2]), Earth Science [http://nasascience.nasa.gov/earth-science [3]), Heliophysics [http://nasascience.nasa.gov/heliophysics [4]), and Planetary Science [http://nasascience.nasa.gov/planetary-science [5]). 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.

Sub Topics:

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. 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 CO₂ 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 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).

- 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:
  - Length:
  - 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 [7]) 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 [6]) such as PATH, SCLP, and GACM and the Beyond Einstein Inflation Probe (Inflation Probe - cosmic microwave background, http://science.gsfc.nasa.gov/660/research/ [8]):

- 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 [6]), planetary science (http://www.nap.edu/catalog/10432.html [9]), and astronomy and astrophysics(http://www.nap.edu/books/0309070317/html/ [10]).


- 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/ [14]). 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 real-time operation on an FPGA.

- **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%

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  - Center Frequencies: 35, 94 GHz
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• **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

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- 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.

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].

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 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, [14]). 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 ([15]) and Stellar Imager ([16]):

- 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 < 100 nm. 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) [17]

Specific mission pages:

EXIST: [http://exist.gsfc.nasa.gov/](http://exist.gsfc.nasa.gov/) [18],

IXO: [http://htxs.gsfc.nasa.gov/index.html](http://htxs.gsfc.nasa.gov/index.html) [19],

Future Planetary Programs: [http://nasascience.nasa.gov/planetary-science/mission_list](http://nasascience.nasa.gov/planetary-science/mission_list) [20],

Earth Science Decadel Missions: [http://www.nap.edu/catalog/11820.html](http://www.nap.edu/catalog/11820.html) [6]

Helio Probes: [http://nasascience.nasa.gov/heliophysics/mission_list](http://nasascience.nasa.gov/heliophysics/mission_list) [21]

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

- 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 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

- 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 (~10^6), low noise, fast time response (2 to 10 x 10 mm^2. Focal plane mass must be minimized (~^2 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 [4]) 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 [22]), 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 [23]) 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/ [24]), Safir (http://safir.jpl.nasa.gov/ [25]), 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.

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:


- 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 [26]. 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 [27].

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-pixilated 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 -40°C to +85°C 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.

**Advanced Telescope Systems Topic S2**

The NASA Science Missions Directorate seeks technology for cost-effective high-performance advanced space telescopes for astrophysics and Earth science. Astrophysics applications require large aperture light-weight highly reflecting mirrors, deployable large structures and innovative metrology, control of unwanted radiation for high-contrast optics, precision formation flying for synthetic aperture telescopes, and cryogenic optics to enable far infrared telescopes. A few of the new astrophysics telescopes and their subsystems will require operation at cryogenic temperatures as cold a 4-degrees Kelvin. This topic will consider technologies necessary to enable future
telescopes and observatories collecting electromagnetic bands, ranging from UV to millimeter waves, and also include gravity waves. The subtopics will consider all technologies associated with the collection and combination of observable signals. Earth science requires modest apertures in the 2 to 4 meter size category that are cost effective. New technologies in innovative mirror materials, such as silicon, silicon carbide and nanolaminates, innovative structures, including nanotechnology, and wavefront sensing and control are needed to build telescope for Earth science that have the potential to cost between $50 to $150M.

Sub Topics:

**S2.01 Precision Spacecraft Formations for Telescope Systems**

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

This subtopic seeks hardware and software technologies necessary to establish, maintain, and operate precision spacecraft formations to a level that enables cost effective large aperture and separated spacecraft optical telescopes and interferometers (e.g., [http://planetquest.jpl.nasa.gov/TPF/][30], [http://instrument.jpl.nasa.gov/steller/][31]). Also sought are technologies (analysis, algorithms, and testbeds) to enable detailed analysis, synthesis, modeling, and visualization of such distributed systems.

Formation flight can synthesize large effective telescope apertures through, multiple, collaborative, smaller telescopes in a precision formation. Large effective apertures can also be achieved by tiling curved segments to form an aperture larger than can be achieved in a single launch, for deep-space high resolution imaging of faint astrophysical sources. These formations require the capability for autonomous precision alignment and synchronized maneuvers, reconfigurations, and collision avoidance. The spacecraft also require onboard capability for optimal path planning and time optimal maneuver design and execution.

Innovations are solicited for: (a) sensor systems for inertial alignment of multiple vehicles with separations of tens of meters to thousands of kilometers to accuracy of 1 - 50 milli-arcseconds (b) development of nanometer to sub-nanometer metrology for measuring inter-spacecraft range and/or bearing for space telescopes and interferometers (c) control approaches to maintain line-of-sight between two vehicles in inertial space near Sun-Earth L2 to milli-arcsecond levels accuracy (d) development of combined cm-to-nanometer-level precision formation flying control of numerous spacecraft and their optics to enable large baseline, sparse aperture UV/optical and X-ray telescopes and interferometers for ultra-high angular resolution imagery. Proposals addressing staged-control experiments, which combine coarse formation control with fine-level wavefront sensing based control are encouraged.

Innovations are also solicited for distributed spacecraft systems in the following areas:

- Distributed, multi-timing, high fidelity simulations;
- Formation modeling techniques;
- Precision guidance and control architectures and design methodologies;
- Centralized and decentralized formation estimation;
- Distributed sensor fusion;
- RF and optical precision metrology systems;
• Formation sensors;
• Precision microthrusters/actuators;
• Autonomous reconfigurable formation techniques;
• Optimal, synchronized, maneuver design methodologies;
• Collision avoidance mechanisms;
• Formation management and station keeping.

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.

S2.02 Proximity Glare Suppression for Astronomical Coronagraphy

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

This subtopic addresses the unique problem of imaging and spectroscopic characterization of faint astrophysical objects that are located within the obscuring glare of much brighter stellar sources and innovative advanced wavefront sensing and control for cost-effective space telescopes. Examples include planetary systems beyond our own, the detailed inner structure of galaxies with very bright nuclei, binary star formation, and stellar evolution. Contrast ratios of one million to ten billion over an angular spatial scale of 0.05-1.5 arcsec are typical of these objects. Achieving a very low background requires control of both scattered and diffracted light. The failure to control either amplitude or phase fluctuations in the optical train severely reduces the effectiveness of starlight cancellation schemes.

This innovative research focuses on advances in coronagraphic instruments, starlight cancellation instruments, and potential occulting technologies that operate at visible and infrared wavelengths. The ultimate application of these instruments is to operate in space as part of a future observatory mission. Much of the scientific instrumentation used in future NASA observatories for the astrophysical sciences will require control of unwanted radiation (thermal and scattered) across a modest field of view. The performance and observing efficiency of astrophysics instruments, however, must be greatly enhanced. The instrument components are expected to offer much higher optical throughput, larger fields of view, and better detector performance. The wavelengths of primary interest extend from the visible to the thermal infrared. Measurement techniques include imaging, photometry, spectroscopy, and polarimetry. There is interest in component development, and innovative instrument design, as well as in the fabrication of subsystem devices to include, but not limited to, the following areas:

Starlight Suppression Technologies
- Advanced starlight canceling coronagraphic instrument concepts;
- Advanced aperture apodization and aperture shaping techniques;
- Advanced apodization mask or occulting spot fabrication technology controlling smooth density gradients to 10^-4 with spatial resolutions ~1 µm, low dispersion, and low dependence of phase on optical density;
- Metrology for detailed evaluation of compact, deep density apodizing masks, Lyot stops, and other types of graded and binary mask elements. Development of a system to measure spatial optical density, phase inhomogeneity, scattering, spectral dispersion, thermal variations, and to otherwise estimate the accuracy of masks and stops is needed;
- Interferometric starlight cancellation instruments and techniques to include aperture synthesis and single input beam combination strategies;
- Pupil remapping technologies to achieve beam apodization;
- Techniques to characterize highly aspheric optics;
- Methods to distinguish the coherent and incoherent scatter in a broad band speckle field;
- Methods of polarization control and polarization apodization; and
- Components and methods to insure amplitude uniformity in both coronagraphs and interferometers, specifically materials, processes, and metrology to insure coating uniformity.
- Coherent fiber bundles consisting of up to 10^4 fibers with lenslets on both input and output side, such that both spatial and temporal coherence is maintained across the fiber bundle for possible wavefront/amplitude control through the fiber bundle.

**Wavefront Control Technologies**

- Development of small stroke, high precision, deformable mirrors and associated driving electronics scalable to 104 or more actuators (both to further the state-of-the-art towards flight-like hardware and to explore novel concepts). Multiple deformable mirror technologies in various phases of development and processes are encouraged to ultimately improve the state-of-the-art in deformable mirror technology. Process improvements are needed to improve repeatability, yield, and performance precision of current devices;
- Development of instruments to perform broad-band sensing of wavefronts and distinguish amplitude and phase in the wavefront;
- Adaptive optics actuators, integrated mirror/actuator programmable deformable mirror;
- Reliability and qualification of actuators and structures in deformable mirrors to eliminate or mitigate single actuator failures;
- Multiplexer development for electrical connection to deformable mirrors that has ultra-low power dissipation; and
- High precision wavefront error sensing and control techniques to improve and advance coronagraphic imaging performance.
Optical Coating and Measurement Technologies

- Instruments capable of measuring polarization cross-talk and birefringence to parts per million;
- Highly reflecting broadband coatings for large (> 1 m diameter) optics
- Polarization-insensitive coatings for large optics

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.

S2.03 Precision Deployable Optical Structures and Metrology

Lead Center: JPL

Participating Center(s): GSFC, LaRC

Planned future NASA Missions in astrophysics, such as: Single Aperture Far-IR (SAFIR) telescope; Terrestrial Planet Finder (TPF); Coronagraph, External Occulter and Interferometer, Advanced Technology Large-Aperture Space Telescope (ATLAST); Life Finder; and Submillimeter Probe of the Evolution of Cosmic Structure (SPECS); and the UV Optical Imager (UVOIR) require 10 - 30 m class cost effective telescope observatories that are diffraction limited at wavelengths from the visible to the far IR, and operate at temperatures from 4 - 300 K. The desired areal density is 1 - 10 kg/m². Static and dynamic wavefront error tolerances to thermal and dynamic perturbations may be achieved through passive means (e.g., via a high stiffness system, passive thermal control, jitter isolation or damping) or through active opto-mechanical control. Large deployable multi-layer structures in support of sunshades for passive thermal control and 20m to 50m class planet finding external occulters are also relevant technologies. Potential architecture implementations must package into an existing launch volume, deploy and be self-aligning to the micron level. The target space environment is expected to be L2.

This subtopic solicits proposals to develop enabling, cost effective component and subsystem technology for these telescopes. Research areas of particular interest include:

- Precision deployable structures and metrology (i.e., innovative active or passive deployable primary or secondary support structures);
- Innovative concepts for packaging fully integrated (i.e., including power distribution, sensing, and control components);
- Distributed and localized actuation systems;
- Deployment packaging and mechanisms;
• Active opto-mechanical control distributed on or within the structure;

• Actuator systems for alignment of reflector panels (order of cm stroke actuators, lightweight, nanometer stability);

• Innovative architectures, materials, packaging and deployment of large sunshields and external occulters;

• Mechanical, inflatable, or other deployable technologies;

• New thermally-stable materials (CTE
• Innovative ground testing and verification methodologies; and

• New approaches for achieving packagable depth in primary mirror support structures.

Also of interest are:

• Innovative metrology systems for direct measurement of the optical elements or their supporting structure;

• Requirements for micron level absolute and subnanometer relative metrology for multiple locations on the primary mirror;

• Measurement of the metering truss;

• Innovative systems, which minimize complexity, mass, power and cost.

The goal for this effort is to mature technologies that can be used to fabricate 10 m class or greater, lightweight, ambient or cryogenic flight-qualified observatory systems. Proposals to fabricate demonstration components and subsystems with direct scalability to flight systems through validated models will be given preference. The target launch volume and expected disturbances, along with the estimate of system performance, should be included in the discussion. A successful proposal shows a path toward a Phase II delivery of demonstration hardware scalable to 3 m for characterization.

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.

S2.04 Advanced Optical Component Systems

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

Future heavy lift launch systems will enable extremely large and/or extremely massive space telescopes. Potential systems include 12 to 30 meter class segmented primary mirrors for UV/optical or infrared wavelengths and 8 to 16 meter class segmented x-ray telescope mirrors.
These potential future space telescopes have very specific mirror technology needs. UV/optical telescopes (such as ATLAST-9 or ATLAST-16) require 1 to 3 meter class mirrors with

In view of the very large total mirror or lens collecting aperture required, affordability or areal cost (cost per square meter of collecting aperture) rather than areal density is probably the single most important system characteristic of an advanced optical system. For example, both x-ray and normal incidence space mirrors currently cost $3 million to $4 million per square meter of optical surface area. This research effort seeks a cost reduction for precision optical components by 20 to 100 times, to less than $100K/m².

The primary purpose of this subtopic is to develop and demonstrate technologies to manufacture ultra-low-cost precision optical systems for very large x-ray, UV/optical or infrared telescopes. Potential solutions include but are not limited to new mirror materials such as Silicon carbide or nanolaminates or carbon-fiber reinforced polymer; or new fabrication processes such as direct precision machining, rapid optical fabrication, slumping or replication technologies to manufacture 1 to 2 meter (or larger) precision quality mirror or lens segments (either normal incidence for UV/optical/infrared or grazing incidence for x-ray).

Another key enabling technology is optical coatings. UV/optical telescopes require broadband (from 100 nm to 2500 nm) high-reflectivity mirror coating with extremely uniform amplitude and polarization properties which can be deposited on 1 to 3 meter class mirror. EUSO requires anti-reflection coatings which can be deposited onto 2.5 meter diameter PMMA Fresnel lenses. In both cases, ability to demonstrate optical performance on 2.5 meter class optical surfaces is important.

Successful proposals will demonstrate prototype manufacturing of a precision mirror or lens system or precision replicating mandrel in the 0.25 to 0.5 meter class with a specific scale up roadmap to 1 to 2+ meter class space qualifiable flight optics systems. Material behavior, process control, optical performance, and mounting/deploying issues should be resolved and demonstrated. The potential for scale-up will need to be addressed from a processing and infrastructure point of view.

An ideal Phase I deliverable would be a near UV, visible or x-ray precision mirror, lens or replicating mandrel of at least 0.25 meters. The Phase II project would further advance the technology to produce a space-qualifiable precision mirror, lens or mandrel greater than 0.5 meters, with a TRL in the 4 to 5 range. Both deliverables would be accompanied by all necessary documentation, including the optical performance assessment and all data on processing and properties of its substrate materials. The Phase II would also include a mechanical and thermal stability analysis.

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.
S2.05 Optics Manufacturing and Metrology for Telescope Optical Surfaces

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

This subtopic focuses primarily on manufacturing and metrology of optical surfaces, especially for very small or very large and/or thin optics. Missions of interest include:

JDEM concepts: [http://jdem.gsfc.nasa.gov](http://jdem.gsfc.nasa.gov) [32],

IXO: [http://ixo.gsfc.nasa.gov](http://ixo.gsfc.nasa.gov) [24],

LISA: [http://lisa.gsfc.nasa.gov](http://lisa.gsfc.nasa.gov) [33],

ICESAT: [http://icesat.gsfc.nasa.gov](http://icesat.gsfc.nasa.gov) [34], CLARREO, and ACE.

ATLAST: [http://www.stsci.edu/institute/atlast](http://www.stsci.edu/institute/atlast) [35]

Optical systems currently being researched for these missions are large area aspheres, requiring accurate figuring and polishing across six orders of magnitude in period. Technologies are sought that will enhance the figure quality of optics in any range as long as the process does not introduce artifacts in other ranges. For example, mm-period polishing should not introduce waviness errors at the 20 mm or 0.05 mm periods in the power spectral density. Also, novel metrological solutions that can measure figure errors over a large fraction of the PSD range are sought, especially techniques and instrumentation that can perform measurements while the optic is mounted to the figuring/polishing machine.

Of particular interest is the area of x-ray optics metrology, including the evaluation of the optical quality of x-ray mirrors and substrates; the general characterization of x-ray mirrors; and the development of new metrology measurement techniques and instrumentation for x-ray mirrors.

By the end of a Phase II program, technologies must be developed to the point where the technique or instrument can dovetail into an existing optics manufacturing facility producing optics at the R&D stage. Metrology instruments should have 5 nm or better surface height resolution and span at least 3 orders of magnitude in lateral spatial frequency.

Examples of technologies and instruments of interest include:

- Interferometric nulling optics for very shallow conical optics used in x-ray telescopes.
- Segmented systems commonly span 60 degrees in azimuth and 200 mm axial length and cone angles vary from 0.1 to 1 degree.
- Low stress metrology mounts that can hold very thin optics without introducing mounting distortion.
- Low normal force figuring/polishing systems operating in the 1 mm to 50 mm period range with minimal impact at significantly smaller and larger period ranges.
In-situ metrology systems that can measure optics and provide feedback to figuring/polishing instruments without removing the part from the spindle.

Innovative mirror substrate materials or manufacturing methods that produce thin mirror substrates that are stiffer and/or lighter than existing materials or methods.

Extreme aspheric and/or anamorphic optics for pupil intensity amplitude apodization (PIAA).

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.

Spacecraft and Platform Subsystems Topic S3

The Science Mission Directorate will carry out the scientific exploration of our Earth, the planets, moons, comets, and asteroids of our Solar System and beyond. SMD's future direction will be moving away from exploratory missions (orbiters and flybys) into more detailed/specific exploration missions that are at or near the surface (landers, rovers, and sample returns) or at more optimal observation points in space. These future destinations will require new vantage points, or would need to integrate or distribute capabilities across multiple assets. Future destinations will also be more challenging to get to, have more extreme environmental conditions and challenges once the spacecraft gets there, and may be a challenge to get a spacecraft or data back from. A major objective of the NASA science spacecraft and platform subsystems development efforts are to enable science measurement capabilities using smaller and lower cost spacecraft to meet multiple mission requirements thus making the best use of our limited resources. To accomplish this objective, NASA is seeking innovations to significantly improve subsystem capabilities while reducing the mass and cost, that would in turn enable increased scientific return for future NASA missions.

A spacecraft bus is made up of many subsystems like: propulsion; thermal control; power and power distribution; attitude control; telemetry command and control; transmitters/antenna; computers/on-board processing/software; and structural elements. This topic area addresses the future needs in many of these sub-system areas, as well as their application to specific spacecraft and platform needs. Innovations for 2010 are sought in the areas of:

- Command and Data Handling, and Instrument Electronics
- Thermal Control Systems
• Power Generation and Conversion
• Propulsion Systems
• Power Management and Storage
• Guidance, Navigation and Control
• Planetary Ascent Vehicles (non-Earth)
• Unmanned Aircraft and Sounding Rocket Technologies
• Terrestrial and Planetary Balloons
• Earth Entry Vehicle Systems

Significant changes to the S3 Topic for 2010 are:

• Consolidation of spacecraft and platform related technologies from S4 Low-cost Small Spacecraft and Technologies into the applicable S3 Subtopics for a more integrated approach to spacecraft and platform subsystems technology development spanning from small to large spacecraft.

• Merged the 2009 subtopics of S3.01 Command, Data Handling, and Electronics, S3.07 Sensor and Platform Data Processing and Control, O1.01 Coding, Modulation, and Compression, and related content from the S4 Topic into a single Command and Data Handling, and Instrument Electronics subtopic.

• Merged the 2009 subtopics of Terrestrial Balloons with Planetary Balloons (from S5) into a single subtopic for balloon technologies.

• Added a new Earth Entry Vehicle Systems subtopic.

The following references discuss some of NASA's science mission and technology needs:

• The 2009-2010 Planetary Science Decadal Survey is currently ongoing and due in 2011. This decadal survey is considering technology needs. [40] http://sites.nationalacademies.org/SSB/CurrentProjects/ssb_052412
Sub Topics:

**S3.01 Command, Data Handling, and Electronics**

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

NASA’s space based observatories, fly by spacecraft, orbiters, landers, and robotic and sample return missions, require robust command and control capabilities. Advances in technologies relevant to command and data handling and instrument electronics are sought to support NASA’s goals and several missions and projects under development.

http://science.nasa.gov/search/?q=missions+under+development [41]  

The subtopic goals are to: (1) develop high-performance processors and memory architectures and reliable electronic systems, (2) develop an avionics architecture that is flexible, scalable, extensible, adaptable, and reusable, and (3) develop tools technologies that can enable rapid deployment of high-reliability, high-performance onboard processing applications and interface to external sensors on flight hardware. The subtopic objective is to elicit novel architectural concepts and component technologies that are realistic and operate effectively and credibly in environments consistent with the future NASA Science missions.

Successful proposal concepts should significantly advance the state-of-the-art. Proposals should clearly (1) state what the product is; (2) identify the needs it addresses; (3) identify the improvements over the current state of the art; (4) outline the feasibility of the technical and programmatic approach; and (5) present how it could be infused into a NASA program. Furthermore, proposals should indicate an understanding of the intended operating environment, including temperature and radiation. It should be noted that environmental requirements can vary significantly from mission to mission. For example, some low earth orbit missions have a total ionizing dose (TID) radiation requirement of less than 10 kRad, while some planetary missions can have requirements well in excess of 1MRad. For descriptions of radiation effects in electronics, the proposer may visit http://radhome.gsfc.nasa.gov/radhome/background.htm [42]. If a Phase II proposal is awarded, the combined Phase I and Phase II developments should produce a prototype that can be characterized by NASA.

The technology priorities sought are listed below.

**C&DH Architectures**

- High performance hardware/software processor platform capable of implementing high-throughput numerically intensive real-time applications that entail autonomous landing and guidance and control. Sensor computations. Key performance metrics must achieve 40 GOPS, 20 GMACS, and 40,000 MIPS with EDAC-protected memory, comprising 256 (TBR) MB DDR volatile for flight software execution and 256 (TBR) MB non-volatile for image storage, respectively. Standard interfaces must include Gigabit Ethernet, RS232 UART serial ports, and control interfaces to Lidar/Camera with a maximum bandwidth of up to 1 Gbps. Platform should be in 6U form factor and consume no greater than 20 W. Processor trades should be conducted to balance size, weight, power against reliability, flexibility, and performance for future space missions. Radiation hardened by design best practices, rapid development tools, and a radiation-tolerant path to space qualification are appealing features. The platform should operate, at reduced capability, during high energy cosmic rays events. Principal capabilities will encompass command generation and
handling, control of safe landing system, sensor data processing and storage, and on-board memory management, optimized for acceptable performance and reliability.

- Novel, miniaturized, low-power C&DH architectures tailored to small spacecraft. Solutions must perform functions of traditional C&DH systems at a fraction of the SWAP (Size, Weight, and Power). Proposed systems should be capable of supporting typical spacecraft C&DH functions and should be radiation tolerant, and should further be compatible with Space Plug and Play (SPA) architectures, including SPA-1.

- Development system design tools that (a) take full advantage of rapid prototyping hardware-in-the-loop (HIL) environments for hybrid processing platforms, and (b) automate/accelerate the deployment of data processing and sensor interface design on flight hardware.

**Discrete Components for C&DH Subsystems**

- Processors - General purpose (processor chips and radiation-hardened by design synthesizable IP cores) and special purpose single-chip components (DSPs), with sustainable processing performance and power efficiency (>40,000 MIPS at >1,000 MIPS/W for general purpose processing platforms, >20 GMACS at >5 GMACS/W for computationally-intensive processing platforms), and tolerance to total dose and single-event radiation effects. Concepts must include tools required to support an integrated hardware/software development flow.

- Radiation-hardened non-volatile low power memories >100KRad.

- Radiation hardened DDR1, DDR2, and DDR3 high speed memories.

**Onboard Network Architectures and Devices**

- Radiation-hardened physical layer components for (copper/fiber-optic) onboard data busses (e.g., SpaceWire, Ethernet, Serial Rapid I/O, Ring Bus) speeds >1Gb/s.

- Power distribution through onboard data network technologies.

- Wireless data network architectures and components.

- Wireless RFID housekeeping sensors and interrogation hardware.

**Tunable, Scalable, Reconfigurable, Adaptive Fault-Tolerant Onboard Processing Architectures**

- Technologies Enabling Use of Commercial Devices for Spaceflight Applications, including Radiation Hardened By Software (RHBS) approaches.

- Highly adaptive reconfigurable computing platforms (including hybrid DSP/FPGA/CPU architectures).

- Tools and methodologies to accelerate development of highly reliable applications on reconfigurable computing platforms.

**Technologies Enabling Custom Radiation-Hardened Component Development**
• Radiation-Hardened-By-Design (RHBD) cell libraries.

• Radiation-hardened Programmable Logic Devices (PLDs) and structured ASIC devices (digital and/or mixed-signal).

• Intellectual Property (IP) cores allowing the implementation of highly reliable System-On-a-Chip (SOC) devices for spacecraft subsystems or instrument electronics. Functions of interest include processors, memory interfaces, and data bus interfaces.

**Novel, Ruggedized Packaging/Interconnect**

• High density packaging (enclosures, printed wiring boards) enabling miniaturization.

• Novel high density and low resistance cabling, including carbon nanotube (CNT) based wiring.

**Data Compression**

• Ground-based high-speed data compression decoder capable of decoding coded bit stream conforming to CCSDS 122.0-B-1 Image Data Compression standard ([www.ccsds.org](http://www.ccsds.org)) [43]), providing over 40 M samples/sec for up to 16-bit image data coded in an embedded bit stream. Spaceflight hardware currently exists to perform the encoding function. The requested decoder would be used for ground processing of a downlinked encoded data stream. The decoder shall not consume more than 5 watts of power at the specified speed.

**Power Conversion and Distribution**

• Radiation-hardened high efficiency Point-Of-Load (POL) down convertor.

• Power distribution through onboard data network technologies.

**S3.02 Thermal Control Systems**

Lead Center: GSFC

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

Future Spacecraft and instruments for NASA's Science Mission Directorate will require increasingly sophisticated thermal control technology. Innovative proposals for the cross-cutting thermal control discipline are sought in the following areas:

• Optical systems, lasers (ICESAT 2), and detectors require tight temperature control, often to better than
/- 1°C. Some new missions such as LISA require thermal gradients held to even tighter micro-degree levels. Methods of precise temperature measurement and control to tight temperature levels are needed.

- New generations of electronics used on numerous missions have higher power densities than in the past. High conductivity, vacuum-compatible interface materials to minimize losses across make/break interfaces are needed to reduce interface temperature gradients and facilitate heat removal.

- Detectors and optical systems at infrared wavelengths require efficient cooling methods to low temperatures. Advanced thermoelectric devices with higher Coefficients of Performance (COP) are required.

- More sensitive instruments are resulting in increased requirements for high electrical conductivity on spacecraft instruments and surfaces. This has increased the need for advanced thermal control coatings, particular with low absorptance, high emittance, and good electrical conductivity.

- Phase change systems are needed for Mars or Lunar applications. Reusable phase change systems are desired which can be employed to absorb transient heat dissipations during instrument operations. Technology is sought for phase change systems, typically near room temperature, which can then either store this energy or provide an exothermic process, which would provide heat for instrument power-on after the dormant phase.

- Future high-powered missions, some possibly nuclear powered, may require active cooling systems to efficiently transport large amounts of heat. These include single and two-phase mechanically pumped fluid loop systems which accommodate multiple heat sources and sinks; and long life, lightweight pumps which are capable of generating a high pressure head. It also includes efficient, lightweight, oil-less, high lift vapor compression systems or novel new technologies for high performance cooling up to 2 KW.

- Exploration science missions beyond earth orbit present engineering challenges requiring systems, which can withstand extreme temperatures ranging from high temperatures on Venus to the cryogenic temperatures of the outer planets. High performance insulation systems, which are more easily fabricated than traditional multi-layer (MLI) systems, are required for both hot and cold environments. Potential applications include traditional vacuum environments, low-pressure carbon dioxide atmospheres on Mars, and high-pressure atmospheres found on Venus.

- Low-Cost Variable Conductance Heat Pipes for Terrestrial Balloons - Please see sub-topic S3.07 Terrestrial and Planetary Balloons to respond to this requirement.

- Thermal Control Systems for S3.10 Earth Entry Systems. Low mass/cost/power/complexity payload thermal control systems are needed, which can maintain the sample temperature in-flight, through impact, and post landing. Candidate thermal control systems must be able to maintain a payload up to 10 kg at temperature levels ranging from cryogenic up to -20°C (depending on specific mission requirements) for up to 1 day after landing/impact, and cannot exceed 20kg in total mass.

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

Note to Proposer: Subtopic X3.04 Thermal Control Systems for Human Spacecraft, under the Exploration Mission Directorate, also addresses thermal control technologies. Proposals more aligned with exploration mission requirements should be proposed in X3.04.
S3.03 Power Generation and Conversion

Future NASA science missions will employ Earth orbiting spacecraft, planetary spacecraft, balloons, aircraft, surface assets, and marine craft as observation platforms. Proposals are solicited to develop advanced power generation and conversion technologies to enable or enhance the capabilities of future science missions. Requirements for these missions are varied and include long life, high reliability, significantly lower mass and volume, higher mass specific power, and improved efficiency over the state of practice for components and systems. Other desired capabilities are high radiation tolerance and the ability to operate in extreme environments (high and low temperatures and over wide temperature ranges).

While power generation technology affects a wide range of NASA missions and operational environments, technologies that provide substantial benefits for key mission applications/capabilities are being sought in the following areas.

Radioisotope Power Conversion

Radioisotope technology enables a wide range of mission opportunities, both near and far from the Sun and hostile planetary environments including high energy radiation, both high and low temperature and diverse atmospheric chemistries. Technology innovations capable of advancing lifetimes, improving efficiency, highly tolerant to hostile environments are desired for all thermal to electric conversion technologies considered here. Specific systems of interest for this solicitation are listed below.

Stirling Power Conversion: advances in, but not limited to, the following:

- System specific mass greater than 10 We/kg
- Highly reliable autonomous control
- Low EMI
- High temperature, high performance materials, 850-1200 C
- Radiation tolerant sensors, materials and electronics

Thermoelectric Power Conversion: advances in, but not limited to, the following:

- High temperature, high efficiency conversion greater than 10%
- Long life, minimal degradation
- Higher power density
Cubesat and Nanosat On-orbit Power Generation

NASA desires to build smaller spacecraft types carrying smaller instrument packages. However, power requirements to accommodate these instruments and spacecraft systems will not necessarily scale down in a similar fashion as spacecraft size. Therefore, power generation and power management technologies are sought that are compatible with small spacecraft geometries and sizes, especially in cubesat and nanosat form factors.

Photovoltaic Energy Conversion

Photovoltaic cell, blanket, and array technologies that lead to significant improvements in overall solar array performance (i.e. conversion efficiency >30%, array mass specific power >300 watts/kilogram, decreased stowed volume, reduced initial and recurring cost, long-term operation in high radiation environments, high power arrays, and a wide range of space environmental operating conditions) are solicited. Technologies specifically addressing the following mission needs are highly sought:

- Photovoltaic cell and blanket technologies capable of low intensity, low-temperature operation applicable to outer planetary (low solar intensity) missions
- Photovoltaic cell, blanket and array technologies capable of enhancing solar array operation in a high intensity, high-temperature environment (i.e. inner planetary and solar probe-type missions)
- Lightweight solar array technologies applicable to solar electric propulsion missions. Current missions being studied require solar arrays that provide 1 to 20 kilowatts of power at 1 AU, are greater than 300 watts/kilogram specific power, can operate in the range of 0.7 to 3 AU, provide operational array voltages up to 150 volts and have a low stowed volume.

Thermophotovoltaic conversion is currently focused on follow-on technology for the International Lunar Network (ILN) and for the outer planets mission. Advances sought, but not limited to, include:

- Low-bandgap cells having high efficiency and high reliability
- High temperature selective emitters
- Low absorptance optical band-pass filters
- Efficient multi-foil insulation

Note to Proposer: Topic X8 under the Exploration Mission Directorate also addresses power technologies (X8.03 Space Nuclear Power Systems, and X8.04 Advanced Photovoltaic Systems). Proposals more aligned with exploration mission requirements should be proposed in X8.
S3.04 Propulsion Systems

The Science Mission Directorate (SMD) needs spacecraft with more demanding propulsive performance and flexibility for more ambitious missions requiring high duty cycles, more challenging environmental conditions, and extended operation. Planetary spacecraft need the ability to rendezvous with, orbit, and conduct in situ exploration of planets, moons, and other small bodies in the solar system (http://www.nap.edu/catalog.php?record_id=10432 [39]). Future spacecraft and constellations of spacecraft will have high-precision propulsion requirements, usually in volume- and power-limited envelopes.

This subtopic seeks innovations to meet SMD propulsion requirements, which are reflected in the goals of NASA’s In-Space Propulsion Technology program to reduce the travel time, mass, and cost of SMD spacecraft. Advancements in chemical and electric propulsion systems related to sample return missions to Mars, small bodies (like asteroids, comets, and Near-Earth Objects), outer planet moons, and Venus are desired. Additional electric propulsion technology innovations are also sought to enable low cost systems for Discovery class missions, and eventually to enable radioisotope electric propulsion (REP) type missions.

The focus of this solicitation is for next generation propulsion systems and components, including high-pressure chemical rocket technologies and low cost/low mass electric propulsion technologies. Specific sample return propulsion technologies of interest include higher-pressure chemical propulsion system components, lightweight propulsion components, and Earth-return vehicle propulsion systems. Propulsion technologies related specifically to planetary ascent vehicles will be sought under S3.08 Planetary Ascent Vehicle.

Chemical Propulsion Systems

Technology needs include:

- Improved materials and manufacturing processes to produce Iridium/Rhenium apogee class thruster chambers with improved mechanical properties targeting a yield stress of 40ksi and an elongation of 10%;
- Advanced nontoxic mono-propellant rockets for in-space applications.

Electric Propulsion Systems

This subtopic also seeks proposals that explore uses of technologies that will provide superior performance in for high specific impulse/low mass electric propulsion systems at low cost. These technologies include:

- Efficient thrusters with up to 1 kW of input power that provide thrust up to 20 mN with a specific impulse between 1600 to 3500 seconds;
- A throttleable dual mode thruster that is capable of operating in both high thrust and high specific impulse
modes for a fixed power;

- High power electric propulsion thrusters (>20 kW) and components including cathodes, ion optics, and low sputtering materials with long life (>1x10^8 N-s).

Proposals should show an understanding of the state of the art, how there technology is superior, and of one or more relevant science needs. The proposals should provide a feasible plan to fully develop a technology and infuse it into a NASA program.

Note to Proposer: Topic X2 under the Exploration Mission Directorate also addresses advanced propulsion. Proposals more aligned with exploration mission requirements should be proposed in X2.

**S3.05 Power Management and Storage**

Future NASA science objectives will include missions such as Earth Orbiting, Venus, Europa, Titan, Lunar Quest and Space Weather. Under this subtopic, proposals are solicited to develop energy storage and power electronics to enable or enhance the capabilities of future science missions. The unique requirements for the power systems for these missions can vary greatly, with advancements in components needed above the current State of the Art (SOA) for long life, high reliability, low mass/volume, radiation tolerance, and wide temperature operation.

**Energy Storage**

Future science missions will require advanced primary and secondary battery systems capable of operating at temperature extremes from -100°C for Titan missions to 400°C to 500°C for Venus missions, and a span of -230°C to +120°C for Lunar Quest. In addition, high energy-density rechargeable electrochemical battery systems that offer greater than 50,000 charge/discharge cycles (10 year operating life) for low-earth-orbiting spacecraft, 20 year life for geosynchronous (GEO) spacecraft, are desired. Advancements to battery energy storage capabilities that address one or more of the above requirements for the stated missions combined with very high specific energy (>200 Wh/kg for secondary battery systems) and energy density, along with radiation tolerance are of interest.

In addition to batteries, other advanced energy storage/load leveling technologies designed to the above mission requirements, such as flywheels, supercapacitors or magnetic energy storage, are of interest. These technologies have the potential to minimize the size and mass of future power systems.

**Power Management and Distribution (PMAD)**

technologies are needed to efficiently manage the system power for these deep space missions. Advances in electrical power technologies are required for the electrical components and systems for these future platforms to address program size, mass, efficiency, capacity, durability, and reliability requirements. Of importance are expected improvements in energy density, speed, efficiency, or wide-temperature operation (-125°C to over 450°C) with a number of thermal cycles. Advancements are sought for power electronic devices, components and packaging for Venus type missions with power ranges of a few watts for minimum missions up to a few kilowatts for large missions.

For the lower power applications (up to 20 watts), NASA desires to build smaller spacecraft types carrying smaller instrument packages. However, power requirements to accommodate these instruments and spacecraft systems will not necessarily shrink in a similar fashion as spacecraft size. Therefore, power management technologies are sought that are compatible with small spacecraft geometries and sizes. These Electrical Power Systems should be compatible with Space Plug and Play (SPA) architectures.

Overall technologies of interest include:

- Intelligent, fault-tolerant electrical components and PMAD systems
- High temperature devices and components (up to 450°C)
- Advanced electronic packaging for thermal control and electromagnetic shielding
- Plug and Play compatibility for low power applications

Power Conversion and Distribution relevant to Command, Data Handling, and Electronics, will be covered under subtopic S3.01.

Power Storage for Terrestrial Balloons will be covered under sub-topic S3.07 Terrestrial and Planetary Balloons.

Research should be conducted to demonstrate technical feasibility during Phase I and show a path toward a Phase II, and when possible, deliver a demonstration unit for NASA testing at the completion of the Phase II contract. Phase II emphasis should be placed on developing and demonstrating the technology under relevant test conditions. Additionally, a path should be outlined that shows how the technology could be commercialized or further developed into science-worthy systems.

Other subtopics, which could potentially benefit from these technology developments include O5 - Low-Cost and Reliable Access to Space (LCRATS), S5.05 - Extreme Environments Technology, and S5.01 - Planetary Entry, Descent and Landing Technology. Battery development could also be beneficial to X6.02 - Advanced Space-rated Batteries, which is investigating some similar technologies in the secondary battery area but with very different operational requirements. Power Management and Distribution could be beneficial to X8.05 - Advanced Power Conversion Systems AND Management and Distribution (PMAD), which is investigating similar technologies, but with very different power levels.
**S3.06 Guidance, Navigation and Control**

Advances in the following areas of guidance, navigation and control are sought.

**Navigation systems** (including multiple sensors and algorithms/estimators, possibly based on existing component technologies) that work collectively on multiple vehicles to enable inertial alignment of the formation of vehicles (i.e., pointing of the line-of-sight defined by fixed points on the vehicles) on the level of milli-arcseconds relative to the background star field.

**Light-weight sensors** (gyroscopic or other approach) to enable milli-arcsecond class pointing measurement for individual large telescopes and low cost small spacecraft.

**Isolated pointing and tracking platforms** (pointing 0.5 arcseconds, jitter to 5 milli-arcsecond), targeted to placing a scientific instrument on GEO communication satellites that can track the sun for > 3 hours/day.

**Working prototypes of GN&C actuators** (e.g., reaction or momentum wheels) that advance mass and technology improvements for small spacecraft use. Such technologies may include such non-contact approaches such as magnetic or gas. Superconducting materials, driven by temperature conditioning may also be appropriate provided that the net power used to drive and condition the "frictionless" wheels is comparable to traditional approaches.

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.

**S3.07 Terrestrial and Planetary Balloons**

All 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.
Innovations in materials, structures, and systems concepts have enabled buoyant vehicles to play an expanding role in planning NASA's future Solar System Exploration Program. Balloons and airships are expected to carry scientific payloads at Titan and Venus that will perform in situ investigations of their atmospheres and near surface environments. Both Titan and Venus feature extreme environments that significantly impact the design of balloons for those two worlds. Proposals are sought in the following areas:

1. **Titan Montgolfiere Balloons:** Recent NASA mission studies have recommended the use of radioisotope-heated Montgolfiere balloons for future in situ Titan exploration. Proposals are sought for the design, fabrication and Earth atmosphere flight testing of prototypes that can support an eventual Titan Montgolfiere balloon mission. Particular importance is attached to the acquisition of test data that can help validate thermodynamic and fluid mechanic models that will ultimately be used to design the Titan flight balloon. The size of balloon required for Titan will be approximately 10 m in diameter and will require 2 kW of thermal energy to float the balloon at an expected Titan temperature of 85 to 95 K. Any proposed Earth-test prototype will require an alternate heat source that nevertheless adequately mimics the effects of using radioisotope energy at Titan.

2. **Gas Management Systems for Titan Aerobots:** Hydrogen-filled aerobots at Titan must contend with the problem of gas leakage over long duration (1 year or more) flights. Proposals are sought for the development and testing of two kinds of prototype devices that can be carried on the aerobot to compensate for these gas leakage problems; one device is to produce make-up hydrogen gas from atmospheric methane; the other device is to remove atmospheric gas (mostly nitrogen) that leaks from the ballonets into the hydrogen-filled blimp. Both kinds of devices will need to operate on no more than 15 W of electrical power each while compensating for a leakage rate of at least 40 g/week of hydrogen or 500 g/week of nitrogen.

3. **Metal Balloons for High Temperature Venus Exploration:** Balloons made of metals are a potential solution to the problem of enabling long duration flight in the hot lower atmosphere of Venus. Proposals are sought for metal balloon concepts and prototypes that provide 1-5 m³ of fully inflated volume, areal densities of 1 kg/m² or less, sulfuric acid compatibility at 85% concentration, and operation at 460 °C for a period of up to 1 year.

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**S3.08 Planetary Ascent Vehicles**

NASA aims to design, build and test vehicles that will be launched from the surface of other planets and small bodies and place a payload, Orbiting Sample (OS), into orbit. We are seeking proposals for the development of innovative technologies to support future planetary ascent vehicles. Immediate focus is the Mars ascent vehicle. Technology innovations should either enhance vehicle capabilities (e.g., launch success probability, mission success, improved performance or margins, and improved environmental robustness) or ease implementation in space borne missions (e.g., reduce size, mass, power, and thermal requirements, improve reliability and ability to withstand the ~20 g lateral g-loading, or lower cost). The areas of interest for this call are listed below.

Alternate propellants, thrusters and propulsion system technologies for the planetary ascent vehicles:

- Higher performing monopropellants with specific impulse >240 secs;
• "Green" propellants;
• High chamber pressure thrusters > 500 psia;
• Pressurization component technologies to reduce system mass (filters, solenoid valves, latch valves, tanks, fill and drain and check valves);
• Small lightweight pump technologies to operate at >500 psi output pressure especially non-electrically driven;
• Non-pyrotechnic isolation valves.

Advanced solid propellant engine system technologies:

• Solid propellant technology with specific impulse performance potential higher than HTPB and CTPB;
• Propellant blend with high performance low storage impacts, and operating capability down to 150 K;
• Low temperature seals and components;
• Light weight and reliable thrust vector control;
• Other lightweight system and component technologies.

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.

Launch vehicle technologies relevant to Earth are not sought under this sub-topic. For launch vehicle technologies related to Earth, see X2.01 Earth-to-Orbit Propulsion. Proposals more aligned with exploration mission requirements should be proposed in X2.01.

**S3.09 Unmanned Aircraft and Sounding Rocket Technologies**

**Sounding Rockets**

The NASA Sounding Rocket Program (NSRP) provides low-cost, sub-orbital access to space in support of space and earth sciences research and technology development sponsored by NASA and other users by providing payload development, launch vehicles, and mission support services. NASA utilizes a variety of vehicle systems comprised of military surplus and commercially available rocket motors, capable of lofting scientific payloads, up to 1300lbs, to altitudes from 100km to 1500km. NASA launches sounding rocket vehicles worldwide, from both land-based and water-based ranges, based on the science needs to study phenomenon in specific locations.
NASA is seeking innovations to enhance capabilities and operations in the following areas:

- Autonomous vehicle environmental diagnostics system capable of monitoring flight loading (thermal, acceleration, stress/strain) for solid rocket vehicle systems.
- Location determination systems to provide over-the-horizon position of buoyant payloads to facilitate expedient location and retrieval from the ocean.
- Flotation systems, ranging from tethered flotation devices to self-encapsulation systems, for augmenting buoyancy of seal payload systems launched from water-based launch ranges.
- High-glide parachute designs capable of deploying at altitudes above 25,000 ft to facilitate mid-air retrieval and/or fly-back/fly-to-point precision landing.

**Unmanned Aircraft Systems**

Unmanned Aircraft Systems (UAS) offer significant potential for Suborbital Scientific Earth Exploration Missions over a very large range of payload complexities, mission durations, altitudes, and extreme environmental conditions. To more fully realize the potential improvement in capabilities for atmospheric sampling and remote sensing, new technologies are needed. Scientific observation and documentation of environmental phenomena on both global and localized scales that will advance climate research and monitoring; e.g., U.S. Global Change Research Program as well as Arctic and Antarctic research activities (Ice Bridge, etc.).

NASA is increasing scientific participation to understand impacts associated with worldwide environmental changes. Capability for suborbital unmanned flight operations in either the North or South Polar Regions are limited because of technology gaps for extremely remote telemetry capabilities and precision flight path control requirements. It is also highly desirable to have UAS ability to perform atmospheric and surface sampling.

1. **Telemetry, Tracking and Control:** Low cost over-the-horizon global networks are needed to enable unmanned collaborative multi-platform earth observation missions that are more efficient and cost effective.

2. **Avionics and Flight Control:**

- **Precision Flight Path Control solutions in smooth atmospheric conditions.**
- **Aircraft control in violent atmospheric conditions.**
- **Low cost (**

Precise/repeatable flight path control capabilities are needed to enable repeat path observations for earth monitoring on seasonal and multi-year cycles. In addition, long endurance atmospheric sampling in extreme inclement weather conditions (hurricanes) and volcanic plumes can provide high fidelity time and spatial resolution.
(3) UA Integrated Vehicle Health Management:

- Fuel Heat/Anti-freezing
- Unmanned platform icing detection and minimization

(4) Guided Dropsondes: NASA Earth Science Research activities could utilize more capable dropsondes than are currently available as market items. Specifically, dropsondes that could effectively be guided through atmospheric regions of interest such as volcanic plumes could enable unprecedented observations of important phenomena. Capabilities of interest include:

- Compatibility with existing drop-sonde dispensing systems deployed on the NASA/NOAA P-3 and planned for the NASA Global Hawk
- Guidance schemes, autonomous or active control
- Cross-range performance and flight path accuracy
- Operational considerations including airspace utilization and conflicting traffic

All 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.

**S3.10 Earth Entry Vehicle Systems**

**S3.03 Power Generation and Conversion**

Lead Center: GRC

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

Future NASA science missions will employ Earth orbiting spacecraft, planetary spacecraft, balloons, aircraft, surface assets, and marine craft as observation platforms. Proposals are solicited to develop advanced power generation and conversion technologies to enable or enhance the capabilities of future science missions. Requirements for these missions are varied and include long life, high reliability, significantly lower mass
and volume, higher mass specific power, and improved efficiency over the state of practice for components and systems. Other desired capabilities are high radiation tolerance and the ability to operate in extreme environments (high and low temperatures and over wide temperature ranges).

While power generation technology affects a wide range of NASA missions and operational environments, technologies that provide substantial benefits for key mission applications/capabilities are being sought in the following areas.

**Radioisotope Power Conversion**
Radioisotope technology enables a wide range of mission opportunities, both near and far from the Sun and hostile planetary environments including high energy radiation, both high and low temperature and diverse atmospheric chemistries. Technology innovations capable of advancing lifetimes, improving efficiency, highly tolerant to hostile environments are desired for all thermal to electric conversion technologies considered here. Specific systems of interest for this solicitation are listed below.

Stirling Power Conversion: advances in, but not limited to, the following:

- System specific mass greater than 10 We/kg
- Highly reliable autonomous control
- Low EMI
- High temperature, high performance materials, 850-1200 C
- Radiation tolerant sensors, materials and electronics

Thermoelectric Power Conversion: advances in, but not limited to, the following:

- High temperature, high efficiency conversion greater than 10%
- Long life, minimal degradation
- Higher power density

**Cubesat and Nanosat On-orbit Power Generation**
NASA desires to build smaller spacecraft types carrying smaller instrument packages. However, power requirements to accommodate these instruments and spacecraft systems will not necessarily scale down in a similar fashion as spacecraft size. Therefore, power generation and power management technologies are sought that are compatible with small spacecraft geometries and sizes, especially in cubesat and nanosat form factors.

**Photovoltaic Energy Conversion**
Photovoltaic cell, blanket, and array technologies that lead to significant improvements in overall solar array performance (i.e. conversion efficiency >30%, array mass specific power >300 watts/kilogram, decreased stowed volume, reduced initial and recurring cost, long-term operation in high radiation environments, high power arrays, and a wide range of space environmental operating conditions) are solicited. Technologies specifically addressing the following mission needs are highly sought:

- Photovoltaic cell and blanket technologies capable of low intensity, low-temperature operation applicable to outer planetary (low solar intensity) missions
- Photovoltaic cell, blanket and array technologies capable of enhancing solar array operation in a high intensity, high-temperature environment (i.e. inner planetary and solar probe-type missions)
- Lightweight solar array technologies applicable to solar electric propulsion missions. Current missions being studied require solar arrays that provide 1 to 20 kilowatts of power at 1 AU, are greater than 300 watts/kilogram specific power, can operate in the range of 0.7 to 3 AU, provide operational array voltages up to 150 volts and have a low stowed volume.

Thermophotovoltaic conversion is currently focused on follow-on technology for the International Lunar Network (ILN) and for the outer planets mission. Advances sought, but not limited to, include:
• Low-bandgap cells having high efficiency and high reliability
• High temperature selective emitters
• Low absorptance optical band-pass filters
• Efficient multi-foil insulation

Note to Proposer: Topic X8 under the Exploration Mission Directorate also addresses power technologies (X8.03 Space Nuclear Power Systems, and X8.04 Advanced Photovoltaic Systems). Proposals more aligned with exploration mission requirements should be proposed in X8.

S3.04 Propulsion Systems

Lead Center: GRC
Participating Center(s): JPL

The Science Mission Directorate (SMD) needs spacecraft with more demanding propulsive performance and flexibility for more ambitious missions requiring high duty cycles, more challenging environmental conditions, and extended operation. Planetary spacecraft need the ability to rendezvous with, orbit, and conduct in situ exploration of planets, moons, and other small bodies in the solar system (http://www.nap.edu/catalog.php?record_id=10432 [39]). Future spacecraft and constellations of spacecraft will have high-precision propulsion requirements, usually in volume- and power-limited envelopes.

This subtopic seeks innovations to meet SMD propulsion requirements, which are reflected in the goals of NASA’s In-Space Propulsion Technology program to reduce the travel time, mass, and cost of SMD spacecraft. Advancements in chemical and electric propulsion systems related to sample return missions to Mars, small bodies (like asteroids, comets, and Near-Earth Objects), outer planet moons, and Venus are desired. Additional electric propulsion technology innovations are also sought to enable low cost systems for Discovery class missions, and eventually to enable radioisotope electric propulsion (REP) type missions.

The focus of this solicitation is for next generation propulsion systems and components, including high-pressure chemical rocket technologies and low cost/low mass electric propulsion technologies. Specific sample return propulsion technologies of interest include higher-pressure chemical propulsion system components, lightweight propulsion components, and Earth-return vehicle propulsion systems. Propulsion technologies related specifically to planetary ascent vehicles will be sought under S3.08 Planetary Ascent Vehicle.

Chemical Propulsion Systems
Technology needs include:

• Improved materials and manufacturing processes to produce Iridium/Rhenium apogee class thruster chambers with improved mechanical properties targeting a yield stress of 40ksi and an elongation of 10%;
• Advanced nontoxic mono-propellant rockets for in-space applications.

Electric Propulsion Systems
This subtopic also seeks proposals that explore uses of technologies that will provide superior performance in for high specific impulse/low mass electric propulsion systems at low cost. These technologies include:

• Efficient thrusters with up to 1 kW of input power that provide thrust up to 20 mN with a specific impulse between 1600 to 3500 seconds;
• A throttleable dual mode thruster that is capable of operating in both high thrust and high specific impulse modes for a fixed power;
• High power electric propulsion thrusters (>20 kW) and components including cathodes, ion optics, and low sputtering materials with long life (>1x108 N-s).

Proposals should show an understanding of the state of the art, how there technology is superior, and of one or more relevant science needs. The proposals should provide a feasible plan to fully develop a technology and infuse it into a NASA program.
Note to Proposer: Topic X2 under the Exploration Mission Directorate also addresses advanced propulsion. Proposals more aligned with exploration mission requirements should be proposed in X2.

**S3.05 Power Management and Storage**

**Lead Center:** GRC

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

Future NASA science objectives will include missions such as Earth Orbiting, Venus, Europa, Titan, Lunar Quest and Space Weather. Under this subtopic, proposals are solicited to develop energy storage and power electronics to enable or enhance the capabilities of future science missions. The unique requirements for the power systems for these missions can vary greatly, with advancements in components needed above the current State of the Art (SOA) for long life, high reliability, low mass/volume, radiation tolerance, and wide temperature operation.

**Energy Storage**

Future science missions will require advanced primary and secondary battery systems capable of operating at temperature extremes from -100°C for Titan missions to 400°C to 500°C for Venus missions, and a span of -230°C to +120°C for Lunar Quest. In addition, high energy-density rechargeable electrochemical battery systems that offer greater than 50,000 charge/discharge cycles (10 year operating life) for low-earth-orbiting spacecraft, 20 year life for geosynchronous (GEO) spacecraft, are desired. Advancements to battery energy storage capabilities that address one or more of the above requirements for the stated missions combined with very high specific energy (>200 Wh/kg for secondary battery systems) and energy density, along with radiation tolerance are of interest.

In addition to batteries, other advanced energy storage/load leveling technologies designed to the above mission requirements, such as flywheels, supercapacitors or magnetic energy storage, are of interest. These technologies have the potential to minimize the size and mass of future power systems.

**Power Management and Distribution (PMAD)**

The "New Frontiers in the Solar System: An Integrated Exploration Strategy" ([http://www.nap.edu/catalog.php?record_id=10432](http://www.nap.edu/catalog.php?record_id=10432)), the 2006 Solar System Exploration Roadmap ([http://nasascience.nasa.gov/about-us/science-strategy](http://nasascience.nasa.gov/about-us/science-strategy)) and the Science Plan for NASA's Science Mission Directorate ([http://nasascience.nasa.gov/about-us/science-strategy](http://nasascience.nasa.gov/about-us/science-strategy)) all describe the need for radioisotope power systems (RPS) for planetary exploration. In conjunction with the RPS, intelligent, fault-tolerant PMAD technologies are needed to efficiently manage the system power for these deep space missions. Advances in electrical power technologies are required for the electrical components and systems for these future platforms to address program size, mass, efficiency, capacity, durability, and reliability requirements. Of importance are expected improvements in energy density, speed, efficiency, or wide-temperature operation (-125°C to over 450°C) with a number of thermal cycles. Advancements are sought for power electronic devices, components and packaging for Venus type missions with power ranges of a few watts for minimum missions up to a few kilowatts for large missions.

For the lower power applications (up to 20 watts), NASA desires to build smaller spacecraft types carrying smaller instrument packages. However, power requirements to accommodate these instruments and spacecraft systems will not necessarily shrink in a similar fashion as spacecraft size. Therefore, power management technologies are sought that are compatible with small spacecraft geometries and sizes. These Electrical Power Systems should be compatible with Space Plug and Play (SPA) architectures.

Overall technologies of interest include:

- Intelligent, fault-tolerant electrical components and PMAD systems
- High temperature devices and components (up to 450°C)
- Advanced electronic packaging for thermal control and electromagnetic shielding
- Plug and Play compatibility for low power applications

Power Conversion and Distribution relevant to Command, Data Handling, and Electronics, will be covered under subtopic S3.01.

Power Storage for Terrestrial Balloons will be covered under sub-topic S3.07 Terrestrial and Planetary Balloons.
Research should be conducted to demonstrate technical feasibility during Phase I and show a path toward a Phase II, and when possible, deliver a demonstration unit for NASA testing at the completion of the Phase II contract. Phase II emphasis should be placed on developing and demonstrating the technology under relevant test conditions. Additionally, a path should be outlined that shows how the technology could be commercialized or further developed into science-worthy systems.

Other subtopics, which could potentially benefit from these technology developments include O5 - Low-Cost and Reliable Access to Space (LCRATS), S5.05 - Extreme Environments Technology, and S5.01 - Planetary Entry, Descent and Landing Technology. Battery development could also be beneficial to X6.02 - Advanced Space-rated Batteries, which is investigating some similar technologies in the secondary battery area but with very different operational requirements. Power Management and Distribution could be beneficial to X8.05 - Advanced Power Conversion Systems AND Management and Distribution (PMAD), which is investigating similar technologies, but with very different power levels.

S3.06 Guidance, Navigation and Control

Lead Center: GSFC

Participating Center(s): ARC, JPL

Advances in the following areas of guidance, navigation and control are sought.

- **Navigation systems** (including multiple sensors and algorithms/estimators, possibly based on existing component technologies) that work collectively on multiple vehicles to enable inertial alignment of the formation of vehicles (i.e., pointing of the line-of-sight defined by fixed points on the vehicles) on the level of milli-arcseconds relative to the background star field.

- **Light-weight sensors** (gyroscopic or other approach) to enable milli-arcsecond class pointing measurement for individual large telescopes and low cost small spacecraft.

- **Isolated pointing and tracking platforms** (pointing 0.5 arcseconds, jitter to 5 milli-arcsecond), targeted to placing a scientific instrument on GEO communication satellites that can track the sun for > 3 hours/day.

- **Working prototypes of GN&C actuators** (e.g., reaction or momentum wheels) that advance mass and technology improvements for small spacecraft use. Such technologies may include such non-contact approaches such as magnetic or gas. Superconducting materials, driven by temperature conditioning may also be appropriate provided that the net power used to drive and condition the "frictionless" wheels is comparable to traditional approaches.

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.

S3.07 Terrestrial and Planetary Balloons

Lead Center: GSFC

Participating Center(s): JPL

All 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.

Terrestrial Scientific Balloons

NASA's Scientific Balloons provide practical and cost effective platforms for conducting discovery science, development and testing for future space instruments, as well as training opportunities for future scientists and engineers. Balloons can reach altitudes above 36 kilometers, with suspended masses up to 3600 kilograms, and can stay aloft for several weeks. Currently, the Balloon Program is on the verge of introducing an advanced balloon system that will enable 100 day missions at mid latitudes and thus resemble the performance of a small spacecraft at a fraction of the cost. In support of this development, NASA is seeking innovative technologies in three key areas to monitor and advance the performance of this new vehicle.

(1) **Power Storage**: Devices or methods to store electrical energy onboard the balloon with lower mass than current
techniques are needed. Long duration balloon flights at mid-latitudes will experience up to 12 hours of darkness, during which electrical power is needed for experiments and NASA support systems. Typically, solar panels are flown to generate power during the daylight hours, and excess power is readily available. This excess power needs to be stored for use during the night. Current power storage techniques consist of rechargeable batteries which range from lead-acid to lithium-ion chemistries. Innovative alternatives to these batteries, either advanced chemistries or alternate power storage techniques such as capacitors or flywheels, which result in overall mass savings are needed. Nominal voltage levels for balloon systems are 28 volts DC, and nominal power levels can vary from 100 watts to 1000 watts. Therefore, power storage requirements range from 1000 watt-hours to 12,000-watt hours or more. Alternative power systems, which do not rely on solar panels, may also be proposed. These alternative systems may use energy storage techniques such as fuel cells or flywheels, which are prepared or charged on the ground prior to flight, and then would provide continuous power throughout the flight at the power levels specified above. Spacecraft power storage requirements are found under subtopic S3.05 Power Management and Storage.

(2) Balloon Instrumentation: Devices or methods are desired to accurately measure ambient air temperature, helium gas temperature, balloon film temperatures, film strain, and tendon load are desired. These measurements are needed to accurately model the balloon performance during a typical flight at altitudes of approximately 36 kilometers. The measurements must compensate for the effects of direct solar radiation through shielding or calculation. Minimal mass and volume are highly desired. Remote sensing of the parameters and non-invasive and non-contact approaches are also desired. The non-invasive and non-contact approaches are highly desired for the thin polyethylene film measurements used as the balloon envelope, with film thickness ranging from 0.8 to 1.5 mil. Strain measurements of these thin films via in-flight photogrammetric techniques would be beneficial. Devices or methods to accurately measure axially loaded tendons on an array of ~50 or up to 300 separate tendons during flight are of interest. Tendons are typically captured at the end fittings via individual pins with loading levels ranging from ~20 N to ~8,000 N per tendon, and can be exposed to temperatures from room temperature to the troposphere temperatures of -90 degrees Celsius or colder. The measurement devices must be compatible with existing NASA balloon packaging, inflation, and launch methods. These instruments must also be able to interface with existing NASA balloon flight support systems or alternatively, a definition of a data acquisition solution be provided. Support telemetry systems are not part of the this initiative; however, data from any sensors (devices) that are selected from this initiative must be able to be stored on board and/or telemetered in-flight using single-channel (two-wire) interface into existing NASA balloon flight support systems. The devices of interest shall be easily integrated and shall have minimal impact on the overall mass of the balloon system.

(3) Low-Cost Variable Conductance Heat Pipes for Balloon Payloads: With the ever-increasing complexity of both scientific instruments and NASA mission support equipment, advanced thermal control techniques are needed. The type of advanced thermal control techniques desired are similar to those utilized on large-budget orbital and deep space payloads (variable conductance heat pipes, diode heat pipes, loop heat pipes, capillary pumped loops, heat switches, louvers) are far more expensive to implement on balloon payloads that their limited budgets can afford. Innovative solutions are sought that would allow these more advanced thermal control measures to be utilized with reduced expense. Spacecraft thermal control requirements are found under subtopic S3.02 Thermal Control Systems.

Though not considered "cutting-edge technology", commercial quality, constant conductance, copper-methanol heat pipes have begun to be utilized on balloon payloads to effectively move heat significant distances. The problem with these devices is that the conductance cannot effectively be reduced under cold operating or cold survival environment conditions without expending significant energy in an active heater to maintain the condenser section warm. It is desirable to develop a cost-effective method of conducting the heat in this manner and allowing the flow to be reduced/eliminated when conditions warrant. Therefore, innovative thermal control techniques and devices developed must be inexpensive to implement. They must function reliably at balloon altitudes of 30-40km and temperature ranges from -90C to +40C. They should require little or no energy consumption and provide the capability of moderating heat flow autonomously or by remote control under certain thermal conditions.

Planetary Balloons
Innovations in materials, structures, and systems concepts have enabled buoyant vehicles to play an expanding role in planning NASA's future Solar System Exploration Program. Balloons and airships are expected to carry scientific payloads at Titan and Venus that will perform in situ investigations of their atmospheres and near surface environments. Both Titan and Venus feature extreme environments that significantly impact the design of balloons for those two worlds. Proposals are sought in the following areas:
(1) Titan Montgolfiere Balloons: Recent NASA mission studies have recommended the use of radioisotope-heated Montgolfiere balloons for future in situ Titan exploration. Proposals are sought for the design, fabrication and Earth atmosphere flight testing of prototypes that can support an eventual Titan Montgolfiere balloon mission. Particular importance is attached to the acquisition of test data that can help validate thermodynamic and fluid mechanic models that will ultimately be used to design the Titan flight balloon. The size of balloon required for Titan will be approximately 10 m in diameter and will require 2 kW of thermal energy to float the balloon at an expected Titan temperature of 85 to 95 K. Any proposed Earth-test prototype will require an alternate heat source that nevertheless adequately mimics the effects of using radioisotope energy at Titan.

(2) Gas Management Systems for Titan Aerobots: Hydrogen-filled aerobots at Titan must contend with the problem of gas leakage over long duration (1 year or more) flights. Proposals are sought for the development and testing of two kinds of prototype devices that can be carried on the aerobot to compensate for these gas leakage problems: one device is to produce make-up hydrogen gas from atmospheric methane; the other device is to remove atmospheric gas (mostly nitrogen) that leaks from the ballonets into the hydrogen-filled blimp. Both kinds of devices will need to operate on no more than 15 W of electrical power each while compensating for a leakage rate of at least 40 g/week of hydrogen or 500 g/week of nitrogen.

(3) Metal Balloons for High Temperature Venus Exploration: Balloons made of metals are a potential solution to the problem of enabling long duration flight in the hot lower atmosphere of Venus. Proposals are sought for metal balloon concepts and prototypes that provide 1-5 m³ of fully inflated volume, areal densities of 1 kg/m² or less, sulfuric acid compatibility at 85% concentration, and operation at 460 °C for a period of up to 1 year.

S3.08 Planetary Ascent Vehicles

Lead Center: GRC
Participating Center(s): AFRC, JPL, MSFC

NASA aims to design, build and test vehicles that will be launched from the surface of other planets and small bodies and place a payload, Orbiting Sample (OS), into orbit. We are seeking proposals for the development of innovative technologies to support future planetary ascent vehicles. Immediate focus is the Mars ascent vehicle. Technology innovations should either enhance vehicle capabilities (e.g., launch success probability, mission success, improved performance or margins, and improved environmental robustness) or ease implementation in space borne missions (e.g., reduce size, mass, power, and thermal requirements, improve reliability and ability to withstand the ~20 g lateral g-loading, or lower cost). The areas of interest for this call are listed below.

Alternate propellants, thrusters and propulsion system technologies for the planetary ascent vehicles:

- Higher performing monopropellants with specific impulse >240 secs;
- "Green" propellants;
- High chamber pressure thrusters > 500 psia;
- Pressurization component technologies to reduce system mass (filters, solenoid valves, latch valves, tanks, fill and drain and check valves);
- Small lightweight pump technologies to operate at >500 psi output pressure especially non-electrically driven;
- Non-pyrotechnic isolation valves.

Advanced solid propellant engine system technologies:

- Solid propellant technology with specific impulse performance potential higher than HTPB and CTPB;
- Propellant blend with high performance low storage impacts, and operating capability down to 150 K;
- Low temperature seals and components;
- Light weight and reliable thrust vector control;
- Other lightweight system and component technologies.

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.
Launch vehicle technologies relevant to Earth are not sought under this sub-topic. For launch vehicle technologies related to Earth, see X2.01 Earth-to-Orbit Propulsion. Proposals more aligned with exploration mission requirements should be proposed in X2.01.

S3.09 Unmanned Aircraft and Sounding Rocket Technologies

Lead Center: GSFC
Participating Center(s): AFRC, ARC, GRC, JPL, LaRC

**Sounding Rockets**
The NASA Sounding Rocket Program (NSRP) provides low-cost, sub-orbital access to space in support of space and earth sciences research and technology development sponsored by NASA and other users by providing payload development, launch vehicles, and mission support services. NASA utilizes a variety of vehicle systems comprised of military surplus and commercially available rocket motors, capable of lofting scientific payloads, up to 1300lbs, to altitudes from 100km to 1500km. NASA launches sounding rocket vehicles worldwide, from both land-based and water-based ranges, based on the science needs to study phenomenon in specific locations.

NASA is seeking innovations to enhance capabilities and operations in the following areas:

- Autonomous vehicle environmental diagnostics system capable of monitoring flight loading (thermal, acceleration, stress/strain) for solid rocket vehicle systems.
- Location determination systems to provide over-the-horizon position of buoyant payloads to facilitate expedient location and retrieval from the ocean.
- Flotation systems, ranging from tethered flotation devices to self-encapsulation systems, for augmenting buoyancy of seal payload systems launched from water-based launch ranges.
- High-glide parachute designs capable of deploying at altitudes above 25,000 ft to facilitate mid-air retrieval and/or fly-back/fly-to-point precision landing.

**Unmanned Aircraft Systems**
Unmanned Aircraft Systems (UAS) offer significant potential for Suborbital Scientific Earth Exploration Missions over a very large range of payload complexities, mission durations, altitudes, and extreme environmental conditions. To more fully realize the potential improvement in capabilities for atmospheric sampling and remote sensing, new technologies are needed. Scientific observation and documentation of environmental phenomena on both global and localized scales that will advance climate research and monitoring; e.g., U.S. Global Change Research Program as well as Arctic and Antarctic research activities (Ice Bridge, etc.).

NASA is increasing scientific participation to understand impacts associated with worldwide environmental changes. Capability for suborbital unmanned flight operations in either the North or South Polar Regions are limited because of technology gaps for extremely remote telemetry capabilities and precision flight path control requirements. It is also highly desirable to have UAS ability to perform atmospheric and surface sampling.

(1) Telemetry, Tracking and Control: Low cost over-the-horizon global networks are needed to enable unmanned collaborative multi-platform earth observation missions that are more efficient and cost effective.

(2) Avionics and Flight Control:

- Precision Flight Path Control solutions in smooth atmospheric conditions.
- Aircraft control in violent atmospheric conditions.
- Low cost (<$20k), High precision inertial navigation systems (greater than 1/10th degree accuracy and knowledge)

Precise/repeatable flight path control capabilities are needed to enable repeat path observations for earth monitoring on seasonal and multi-year cycles. In addition, long endurance atmospheric sampling in extreme inclement weather conditions (hurricanes) and volcanic plumes can provide high fidelity time and spatial resolution data.
(3) UA Integrated Vehicle Health Management:

- Fuel Heat/Anti-freezing
- Unmanned platform icing detection and minimization

(4) Guided Dropsondes: NASA Earth Science Research activities could utilize more capable dropsondes than are currently available as market items. Specifically, dropsondes that could effectively be guided through atmospheric regions of interest such as volcanic plumes could enable unprecedented observations of important phenomena. Capabilities of interest include:

- Compatibility with existing drop-sonde dispensing systems deployed on the NASA/NOAA P-3 and planned for the NASA Global Hawk
- Guidance schemes, autonomous or active control
- Cross-range performance and flight path accuracy
- Operational considerations including airspace utilization and conflicting traffic

All 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.

S3.10 Earth Entry Vehicle Systems

Lead Center: LaRC

Participating Center(s): ARC

This subtopic seeks innovations to meet Science Mission Directorate (SMD) requirements for Earth Entry Vehicles (EEV). Advancements in materials, structures, and systems related to sample return missions to the Moon, planetary bodies (e.g., Mars and Venus), small bodies (e.g., asteroids, comets, and Near-Earth Objects) and outer planet bodies are desired.

EEVs provide several challenges to current material and structural designs in several areas. New classes of structure and impact materials are needed which are lightweight and versatile, remaining stiff during impact with soft surfaces while providing low impact loads when crashing with impact to hard surfaces. Lightweight structures that are suitable for thermal protection system (TPS) substructures, including serving as a thermal barrier or sink, are also desired. Current EEV concepts are blunt-body vehicles (60-degree sphere cones) that are 0.5 to 2.0 meters in diameter, entering Earth's atmosphere at 11-16 km/s.

This subtopic also seeks proposals that explore new technologies in several key vehicle systems that include:

- Low mass/cost/complexity, high reliability impact attenuation systems capable of keeping peak impact loads below 1500 g's under nominal conditions, or 2500 g's under off-nominal conditions (i.e. impact with a rock or hard man-made surface, e.g. concrete road). Payload stroke resulting from compression of candidate impact foam must not exceed 2.5% of the vehicle overall diameter.
- Lightweight structures that are suitable for TPS substructures (i.e., lightweight, stiff, good insulator).
- Mid-density robust ablator systems that can be tailored to entry heating for a range of missions from high speed to low speed, and are easy to manufacture across the range of possible vehicle scales.
- Adhesives that are compatible with lightweight structures and TPS.
- Passive (or nearly passive), self-contained methods of determining whether a micrometeoroid strike (of the TPS) has occurred.
- Low mass, low power, reliable self-contained beacon for EEV retrieval.
- Candidate beacon mass must not exceed 100g (including power and activation) and must provide a reliable signal for up to 2 days after landing/impact.
- Low mass, low power, reliable, self-contained GPS with broadcast system and the antenna to beam the trajectory and landing location information to IRIDIUM or other easily accessible commercial global communication systems as an aid to locating the landed EEV.
- Thermal control system technologies for EEVs will be covered under sub-topic S3.02 Thermal Control
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.

Other subtopics that could be soliciting entry, descent, and landing related technology developments include S5.01 Entry, Descent and Landing Technologies, X9.01 Ablative Thermal Protection Systems, and X9.02 Advanced Integrated Hypersonic Entry Systems. Proposals more aligned with exploration mission requirements should be proposed in X9.

Low-Cost Small Spacecraft and Technologies Topic S4

This subtopic is targeted at the development of technologies and systems, which can enable the realization of small spacecraft science missions. While small spacecraft have the benefit of reduced launch costs by virtue of their lower mass, they may be currently limited in performance and their capacity to provide on-orbit resources to payload and instrument systems. With the incorporation of smaller bus technologies, launch costs, as well as total life cycle costs, can continue to be reduced, while still achieving and expanding NASA's mission objectives.

The Low-Cost Small Spacecraft and Technologies category is focused on the identification and development of specific key spacecraft technologies primarily in the areas of integrated avionics, attitude determination and control including de-orbit technologies, and spacecraft power generation and management. The primary thrust of this topic is directed at reducing the footprint and resources that these bus subsystems require (size, weight, and power), allowing more of these critical resources to be shifted to payload and instrument systems, and to further reduce the overall launch mass and volume requirements for small spacecraft.

Note that related topics of interest to S4 Low-cost Small Spacecraft and Technologies may be found in other areas of the solicitation: S3.01 Command, Data Handling and Electronics; S3.03 Power Generation and Conversion; and S3.05 Power Management and Storage.

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.

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

Sub Topics:

**S4.01 De-orbit Devices/Technologies for Small Spacecraft**

*Lead Center: ARC*

*Participating Center(s): GRC, KSC*

NASA intends to place small spacecraft (
S4.02 Miniature Integrated Payload Suites

Lead Center: ARC

Participating Center(s): GSFC

In order to fully realize the economy, launch frequency, and science utility benefits that small spacecraft represent, a new generation of MEMS-based sensor suites are desired. These sensors could be the result of miniaturization and repacking of existing sensors, or consist of novel devices and technologies that can accomplish similar measurements of larger systems in a fraction of the current size, weight and power. In addition, these suites would contain the necessary data processing and power conditioning systems to support routine operation. Compatibility with Space Plug and Play (SPA) or similar architectures that streamline system integration processes is also desired.

Robotic Exploration Technologies Topic S5

NASA is pursuing technologies to enable robotic exploration of the Solar System including its planets, their moons, and small bodies. NASA has a development program that includes technologies for the atmospheric entry, descent, and landing, mobility systems, extreme environments technology, sample acquisition and preparation for in situ experiments, and in situ planetary science instruments. Robotic exploration missions that are planned include a Europa Jupiter System mission, Titan Saturn System mission, Venus In Situ Explorer, sample return from Comet or Asteroid and lunar south polar basin and continued Mars exploration missions launching every 26 months including a network lander mission, an Astrobiology Field Laboratory, a Mars Sample Return mission and other rover missions. Numerous new technologies will be required to enable such ambitious missions. The solicitation for in situ planetary instruments can be found in the in situ instruments section of this solicitation. See URL: http://solarsystem.nasa.gov/missions/index.cfm [44] for mission information. See URL: http://marsprogram.jpl.nasa.gov/ [45] for additional information on Mars Exploration.

Sub Topics:

S5.01 Planetary Entry, Descent and Landing Technology

Lead Center: JPL

Participating Center(s): ARC, JSC, LaRC

NASA seeks innovative sensor technologies to enhance success for entry, descent and landing (EDL) operations on missions to Mars. Sensing technologies are desired which determine the entry point of the spacecraft in the Mars atmosphere; provide inputs to systems that control spacecraft trajectory, speed, and orientation to the surface; locate the spacecraft relative to the Martian surface; evaluate potential hazards at the landing site; and determine when the spacecraft has touched down. Appropriate sensing technologies for this topic should provide measurements of physical forces or properties that support some aspect of EDL operations. NASA also seeks to
use measurements made during EDL to better characterize the Martian atmosphere, providing data for improving atmospheric modeling for future landers. Proposals are invited for innovative sensor technologies that improve the reliability of EDL operations.

Products or technologies are sought that can be made compatible with the environmental conditions of spaceflight and the rigors of landing on the Martian surface. Successful candidate sensor technologies can address this call by:

- Providing critical measurements during the entry phase (e.g., pressure and/or temperature sensors embedded into the aeroshell);
- Improving the accuracy on measurements needed for guidance decisions (e.g., surface relative velocities
- Extending the range over which such measurements are collected (e.g., providing a method of imaging through the aeroshell, or terrain-relative navigation that does not require imaging through the aeroshell);
- Enhancing the situational awareness during landing by identifying hazards (rocks > 20cm height, slopes > 0.05 radians, craters > 1m diameter) and distinguishing between favorable and unfavorable landing materials (e.g., differentiate bowls of dust from solid rock)
- Substantially reducing the amount of external processing needed to calculate the measurements or provide high performance flight qualified processing with low mass and power (e.g., 1 GFLOPS processing in
- Decoupling spacecraft attitude from instrument pointing through the development of fast gimbals that are low mass and power (2rad/s² accelerations, 2 rad/s rates with mass
- Improving landing site map accuracy and resolution while also providing a means for validating the generated map (10cm resolution elevation with 5cm height errors and map tie errors
- Providing modular and low mass spacecraft to spacecraft navigation systems that work through all of EDL (e.g. orbiter to lander during entry or lander to surface rover).
- Monitoring local environmental (weather) conditions on the surface to facilitate forecasting of wind velocities up to ~10km altitude above the surface in preparation for landing (for missions targeted to land near previously landed assets)
- Significantly reducing the impact of incorporating such sensors on the spacecraft in terms of volume, mass, placement, or cost.

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.

Other subtopics that could be soliciting entry, descent, and landing related technology developments include S1.01 Laser and Lidar System Components, S3.10 Earth Entry Vehicle Systems, X9.01 Ablative Thermal Protection Systems, and X9.02 Advanced Integrated Hypersonic Entry Systems. Proposals more aligned with exploration mission requirements should be proposed in X9.
S5.02 Sample Collection, Processing, and Handling

Lead Center: JPL

Participating Center(s): ARC, GSFC, JSC

Robust systems for sample acquisition, handling and processing are critical to the next generation of robotic explorers for investigation of planetary bodies ([http://books.nap.edu/openbook.php?record_id=10432&page=R1](http://books.nap.edu/openbook.php?record_id=10432&page=R1) [46]). Limited spacecraft resources (power, volume, mass, computational capabilities, and telemetry bandwidth) demand innovative, integrated sampling systems that can survive and operate in challenging environments (extremes in temperature, pressure, gravity, vibration and thermal cycling). Special interest lies in sampling systems and components (actuators, gearboxes, etc.) that are suitable for use in the extremely hot high-pressure environment at the Venusian surface (460ºC, 93 bar). Relevant systems could be integrated on multiple platforms, however of primary interest are samplers that could be mounted on a mobile platform, such as a rover. For reference, current Mars-relevant rovers range in mass from 200 - 800 kg.

### Sample Acquisition

Research should be conducted to develop compact, low-power, lightweight subsurface sampling systems that can obtain 1 cm diameter cores of consolidated material (e.g., rock, icy regolith) up to 10 cm below the surface. Systems should be capable of autonomously acquiring and ejecting samples reliably. Also of interest are methods of autonomously exposing rock interiors from below weathered rind layers. Other sample types of interest are unconsolidated regolith, dust, and atmospheric gas.

### Sample Manipulation (core management, sub-sampling/sorting, powder transport)

Sample manipulation technologies are needed to enable handling and transfer of structured and unstructured samples from a sampling device to instruments and sample processing systems. Core, cuttings, and regolith samples may be variable in size and composition, so a sample manipulation system needs to be flexible enough to handle the sample variability. Core samples will be on the order of 1 cm diameter and up to 10 cm long. Soil and rock fragment samples will be of similar volumes.

### Sample Integrity (encapsulation and contamination)

For a sample return mission, it is critical to find solutions for maintaining physical integrity of the sample during the surface mission (rover driving loads, diurnal temperature fluctuations) as well as the return to Earth (cruise, atmospheric entry and impact). Technologies are needed for characterizing state of sample in situ - physical integrity (e.g., cracked, crushed), sample volume, mass or temperature, as well as retention of volatiles in solid (core, regolith) samples, and retention of atmospheric gas samples.

Also of particular need are means of acquiring subsurface rock and regolith samples with minimum contamination. This contamination may include contaminants in the sampling tool itself, material from one location contaminating samples collected at another location (sample cross-contamination), or Earth-source microorganisms brought to the Martian surface prior to drilling (‘clean’ sampling from a ‘dirty’ surface). Consideration should be given to use of materials and processes compatible with 110 - 125°C dry heat sterilization. In situ sterilization may be explored, as well as innovative mechanical or system solutions - e.g., single-use sample "sleeves," or fully-integrated sample acquisition and encapsulation systems.

For a sample return mission, sample transfer of a payload into a planetary ascent vehicle: Automated payload...
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.

S5.03 Surface and Subsurface Robotic Exploration

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

Technologies are needed to enable access, mobility, and sample acquisition at surface and subsurface sampling sites of scientific interest on Mars, Venus, small planetary bodies, and the moons of the Earth, Mars, Jovian and Saturnian systems. Many scientifically valuable sites are accessible only via terrain that is too difficult for state-of-the-art planetary rovers to traverse in terms of ground slope, rock obstacle size, plateaus, and non-cohesive soils types. Sites include crater walls, canyons, gullies, sand dunes, and high rock density regions. Tethered systems, non-wheeled systems, and marsupial systems are examples of mobility technologies that are of interest. These technologies could enable new approaches for deployment, retrieval, access, and mobility.

A variety of mobility system architectures can be considered. Single vehicle systems might utilize a 200 kg class rover and dual vehicle systems might utilize a 500 - 800 kg primary vehicle that provides long traverse to the vicinity of a challenging site and then deployment of a smaller 20 - 50 kg vehicle with steep mobility capability for access and sampling at the site.

For surface and subsurface sampling, advanced manipulation technologies are needed to deploy instruments and tools from landers and rovers. Technologies to enable acquisition of subsurface samples are also needed. For Mars and Venus, technologies are needed to acquire core samples in the shallow subsurface to about 10cm and to enable subsurface sampling in multiple holes at least 1 - 3 meters deep through rock, regolith, or ice compositions. Shallow subsurface sampling systems need to be low mass and deeper subsurface sampling solutions need to be integratable onto 500 - 800 kg stationary landers and mobile platforms. For Europa, penetrators and tools to allow deep drilling are needed to sample and bore the outer water-ice layer and through 10 to 30km to a potential liquid ocean below.

Consideration should be given for potential failure scenarios, such as platform slip and borehole misalignment for integrated systems, and the challenges of dry drilling into mixed media including icy mixtures of rock and regolith. Systems should ensure minimal contamination of samples from Earth-source contaminants and cross-contamination from samples at different locations or depths.

Innovative component technologies for low mass, low power, and modular systems tolerant to the in-situ environment are of particular interest. For Europa, the radiation environment is estimated at 2.9 Mrad total ionizing dose (TID) behind 100 mil thick aluminum. Technical feasibility should be demonstrated during Phase I and a full capability unit of at least TRL level 4 should be delivered in Phase II. Specific areas of interest include the following:
• Tether play-out and retrieval systems including tension and length sensing;
• Low-mass tether cables with power and communication;
• Steep terrain adherence for vertical and horizontal mobility;
• Modular actuators with 1000:1 scale gear ratios;
• Electro-mechanical couplers to enable change out of instruments on an arm end-effector;
• Drill, core, penetrator, and boring systems for subsurface sampling to 10cm, 1m, 3m, and deep subsurface;
• Shared intelligence allowing systems to collaborate and adapt exploration scenarios to new conditions.

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

S5.04 Rendezvous and Docking Technologies for Orbiting Sample Capture

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

NASA seeks an innovative suite of products or technologies that will enable and enhance the successful tracking and capture of a sample canister in Mars orbit in anticipation of the start of a Mars Sample Return (MSR) mission in the next decade.

The principal means of detection and tracking of the Orbiting Sample Canister (OSC) is optically with visual-band cameras. The challenging technology of long-range optical sensors for detection and distant tracking is not part of this call, however, short-range optical (or other) sensors and an on-sample radio-metric-based back-up detection and tracking method is desired, including a low-power, low-mass illuminator for short-range imaging of up to 0.5km.

Sample capture mechanisms are sought, of very low mass and volume, and of low complexity and extremely high reliability, including detection of contact with the capture mechanism. Appropriate on-sample radio-beacons are sought that are compatible with NASA's radio systems, in particular, the Electra onboard programmable radio system; requirements for these beacons are for long life, and independent initiation of on-orbit operation. Solutions are sought that are either battery powered or via solar cells that do not reduce the overall OSC outer shell visual albedo below 0.5. Sample capture mechanisms should include close-proximity/contact sensors, including immediate-field imaging.
Methods are sought to provide a practice mechanism for testing rendezvous and proximity operations with a test sample canister in Earth or Mars orbit. The test carrier and release mechanism must be of very low mass and volume, and the test sample canister(s) should carry a radio beacon. Test OSC canisters should be of limited life after release, ceasing broadcast, and degrading in surface reflectance in approximately one month after release to avoid confusion with the actual canister. The test articles may be deployed and used on a previous mission to MSR, or on the actual MSR mission for operational readiness testing.

Products or technologies are sought that can be made compatible with the environmental conditions of interplanetary spaceflight and the rigors normal Mars orbits. Proposals should show an understanding of proposals and plans for previous NASA-supported Mars Sample Return relevant missions and mission concepts, and present a feasible plan to fully develop a technology and infuse it into a NASA program. Successful candidate products or technologies can address this call by providing one or more of the following functions, and giving estimated expected performance capabilities of the approach, including, but not limited to, accuracies, ranges, limits of operation, references to previous or related flight experience:

- Autonomously actuated mechanisms for orbiting sample capture of the OSC
  - Mechanical capture mechanisms
  - Transfer mechanisms from capture device to containment transfer mechanism

- Optical and contact sensors
  - Near field imagers (optical or other) (e.g. 10m to 1km)
  - Immediate field imagers (optical) (0.25 to 10m)
  - Detection of OSC for triggering capture mechanism
  - Near field illuminator

- Coherent Radio Doppler and range beacon (high-performance)
  - Low power, low mass and long life beacon for detection aid
  - 2-way communication for activation, ranging and coherency via NASA’s Electra radio interface
  - Programmable intermittent transmission for power saving and very long dormancy period
  - Battery or solar powered, preserving 0.5 visual albedo of OSC

- Simple Radio beacon (low-performance)
  - Simple 1-way beacon, for long-range detection and 1-way Electra Doppler extraction
  - Timer activated, multi-year dormant life, and long active life battery, or solar powered - preserving
0.5 visual albedo of OSC

- Low-mass, low-cost sample OSC for proximity operations operational readiness tests
  - A simple, low-cost, low-mass practice sample canister that could be deployed in Earth or Mars orbit and provide low-risk practice runs, either for a precursor mission, or with the actual MSR.
  - The readiness test exercise would not necessarily capture the test article in the capture mechanism for the actual MSR flight, but only perform the rendezvous and proximity ops operations sufficient to demonstrate very high likelihood of actual OSC capture.

### S5.05 Extreme Environments Technology

#### Lead Center: JPL

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

#### High Temperature, High Pressure, and Chemically Corrosive Environments

NASA is interested in expanding its ability to explore the deep atmosphere and surface of Venus through the use of long-lived (days or weeks) balloons and landers. Survivability in extreme high temperatures and high pressures is also required for deep atmospheric probes to giant planets. Proposals are sought for technologies that enable the in situ exploration of the surface and deep atmosphere of Venus and the deep atmospheres of Jupiter or Saturn for future NASA missions. Venus features a dense, CO$_2$ atmosphere completely covered by sulfuric acid clouds at about 55 km above the surface, a surface temperature of about 486 degrees Centigrade and a surface pressure of about 90 bars. Technologies of interest include high temperature and acid resistant high strength-to-weight textile materials for landing systems (balloons, parachutes, tethers, bridles, airbags), high temperature electronics components, high temperature energy storage systems, light mass refrigeration systems, high-temperature motors and actuators for robotic arms and other mechanisms, high temperature drills, phase change materials for short term thermal maintenance, low conductivity and high-compressive strength insulation materials, high temperature optical window systems (that are transparent in IR, visible and UV wavelengths) and advanced materials with high specific heat capacity and strength for pressure vessel construction, and pressure vessel components compatible with materials such as steal, titanium and beryllium such as low leak rate wide temperature (-50 degrees Centigrade C to 500 degrees Centigrade) seals capable of operating between 0 and 90 bars.

#### Low Temperature Environments

Low temperature survivability is required for surface missions to Titan (-180 degrees Centigrade), Europa surface (-220 degrees Centigrade), Ganymede (-200 degrees Centigrade) and comets. Also the Earth’s Moon equatorial regions experience wide temperature swings from -180 degrees Centigrade to +130 degrees Centigrade during the lunar day/night cycle, and the sustained temperature at the shadowed regions of lunar poles can be as low as -230 degrees Centigrade. Mars diurnal temperature changes from about -120 degrees Centigrade to +20 degrees Centigrade. Also for the baseline concept for Europa Jupiter System Mission (EJSM), with a mission life of 10 years, the radiation environment is estimated at 2.9 Mega-rad total ionizing dose (TID) behind 100 mil thick aluminum. Proposals are sought for technologies that enable NASA's long duration missions to low temperature and wide temperature environments. Technologies of interests include low-temperature resistant high strength-weight textiles for landing systems (parachutes, air bags), low power radiation-tolerant /radiation hardened RF electronics, radiation-tolerant / radiation hardened mixed signal electronics, radiation-tolerant / radiation hardened power electronics, radiation-tolerant/ radiation hardened high speed fiber optic transceivers, radiation-tolerant/ radiation hardened electronic packaging (including, shielding, passives, connectors, wiring harness and materials...
used in advanced electronics assembly), actuators and energy storage sources capable of operating across an ultra-wide temperature range from -230 degrees Centigrade to 200 degrees Centigrade and Computer Aided Design (CAD) tools for modeling and predicting the electrical performance, reliability, and life cycle for low-temperature electronic systems and components.

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

S5.06 Planetary Protection

Lead Center: JPL
Participating Center(s): LaRC

NASA seeks innovative technologies to facilitate meeting Back Planetary Protection objectives for a potential Mars Sample Return mission and to facilitate Forward Planetary Protection implementation for a potential mission to Europa.

Back Planetary Protection deals with the possibility that Mars material may pose a biological threat to the Earth's biosphere. This leads to a constraint that returned samples of Mars material be contained with extraordinary robustness until they can be tested and proved harmless or be sterilized by an accepted method. Achieving this containment goal will require new technology for several functions. Containment assurance requires "breaking the chain of contact" with Mars: the exterior of the sample container must not be contaminated with Mars material. Also, the integrity of the containment must be verified, the sample container and its seals must survive the worst-case Earth impact corresponding to the candidate mission profile, and the Earth entry vehicle (EEV) must withstand the thermal and structural rigors of Earth atmosphere entry - all with an unprecedented degree of confidence.

Back Planetary Protection technologies for the following MSR functions are included in this call:

- Container Design, Sealing, and Verification: Options for sealing the sample container include brazing, explosive welding, and various types of soft seals, with sealing performed either on the Mars surface or in orbit. Confirmation of sealing can be provided by observation of sealing system parameters and by leak detection after sealing. Wireless data and power transmission may be needed for leak detection. Additional containment using a flexible liner within the EEV that is sealed while in Mars orbit has also been considered. Further validation prior to Earth entry may also be needed.

- Breaking-the-Chain and Dust Mitigation: Several paths have been identified that would result in Mars material contaminating the outside of the sealed sample container and/or the Earth return vehicle (ERV). Technology options for mitigation include ejection of containment layers during ascent and orbit and/or capturing a contaminated "Orbiting Sample" into a clean container on the ERV and then ejecting the capture device.
Meteoroid Protection and Breach Detection: Protection is required for both the sample container and the EEV heat shield, with the later appearing to be the more challenging technology requirement. New lightweight shielding techniques are needed. Even with these the shield may be excessively heavy leading to a requirement for technology to detect a breach of the shield or damage to the EEV.

Entry, Descent, and Landing: The EEV should be aerodynamically self-righting and should provide shock attenuation for the sample container consistent with the planned no-parachute descent.

PRA and Reliability Analysis: Obtaining approval to proceed with an MSR mission is likely to involve quantitative assessment of the probability of containment loss. This will benefit from advances in the state of the art of probabilistic risk assessment for complex space systems and of reliability analysis of the spacecraft components involved.

Technologies are desired for the Europa mission that allow sterilization of previously non-sterilizable flight hardware by either i) dry heat processing or ii) gamma irradiation. NASA also seeks to use iii) hydrogen peroxide vapor processes for re-sterilization of assembled flight hardware elements. Proposals are invited for innovative approaches to sterilization of flight hardware in the pre-flight environment using this technology. Note: this call is not for novel sterilization processes.

For Europa, products and technologies are sought that can be demonstrated to be compatible with the three identified sterilization processes, as well as the environmental conditions of spaceflight and the Jovian system. Candidate technologies for the following functions and capabilities are included in this call:

- Sterilization Process Compatibility: Options for proving compatibility of novel product elements (materials, parts) with recognized spacecraft sterilization process parameters are desired.

- Redesign for Sterilization: Development of alternative solutions for spacecraft hardware is needed where there are known sterilization process incompatibilities, for example for heat tolerant sensors, seals (battery, valve), optical coating applications.

- Biobarrier Technology: Demonstration of novel biobarrier and recontamination prevention approaches for spacecraft hardware is needed when applying one or more of these three sterilization processes.

Proposals should show an understanding of one or more relevant technology needs and present a feasible plan to fully develop a technology and infuse it into a NASA program.
Information Technologies Topic S6

NASA Missions and Programs create a wealth of science data and information that are essential to understanding our earth, our solar system and the universe. Advancements in information technology will allow many people within and beyond the Agency to more effectively analyze and apply this data to create knowledge. In particular, modeling and simulation are being used more pervasively throughout NASA, for both engineering and science pursuits, than ever before. These are tools that allow high fidelity simulations of systems in environments that are difficult or impossible to create on Earth, allow removal of humans from experiments in dangerous situations, and provide visualizations of datasets that are extremely large and complicated. In many of these situations, assimilation of real data into a highly sophisticated physics model is needed. Information technology is also being used to allow better access to science data, more effective and robust tools for analyzing and manipulating data, and better methods for collaboration between scientists or other interested parties. The desired end result is to see that NASA science information be used to generate the maximum possible impact to the nation: to advance scientific knowledge and technological capabilities, to inspire and motivate the nation's students and teachers, and to engage and educate the public.

Sub Topics:

S6.01 Technologies for Large-Scale Numerical Simulation

Lead Center: ARC
Participating Center(s): GSFC

NASA scientists and engineers are increasingly turning to large-scale numerical simulation on supercomputers to advance understanding of complex Earth and astrophysical systems, and to conduct high-fidelity aerospace engineering analyses. The goal of this subtopic is to increase the mission impact of NASA's investments in supercomputing systems and associated operations and services. Specific objectives are to:

- Decrease the barriers to entry for prospective supercomputing users;
- Minimize the supercomputer user's total time-to-solution (e.g., time to discover, understand, predict, or design);
- Increase the achievable scale and complexity of computational analysis, data ingest, and data communications;
- Reduce the cost of providing a given level of supercomputing performance on NASA applications; and
- Enhance the efficiency and effectiveness of NASA's supercomputing operations and services.

Expected outcomes are to improve the productivity of NASA's supercomputing users, broaden NASA's supercomputing user base, accelerate advancement of NASA science and engineering, and benefit the supercomputing community through dissemination of operational best practices.

The approach of this subtopic is to seek novel software and hardware technologies that provide notable benefits to NASA's supercomputing users and facilities, and to infuse these technologies into NASA supercomputing operations. Successful technology development efforts under this subtopic would be considered for follow-on funding by, and infusion into, NASA's high-end computing (HEC) projects: the High End Computing Capability project at Ames and the Scientific Computing project at Goddard. To assure maximum relevance to NASA, funded SBIR contracts under this subtopic should engage in direct interactions with one or both HEC projects, and with key HEC users where appropriate. Research should be conducted to demonstrate technical feasibility and NASA relevance during Phase I and show a path toward a Phase II prototype demonstration.
Offerors should demonstrate awareness of the state-of-the-art of their proposed technology, and should leverage existing commercial capabilities and research efforts where appropriate. Open source software and open standards are strongly preferred. Note that the NASA supercomputing environment is characterized by: HEC systems operating behind a firewall to meet strict IT security requirements, communication-intensive applications, massive computations requiring high concurrency, complex computational workflows and immense datasets, and the need to support hundreds of complex application codes; many of which are frequently updated by the user/developer. As a result, solutions that involve the following must clearly explain how they would work in the NASA environment: Grid computing, web services, client-server models, embarrassingly parallel computations, and technologies that require significant application re-engineering. Projects need not benefit all NASA HEC users or application codes, but demonstrating applicability to an important NASA discipline, or even a key NASA application code, could provide significant value.

Specific technology areas of interest include:

- **Efficient Computing**: In spite of the rapidly increasing capability and efficiency of supercomputers, NASA's HEC facilities cannot purchase, power, and cool sufficient HEC resources to satisfy all user demands. This subtopic element seeks dramatically more efficient and effective supercomputing approaches in terms of their ability to supply increased HEC capability or capacity per dollar and/or per Watt for real NASA applications. Examples include novel computational accelerators and architectures, more capable storage/interconnect/visualization technologies, improved algorithms for key codes, and power-aware computing technologies and techniques.

- **Integrated Environments**: The user interface to a supercomputer is typically a command line in a text window. This subtopic element seeks more intuitive, intelligent, user-customizable, and integrated interfaces to supercomputing resources, enabling users to more completely leverage the power of HEC to increase their productivity. Such an interface could enhance many essential supercomputing tasks: accessing and managing resources, training, getting services, developing codes, running computations, managing files and data, analyzing and visualizing results, transmitting data, collaborating, etc.

- **Cloud Supercomputing**: Cloud computing has made tremendous promises, and demonstrated some success, for business computing: on-demand resource availability, resource virtualization, automated job migration, increased system availability, customized software environments, a web user interface, increased system reliability, and more. This subtopic element seeks technologies that enable Cloud computing to be used for efficient and effective supercomputing operations.

**S6.02 Earth Science Applied Research and Decision Support**

*Lead Center: SSC*

*Participating Center(s): ARC, JPL*

The NASA Applied Sciences Program ([http://nasascience.nasa.gov/earth-science/applied-sciences](http://nasascience.nasa.gov/earth-science/applied-sciences)) seeks innovative and unique approaches to increase the utilization and extend the benefit of Earth Science research data to better meet societal needs. One area of interest is new decision support tools and systems for a variety of ecological applications such as managing coastal environments, natural resources or natural disasters.
This subtopic seeks new, advanced information systems and decision environments that take full advantage of multiple data sources and platforms. Tailored distribution networks and timely products delivered to a broad range of users are needed to support applications in disaster management, resource management, energy and urban sustainability.

- Development of new integrated multiple user requirements knowledge databases and archival library tools to support researchers and promote infusion of successful technologies into existing processes.
- Development of new decision support strategies and presentation methodologies for applied earth science applications to reduce risk, cost, and time.

This subtopic is also soliciting proposals for utilities, plug-ins or enhancements to open source geobrowsers that improve their utility for earth science research and decision support. Examples of geobrowsers include NASA World Wind, World Wind Java (http://worldwindcentral.com/wiki/Main_page [49]) and COAST (http://www.coastal.ssc.nasa.gov/coast/COAST.aspx [50]). Special consideration will be given to tools for COAST. Examples of specific interest are:

- Tools and utilities to support creation or simplify the import and integration of new datasets;
- Tools and utilities to discover and integrate existing web-enabled sensor data (e.g., webcams, meteorology stations, beach monitors);
- Innovative output mechanisms for data layer sharing and collaboration;
- Enhancements to visualization of custom 3rd dimensional data;
- Enhancements to real time animation capabilities, or incorporation of existing animations into a geobrowser;
- Plug-ins that enable visualization of high resolution imagery in a COAST accessible data viewer;
- Utilities that enable regional estuarine or bay data compilations that are of interest to the major coastal ecosystem managers in those areas;
- Applications that subset, filter, merge, and reformat existing spatial data; provide links to attribute data; or visualize spatial or temporal analytic results in innovative value added fashion within the application.

Proposals should present a feasible plan to fully develop and apply the subject technology.

S6.03 Algorithms for Science Data Processing and Analysis

Lead Center: GSFC

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

This subtopic seeks technical innovation and unique approaches for the processing and the analysis of data from NASA science missions. Analysis of NASA science data enables insights into dynamic systems such as the sun,
oceans, and earth's climate in addition to looking back in time to explore the origins of the universe. Complex algorithms and intensive data processing are needed to understand and utilize this data. Advances in such algorithms will support science data analysis and decision support systems related to current and future missions and mission concepts such as:

- Current operational missions listed at [http://www.nasa.gov/missions/current/index.html](http://www.nasa.gov/missions/current/index.html) [51]
- Lunar Atmosphere and Dust Environment Explorer (LADEE) ([http://nasascience.nasa.gov/missions/ladee](http://nasascience.nasa.gov/missions/ladee)) [57]
- Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) ([http://crism.jhuapl.edu](http://crism.jhuapl.edu)) [59]

Research proposed to this subtopic should demonstrate technical feasibility during Phase I, in partnership with scientists, and subsequently show a path toward a Phase II prototype demonstration, with significant communication with missions and programs to ensure a successful Phase III infusion. It is highly desirable that the proposed projects lead to software that is infused into NASA programs and projects. Innovations are sought in data processing and analysis algorithms in the following areas:

- **Optimization of Algorithms and Computational Methods** that increase the utility of scientific research data for models, data assimilation, simulations, and visualizations. Of particular interest are innovative computational methods that will dramatically increase algorithm efficiency as well as the performance of scientific applications. Success will be measured by both speed improvements and output validation.

- **Improvement of Data Collection** by identifying data gaps in real-time, and/or derive information through synthesis of data from multiple sources. The ultimate goal is to increase the value of data collected in terms of scientific discovery and application; examples are long-term global and local models and decision support systems for national and humanitarian applications.

- **Frameworks and Related Tools for Processing, Analyzing and Fusing** image and vector data for the purpose of analyzing NASA's astrophysics, heliophysics, planetary and earth science mission data and therefore enable the advancement of NASA's scientific objectives. Of particular interest are open source frameworks or framework components that would enable sharing and validation of tools and algorithms.

Tools and products developed under this subtopic may be used for broad public dissemination or for use within a narrow scientific community. These tools can be plug-ins or enhancements to existing software or on-line data/computing services. They also can be new stand-alone applications or web services, provided that they are compatible with most widely used computer platforms and exchange information effectively (via standard protocols and file formats) with existing, standard or prevalent applications. To promote interoperability, tools shall use industry standard protocols, formats, and APIs (Application Programming Interfaces), including compliance with the FDGC (Federal Geographic Data Committee) and OGC (Open Geospatial Consortium) standards as appropriate.
S6.04 Science Data Discovery in Extremely Large Data Environments

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

This subtopic focuses on supporting science data discovery for extremely large data environments through developing innovative cloud and large cluster based science data discover applications, application development tools, and performance monitoring tools. Specific areas for which proposals are being sought:

- **Science discovery applications**: Applications for science data discovery, data mining, data search, and data sub setting that scale to extremely large data sets in cloud or large cluster computing environments.
- **Application development tools**: Integrated ecosystem of tools for developing applications for high performance processing environments, including cloud computing, high performance cluster, and GPU processing environments, that support software development for science data discovery applications, including support for compilation, debugging, and parallelization.
- **Performance monitoring tools**: Integrated tools to collect, analyze, store, and present performance data for cloud computing and large scale cluster environments, including tools to collect data throughput of system hardware and software components such as node and network interconnects (GbE, 10 GbE, and Infiniband), storage area networks, and disk subsystems, and tools to capture data on a user configured basis, that allow extensibility for new metrics, and verification of the configuration and health of a system.

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

S6.05 Software Engineering Tools for Scientific Models

Lead Center: GSFC

This subtopic seeks to improve the productivity and quality of NASA's scientific modeling endeavors through customized tools, which enable and encourage improved software engineering practices. Because many of NASA's principal scientific models have evolved over decades to be hundreds of thousands of lines long with contributions from a wide variety of scientists, much of the software has become "brittle" in the sense that it has become difficult to extend, couple, and optimize. In other software communities (and other programming languages), access to modern software tools has enabled large gains in productivity by providing high-level tools for isolating software defects (bugs) as well as by automating common, albeit tedious, software processes. The goal is to extend these capabilities to support the Fortran programming language so that NASA's scientific models can extract similar benefits.

Target Programs, Missions and Mission Classes
Advances in developer productivity would be of significant benefit to several research and analysis programs within the Science Mission Directorate including:

- High-End Computing Program (http://hec.nasa.gov [62])
- Modeling, Analysis, and Prediction Program (http://map.nasa.gov [63])

**Technology Areas**

The objective is to create a suite of software tools, which directly ameliorate the most significant bottlenecks to productivity in the development of scientific models:

- Tools that assist in the construction of fine-grained unit-level software tests based upon existing functionality in a legacy Fortran application. Although tests written by developers are desirable, such tests are exceedingly difficult to create for legacy numerical software. Suites of these tests could provide a significant element of risk-reduction for maintenance and extension of these models, and would be incorporated into some sort of unit-testing framework.
- Tools that reduce cost and risk for maintaining and extending legacy scientific software. Desirable to be integrated within other common development tools.
- Tools that enable high-level source code transformations ("refactorings"). Although refactoring support for Fortran is improving rapidly (http://www.eclipse.org/photran/ [64]), substantial opportunities exist for new refactorings targeted at NASA's scientific computing needs.

Tools and products developed under this subtopic may be used for broad public dissemination or for use within a narrow scientific community. These tools can be plug-ins or enhancements to existing software or on-line data/computing services. They also can be new stand-alone applications or web services, provided that they are compatible with most widely used computer platforms and exchange information effectively (via standard protocols and file formats) with existing, standard or prevalent applications. To promote interoperability, tools shall use industry standard protocols, formats, and APIs (Application Programming Interfaces).

It is highly desirable that the proposed projects lead to software that is infused into NASA programs and projects.
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. 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 CO₂ 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 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).

- 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). 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:
- Length:
- 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 [7]) _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 [6]) such as PATH, SCLP, and GACM and the Beyond Einstein Inflation Probe (Inflation Probe - cosmic microwave background, http://science.gsfc.nasa.gov/660/research/ [8]).

- 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.
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 [6]), planetary science (http://www.nap.edu/catalog/10432.html [9]), and astronomy and astrophysics(http://www.nap.edu/books/0309070317/html/ [10]).


- 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/ [14]). 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 [15]) and Stellar Imager (http://hires.gsfc.nasa.gov/si/ [16]):

- 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).

Sub Topics:

Active Microwave Technologies Topic S1.02
NASA employs active sensors (radars) for a wide range of remote sensing applications (for example, see: http://www.nap.edu/catalog/11820.html [6]). 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:** <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 real-time 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

Sub Topics:
Passive Microwave Technologies Topic S1.03
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 [7]) 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 [6]) such as PATH, SCLP, and GACM and the Beyond Einstein Inflation Probe (Inflation Probe - cosmic microwave background, http://science.gsfc.nasa.gov/660/research/ [8]).

- 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.
- 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.

Sub Topics:
Sensor and Detector Technology for Visible, IR, Far IR and Submillimeter Topic S1.04
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 [6]), planetary science (http://www.nap.edu/catalog/10432.html [9]), and astronomy and astrophysics (http://www.nap.edu/books/0309070317/html/ [10]).

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/ [14]). 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 [15]) and Stellar Imager (http://hires.gsfc.nasa.gov/si/ [16]):

- 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 < 100 nm. 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).

Sub Topics:
Detector Technologies for UV, X-Ray, Gamma-Ray and Cosmic-Ray Instruments Topic S1.05
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:


Specific mission pages:

EXIST: http://exist.gsfc.nasa.gov/ [18],
IXO: http://htxs.gsfc.nasa.gov/index.html [19],
Future Planetary Programs: http://nasascience.nasa.gov/planetary-science/mission_list [20],

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 (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 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 (~10^6), low noise, fast time response (2 to 10 x 10 mm^2. Focal plane mass must be minimized (^2 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.

Sub Topics:
Parties and Field Sensors and Instrument Enabling Technologies Topic S1.06
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 [4]) 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 humancrewed 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 [22]), 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 [23]) 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.

Sub Topics:
Cryogenic Systems for Sensors and Detectors Topic S1.07
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/[24]), Safir (http://safir.jpl.nasa.gov/[25]), 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.

Sub Topics:
In Situ Airborne, Surface, and Submersible Instruments for Earth Science Topic S1.08

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.

Sub Topics:
In Situ Sensors and Sensor Systems for Planetary Science Topic S1.09
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 [26]. 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 [27].

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.

Sub Topics:
Space Geodetic Observatory Components Topic S1.10
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-pixilated 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.

Sub Topics:
Lunar Science Instruments and Technology Topic S1.11
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) [29]). 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.
Sub Topics:

Precision Spacecraft Formations for Telescope Systems Topic S2.01
This subtopic seeks hardware and software technologies necessary to establish, maintain, and operate precision spacecraft formations to a level that enables cost effective large aperture and separated spacecraft optical telescopes and interferometers (e.g., http://planetquest.jpl.nasa.gov/TPF/ [30], http://instrument.jpl.nasa.gov/steller/ [31]). Also sought are technologies (analysis, algorithms, and testbeds) to enable detailed analysis, synthesis, modeling, and visualization of such distributed systems.

Formation flight can synthesize large effective telescope apertures through, multiple, collaborative, smaller telescopes in a precision formation. Large effective apertures can also be achieved by tiling curved segments to form an aperture larger than can be achieved in a single launch, for deep-space high resolution imaging of faint astrophysical sources. These formations require the capability for autonomous precision alignment and synchronized maneuvers, reconfigurations, and collision avoidance. The spacecraft also require onboard capability for optimal path planning and time optimal maneuver design and execution.

Innovations are solicited for: (a) sensor systems for inertial alignment of multiple vehicles with separations of tens of meters to thousands of kilometers to accuracy of 1 - 50 milli-arcseconds (b) development of nanometer to sub-nanometer metrology for measuring inter-spacecraft range and/or bearing for space telescopes and interferometers (c) control approaches to maintain line-of-sight between two vehicles in inertial space near Sun-Earth L2 to milli-arcsecond levels accuracy (d) development of combined cm-to-nanometer-level precision formation flying control of numerous spacecraft and their optics to enable large baseline, sparse aperture UV/optical and X-ray telescopes and interferometers for ultra-high angular resolution imagery. Proposals addressing staged-control experiments, which combine coarse formation control with fine-level wavefront sensing based control are encouraged.

Innovations are also solicited for distributed spacecraft systems in the following areas:

- Distributed, multi-timing, high fidelity simulations;
- Formation modeling techniques;
- Precision guidance and control architectures and design methodologies;
- Centralized and decentralized formation estimation;
- Distributed sensor fusion;
- RF and optical precision metrology systems;
- Formation sensors;
- Precision microthrusters/actuators;
- Autonomous reconfigurable formation techniques;
- Optimal, synchronized, maneuver design methodologies;
- Collision avoidance mechanisms;
- Formation management and station keeping.

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.

Sub Topics:

**Proximity Glare Suppression for Astronomical Coronagraphy Topic S2.02**

This subtopic addresses the unique problem of imaging and spectroscopic characterization of faint astrophysical objects that are located within the obscuring glare of much brighter stellar sources and innovative advanced wavefront sensing and control for cost-effective space telescopes. Examples include planetary systems beyond our own, the detailed inner structure of galaxies with very bright nuclei, binary star formation, and stellar evolution. Contrast ratios of one million to ten billion over an angular spatial scale of 0.05-1.5 arcsec are typical of these objects. Achieving a very low background requires control of both scattered and diffracted light. The failure to control either amplitude or phase fluctuations in the optical train severely reduces the effectiveness of starlight cancellation schemes.

This innovative research focuses on advances in coronagraphic instruments, starlight cancellation instruments, and potential occulting technologies that operate at visible and infrared wavelengths. The ultimate application of these instruments is to operate in space as part of a future observatory mission. Much of the scientific instrumentation used in future NASA observatories for the astrophysical sciences will require control of unwanted radiation (thermal and scattered) across a modest field of view. The performance and observing efficiency of astrophysics instruments, however, must be greatly enhanced. The instrument components are expected to offer much higher optical throughput, larger fields of view, and better detector performance. The wavelengths of primary interest extend from the visible to the thermal infrared. Measurement techniques include imaging, photometry, spectroscopy, and polarimetry. There is interest in component development, and innovative instrument design, as well as in the fabrication of subsystem devices to include, but not limited to, the following areas:

**Starlight Suppression Technologies**

- Advanced starlight canceling coronagraphic instrument concepts;
• Advanced aperture apodization and aperture shaping techniques;

• Advanced apodization mask or occulting spot fabrication technology controlling smooth density gradients to 10^-4 with spatial resolutions ~1 µm, low dispersion, and low dependence of phase on optical density;

• Metrology for detailed evaluation of compact, deep density apodizing masks, Lyot stops, and other types of graded and binary mask elements. Development of a system to measure spatial optical density, phase inhomogeneity, scattering, spectral dispersion, thermal variations, and to otherwise estimate the accuracy of masks and stops is needed;

• Interferometric starlight cancellation instruments and techniques to include aperture synthesis and single input beam combination strategies;

• Pupil remapping technologies to achieve beam apodization;

• Techniques to characterize highly aspheric optics;

• Methods to distinguish the coherent and incoherent scatter in a broad band speckle field;

• Methods of polarization control and polarization apodization; and

• Components and methods to insure amplitude uniformity in both coronagraphs and interferometers, specifically materials, processes, and metrology to insure coating uniformity.

• Coherent fiber bundles consisting of up to 10^4 fibers with lenslets on both input and output side, such that both spatial and temporal coherence is maintained across the fiber bundle for possible wavefront/amplitude control through the fiber bundle.

**Wavefront Control Technologies**

• Development of small stroke, high precision, deformable mirrors and associated driving electronics scalable to 10^4 or more actuators (both to further the state-of-the-art towards flight-like hardware and to explore novel concepts). Multiple deformable mirror technologies in various phases of development and processes are encouraged to ultimately improve the state-of-the-art in deformable mirror technology. Process improvements are needed to improve repeatability, yield, and performance precision of current devices;

• Development of instruments to perform broad-band sensing of wavefronts and distinguish amplitude and phase in the wavefront;

• Adaptive optics actuators, integrated mirror/actuator programmable deformable mirror;

• Reliability and qualification of actuators and structures in deformable mirrors to eliminate or mitigate single actuator failures;

• Multiplexer development for electrical connection to deformable mirrors that has ultra-low power dissipation; and

• High precision wavefront error sensing and control techniques to improve and advance coronagraphic imaging performance.

**Optical Coating and Measurement Technologies**
• Instruments capable of measuring polarization cross-talk and birefringence to parts per million;
• Highly reflecting broadband coatings for large (> 1 m diameter) optics
• Polarization-insensitive coatings for large optics

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.

Sub Topics:
   Precision Deployable Optical Structures and Metrology Topic S2.03
Planned future NASA Missions in astrophysics, such as: Single Aperture Far-IR (SAFIR) telescope; Terrestrial Planet Finder (TPF); Coronagraph, External Occulter and Interferometer, Advanced Technology Large-Aperture Space Telescope (ATLAST); Life Finder; and Submillimeter Probe of the Evolution of Cosmic Structure (SPECS); and the UV Optical Imager (UVOIR) require 10 - 30 m class cost effective telescope observatories that are diffraction limited at wavelengths from the visible to the far IR, and operate at temperatures from 4 - 300 K. The desired areal density is 1 - 10 kg/m². Static and dynamic wavefront error tolerances to thermal and dynamic perturbations may be achieved through passive means (e.g., via a high stiffness system, passive thermal control, jitter isolation or damping) or through active opto-mechanical control. Large deployable multi-layer structures in support of sunshades for passive thermal control and 20m to 50m class planet finding external occulters are also relevant technologies. Potential architecture implementations must package into an existing launch volume, deploy and be self-aligning to the micron level. The target space environment is expected to be L2.

This subtopic solicits proposals to develop enabling, cost effective component and subsystem technology for these telescopes. Research areas of particular interest include:

• Precision deployable structures and metrology (i.e., innovative active or passive deployable primary or secondary support structures);
• Innovative concepts for packaging fully integrated (i.e., including power distribution, sensing, and control components);
• Distributed and localized actuation systems;
• Deployment packaging and mechanisms;
• Active opto-mechanical control distributed on or within the structure;
• Actuator systems for alignment of reflector panels (order of cm stroke actuators, lightweight, nanometer stability);
• Innovative architectures, materials, packaging and deployment of large sunshields and external occulters;
Mechanical, inflatable, or other deployable technologies;
New thermally-stable materials (CTE)
Innovative ground testing and verification methodologies; and
New approaches for achieving packagable depth in primary mirror support structures.

Also of interest are:

- Innovative metrology systems for direct measurement of the optical elements or their supporting structure;
- Requirements for micron level absolute and subnanometer relative metrology for multiple locations on the primary mirror;
- Measurement of the metering truss;
- Innovative systems, which minimize complexity, mass, power and cost.

The goal for this effort is to mature technologies that can be used to fabricate 10 m class or greater, lightweight, ambient or cryogenic flight-qualified observatory systems. Proposals to fabricate demonstration components and subsystems with direct scalability to flight systems through validated models will be given preference. The target launch volume and expected disturbances, along with the estimate of system performance, should be included in the discussion. A successful proposal shows a path toward a Phase II delivery of demonstration hardware scalable to 3 m for characterization.

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.

Sub Topics:
Advanced Optical Component Systems Topic S2.04
Future heavy lift launch systems will enable extremely large and/or extremely massive space telescopes. Potential systems include 12 to 30 meter class segmented primary mirrors for UV/optical or infrared wavelengths and 8 to 16 meter class segmented x-ray telescope mirrors.

These potential future space telescopes have very specific mirror technology needs. UV/optical telescopes (such as ATLAST-9 or ATLAST-16) require 1 to 3 meter class mirrors with

In view of the very large total mirror or lens collecting aperture required, affordability or areal cost (cost per square meter of collecting aperture) rather than areal density is probably the single most important system characteristic of an advanced optical system. For example, both x-ray and normal incidence space mirrors currently cost $3 million to $4 million per square meter of optical surface area. This research effort seeks a cost reduction for precision optical components by 20 to 100 times, to less than $100K/m².
The primary purpose of this subtopic is to develop and demonstrate technologies to manufacture ultra-low-cost precision optical systems for very large x-ray, UV/optical or infrared telescopes. Potential solutions include but are not limited to new mirror materials such as Silicon carbide or nanolaminates or carbon-fiber reinforced polymer; or new fabrication processes such as direct precision machining, rapid optical fabrication, slumping or replication technologies to manufacture 1 to 2 meter (or larger) precision quality mirror or lens segments (either normal incidence for UV/optical/infrared or grazing incidence for x-ray).

Another key enabling technology is optical coatings. UV/optical telescopes require broadband (from 100 nm to 2500 nm) high-reflectivity mirror coating with extremely uniform amplitude and polarization properties which can be deposited on 1 to 3 meter class mirror. EUSO requires anti-reflection coatings which can be deposited onto 2.5 meter diameter PMMA Fresnel lenses. In both cases, ability to demonstrate optical performance on 2.5 meter class optical surfaces is important.

Successful proposals will demonstrate prototype manufacturing of a precision mirror or lens system or precision replicating mandrel in the 0.25 to 0.5 meter class with a specific scale up roadmap to 1 to 2+ meter class space qualifiable flight optics systems. Material behavior, process control, optical performance, and mounting/deploying issues should be resolved and demonstrated. The potential for scale-up will need to be addressed from a processing and infrastructure point of view.

An ideal Phase I deliverable would be a near UV, visible or x-ray precision mirror, lens or replicating mandrel of at least 0.25 meters. The Phase II project would further advance the technology to produce a space-qualifiable precision mirror, lens or mandrel greater than 0.5 meters, with a TRL in the 4 to 5 range. Both deliverables would be accompanied by all necessary documentation, including the optical performance assessment and all data on processing and properties of its substrate materials. The Phase II would also include a mechanical and thermal stability analysis.

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.

Sub Topics:
Optics Manufacturing and Metrology for Telescope Optical Surfaces Topic S2.05
This subtopic focuses primarily on manufacturing and metrology of optical surfaces, especially for very small or very large and/or thin optics. Missions of interest include:

JDEM concepts: [http://jdem.gsfc.nasa.gov](http://jdem.gsfc.nasa.gov) [32],

IXO: [http://ixo.gsfc.nasa.gov](http://ixo.gsfc.nasa.gov) [24],

LISA: [http://lisa.gsfc.nasa.gov](http://lisa.gsfc.nasa.gov) [33],

ICESAT: [http://icesat.gsfc.nasa.gov](http://icesat.gsfc.nasa.gov) [34], CLARREO, and ACE.
Optical systems currently being researched for these missions are large area aspheres, requiring accurate figuring and polishing across six orders of magnitude in period. Technologies are sought that will enhance the figure quality of optics in any range as long as the process does not introduce artifacts in other ranges. For example, mm-period polishing should not introduce waviness errors at the 20 mm or 0.05 mm periods in the power spectral density. Also, novel metrological solutions that can measure figure errors over a large fraction of the PSD range are sought, especially techniques and instrumentation that can perform measurements while the optic is mounted to the figuring/polishing machine.

Of particular interest is the area of x-ray optics metrology, including the evaluation of the optical quality of x-ray mirrors and substrates; the general characterization of x-ray mirrors; and the development of new metrology measurement techniques and instrumentation for x-ray mirrors.

By the end of a Phase II program, technologies must be developed to the point where the technique or instrument can dovetail into an existing optics manufacturing facility producing optics at the R&D stage. Metrology instruments should have 5 nm or better surface height resolution and span at least 3 orders of magnitude in lateral spatial frequency.

Examples of technologies and instruments of interest include:

- Interferometric nulling optics for very shallow conical optics used in x-ray telescopes.
- Segmented systems commonly span 60 degrees in azimuth and 200 mm axial length and cone angles vary from 0.1 to 1 degree.
- Low stress metrology mounts that can hold very thin optics without introducing mounting distortion.
- Low normal force figuring/polishing systems operating in the 1 mm to 50 mm period range with minimal impact at significantly smaller and larger period ranges.
- In-situ metrology systems that can measure optics and provide feedback to figuring/polishing instruments without removing the part from the spindle.
- Innovative mirror substrate materials or manufacturing methods that produce thin mirror substrates that are stiffer and/or lighter than existing materials or methods.
- Extreme aspheric and/or anamorphic optics for pupil intensity amplitude apodization (PIAA).

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.
Sub Topics:
Command, Data Handling, and Electronics Topic S3.01

NASA's space based observatories, fly by spacecraft, orbiters, landers, and robotic and sample return missions, require robust command and control capabilities. Advances in technologies relevant to command and data handling and instrument electronics are sought to support NASA's goals and several missions and projects under development.

http://science.nasa.gov/search/?q=missions+under+development [41]

The subtopic goals are to: (1) develop high-performance processors and memory architectures and reliable electronic systems, (2) develop an avionics architecture that is flexible, scalable, extensible, adaptable, and reusable, and (3) develop tools technologies that can enable rapid deployment of high-reliability, high-performance onboard processing applications and interface to external sensors on flight hardware. The subtopic objective is to elicit novel architectural concepts and component technologies that are realistic and operate effectively and credibly in environments consistent with the future NASA Science missions.

Successful proposal concepts should significantly advance the state-of-the-art. Proposals should clearly (1) state what the product is; (2) identify the needs it addresses; (3) identify the improvements over the current state of the art; (4) outline the feasibility of the technical and programmatic approach; and (5) present how it could be infused into a NASA program. Furthermore, proposals should indicate an understanding of the intended operating environment, including temperature and radiation. It should be noted that environmental requirements can vary significantly from mission to mission. For example, some low earth orbit missions have a total ionizing dose (TID) radiation requirement of less than 10 kRad, while some planetary missions can have requirements well in excess of 1MRad. For descriptions of radiation effects in electronics, the proposer may visit http://radhome.gsfc.nasa.gov/radhome/background.htm [42]. If a Phase II proposal is awarded, the combined Phase I and Phase II developments should produce a prototype that can be characterized by NASA.

The technology priorities sought are listed below.

C&DH Architectures

- High performance hardware/software processor platform capable of implementing high-throughput numerically intensive real-time applications that entail autonomous landing and guidance and control. Sensor computations. Key performance metrics must achieve 40 GOPS, 20 GMACS, and 40,000 MIPS with EDAC-protected memory, comprising 256 (TBR) MB DDR volatile for flight software execution and 256 (TBR) MB non-volatile for image storage, respectively. Standard interfaces must include Gigabit Ethernet, RS232 UART serial ports, and control interfaces to Lidar/Camera with a maximum bandwidth of up to 1
Gbps. Platform should be in 6U form factor and consume no greater than 20 W. Processor trades should be conducted to balance size, weight, power against reliability, flexibility, and performance for future space missions. Radiation hardened by design best practices, rapid development tools, and a radiation-tolerant path to space qualification are appealing features. The platform should operate, at reduced capability, during high energy cosmic rays events. Principal capabilities will encompass command generation and handling, control of safe landing system, sensor data processing and storage, and on-board memory management, optimized for acceptable performance and reliability.

- Novel, miniaturized, low-power C&DH architectures tailored to small spacecraft. Solutions must perform functions of traditional C&DH systems at a fraction of the SWAP (Size, Weight, and Power). Proposed systems should be capable of supporting typical spacecraft C&DH functions and should be radiation tolerant, and should further be compatible with Space Plug and Play (SPA) architectures, including SPA-1.

- Development system design tools that (a) take full advantage of rapid prototyping hardware-in-the-loop (HIL) environments for hybrid processing platforms, and (b) automate/accelerate the deployment of data processing and sensor interface design on flight hardware.

### Discrete Components for C&DH Subsystems

- Processors - General purpose (processor chips and radiation-hardened by design synthesizable IP cores) and special purpose single-chip components (DSPs), with sustainable processing performance and power efficiency (>40,000 MIPS at >1,000 MIPS/W for general purpose processing platforms, >20 GMACs at >5 GMACS/W for computationally-intensive processing platforms), and tolerance to total dose and single-event radiation effects. Concepts must include tools required to support an integrated hardware/software development flow.

- Radiation-hardened non-volatile low power memories >100KRad.

- Radiation hardened DDR1, DDR2, and DDR3 high speed memories.

### Onboard Network Architectures and Devices

- Radiation-hardened physical layer components for (copper/fiber-optic) onboard data busses (e.g., SpaceWire, Ethernet, Serial Rapid I/O, Ring Bus) speeds >1Gb/s.

- Power distribution through onboard data network technologies.

- Wireless data network architectures and components.

- Wireless RFID housekeeping sensors and interrogation hardware.

### Tunable, Scalable, Reconfigurable, Adaptive Fault-Tolerant Onboard Processing Architectures

- Technologies Enabling Use of Commercial Devices for Spaceflight Applications, including Radiation Hardened By Software (RHBS) approaches.

- Highly adaptive reconfigurable computing platforms (including hybrid DSP/FPGA/CPU architectures).

- Tools and methodologies to accelerate development of highly reliable applications on reconfigurable computing platforms.
Technologies Enabling Custom Radiation-Hardened Component Development

- Radiation-Hardened-By-Design (RHBD) cell libraries.
- Radiation-hardened Programmable Logic Devices (PLDs) and structured ASIC devices (digital and/or mixed-signal).
- Intellectual Property (IP) cores allowing the implementation of highly reliable System-On-a-Chip (SOC) devices for spacecraft subsystems or instrument electronics. Functions of interest include processors, memory interfaces, and data bus interfaces.

Novel, Ruggedized Packaging/Interconnect

- High density packaging (enclosures, printed wiring boards) enabling miniaturization.
- Novel high density and low resistance cabling, including carbon nanotube (CNT) based wiring.

Data Compression

- Ground-based high-speed data compression decoder capable of decoding coded bit stream conforming to CCSDS 122.0-B-1 Image Data Compression standard (www.ccsds.org [43]), providing over 40 M samples/sec for up to 16-bit image data coded in an embedded bit stream. Spaceflight hardware currently exists to perform the encoding function. The requested decoder would be used for ground processing of a downlinked encoded data stream. The decoder shall not consume more than 5 watts of power at the specified speed.

Power Conversion and Distribution

- Radiation-hardened high efficiency Point-Of-Load (POL) down converor.
- Power distribution through onboard data network technologies.

Sub Topics:

Thermal Control Systems Topic S3.02

Future Spacecraft and instruments for NASA's Science Mission Directorate will require increasingly sophisticated thermal control technology. Innovative proposals for the cross-cutting thermal control discipline are sought in the following areas:
- Optical systems, lasers (ICESAT 2), and detectors require tight temperature control, often to better than ±1°C. Some new missions such as LISA require thermal gradients held to even tighter micro-degree levels. Methods of precise temperature measurement and control to tight temperature levels are needed.

- New generations of electronics used on numerous missions have higher power densities than in the past. High conductivity, vacuum-compatible interface materials to minimize losses across make/break interfaces are needed to reduce interface temperature gradients and facilitate heat removal.

- Detectors and optical systems at infrared wavelengths require efficient cooling methods to low temperatures. Advanced thermoelectric devices with higher Coefficients of Performance (COP) are required.

- More sensitive instruments are resulting in increased requirements for high electrical conductivity on spacecraft instruments and surfaces. This has increased the need for advanced thermal control coatings, particular with low absorptance, high emittance, and good electrical conductivity.

- Phase change systems are needed for Mars or Lunar applications. Reusable phase change systems are desired which can be employed to absorb transient heat dissipations during instrument operations. Technology is sought for phase change systems, typically near room temperature, which can then either store this energy or provide an exothermic process, which would provide heat for instrument power-on after the dormant phase.

- Future high-powered missions, some possibly nuclear powered, may require active cooling systems to efficiently transport large amounts of heat. These include single and two-phase mechanically pumped fluid loop systems which accommodate multiple heat sources and sinks; and long life, lightweight pumps which are capable of generating a high pressure head. It also includes efficient, lightweight, oil-less, high lift vapor compression systems or novel new technologies for high performance cooling up to 2 KW.

- Exploration science missions beyond earth orbit present engineering challenges requiring systems, which can withstand extreme temperatures ranging from high temperatures on Venus to the cryogenic temperatures of the outer planets. High performance insulation systems, which are more easily fabricated than traditional multi-layer (MLI) systems, are required for both hot and cold environments. Potential applications include traditional vacuum environments, low-pressure carbon dioxide atmospheres on Mars, and high-pressure atmospheres found on Venus.

- Low-Cost Variable Conductance Heat Pipes for Terrestrial Balloons - Please see sub-topic S3.07 Terrestrial and Planetary Balloons to respond to this requirement.

- Thermal Control Systems for S3.10 Earth Entry Systems. Low mass/cost/power/complexity payload thermal control systems are needed, which can maintain the sample temperature in-flight, through impact, and post landing. Candidate thermal control systems must be able to maintain a payload up to 10 kg at temperature levels ranging from cryogenic up to -20°C (depending on specific mission requirements) for up to 1 day after landing/impact, and cannot exceed 20 kg in total mass.

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

Note to Proposer: Subtopic X3.04 Thermal Control Systems for Human Spacecraft, under the Exploration Mission Directorate, also addresses thermal control technologies. Proposals more aligned with exploration mission requirements should be proposed in X3.04.
S3.03 Power Generation and Conversion

Future NASA science missions will employ Earth orbiting spacecraft, planetary spacecraft, balloons, aircraft, surface assets, and marine craft as observation platforms. Proposals are solicited to develop advanced power generation and conversion technologies to enable or enhance the capabilities of future science missions. Requirements for these missions are varied and include long life, high reliability, significantly lower mass and volume, higher mass specific power, and improved efficiency over the state of practice for components and systems. Other desired capabilities are high radiation tolerance and the ability to operate in extreme environments (high and low temperatures and over wide temperature ranges).

While power generation technology affects a wide range of NASA missions and operational environments, technologies that provide substantial benefits for key mission applications/capabilities are being sought in the following areas.

Radioisotope Power Conversion

Radioisotope technology enables a wide range of mission opportunities, both near and far from the Sun and hostile planetary environments including high energy radiation, both high and low temperature and diverse atmospheric chemistries. Technology innovations capable of advancing lifetimes, improving efficiency, highly tolerant to hostile environments are desired for all thermal to electric conversion technologies considered here. Specific systems of interest for this solicitation are listed below.

Stirling Power Conversion: advances in, but not limited to, the following:

- System specific mass greater than 10 We/kg
- Highly reliable autonomous control
- Low EMI
- High temperature, high performance materials, 850-1200 C
- Radiation tolerant sensors, materials and electronics

Thermoelectric Power Conversion: advances in, but not limited to, the following:

- High temperature, high efficiency conversion greater than 10%
- Long life, minimal degradation
Higher power density

Cubesat and Nanosat On-orbit Power Generation

NASA desires to build smaller spacecraft types carrying smaller instrument packages. However, power requirements to accommodate these instruments and spacecraft systems will not necessarily scale down in a similar fashion as spacecraft size. Therefore, power generation and power management technologies are sought that are compatible with small spacecraft geometries and sizes, especially in cubesat and nanosat form factors.

Photovoltaic Energy Conversion

Photovoltaic cell, blanket, and array technologies that lead to significant improvements in overall solar array performance (i.e. conversion efficiency >30%, array mass specific power >300 watts/kilogram, decreased stowed volume, reduced initial and recurring cost, long-term operation in high radiation environments, high power arrays, and a wide range of space environmental operating conditions) are solicited. Technologies specifically addressing the following mission needs are highly sought:

- Photovoltaic cell and blanket technologies capable of low intensity, low-temperature operation applicable to outer planetary (low solar intensity) missions
- Photovoltaic cell, blanket and array technologies capable of enhancing solar array operation in a high intensity, high-temperature environment (i.e. inner planetary and solar probe-type missions)
- Lightweight solar array technologies applicable to solar electric propulsion missions. Current missions being studied require solar arrays that provide 1 to 20 kilowatts of power at 1 AU, are greater than 300 watts/kilogram specific power, can operate in the range of 0.7 to 3 AU, provide operational array voltages up to 150 volts and have a low stowed volume.

Thermophotovoltaic conversion is currently focused on follow-on technology for the International Lunar Network (ILN) and for the outer planets mission. Advances sought, but not limited to, include:

- Low-bandgap cells having high efficiency and high reliability
- High temperature selective emitters
- Low absorptance optical band-pass filters
- Efficient multi-foil insulation

Note to Proposer: Topic X8 under the Exploration Mission Directorate also addresses power technologies (X8.03 Space Nuclear Power Systems, and X8.04 Advanced Photovoltaic Systems). Proposals more aligned with exploration mission requirements should be proposed in X8.
**S3.04 Propulsion Systems**

The Science Mission Directorate (SMD) needs spacecraft with more demanding propulsive performance and flexibility for more ambitious missions requiring high duty cycles, more challenging environmental conditions, and extended operation. Planetary spacecraft need the ability to rendezvous with, orbit, and conduct in situ exploration of planets, moons, and other small bodies in the solar system ([http://www.nap.edu/catalog.php?record_id=10432](http://www.nap.edu/catalog.php?record_id=10432) [39]). Future spacecraft and constellations of spacecraft will have high-precision propulsion requirements, usually in volume- and power-limited envelopes.

This subtopic seeks innovations to meet SMD propulsion requirements, which are reflected in the goals of NASA’s In-Space Propulsion Technology program to reduce the travel time, mass, and cost of SMD spacecraft. Advancements in chemical and electric propulsion systems related to sample return missions to Mars, small bodies (like asteroids, comets, and Near-Earth Objects), outer planet moons, and Venus are desired. Additional electric propulsion technology innovations are also sought to enable low cost systems for Discovery class missions, and eventually to enable radioisotope electric propulsion (REP) type missions.

The focus of this solicitation is for next generation propulsion systems and components, including high-pressure chemical rocket technologies and low cost/low mass electric propulsion technologies. Specific sample return propulsion technologies of interest include higher-pressure chemical propulsion system components, lightweight propulsion components, and Earth-return vehicle propulsion systems. Propulsion technologies related specifically to planetary ascent vehicles will be sought under S3.08 Planetary Ascent Vehicle.

**Chemical Propulsion Systems**

Technology needs include:

- Improved materials and manufacturing processes to produce Iridium/Rhenium apogee class thruster chambers with improved mechanical properties targeting a yield stress of 40ksi and an elongation of 10%;

- Advanced nontoxic mono-propellant rockets for in-space applications.

**Electric Propulsion Systems**

This subtopic also seeks proposals that explore uses of technologies that will provide superior performance in for high specific impulse/low mass electric propulsion systems at low cost. These technologies include:

- Efficient thrusters with up to 1 kW of input power that provide thrust up to 20 mN with a specific impulse between 1600 to 3500 seconds;
A throttleable dual mode thruster that is capable of operating in both high thrust and high specific impulse modes for a fixed power;

High power electric propulsion thrusters (>20 kW) and components including cathodes, ion optics, and low sputtering materials with long life (>1x10^8 N-s).

Proposals should show an understanding of the state of the art, how there technology is superior, and of one or more relevant science needs. The proposals should provide a feasible plan to fully develop a technology and infuse it into a NASA program.

Note to Proposer: Topic X2 under the Exploration Mission Directorate also addresses advanced propulsion. Proposals more aligned with exploration mission requirements should be proposed in X2.

**S3.05 Power Management and Storage**

**Future NASA science objectives will include missions such as Earth Orbiting, Venus, Europa, Titan, Lunar Quest and Space Weather. Under this subtopic, proposals are solicited to develop energy storage and power electronics to enable or enhance the capabilities of future science missions. The unique requirements for the power systems for these missions can vary greatly, with advancements in components needed above the current State of the Art (SOA) for long life, high reliability, low mass/volume, radiation tolerance, and wide temperature operation.**

**Energy Storage**

**Future science missions will require advanced primary and secondary battery systems capable of operating at temperature extremes from -100°C for Titan missions to 400°C to 500°C for Venus missions, and a span of -230°C to +120°C for Lunar Quest. In addition, high energy-density rechargeable electrochemical battery systems that offer greater than 50,000 charge/discharge cycles (10 year operating life) for low-earth-orbiting spacecraft, 20 year life for geosynchronous (GEO) spacecraft, are desired. Advancements to battery energy storage capabilities that address one or more of the above requirements for the stated missions combined with very high specific energy (>200 Wh/kg for secondary battery systems) and energy density, along with radiation tolerance are of interest.**

In addition to batteries, other advanced energy storage/load leveling technologies designed to the above mission requirements, such as flywheels, supercapacitors or magnetic energy storage, are of interest. These technologies have the potential to minimize the size and mass of future power systems.

**Power Management and Distribution (PMAD)**

power systems (RPS) for planetary exploration. In conjunction with the RPS, intelligent, fault-tolerant PMAD technologies are needed to efficiently manage the system power for these deep space missions. Advances in electrical power technologies are required for the electrical components and systems for these future platforms to address program size, mass, efficiency, capacity, durability, and reliability requirements. Of importance are expected improvements in energy density, speed, efficiency, or wide-temperature operation (-125°C to over 450°C) with a number of thermal cycles. Advancements are sought for power electronic devices, components and packaging for Venus type missions with power ranges of a few watts for minimum missions up to a few kilowatts for large missions.

For the lower power applications (up to 20 watts), NASA desires to build smaller spacecraft types carrying smaller instrument packages. However, power requirements to accommodate these instruments and spacecraft systems will not necessarily shrink in a similar fashion as spacecraft size. Therefore, power management technologies are sought that are compatible with small spacecraft geometries and sizes. These Electrical Power Systems should be compatible with Space Plug and Play (SPA) architectures.

Overall technologies of interest include:

- Intelligent, fault-tolerant electrical components and PMAD systems
- High temperature devices and components (up to 450°C)
- Advanced electronic packaging for thermal control and electromagnetic shielding
- Plug and Play compatibility for low power applications

Power Conversion and Distribution relevant to Command, Data Handling, and Electronics, will be covered under subtopic S3.01.

Power Storage for Terrestrial Balloons will be covered under sub-topic S3.07 Terrestrial and Planetary Balloons.

Research should be conducted to demonstrate technical feasibility during Phase I and show a path toward a Phase II, and when possible, deliver a demonstration unit for NASA testing at the completion of the Phase II contract. Phase II emphasis should be placed on developing and demonstrating the technology under relevant test conditions. Additionally, a path should be outlined that shows how the technology could be commercialized or further developed into science-worthy systems.

Other subtopics, which could potentially benefit from these technology developments include O5 - Low-Cost and Reliable Access to Space (LCRATS), S5.05 - Extreme Environments Technology, and S5.01 - Planetary Entry, Descent and Landing Technology. Battery development could also be beneficial to X6.02 - Advanced Space-rated Batteries, which is investigating some similar technologies in the secondary battery area but with very different operational requirements. Power Management and Distribution could be beneficial to X8.05 - Advanced Power Conversion Systems AND Management and Distribution (PMAD), which is investigating similar technologies, but with very different power levels.
S3.06 Guidance, Navigation and Control

Advances in the following areas of guidance, navigation and control are sought.

Navigation systems (including multiple sensors and algorithms/estimators, possibly based on existing component technologies) that work collectively on multiple vehicles to enable inertial alignment of the formation of vehicles (i.e., pointing of the line-of-sight defined by fixed points on the vehicles) on the level of milli-arcseconds relative to the background star field.

Light-weight sensors (gyroscopic or other approach) to enable milli-arcsecond class pointing measurement for individual large telescopes and low cost small spacecraft.

Isolated pointing and tracking platforms (pointing 0.5 arcseconds, jitter to 5 milli-arcsecond), targeted to placing a scientific instrument on GEO communication satellites that can track the sun for > 3 hours/day.

Working prototypes of GN&C actuators (e.g., reaction or momentum wheels) that advance mass and technology improvements for small spacecraft use. Such technologies may include such non-contact approaches such as magnetic or gas. Superconducting materials, driven by temperature conditioning may also be appropriate provided that the net power used to drive and condition the "frictionless" wheels is comparable to traditional approaches.

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.

S3.07 Terrestrial and Planetary Balloons

All 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.

Terrestrial Scientific Balloons Planetary Balloons
Innovations in materials, structures, and systems concepts have enabled buoyant vehicles to play an expanding role in planning NASA's future Solar System Exploration Program. Balloons and airships are expected to carry scientific payloads at Titan and Venus that will perform in situ investigations of their atmospheres and near surface environments. Both Titan and Venus feature extreme environments that significantly impact the design of balloons for those two worlds. Proposals are sought in the following areas:

(1) Titan Montgolfiere Balloons: Recent NASA mission studies have recommended the use of radioisotope-heated Montgolfiere balloons for future in situ Titan exploration. Proposals are sought for the design, fabrication and Earth atmosphere flight testing of prototypes that can support an eventual Titan Montgolfiere balloon mission. Particular importance is attached to the acquisition of test data that can help validate thermodynamic and fluid mechanic models that will ultimately be used to design the Titan flight balloon. The size of balloon required for Titan will be approximately 10 m in diameter and will require 2 kW of thermal energy to float the balloon at an expected Titan temperature of 85 to 95 K. Any proposed Earth-test prototype will require an alternate heat source that nevertheless adequately mimics the effects of using radioisotope energy at Titan.

(2) Gas Management Systems for Titan Aerobots: Hydrogen-filled aerobots at Titan must contend with the problem of gas leakage over long duration (1 year or more) flights. Proposals are sought for the development and testing of two kinds of prototype devices that can be carried on the aerobot to compensate for these gas leakage problems: one device is to produce make-up hydrogen gas from atmospheric methane; the other device is to remove atmospheric gas (mostly nitrogen) that leaks from the ballonets into the hydrogen-filled blimp. Both kinds of devices will need to operate on no more than 15 W of electrical power each while compensating for a leakage rate of at least 40 g/week of hydrogen or 500 g/week of nitrogen.

(3) Metal Balloons for High Temperature Venus Exploration: Balloons made of metals are a potential solution to the problem of enabling long duration flight in the hot lower atmosphere of Venus. Proposals are sought for metal balloon concepts and prototypes that provide 1-5 m³ of fully inflated volume, areal densities of 1 kg/m² or less, sulfuric acid compatibility at 85% concentration, and operation at 460 °C for a period of up to 1 year.

S3.08 Planetary Ascent Vehicles

NASA aims to design, build and test vehicles that will be launched from the surface of other planets and small bodies and place a payload, Orbiting Sample (OS), into orbit. We are seeking proposals for the development of innovative technologies to support future planetary ascent vehicles. Immediate focus is the Mars ascent vehicle. Technology innovations should either enhance vehicle capabilities (e.g., launch success probability, mission success, improved performance or margins, and improved environmental robustness) or ease implementation in space borne missions (e.g., reduce size, mass, power, and thermal requirements, improve reliability and ability to withstand the ~20 g lateral g-loading, or lower cost). The areas of interest for this call are listed below.

Alternate propellants, thrusters and propulsion system technologies for the planetary ascent vehicles:
Higher performing monopropellants with specific impulse >240 secs;

"Green" propellants;

High chamber pressure thrusters > 500 psia;

Pressurization component technologies to reduce system mass (filters, solenoid valves, latch valves, tanks, fill and drain and check valves);

Small lightweight pump technologies to operate at >500 psi output pressure especially non-electrically driven;

Non-pyrotechnic isolation valves.

Advanced solid propellant engine system technologies:

- Solid propellant technology with specific impulse performance potential higher than HTPB and CTPB;
- Propellant blend with high performance low storage impacts, and operating capability down to 150 K;
- Low temperature seals and components;
- Light weight and reliable thrust vector control;
- Other lightweight system and component technologies.

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.

Launch vehicle technologies relevant to Earth are not sought under this sub-topic. For launch vehicle technologies related to Earth, see X2.01 Earth-to-Orbit Propulsion. Proposals more aligned with exploration mission requirements should be proposed in X2.01.

**S3.09 Unmanned Aircraft and Sounding Rocket Technologies**

**Sounding Rockets**

The NASA Sounding Rocket Program (NSRP) provides low-cost, sub-orbital access to space in support of space and earth sciences research and technology development sponsored by NASA and other users by providing payload development, launch vehicles, and mission support services. NASA utilizes a variety of vehicle systems comprised of military surplus and commercially available rocket motors, capable of lofting scientific payloads, up to 1300lbs, to altitudes from 100km to 1500km. NASA launches sounding rocket vehicles worldwide, from both land-based and water-based ranges, based on the science needs to study phenomenon in specific locations.
NASA is seeking innovations to enhance capabilities and operations in the following areas:

- Autonomous vehicle environmental diagnostics system capable of monitoring flight loading (thermal, acceleration, stress/strain) for solid rocket vehicle systems.
- Location determination systems to provide over-the-horizon position of buoyant payloads to facilitate expedient location and retrieval from the ocean.
- Flotation systems, ranging from tethered flotation devices to self-encapsulation systems, for augmenting buoyancy of seal payload systems launched from water-based launch ranges.
- High-glide parachute designs capable of deploying at altitudes above 25,000 ft to facilitate mid-air retrieval and/or fly-back/fly-to-point precision landing.

Unmanned Aircraft Systems

Unmanned Aircraft Systems (UAS) offer significant potential for Suborbital Scientific Earth Exploration Missions over a very large range of payload complexities, mission durations, altitudes, and extreme environmental conditions. To more fully realize the potential improvement in capabilities for atmospheric sampling and remote sensing, new technologies are needed. Scientific observation and documentation of environmental phenomena on both global and localized scales that will advance climate research and monitoring; e.g., U.S. Global Change Research Program as well as Arctic and Antarctic research activities (Ice Bridge, etc.).

NASA is increasing scientific participation to understand impacts associated with worldwide environmental changes. Capability for suborbital unmanned flight operations in either the North or South Polar Regions are limited because of technology gaps for extremely remote telemetry capabilities and precision flight path control requirements. It is also highly desirable to have UAS ability to perform atmospheric and surface sampling.

(1) Telemetry, Tracking and Control: Low cost over-the-horizon global networks are needed to enable unmanned collaborative multi-platform earth observation missions that are more efficient and cost effective.

(2) Avionics and Flight Control:

- Precision Flight Path Control solutions in smooth atmospheric conditions.
- Aircraft control in violent atmospheric conditions.
- Low cost

Precise/repeatable flight path control capabilities are needed to enable repeat path observations for earth monitoring on seasonal and multi-year cycles. In addition, long endurance atmospheric sampling in extreme
inclement weather conditions (hurricanes) and volcanic plumes can provide high fidelity time and spatial resolution data.

(3) UA Integrated Vehicle Health Management:

- Fuel Heat/Anti-freezing
- Unmanned platform icing detection and minimization

(4) Guided Dropsondes: NASA Earth Science Research activities could utilize more capable dropsondes than are currently available as market items. Specifically, dropsondes that could effectively be guided through atmospheric regions of interest such as volcanic plumes could enable unprecedented observations of important phenomena. Capabilities of interest include:

- Compatibility with existing drop-sonde dispensing systems deployed on the NASA/NOAA P-3 and planned for the NASA Global Hawk
- Guidance schemes, autonomous or active control
- Cross-range performance and flight path accuracy
- Operational considerations including airspace utilization and conflicting traffic

All 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.

**S3.10 Earth Entry Vehicle Systems**

Sub Topics:

**Power Generation and Conversion Topic S3.03**

Future NASA science missions will employ Earth orbiting spacecraft, planetary spacecraft, balloons, aircraft, surface assets, and marine craft as observation platforms. Proposals are solicited to develop advanced power generation and conversion technologies to enable or enhance the capabilities of future science missions. Requirements for these missions are varied and include long life, high reliability, significantly lower mass and volume, higher mass specific power, and improved efficiency over the state of practice for components and systems. Other desired capabilities are high radiation tolerance and the ability to operate in extreme environments (high and low temperatures and over wide temperature ranges).
While power generation technology affects a wide range of NASA missions and operational environments, technologies that provide substantial benefits for key mission applications/capabilities are being sought in the following areas.

Radioisotope Power Conversion
Radioisotope technology enables a wide range of mission opportunities, both near and far from the Sun and hostile planetary environments including high energy radiation, both high and low temperature and diverse atmospheric chemistries. Technology innovations capable of advancing lifetimes, improving efficiency, highly tolerant to hostile environments are desired for all thermal to electric conversion technologies considered here. Specific systems of interest for this solicitation are listed below.

Stirling Power Conversion: advances in, but not limited to, the following:

- System specific mass greater than 10 We/kg
- Highly reliable autonomous control
- Low EMI
- High temperature, high performance materials, 850-1200 C
- Radiation tolerant sensors, materials and electronics

Thermoelectric Power Conversion: advances in, but not limited to, the following:

- High temperature, high efficiency conversion greater than 10%
- Long life, minimal degradation
- Higher power density

Cubesat and Nanosat On-orbit Power Generation
NASA desires to build smaller spacecraft types carrying smaller instrument packages. However, power requirements to accommodate these instruments and spacecraft systems will not necessarily scale down in a similar fashion as spacecraft size. Therefore, power generation and power management technologies are sought that are compatible with small spacecraft geometries and sizes, especially in cubesat and nanosat form factors.

Photovoltaic Energy Conversion
Photovoltaic cell, blanket, and array technologies that lead to significant improvements in overall solar array performance (i.e. conversion efficiency >30%, array mass specific power >300watts/kilogram, decreased stowed volume, reduced initial and recurring cost, long-term operation in high radiation environments, high power arrays, and a wide range of space environmental operating conditions) are solicited. Technologies specifically addressing the following mission needs are highly sought:

- Photovoltaic cell and blanket technologies capable of low intensity, low-temperature operation applicable to outer planetary (low solar intensity) missions
- Photovoltaic cell, blanket and array technologies capable of enhancing solar array operation in a high intensity, high-temperature environment (i.e. inner planetary and solar probe-type missions)
- Lightweight solar array technologies applicable to solar electric propulsion missions. Current missions being studied require solar arrays that provide 1 to 20 kilowatts of power at 1 AU, are greater than 300 watts/kilogram specific power, can operate in the range of 0.7 to 3 AU, provide operational array voltages up to 150 volts and have a low stowed volume.

Thermophotovoltaic conversion is currently focused on follow-on technology for the International Lunar Network (ILN) and for the outer planets mission. Advances sought, but not limited to, include:

- Low-bandgap cells having high efficiency and high reliability
- High temperature selective emitters
- Low absorptance optical band-pass filters
Efficient multi-foil insulation

Note to Proposer: Topic X8 under the Exploration Mission Directorate also addresses power technologies (X8.03 Space Nuclear Power Systems, and X8.04 Advanced Photovoltaic Systems). Proposals more aligned with exploration mission requirements should be proposed in X8.

Sub Topics:

Propulsion Systems Topic S3.04
The Science Mission Directorate (SMD) needs spacecraft with more demanding propulsive performance and flexibility for more ambitious missions requiring high duty cycles, more challenging environmental conditions, and extended operation. Planetary spacecraft need the ability to rendezvous with, orbit, and conduct in situ exploration of planets, moons, and other small bodies in the solar system (http://www.nap.edu/catalog.php?record_id=10432 [39]). Future spacecraft and constellations of spacecraft will have high-precision propulsion requirements, usually in volume- and power-limited envelopes.

This subtopic seeks innovations to meet SMD propulsion requirements, which are reflected in the goals of NASA’s In-Space Propulsion Technology program to reduce the travel time, mass, and cost of SMD spacecraft. Advancements in chemical and electric propulsion systems related to sample return missions to Mars, small bodies (like asteroids, comets, and Near-Earth Objects), outer planet moons, and Venus are desired. Additional electric propulsion technology innovations are also sought to enable low cost systems for Discovery class missions, and eventually to enable radioisotope electric propulsion (REP) type missions.

The focus of this solicitation is for next generation propulsion systems and components, including high-pressure chemical rocket technologies and low cost/low mass electric propulsion technologies. Specific sample return propulsion technologies of interest include higher-pressure chemical propulsion system components, lightweight propulsion components, and Earth-return vehicle propulsion systems. Propulsion technologies related specifically to planetary ascent vehicles will be sought under S3.08 Planetary Ascent Vehicle.

Chemical Propulsion Systems
Technology needs include:

- Improved materials and manufacturing processes to produce Iridium/Rhenium apogee class thruster chambers with improved mechanical properties targeting a yield stress of 40ksi and an elongation of 10%;
- Advanced nontoxic mono-propellant rockets for in-space applications.

Electric Propulsion Systems
This subtopic also seeks proposals that explore uses of technologies that will provide superior performance in for high specific impulse/low mass electric propulsion systems at low cost. These technologies include:

- Efficient thrusters with up to 1 kW of input power that provide thrust up to 20 mN with a specific impulse between 1600 to 3500 seconds;
- A throttleable dual mode thruster that is capable of operating in both high thrust and high specific impulse modes for a fixed power;
- High power electric propulsion thrusters (>20 kW) and components including cathodes, ion optics, and low sputtering materials with long life (>1x108 N-s).

Proposals should show an understanding of the state of the art, how there technology is superior, and of one or more relevant science needs. The proposals should provide a feasible plan to fully develop a technology and infuse it into a NASA program.

Note to Proposer: Topic X2 under the Exploration Mission Directorate also addresses advanced propulsion. Proposals more aligned with exploration mission requirements should be proposed in X2.

Sub Topics:

Power Management and Storage Topic S3.05
Future NASA science objectives will include missions such as Earth Orbiting, Venus, Europa, Titan, Lunar Quest and Space Weather. Under this subtopic, proposals are solicited to develop energy storage and power electronics to enable or enhance the capabilities of future science missions. The unique requirements for the power systems for these missions can vary greatly, with advancements in components needed above the current State of the Art (SOA) for long life, high reliability, low mass/volume, radiation tolerance, and wide temperature operation.
Energy Storage

Future science missions will require advanced primary and secondary battery systems capable of operating at temperature extremes from -100°C for Titan missions to 400°C to 500°C for Venus missions, and a span of -230°C to +120°C for Lunar Quest. In addition, high energy-density rechargeable electrochemical battery systems that offer greater than 50,000 charge/discharge cycles (10 year operating life) for low-earth-orbiting spacecraft, 20 year life for geosynchronous (GEO) spacecraft, are desired. Advancements to battery energy storage capabilities that address one or more of the above requirements for the stated missions combined with very high specific energy (>200 Wh/kg for secondary battery systems) and energy density, along with radiation tolerance are of interest.

In addition to batteries, other advanced energy storage/load leveling technologies designed to the above mission requirements, such as flywheels, supercapacitors or magnetic energy storage, are of interest. These technologies have the potential to minimize the size and mass of future power systems.

Power Management and Distribution (PMAD)

The "New Frontiers in the Solar System: An Integrated Exploration Strategy" ([http://www.nap.edu/catalog.php?record_id=10432][39]), the 2006 Solar System Exploration Roadmap ([http://nasascience.nasa.gov/about-us/science-strategy][36]) and the Science Plan for NASA's Science Mission Directorate ([http://nasascience.nasa.gov/about-us/science-strategy][36]) all describe the need for radioisotope power systems (RPS) for planetary exploration. In conjunction with the RPS, intelligent, fault-tolerant PMAD technologies are needed to efficiently manage the system power for these deep space missions. Advances in electrical power technologies are required for the electrical components and systems for these future platforms to address program size, mass, efficiency, capacity, durability, and reliability requirements. Of importance are expected improvements in energy density, speed, efficiency, or wide-temperature operation (-125°C to over 450°C) with a number of thermal cycles. Advancements are sought for power electronic devices, components and packaging for Venus type missions with power ranges of a few watts for minimum missions up to a few kilowatts for large missions.

For the lower power applications (up to 20 watts), NASA desires to build smaller spacecraft types carrying smaller instrument packages. However, power requirements to accommodate these instruments and spacecraft systems will not necessarily shrink in a similar fashion as spacecraft size. Therefore, power management technologies are sought that are compatible with small spacecraft geometries and sizes. These Electrical Power Systems should be compatible with Space Plug and Play (SPA) architectures.

Overall technologies of interest include:

- Intelligent, fault-tolerant electrical components and PMAD systems
- High temperature devices and components (up to 450°C)
- Advanced electronic packaging for thermal control and electromagnetic shielding
- Plug and Play compatibility for low power applications

Power Conversion and Distribution relevant to Command, Data Handling, and Electronics, will be covered under subtopic S3.01.

Power Storage for Terrestrial Balloons will be covered under sub-topic S3.07 Terrestrial and Planetary Balloons.

Research should be conducted to demonstrate technical feasibility during Phase I and show a path toward a Phase II, and when possible, deliver a demonstration unit for NASA testing at the completion of the Phase II contract. Phase II emphasis should be placed on developing and demonstrating the technology under relevant test conditions. Additionally, a path should be outlined that shows how the technology could be commercialized or further developed into science-worthy systems.

Other subtopics, which could potentially benefit from these technology developments include O5 - Low-Cost and Reliable Access to Space (LCRATS), S5.05 - Extreme Environments Technology, and S5.01 - Planetary Entry, Descent and Landing Technology. Battery development could also be beneficial to X6.02 - Advanced Space-rated Batteries, which is investigating some similar technologies in the secondary battery area but with very different operational requirements. Power Management and Distribution could be beneficial to X8.05 - Advanced Power Conversion Systems AND Management and Distribution (PMAD), which is investigating similar technologies, but
with very different power levels.

Sub Topics:
Guidance, Navigation and Control Topic S3.06
Advances in the following areas of guidance, navigation and control are sought.

**Navigation systems** (including multiple sensors and algorithms/estimators, possibly based on existing component technologies) that work collectively on multiple vehicles to enable inertial alignment of the formation of vehicles (i.e., pointing of the line-of-sight defined by fixed points on the vehicles) on the level of milli-arcseconds relative to the background star field.

**Light-weight sensors** (gyroscopic or other approach) to enable milli-arcsecond class pointing measurement for individual large telescopes and low cost small spacecraft.

**Isolated pointing and tracking platforms** (pointing 0.5 arcseconds, jitter to 5 milli-arcsecond), targeted to placing a scientific instrument on GEO communication satellites that can track the sun for > 3 hours/day.

**Working prototypes of GN&C actuators** (e.g., reaction or momentum wheels) that advance mass and technology improvements for small spacecraft use. Such technologies may include such non-contact approaches such as magnetic or gas. Superconducting materials, driven by temperature conditioning may also be appropriate provided that the net power used to drive and condition the "frictionless" wheels is comparable to traditional approaches.

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.

Sub Topics:
Terrestrial and Planetary Balloons Topic S3.07
All 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.

**Terrestrial Scientific Balloons**
NASA’s Scientific Balloons provide practical and cost effective platforms for conducting discovery science, development and testing for future space instruments, as well as training opportunities for future scientists and engineers. Balloons can reach altitudes above 36 kilometers, with suspended masses up to 3600 kilograms, and can stay afloat for several weeks. Currently, the Balloon Program is on the verge of introducing an advanced balloon system that will enable 100 day missions at mid latitudes and thus resemble the performance of a small spacecraft at a fraction of the cost. In support of this development, NASA is seeking innovative technologies in three key areas to monitor and advance the performance of this new vehicle.

1. **Power Storage**: Devices or methods to store electrical energy onboard the balloon with lower mass than current techniques are needed. Long duration balloon flights at mid-latitudes will experience up to 12 hours of darkness, during which electrical power is needed for experiments and NASA support systems. Typically, solar panels are flown to generate power during the daylight hours, and excess power is readily available. This excess power needs to be stored for use during the night. Current power storage techniques consist of rechargeable batteries which range from lead-acid to lithium-ion chemistries. Innovative alternatives to these batteries, either advanced chemistries or alternate power storage techniques such as capacitors or flywheels, which result in overall mass savings are needed. Nominal voltage levels for balloon systems are 28 volts DC, and nominal power levels can vary from 100 watts to 1000 watts. Therefore, power storage requirements range from 1000 watt-hours to 12,000-watt hours or more. Alternative power systems, which do not rely on solar panels, may also be proposed. These alternative systems may use energy storage techniques such as fuel cells or flywheels, which are prepared or charged on the ground prior to flight, and then would provide continuous power throughout the flight at the power levels specified above. Spacecraft power storage requirements are found under subtopic S3.05 Power Management and Storage.

2. **Balloon Instrumentation**: Devices or methods are desired to accurately measure ambient air temperature, helium gas temperature, balloon film temperatures, film strain, and tendon load are desired. These measurements are needed to accurately model the balloon performance during a typical flight at altitudes of approximately 36 kilometers. The measurements must compensate for the effects of direct solar radiation through shielding or calculation. Minimal mass and volume are highly desired. Remote sensing of the parameters and non-invasive and non-contact approaches are also desired. The non-invasive and non-contact approaches are highly desired for the thin polyethylene film measurements used as the balloon envelope, with film thickness ranging from 0.8 to 1.5 mil.
Strain measurements of these thin films via in-flight photogrammetric techniques would be beneficial. Devices or methods to accurately measure axially loaded tendons on an array of ~50 or up to 300 separate tendons during flight are of interest. Tendons are typically captured at the end fittings via individual pins with loading levels ranging from ~20 N to ~8,000 N per tendon, and can be exposed to temperatures from room temperature to the tropospheric temperatures of -90 degrees Celsius or colder. The measurement devices must be compatible with existing NASA balloon packaging, inflation, and launch methods. These instruments must also be able to interface with existing NASA balloon flight support systems or alternatively, a definition of a data acquisition solution be provided. Support telemetry systems are not part of the this initiative; however, data from any sensors (devices) that are selected from this initiative must be able to be stored on board and/or telemetered in-flight using single-channel (two-wire) interface into existing NASA balloon flight support systems. The devices of interest shall be easily integrated and shall have minimal impact on the overall mass of the balloon system.

(3) Low-Cost Variable Conductance Heat Pipes for Balloon Payloads: With the ever-increasing complexity of both scientific instruments and NASA mission support equipment, advanced thermal control techniques are needed. The type of advanced thermal control techniques desired are similar to those utilized on large-budget orbital and deep space payloads (variable conductance heat pipes, diode heat pipes, loop heat pipes, capillary pumped loops, heat switches, louvers) are far more expensive to implement on balloon payloads that their limited budgets can afford. Innovative solutions are sought that would allow these more advanced thermal control measures to be utilized with reduced expense. Spacecraft thermal control requirements are found under subtopic S3.02 Thermal Control Systems.

Though not considered "cutting-edge technology", commercial quality, constant conductance, copper-methanol heat pipes have begun to be utilized on balloon payloads to effectively move heat significant distances. The problem with these devices is that the conductance cannot effectively be reduced under cold operating or cold survival environment conditions without expending significant energy in an active heater to maintain the condenser section warm. It is desirable to develop a cost-effective method of conducting the heat in this manner and allowing the flow to be reduced/eliminated when conditions warrant. Therefore, innovative thermal control techniques and devices developed must be inexpensive to implement. They must function reliably at balloon altitudes of 30-40km and temperature ranges from -90C to +40C. They should require little or no energy consumption and provide the capability of moderating heat flow autonomously or by remote control under certain thermal conditions.

Planetary Balloons

Innovations in materials, structures, and systems concepts have enabled buoyant vehicles to play an expanding role in planning NASA's future Solar System Exploration Program. Balloons and airships are expected to carry scientific payloads at Titan and Venus that will perform in situ investigations of their atmospheres and near surface environments. Both Titan and Venus feature extreme environments that significantly impact the design of balloons for those two worlds. Proposals are sought in the following areas:

(1) Titan Montgolfiere Balloons: Recent NASA mission studies have recommended the use of radioisotope-heated Montgolfiere balloons for future in situ Titan exploration. Proposals are sought for the design, fabrication and Earth atmosphere flight testing of prototypes that can support an eventual Titan Montgolfiere balloon mission. Particular importance is attached to the acquisition of test data that can help validate thermodynamic and fluid mechanic models that will ultimately be used to design the Titan flight balloon. The size of balloon required for Titan will be approximately 10 m in diameter and will require 2 kW of thermal energy to float the balloon at an expected Titan temperature of 85 to 95 K. Any proposed Earth-test prototype will require an alternate heat source that nevertheless adequately mimics the effects of using radioisotope energy at Titan.

(2) Gas Management Systems for Titan Aerobots: Hydrogen-filled aerobots at Titan must contend with the problem of gas leakage over long duration (1 year or more) flights. Proposals are sought for the development and testing of two kinds of prototype devices that can be carried on the aerobot to compensate for these gas leakage problems: one device is to produce make-up hydrogen gas from atmospheric methane; the other device is to remove atmospheric gas (mostly nitrogen) that leaks from the ballonets into the hydrogen-filled blimp. Both kinds of devices will need to operate on no more than 15 W of electrical power each while compensating for a leakage rate of at least 40 g/week of hydrogen or 500 g/week of nitrogen.

(3) Metal Balloons for High Temperature Venus Exploration: Balloons made of metals are a potential solution to the problem of enabling long duration flight in the hot lower atmosphere of Venus. Proposals are sought for metal balloon concepts and prototypes that provide 1-5 m³ of fully inflated volume, areal densities of 1 kg/m² or less, sulfuric acid compatibility at 85% concentration, and operation at 460 °C for a period of up to 1 year.
Sub Topics:

Planetary Ascent Vehicles Topic S3.08

NASA aims to design, build and test vehicles that will be launched from the surface of other planets and small bodies and place a payload, Orbiting Sample (OS), into orbit. We are seeking proposals for the development of innovative technologies to support future planetary ascent vehicles. Immediate focus is the Mars ascent vehicle. Technology innovations should either enhance vehicle capabilities (e.g., launch success probability, mission success, improved performance or margins, and improved environmental robustness) or ease implementation in space borne missions (e.g., reduce size, mass, power, and thermal requirements, improve reliability and ability to withstand the ~20 g lateral g-loading, or lower cost). The areas of interest for this call are listed below.

Alternate propellants, thrusters and propulsion system technologies for the planetary ascent vehicles:

- Higher performing monopropellants with specific impulse >240 secs;
- "Green" propellants;
- High chamber pressure thrusters > 500 psia;
- Pressurization component technologies to reduce system mass (filters, solenoid valves, latch valves, tanks, fill and drain and check valves);
- Small lightweight pump technologies to operate at >500 psi output pressure especially non-electrically driven;
- Non-pyrotechnic isolation valves.

Advanced solid propellant engine system technologies:

- Solid propellant technology with specific impulse performance potential higher than HTPB and CTPB;
- Propellant blend with high performance low storage impacts, and operating capability down to 150 K;
- Low temperature seals and components;
- Light weight and reliable thrust vector control;
- Other lightweight system and component technologies.

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.

Launch vehicle technologies relevant to Earth are not sought under this sub-topic. For launch vehicle technologies related to Earth, see X2.01 Earth-to-Orbit Propulsion. Proposals more aligned with exploration mission requirements should be proposed in X2.01.

Sub Topics:

Unmanned Aircraft and Sounding Rocket Technologies Topic S3.09

Sounding Rockets

The NASA Sounding Rocket Program (NSRP) provides low-cost, sub-orbital access to space in support of space and earth sciences research and technology development sponsored by NASA and other users by providing payload development, launch vehicles, and mission support services. NASA utilizes a variety of vehicle systems comprised of military surplus and commercially available rocket motors, capable of lofting scientific payloads, up to 1300lbs, to altitudes from 100km to 1500km. NASA launches sounding rocket vehicles worldwide, from both land-based and water-based ranges, based on the science needs to study phenomenon in specific locations.

NASA is seeking innovations to enhance capabilities and operations in the following areas:

- Autonomous vehicle environmental diagnostics system capable of monitoring flight loading (thermal, acceleration, stress/strain) for solid rocket vehicle systems.
- Location determination systems to provide over-the-horizon position of buoyant payloads to facilitate expedient location and retrieval from the ocean.
- Flotation systems, ranging from tethered flotation devices to self-encapsulation systems, for augmenting buoyancy of seal payload systems launched from water-based launch ranges.
- High-glide parachute designs capable of deploying at altitudes above 25,000 ft to facilitate mid-air retrieval and/or fly-back/fly-to-point precision landing.
Unmanned Aircraft Systems

Unmanned Aircraft Systems (UAS) offer significant potential for Suborbital Scientific Earth Exploration Missions over a very large range of payload complexities, mission durations, altitudes, and extreme environmental conditions. To more fully realize the potential improvement in capabilities for atmospheric sampling and remote sensing, new technologies are needed. Scientific observation and documentation of environmental phenomena on both global and localized scales that will advance climate research and monitoring; e.g., U.S. Global Change Research Program as well as Arctic and Antarctic research activities (Ice Bridge, etc.).

NASA is increasing scientific participation to understand impacts associated with worldwide environmental changes. Capability for suborbital unmanned flight operations in either the North or South Polar Regions are limited because of technology gaps for extremely remote telemetry capabilities and precision flight path control requirements. It is also highly desirable to have UAS ability to perform atmospheric and surface sampling.

1) Telemetry, Tracking and Control: Low cost over-the-horizon global networks are needed to enable unmanned collaborative multi-platform earth observation missions that are more efficient and cost effective.

2) Avionics and Flight Control:
   - Precision Flight Path Control solutions in smooth atmospheric conditions.
   - Aircraft control in violent atmospheric conditions.
   - Low cost (<$20k), High precision inertial navigation systems (greater than 1/10th degree accuracy and knowledge)

Precise/repeatable flight path control capabilities are needed to enable repeat path observations for earth monitoring on seasonal and multi-year cycles. In addition, long endurance atmospheric sampling in extreme inclement weather conditions (hurricanes) and volcanic plumes can provide high fidelity time and spatial resolution data.

3) UA Integrated Vehicle Health Management:
   - Fuel Heat/Anti-freezing
   - Unmanned platform icing detection and minimization

4) Guided Dropsondes: NASA Earth Science Research activities could utilize more capable dropsondes than are currently available as market items. Specifically, dropsondes that could effectively be guided through atmospheric regions of interest such as volcanic plumes could enable unprecedented observations of important phenomena. Capabilities of interest include:
   - Compatibility with existing drop-sonde dispensing systems deployed on the NASA/NOAA P-3 and planned for the NASA Global Hawk
   - Guidance schemes, autonomous or active control
   - Cross-range performance and flight path accuracy
   - Operational considerations including airspace utilization and conflicting traffic

All 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.

Sub Topics:
Earth Entry Vehicle Systems Topic S3.10
This subtopic seeks innovations to meet Science Mission Directorate (SMD) requirements for Earth Entry Vehicles (EEV). Advancements in materials, structures, and systems related to sample return missions to the Moon, planetary bodies (e.g., Mars and Venus), small bodies (e.g., asteroids, comets, and Near-Earth Objects) and outer planet bodies are desired.

EEVs provide several challenges to current material and structural designs in several areas. New classes of structure and impact materials are needed which are lightweight and versatile, remaining stiff during impact with soft surfaces while providing low impact loads when crushing with impact to hard surfaces. Lightweight structures that are suitable for thermal protection system (TPS) substructures, including serving as a thermal barrier or sink,
are also desired. Current EEV concepts are blunt-body vehicles (60-degree sphere cones) that are 0.5 to 2.0
meters in diameter, entering Earth's atmosphere at 11-16 km/s.

This subtopic also seeks proposals that explore new technologies in several key vehicle systems that include:

- Low mass/cost/complexity, high reliability impact attenuation systems capable of keeping peak impact loads
  below 1500 g's under nominal conditions, or 2500 g's under off-nominal conditions (i.e. impact with a rock
  or hard man-made surface, e.g. concrete road). Payload stroke resulting from compression of candidate
  impact foam must not exceed 2.5% of the vehicle overall diameter.
- Lightweight structures that are suitable for TPS substructures (i.e., lightweight, stiff, good insulator).
- Mid-density robust ablator systems that can be tailored to entry heating for a range of missions from high
  speed to low speed, and are easy to manufacture across the range of possible vehicle scales.
- Adhesives that are compatible with lightweight structures and TPS.
- Passive (or nearly passive), self-contained methods of determining whether a micrometeoroid strike (of the
  TPS) has occurred.
- Low mass, low power, reliable self-contained beacon for EEV retrieval.
- Candidate beacon mass must not exceed 100g (including power and activation) and must provide a reliable
  signal for up to 2 days after landing/impact.
- Low mass, low power, reliable, self-contained GPS with broadcast system and the antenna to beam the
  trajectory and landing location information to IRIDIUM or other easily accessible commercial global
  communication systems as an aid to locating the landed EEV.
- Thermal control system technologies for EEVs will be covered under sub-topic S3.02 thermal Control
  Systems.
- EEV closing and locking mechanism(s) that are reliable and easily verifiable.

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.

Other subtopics that could be soliciting entry, descent, and landing related technology developments include S5.01
Entry, Descent and Landing Technologies, X9.01 Ablative Thermal Protection Systems, and X9.02 Advanced
Integrated Hypersonic Entry Systems. Proposals more aligned with exploration mission requirements should be
proposed in X9.

Sub Topics:
- De-orbit Devices/Technologies for Small Spacecraft Topic S4.01
  NASA intends to place small spacecraft (}

Sub Topics:
- Miniature Integrated Payload Suites Topic S4.02
  In order to fully realize the economy, launch frequency, and science utility benefits that small spacecraft represent,
  a new generation of MEMS-based sensor suites are desired. These sensors could be the result of miniaturization
  and repacking of existing sensors, or consist of novel devices and technologies that can accomplish similar
  measurements of larger systems in a fraction of the current size, weight and power. In addition, these suites would
  contain the necessary data processing and power conditioning systems to support routine operation. Compatibility
  with Space Plug and Play (SPA) or similar architectures that streamline system integration processes is also
  desired.
NASA seeks innovative sensor technologies to enhance success for entry, descent and landing (EDL) operations on missions to Mars. Sensing technologies are desired which determine the entry point of the spacecraft in the Mars atmosphere; provide inputs to systems that control spacecraft trajectory, speed, and orientation to the surface; locate the spacecraft relative to the Martian surface; evaluate potential hazards at the landing site; and determine when the spacecraft has touched down. Appropriate sensing technologies for this topic should provide measurements of physical forces or properties that support some aspect of EDL operations. NASA also seeks to use measurements made during EDL to better characterize the Martian atmosphere, providing data for improving atmospheric modeling for future landers. Proposals are invited for innovative sensor technologies that improve the reliability of EDL operations.

Products or technologies are sought that can be made compatible with the environmental conditions of spaceflight and the rigors of landing on the Martian surface. Successful candidate sensor technologies can address this call by:

- Providing critical measurements during the entry phase (e.g., pressure and/or temperature sensors embedded into the aeroshell);
- Improving the accuracy on measurements needed for guidance decisions (e.g., surface relative velocities);
- Extending the range over which such measurements are collected (e.g., providing a method of imaging through the aeroshell, or terrain-relative navigation that does not require imaging through the aeroshell);
- Enhancing the situational awareness during landing by identifying hazards (rocks > 20cm height, slopes > 0.05 radians, craters > 1m diameter) and distinguishing between favorable and unfavorable landing materials (e.g., differentiate bowls of dust from solid rock);
- Substantially reducing the amount of external processing needed to calculate the measurements or provide high performance flight qualified processing with low mass and power (e.g., 1 GFLOPS processing in Decoupling spacecraft attitude from instrument pointing through the development of fast gimbals that are low mass and power (2rad/s² accelerations, 2 rad/s rates with mass);
- Improving landing site map accuracy and resolution while also providing a means for validating the generated map (10cm resolution elevation with 5cm height errors and map tie errors);
- Providing modular and low mass spacecraft to spacecraft navigation systems that work through all of EDL (e.g. orbiter to lander during entry or lander to surface rover);
- Monitoring local environmental (weather) conditions on the surface to facilitate forecasting of wind velocities up to ~10km altitude above the surface in preparation for landing (for missions targeted to land near previously landed assets);
- Significantly reducing the impact of incorporating such sensors on the spacecraft in terms of volume, mass, placement, or cost.
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.

Other subtopics that could be soliciting entry, descent, and landing related technology developments include S1.01 Laser and Lidar System Components, S3.10 Earth Entry Vehicle Systems, X9.01 Ablative Thermal Protection Systems, and X9.02 Advanced Integrated Hypersonic Entry Systems. Proposals more aligned with exploration mission requirements should be proposed in X9.

Sub Topics:

**Sample Collection, Processing, and Handling Topic S5.02**
Robust systems for sample acquisition, handling and processing are critical to the next generation of robotic explorers for investigation of planetary bodies (http://books.nap.edu/openbook.php?record_id=10432&page=R1 [46]). Limited spacecraft resources (power, volume, mass, computational capabilities, and telemetry bandwidth) demand innovative, integrated sampling systems that can survive and operate in challenging environments (extremes in temperature, pressure, gravity, vibration and thermal cycling). Special interest lies in sampling systems and components (actuators, gearboxes, etc.) that are suitable for use in the extremely hot high-pressure environment at the Venusian surface (460°C, 93 bar). Relevant systems could be integrated on multiple platforms, however of primary interest are samplers that could be mounted on a mobile platform, such as a rover. For reference, current Mars-relevant rovers range in mass from 200 - 800 kg.

**Sample Acquisition**

Research should be conducted to develop compact, low-power, lightweight subsurface sampling systems that can obtain 1 cm diameter cores of consolidated material (e.g., rock, icy regolith) up to 10 cm below the surface. Systems should be capable of autonomously acquiring and ejecting samples reliably. Also of interest are methods of autonomously exposing rock interiors from below weathered rind layers. Other sample types of interest are unconsolidated regolith, dust, and atmospheric gas.

**Sample Manipulation (core management, sub-sampling/sorting, powder transport)**

Sample manipulation technologies are needed to enable handling and transfer of structured and unstructured samples from a sampling device to instruments and sample processing systems. Core, cuttings, and regolith samples may be variable in size and composition, so a sample manipulation system needs to be flexible enough to handle the sample variability. Core samples will be on the order of 1 cm diameter and up to 10 cm long. Soil and rock fragment samples will be of similar volumes.

**Sample Integrity (encapsulation and contamination)**

For a sample return mission, it is critical to find solutions for maintaining physical integrity of the sample during the surface mission (rover driving loads, diurnal temperature fluctuations) as well as the return to Earth (cruise, atmospheric entry and impact). Technologies are needed for characterizing state of sample in situ - physical integrity (e.g., cracked, crushed), sample volume, mass or temperature, as well as retention of volatiles in solid
core, regolith) samples, and retention of atmospheric gas samples.

Also of particular need are means of acquiring subsurface rock and regolith samples with minimum contamination. This contamination may include contaminants in the sampling tool itself, material from one location contaminating samples collected at another location (sample cross-contamination), or Earth-source microorganisms brought to the Martian surface prior to drilling ('clean' sampling from a 'dirty' surface). Consideration should be given to use of materials and processes compatible with 110 - 125°C dry heat sterilization. In situ sterilization may be explored, as well as innovative mechanical or system solutions - e.g., single-use sample "sleeves," or fully-integrated sample acquisition and encapsulation systems.

For a sample return mission, sample transfer of a payload into a planetary ascent vehicle: Automated payload transfer mechanisms; and Orbiting Sample (OS) sealing techniques.

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.

Sub Topics:

Surface and Subsurface Robotic Exploration Topic S5.03

Technologies are needed to enable access, mobility, and sample acquisition at surface and subsurface sampling sites of scientific interest on Mars, Venus, small planetary bodies, and the moons of the Earth, Mars, Jovian and Saturnian systems. Many scientifically valuable sites are accessible only via terrain that is too difficult for state-of-the-art planetary rovers to traverse in terms of ground slope, rock obstacle size, plateaus, and non-cohesive soils types. Sites include crater walls, canyons, gullies, sand dunes, and high rock density regions. Tethered systems, non-wheeled systems, and marsupial systems are examples of mobility technologies that are of interest. These technologies could enable new approaches for deployment, retrieval, access, and mobility.

A variety of mobility system architectures can be considered. Single vehicle systems might utilize a 200 kg class rover and dual vehicle systems might utilize a 500 - 800 kg primary vehicle that provides long traverse to the vicinity of a challenging site and then deployment of a smaller 20 - 50 kg vehicle with steep mobility capability for access and sampling at the site.

For surface and subsurface sampling, advanced manipulation technologies are needed to deploy instruments and tools from landers and rovers. Technologies to enable acquisition of subsurface samples are also needed. For Mars and Venus, technologies are needed to acquire core samples in the shallow subsurface to about 10cm and to enable subsurface sampling in multiple holes at least 1 - 3 meters deep through rock, regolith, or ice compositions. Shallow subsurface sampling systems need to be low mass and deeper subsurface sampling solutions need to be integratable onto 500 - 800 kg stationary landers and mobile platforms. For Europa, penetrators and tools to allow deep drilling are needed to sample and bore the outer water-ice layer and through 10 to 30km to a potential liquid ocean below.

Consideration should be given for potential failure scenarios, such as platform slip and borehole misalignment for integrated systems, and the challenges of dry drilling into mixed media including icy mixtures of rock and regolith. Systems should ensure minimal contamination of samples from Earth-source contaminants and cross-contamination from samples at different locations or depths.
Innovative component technologies for low mass, low power, and modular systems tolerant to the in-situ environment are of particular interest. For Europa, the radiation environment is estimated at 2.9 Mrad total ionizing dose (TID) behind 100 mil thick aluminum. Technical feasibility should be demonstrated during Phase I and a full capability unit of at least TRL level 4 should be delivered in Phase II. Specific areas of interest include the following:

- Tether play-out and retrieval systems including tension and length sensing;
- Low-mass tether cables with power and communication;
- Steep terrain adherence for vertical and horizontal mobility;
- Modular actuators with 1000:1 scale gear ratios;
- Electro-mechanical couplers to enable change out of instruments on an arm end-effector;
- Drill, core, penetrator, and boring systems for subsurface sampling to 10cm, 1 m, 3 m, and deep subsurface;
- Shared intelligence allowing systems to collaborate and adapt exploration scenarios to new conditions.

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

Sub Topics:
Rendezvous and Docking Technologies for Orbiting Sample Capture Topic S5.04

NASA seeks an innovative suite of products or technologies that will enable and enhance the successful tracking and capture of a sample canister in Mars orbit in anticipation of the start of a Mars Sample Return (MSR) mission in the next decade.

The principal means of detection and tracking of the Orbiting Sample Canister (OSC) is optically with visual-band cameras. The challenging technology of long-range optical sensors for detection and distant tracking is not part of this call, however, short-range optical (or other) sensors and an on-sample radio-metric-based back-up detection and tracking method is desired, including a low-power, low-mass illuminator for short-range imaging of up to 0.5km.

Sample capture mechanisms are sought, of very low mass and volume, and of low complexity and extremely high reliability, including detection of contact with the capture mechanism. Appropriate on-sample radio-beacons are sought that are compatible with NASA’s radio systems, in particular, the Electra onboard programmable radio system; requirements for these beacons are for long life, and independent initiation of on-orbit operation. Solutions are sought that are either battery powered or via solar cells that do not reduce the overall OSC outer shell visual...
albedo below 0.5. Sample capture mechanisms should include close-proximity/contact sensors, including immediate-field imaging.

Methods are sought to provide a practice mechanism for testing rendezvous and proximity operations with a test sample canister in Earth or Mars orbit. The test carrier and release mechanism must be of very low mass and volume, and the test sample canister(s) should carry a radio beacon. Test OSC canisters should be of limited life after release, ceasing broadcast, and degrading in surface reflectance in approximately one month after release to avoid confusion with the actual canister. The test articles may be deployed and used on a previous mission to MSR, or on the actual MSR mission for operational readiness testing.

Products or technologies are sought that can be made compatible with the environmental conditions of interplanetary spaceflight and the rigors normal Mars orbits. Proposals should show an understanding of proposals and plans for previous NASA-supported Mars Sample Return relevant missions and mission concepts, and present a feasible plan to fully develop a technology and infuse it into a NASA program. Successful candidate products or technologies can address this call by providing one or more of the following functions, and giving estimated expected performance capabilities of the approach, including, but not limited to, accuracies, ranges, limits of operation, references to previous or related flight experience:

- Autonomously actuated mechanisms for orbiting sample capture of the OSC
  - Mechanical capture mechanisms
  - Transfer mechanisms from capture device to containment transfer mechanism

- Optical and contact sensors
  - Near field imagers (optical or other) (e.g. 10m to 1km)
  - Immediate field imagers (optical) (0.25 to 10m)
  - Detection of OSC for triggering capture mechanism
  - Near field illuminator

- Coherent Radio Doppler and range beacon (high-performance)
  - Low power, low mass and long life beacon for detection aid
  - 2-way communication for activation, ranging and coherency via NASA’s Electra radio interface
  - Programmable intermittent transmission for power saving and very long dormancy period
  - Battery or solar powered, preserving 0.5 visual albedo of OSC

- Simple Radio beacon (low-performance)
- Simple 1-way beacon, for long-range detection and 1-way Electra Doppler extraction
- Timer activated, multi-year dormant life, and long active life battery, or solar powered - preserving 0.5 visual albedo of OSC

- Low-mass, low-cost sample OSC for proximity operations operational readiness tests

- A simple, low-cost, low-mass practice sample canister that could be deployed in Earth or Mars orbit and provide low-risk practice runs, either for a precursor mission, or with the actual MSR.
- The readiness test exercise would not necessarily capture the test article in the capture mechanism for the actual MSR flight, but only perform the rendezvous and proximity ops operations sufficient to demonstrate very high likelihood of actual OSC capture.

Sub Topics:
- Extreme Environments Technology Topic S5.05
- High Temperature, High Pressure, and Chemically Corrosive Environments

NASA is interested in expanding its ability to explore the deep atmosphere and surface of Venus through the use of long-lived (days or weeks) balloons and landers. Survivability in extreme high temperatures and high pressures is also required for deep atmospheric probes to giant planets. Proposals are sought for technologies that enable the in situ exploration of the surface and deep atmosphere of Venus and the deep atmospheres of Jupiter or Saturn for future NASA missions. Venus features a dense, CO$_2$ atmosphere completely covered by sulfuric acid clouds at about 55 km above the surface, a surface temperature of about 486 degrees Centigrade and a surface pressure of about 90 bars. Technologies of interest include high temperature and acid resistant high strength-to-weight textile materials for landing systems (balloons, parachutes, tethers, bridles, airbags), high temperature electronics components, high temperature energy storage systems, light mass refrigeration systems, high-temperature motors and actuators for robotic arms and other mechanisms, high temperature drills, phase change materials for short term thermal maintenance, low conductivity and high-compressive strength insulation materials, high temperature optical window systems (that are transparent in IR, visible and UV wavelengths) and advanced materials with high specific heat capacity and strength for pressure vessel construction, and pressure vessel components compatible with materials such as steal, titanium and beryllium such as low leak rate wide temperature (-50 degrees Centigrade C to 500 degrees Centigrade) seals capable of operating between 0 and 90 bars.

Low Temperature Environments

Low temperature survivability is required for surface missions to Titan (-180 degrees Centigrade), Europa surface (-220 degrees Centigrade), Ganymede (-200 degrees Centigrade) and comets. Also the Earth's Moon equatorial regions experience wide temperature swings from -180 degrees Centigrade to +130 degrees Centigrade during the lunar day/night cycle, and the sustained temperature at the shadowed regions of lunar poles can be as low as -230 degrees Centigrade. Mars diurnal temperature changes from about -120 degrees Centigrade to +20 degrees Centigrade. Also for the baseline concept for Europa Jupiter System Mission (EJSM), with a mission life of 10 years, the radiation environment is estimated at 2.9 Mega-rad total ionizing dose (TID) behind 100 mil thick aluminum. Proposals are sought for technologies that enable NASA's long duration missions to low temperature and wide temperature environments. Technologies of interests include low-temperature resistant high strength-weight textiles for landing systems (parachutes, air bags), low power radiation-tolerant /radiation hardened RF electronics, radiation-tolerant / radiation hardened mixed signal electronics, radiation-tolerant / radiation hardened power electronics, radiation-tolerant/ radiation hardened high speed fiber optic transceivers, radiation-tolerant/ radiation hardened electronic packaging (including, shielding, passives, connectors, wiring harness and materials
used in advanced electronics assembly), actuators and energy storage sources capable of operating across an ultra-wide temperature range from -230 degrees Centigrade to 200 degrees Centigrade and Computer Aided Design (CAD) tools for modeling and predicting the electrical performance, reliability, and life cycle for low-temperature electronic systems and components.

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

Sub Topics:
Planetary Protection Topic S5.06
NASA seeks innovative technologies to facilitate meeting Back Planetary Protection objectives for a potential Mars Sample Return mission and to facilitate Forward Planetary Protection implementation for a potential mission to Europa.

Back Planetary Protection deals with the possibility that Mars material may pose a biological threat to the Earth's biosphere. This leads to a constraint that returned samples of Mars material be contained with extraordinary robustness until they can be tested and proved harmless or be sterilized by an accepted method. Achieving this containment goal will require new technology for several functions. Containment assurance requires "breaking the chain of contact" with Mars: the exterior of the sample container must not be contaminated with Mars material. Also, the integrity of the containment must be verified, the sample container and its seals must survive the worst-case Earth impact corresponding to the candidate mission profile, and the Earth entry vehicle (EEV) must withstand the thermal and structural rigors of Earth atmosphere entry - all with an unprecedented degree of confidence.

Back Planetary Protection technologies for the following MSR functions are included in this call:

- Container Design, Sealing, and Verification: Options for sealing the sample container include brazing, explosive welding, and various types of soft seals, with sealing performed either on the Mars surface or in orbit. Confirmation of sealing can be provided by observation of sealing system parameters and by leak detection after sealing. Wireless data and power transmission may be needed for leak detection. Additional containment using a flexible liner within the EEV that is sealed while in Mars orbit has also been considered. Further validation prior to Earth entry may also be needed.

- Breaking-the-Chain and Dust Mitigation: Several paths have been identified that would result in Mars material contaminating the outside of the sealed sample container and/or the Earth return vehicle (ERV). Technology options for mitigation include ejection of containment layers during ascent and orbit and/or capturing a contaminated "Orbiting Sample" into a clean container on the ERV and then ejecting the capture device.

- Meteoroid Protection and Breach Detection: Protection is required for both the sample container and the EEV heat shield, with the later appearing to be the more challenging technology requirement. New lightweight shielding techniques are needed. Even with these the shield may be excessively heavy leading to a requirement for technology to detect a breach of the shield or damage to the EEV.
Entry, Descent, and Landing: The EEV should be aerodynamically self-righting and should provide shock attenuation for the sample container consistent with the planned no-parachute descent.

PRA and Reliability Analysis: Obtaining approval to proceed with an MSR mission is likely to involve quantitative assessment of the probability of containment loss. This will benefit from advances in the state of the art of probabilistic risk assessment for complex space systems and of reliability analysis of the spacecraft components involved.

Technologies are desired for the Europa mission that allow sterilization of previously non-sterilizable flight hardware by either i) dry heat processing or ii) gamma irradiation. NASA also seeks to use iii) hydrogen peroxide vapor processes for re-sterilization of assembled flight hardware elements. Proposals are invited for innovative approaches to sterilization of flight hardware in the pre-flight environment using this technology. Note: this call is not for novel sterilization processes.

For Europa, products and technologies are sought that can be demonstrated to be compatible with the three identified sterilization processes, as well as the environmental conditions of spaceflight and the Jovian system. Candidate technologies for the following functions and capabilities are included in this call:

- Sterilization Process Compatibility: Options for proving compatibility of novel product elements (materials, parts) with recognized spacecraft sterilization process parameters are desired.
- Redesign for Sterilization: Development of alternative solutions for spacecraft hardware is needed where there are known sterilization process incompatibilities, for example for heat tolerant sensors, seals (battery, valve), optical coating applications.
- BiobARRIER Technology: Demonstration of novel biobarrier and recontamination prevention approaches for spacecraft hardware is needed when applying one or more of these three sterilization processes.

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

Sub Topics:
Technologies for Large-Scale Numerical Simulation Topic S6.01
advance understanding of complex Earth and astrophysical systems, and to conduct high-fidelity aerospace engineering analyses. The goal of this subtopic is to increase the mission impact of NASA's investments in supercomputing systems and associated operations and services. Specific objectives are to:

- Decrease the barriers to entry for prospective supercomputing users;
- Minimize the supercomputer user's total time-to-solution (e.g., time to discover, understand, predict, or design);
- Increase the achievable scale and complexity of computational analysis, data ingest, and data communications;
- Reduce the cost of providing a given level of supercomputing performance on NASA applications; and
- Enhance the efficiency and effectiveness of NASA's supercomputing operations and services.

Expected outcomes are to improve the productivity of NASA's supercomputing users, broaden NASA's supercomputing user base, accelerate advancement of NASA science and engineering, and benefit the supercomputing community through dissemination of operational best practices.

The approach of this subtopic is to seek novel software and hardware technologies that provide notable benefits to NASA's supercomputing users and facilities, and to infuse these technologies into NASA supercomputing operations. Successful technology development efforts under this subtopic would be considered for follow-on funding by, and infusion into, NASA's high-end computing (HEC) projects: the High End Computing Capability project at Ames and the Scientific Computing project at Goddard. To assure maximum relevance to NASA, funded SBIR contracts under this subtopic should engage in direct interactions with one or both HEC projects, and with key HEC users where appropriate. Research should be conducted to demonstrate technical feasibility and NASA relevance during Phase I and show a path toward a Phase II prototype demonstration.

Offerors should demonstrate awareness of the state-of-the-art of their proposed technology, and should leverage existing commercial capabilities and research efforts where appropriate. Open source software and open standards are strongly preferred. Note that the NASA supercomputing environment is characterized by: HEC systems operating behind a firewall to meet strict IT security requirements, communication-intensive applications, massive computations requiring high concurrency, complex computational workflows and immense datasets, and the need to support hundreds of complex application codes; many of which are frequently updated by the user/developer. As a result, solutions that involve the following must clearly explain how they would work in the NASA environment: Grid computing, web services, client-server models, embarrassingly parallel computations, and technologies that require significant application re-engineering. Projects need not benefit all NASA HEC users or application codes, but demonstrating applicability to an important NASA discipline, or even a key NASA application code, could provide significant value.

Specific technology areas of interest include:

- **Efficient Computing**: In spite of the rapidly increasing capability and efficiency of supercomputers, NASA's HEC facilities cannot purchase, power, and cool sufficient HEC resources to satisfy all user demands. This subtopic element seeks dramatically more efficient and effective supercomputing approaches in terms of their ability to supply increased HEC capability or capacity per dollar and/or per Watt for real NASA applications. Examples include novel computational accelerators and architectures, more
capable storage/interconnect/visualization technologies, improved algorithms for key codes, and power-aware "Green" computing technologies and techniques.

- **Integrated Environments:** The user interface to a supercomputer is typically a command line in a text window. This subtopic element seeks more intuitive, intelligent, user-customizable, and integrated interfaces to supercomputing resources, enabling users to more completely leverage the power of HEC to increase their productivity. Such an interface could enhance many essential supercomputing tasks: accessing and managing resources, training, getting services, developing codes, running computations, managing files and data, analyzing and visualizing results, transmitting data, collaborating, etc.

- **Cloud Supercomputing:** Cloud computing has made tremendous promises, and demonstrated some success, for business computing: on-demand resource availability, resource virtualization, automated job migration, increased system availability, customized software environments, a web user interface, increased system reliability, and more. This subtopic element seeks technologies that enable Cloud computing to be used for efficient and effective supercomputing operations.

Sub Topics:
Earth Science Applied Research and Decision Support Topic S6.02

The NASA Applied Sciences Program ([http://nasascience.nasa.gov/earth-science/applied-sciences](http://nasascience.nasa.gov/earth-science/applied-sciences) [48]) seeks innovative and unique approaches to increase the utilization and extend the benefit of Earth Science research data to better meet societal needs. One area of interest is new decision support tools and systems for a variety of ecological applications such as managing coastal environments, natural resources or natural disasters.

This subtopic seeks new, advanced information systems and decision environments that take full advantage of multiple data sources and platforms. Tailored distribution networks and timely products delivered to a broad range of users are needed to support applications in disaster management, resource management, energy and urban sustainability.

- Development of new integrated multiple user requirements knowledge databases and archival library tools to support researchers and promote infusion of successful technologies into existing processes.
- Development of new decision support strategies and presentation methodologies for applied earth science applications to reduce risk, cost, and time.

This subtopic is also soliciting proposals for utilities, plug-ins or enhancements to open source geobrowsers that improve their utility for earth science research and decision support. Examples of geobrowsers include NASA World Wind, World Wind Java ([http://worldwindcentral.com/wiki/Main_page](http://worldwindcentral.com/wiki/Main_page) [49]) and COAST ([http://www.coastal.ssc.nasa.gov/coast/COAST.aspx](http://www.coastal.ssc.nasa.gov/coast/COAST.aspx) [50]). Special consideration will be given to tools for COAST. Examples of specific interest are:

- Tools and utilities to support creation or simplify the import and integration of new datasets;
- Tools and utilities to discover and integrate existing web-enabled sensor data (e.g., webcams, meteorology stations, beach monitors);
- Innovative output mechanisms for data layer sharing and collaboration;
- Enhancements to visualization of custom 3rd dimensional data;
• Enhancements to real time animation capabilities, or incorporation of existing animations into a geobrowser;
• Plug-ins that enable visualization of high resolution imagery in a COAST accessible data viewer;
• Utilities that enable regional estuarine or bay data compilations that are of interest to the major coastal ecosystem managers in those areas;
• Applications that subset, filter, merge, and reformat existing spatial data; provide links to attribute data; or visualize spatial or temporal analytic results in innovative value added fashion within the application.

Proposals should present a feasible plan to fully develop and apply the subject technology.

Sub Topics:
Algorithms for Science Data Processing and Analysis Topic S6.03

This subtopic seeks technical innovation and unique approaches for the processing and the analysis of data from NASA science missions. Analysis of NASA science data enables insights into dynamic systems such as the sun, oceans, and earth's climate in addition to looking back in time to explore the origins of the universe. Complex algorithms and intensive data processing are needed to understand and utilize this data. Advances in such algorithms will support science data analysis and decision support systems related to current and future missions and mission concepts such as:

• Current operational missions listed at http://www.nasa.gov/missions/current/index.html [51]
• All Earth Science Decadal Survey missions including HyspIRI (http://hyspiri.jpl.nasa.gov/ [52]) and DESDynI (http://desdyni.jpl.nasa.gov/ [53])
• Landsat Data Continuity Mission (LDCM) (http://ldcm.nasa.gov/ [54])
• NPOES Preparatory Project (NPP) (http://jointmission.gsfc.nasa.gov/ [55])
• Lunar Reconnaissance Orbiter (LRO), (http://lunar.gsfc.nasa.gov/ [56])
• Lunar Atmosphere and Dust Environment Explorer (LADEE) (http://nasascience.nasa.gov/missions/ladee [57])
• Moon Mineralogy Mapper (M3) on Chandrayaan (http://moonmineralogymapper.jpl.nasa.gov/ [58])
• Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) (http://crism.jhuapl.edu [59])
• Visual Infrared Mapping Spectrometer (VIMS) on Cassini (http://saturn.jpl.nasa.gov/spacecraft/cassiniorbiter/instruments/instrumentscassinivims/ [60])
• James Webb Space Telescope (JWST) (http://www.jwst.nasa.gov/ [61])

Research proposed to this subtopic should demonstrate technical feasibility during Phase I, in partnership with scientists, and subsequently show a path toward a Phase II prototype demonstration, with significant communication with missions and programs to ensure a successful Phase III infusion. It is highly desirable that the proposed projects lead to software that is infused into NASA programs and projects. Innovations are sought in data processing and analysis algorithms in the following areas:

• **Optimization of Algorithms and Computational Methods** that increase the utility of scientific research data for models, data assimilation, simulations, and visualizations. Of particular interest are innovative computational methods that will dramatically increase algorithm efficiency as well as the performance of scientific applications. Success will be measured by both speed improvements and output validation.
• **Improvement of Data Collection** by identifying data gaps in real-time, and/or derive information through synthesis of data from multiple sources. The ultimate goal is to increase the value of data collected in terms of scientific discovery and application; examples are long-term global and local models and decision support systems for national and humanitarian applications.

• **Frameworks and Related Tools for Processing, Analyzing and Fusing** image and vector data for the purpose of analyzing NASA's astrophysics, heliophysics, planetary and earth science mission data and therefore enable the advancement of NASA's scientific objectives. Of particular interest are open source frameworks or framework components that would enable sharing and validation of tools and algorithms.

Tools and products developed under this subtopic may be used for broad public dissemination or for use within a narrow scientific community. These tools can be plug-ins or enhancements to existing software or on-line data/computing services. They also can be new stand-alone applications or web services, provided that they are compatible with most widely used computer platforms and exchange information effectively (via standard protocols and file formats) with existing, standard or prevalent applications. To promote interoperability, tools shall use industry standard protocols, formats, and APIs (Application Programming Interfaces), including compliance with the FDGC (Federal Geographic Data Committee) and OGC (Open Geospatial Consortium) standards as appropriate.

Sub Topics:

Science Data Discovery in Extremely Large Data Environments Topic S6.04

This subtopic focuses on supporting science data discovery for extremely large data environments through developing innovative cloud and large cluster based science data discover applications, application development tools, and performance monitoring tools. Specific areas for which proposals are being sought:

• **Science discovery applications:** Applications for science data discovery, data mining, data search, and data sub setting that scale to extremely large data sets in cloud or large cluster computing environments.

• **Application development tools:** integrated ecosystem of tools for developing applications for high performance processing environments, including cloud computing, high performance cluster, and GPU processing environments, that support software development for science data discovery applications, including support for compilation, debugging, and parallelization.

• **Performance monitoring tools:** Integrated tools to collect, analyze, store, and present performance data for cloud computing and large scale cluster environments, including tools to collect data throughput of system hardware and software components such as node and network interconnects (Gbe, 10 Gbe, and Infiniband), storage area networks, and disk subsystems, and tools to capture data on a user configured basis, that allow extensibility for new metrics, and verification of the configuration and health of a system.

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

Sub Topics:

Software Engineering Tools for Scientific Models Topic S6.05
This subtopic seeks to improve the productivity and quality of NASA’s scientific modeling endeavors through customized tools, which enable and encourage improved software engineering practices. Because many of NASA’s principal scientific models have evolved over decades to be hundreds of thousands of lines long with contributions from a wide variety of scientists, much of the software has become "brittle" in the sense that it has become difficult to extend, couple, and optimize. In other software communities (and other programming languages), access to modern software tools has enabled large gains in productivity by providing high-level tools for isolating software defects (bugs) as well as by automating common, albeit tedious, software processes. The goal is to extend these capabilities to support the Fortran programming language so that NASA’s scientific models can extract similar benefits.

Target Programs, Missions and Mission Classes

Advances in developer productivity would be of significant benefit to several research and analysis programs within the Science Mission Directorate including:

- High-End Computing Program ([http://hec.nasa.gov](http://hec.nasa.gov) [62])
- Modeling, Analysis, and Prediction Program ([http://map.nasa.gov](http://map.nasa.gov) [63])

Technology Areas

The objective is to create a suite of software tools, which directly ameliorate the most significant bottlenecks to productivity in the development of scientific models:

- Tools that assist in the construction of fine-grained unit-level software tests based upon existing functionality in a legacy Fortran application. Although tests written by developers are desirable, such tests are exceedingly difficult to create for legacy numerical software. Suites of these tests could provide a significant element of risk-reduction for maintenance and extension of these models, and would be incorporated into some sort of unit-testing framework.
- Tools that reduce cost and risk for maintaining and extending legacy scientific software. Desirable to be integrated within other common development tools.
- Tools that enable high-level source code transformations ("refactorings"). Although refactoring support for Fortran is improving rapidly ([http://www.eclipse.org/photran/](http://www.eclipse.org/photran/)[64]), substantial opportunities exist for new refactorings targeted at NASA’s scientific computing needs.

Tools and products developed under this subtopic may be used for broad public dissemination or for use within a narrow scientific community. These tools can be plug-ins or enhancements to existing software or on-line data/computing services. They also can be new stand-alone applications or web services, provided that they are compatible with most widely used computer platforms and exchange information effectively (via standard protocols and file formats) with existing, standard or prevalent applications. To promote interoperability, tools shall use industry standard protocols, formats, and APIs (Application Programming Interfaces).

It is highly desirable that the proposed projects lead to software that is infused into NASA programs and projects.