



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

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. Single longitudinal mode lasers and optical filter technologies for high spectral resolution lidars are also of

interest. Proposals relevant to the development of components that can be used in planned missions or current technology programs are highly encouraged. Examples of planned missions and technology programs are: Laser Interferometer Space Antenna (LISA), Doppler Wind Lidar, Lidar for Surface Topography (LIST), Active Sensing of CO₂ Emissions over Nights, Days, and Seasons (ASCENDS), and Aerosols-Clouds-Ecosystems (ACE). In addition, innovative technologies relevant to the NASA sub-orbital programs, such as Unmanned Aircraft Systems (UAS) and Venture-class focusing on the studies of the Earth climate, carbon cycle, weather, and atmospheric composition, are being sought.

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

- Highly efficient solid state laser transmitter operating in the 1.0 μm - 1.7 μm range with wall-plug efficiency of greater than 25%. The proposed laser must show path in maturing to space applications. The laser transmitter must be capable of single frequency with narrow spectral width capable of generating transform-limited pulses, and M2 beam quality 70% are of interest. Although amplifiers such as planar waveguide or grazing incidence have been shown to generate optical efficiencies >50%, much higher efficiency is needed for space applications. Proposed solutions should incorporate electronics packages suitable for use in aircraft demonstration (i.e., small, well packaged, low power).
- Narrow linewidth laser transmitters and receiver components (seeds, fiber amplifiers, modulators, drivers, etc.) supporting laser absorption spectroscopy applications in the 1.3, 1.5 and 2.0 micron wavelength regimes. The lasers and components should be tunable by several nm, support amplitude modulation at frequencies from 50 KHz to 10 MHz, have frequency stability of less than 3 MHz, and be capable of mixing and simultaneous transmission of multiple lines for differential absorption measurements without introducing non-linear mixing effects. Techniques for cloud and aerosol discrimination are also sought.
- Efficient and compact single mode solid state or fiber lasers operating at 1.5 and 2.0 micron wavelength regimes suitable for direct detection differential absorption lidar (DIAL) and coherent lidar applications. These lasers must meet the following general requirements: pulse energy 0.5 mJ to 50 mJ, repetition rate 10 Hz to 10 kHz, and pulse duration of either 10 nsec or 200 nsec regimes.
- Low noise detectors operating in 1.5 to 2.0 micron wavelength for use in differential absorption lidar (DIAL) instruments measuring CO₂ concentration. Large area (>250 micron dia.) detectors with high quantum efficiency (>75%), noise equivalent power of less than 2×10^{-14} W/Hz^{1/2}, and bandwidth greater than 50 MHz are being sought. Additionally, arrays of 4x4 PIN detectors for coherent detection and avalanche photodiodes with a minimum gain of 10 are of interest. Other detectors relevant to NASA programs are low-noise, high quantum efficiency devices operating at 355 nm, 532 nm, and 1064 nm with gain greater than or equal to 100. These detectors must be linear or correctable for incident power levels ranging from 0.1 pW to 50 nW and have bandwidths exceeding 200 MHz with excellent transient recovery.
- Novel compact solid-state UV laser for Ozone DIAL measurements from surface and airborne UAS science platforms that also enables technology demonstrations for future spaceborne measurements are needed. New and novel technology developments that enable solid-state UV lasers operating within the 280 nm - 320 nm wavelength range (305-320 nm for the spaceborne lasers) generating laser pulses of up to 1 KHz rate and average output power greater than 1 Watt. Operation at two distinct wavelengths separated by 10 nm to 15 nm is required for the Ozone measurements. Scalability of the laser design to power levels greater than 10 W for space deployment is important.
- Novel scanning telescope capable of scanning over 360 degrees in azimuth with nadir angle fixed in the range of 30 to 45 degrees. Clear apertures scalable to 1 m, good optical performance (although diffraction limited performance is not necessary), and high optical efficiency are desired, as is ability to operate at multiple wavelengths from 1064 nm to 355 nm. Optical materials (e.g., substrates and coatings) and

components should be space qualifiable. Phase II should result in a prototype unit capable of demonstration in a high-altitude aircraft environment, with aperture on the order 8 inches. Due to issues with spacecraft momentum compensation and previous investments, concepts for large articulating telescopes will not be considered responsive to this request, nor will holographic substrates.

- Flash Lidar Receiver for planetary landing application with at least 128X128 pixels capable of generating 3-dimensional images and detection of hazardous terrain features, such as rocks, craters and steep slopes from at least 1 km distance. The receiver must include real-time image processing capability with 30 Hz frame rate. Embedded image enhancement and classification algorithms are highly desirable. Proposals for low noise Avalanche Photodiode (APD) arrays with 256x256 pixels format suitable for use in Flash Lidar receiver will be also considered. The detector array must operate in the 1.06 to 1.57 micron region and be able to detect laser pulses with 6 nsec in duration. The array needs to achieve greater than 90% fill factor with a pitch size of 50 to 100 microns with provisions for hybridization with an Integrated Readout Circuit (ROIC).

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

S1.02 Active Microwave Technologies

Lead Center: JPL

Participating Center(s): GSFC, LaRC

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

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

- Frequency: 94 GHz.
- Radiation Efficiency: >70%.
- Polarization isolation = 25 dB.
- Interconnect loss:
- No dielectric materials.

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

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

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

Low-Cost mm-wave Beamforming MMIC Receiver

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

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

High-Speed Radar Distributed Target Simulator

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

Low-Jitter Programmable Delay/Divide Clock Distribution IC

- Total Jitter:
- Fanout: >=10.
- Prog. Delay: up to 192 ns.

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- Delay Resolution: 2 ps.
 - Divide by: 2 or 3.
 - Temp. range: -40 to +80C.
 - Implemented in radiation-hard technology.

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

L-band Array Antennas

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

Fast Turn on and Turn Off Power Amplifiers

To increase solid state radar sensitivity NASA requires compact and high efficiency (> 50%) power amplifiers (> 25 W peak.) in P, L, and X-bands that can be switched off during the receive period to prevent noise leakage. Switch on and switch off times under 1 μ s, stable amplitude (

Small Radar Packaging Concepts for Unmanned Aerial Systems (UAV)

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

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

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

S1.03 Passive Microwave Technologies

Lead Center: GSFC

Participating Center(s): JPL

NASA employs passive microwave and millimeter-wave instruments for a wide range of remote sensing applications from measurements of the Earth's surface and atmosphere (http://www.nap.edu/catalog.php?record_id=11820 [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]):

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

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

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

Lead Center: JPL

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

NASA is seeking new technologies or improvements to existing technologies to meet the detector needs of future missions, as described in the most recent decadal surveys for Earth science (<http://www.nap.edu/catalog/11820.html> [6]), planetary science (<http://www.nap.edu/catalog/10432.html> [9]), and astronomy and astrophysics (<http://www.nap.edu/books/0309070317/html/> [10]).

The following technologies are of interest for the Scanning Microwave Limb Sounder (<http://mls.jpl.nasa.gov/index-cameo.php> [11]) on the Global Atmospheric Composition Mission, Single Aperture Far Infrared (SAFIR) Observatory (<http://safir.jpl.nasa.gov/technologies.shtml> [12]), the SOFIA (Stratospheric Observatory for Infrared Astronomy) airborne observatory (<http://www.sofia.usra.edu/> [13]), and Inflation Probe (cosmic microwave background, <http://science.gsfc.nasa.gov/660/research/> [8]):

- 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).

Thermal imaging, LANDSAT, all IR Earth observing missions:

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

The Geo-CAPE Mission

Wide Field 0.26-15 μ m and Narrow Field 0.35-2.1 μ m. PanFTS 60 μ m pixel pitch, 256 X 256 format with in-pixel ADC digitization ROIC, 16-bit precision, 16kHz frame rate.

S1.05 Detector Technologies for UV, X-Ray, Gamma-Ray and Cosmic-Ray Instruments

Lead Center: GSFC

Participating Center(s): JPL, MSFC

This subtopic covers detector requirements for a broad range of wavelengths from UV through to gamma ray for applications in Astrophysics, Earth science, Heliophysics, and Planetary science. Requirements across the board are for greater numbers of readout pixels, lower power, faster readout rates, greater quantum efficiency, and enhanced energy resolution.

The proposed efforts must be directly linked to a requirement for a NASA mission. These include Explorers, Discovery, Cosmic Origins, Physics of the Cosmos, Vision Missions, and Earth Science Decadal Survey missions. Details of these can be found at the following URLs:

- General Information on Future NASA Missions: <http://www.nasa.gov/missions> [17]
- Specific mission pages: IXO: <http://htxs.gsfc.nasa.gov/index.html> [18], future planetary programs: http://nasascience.nasa.gov/planetary-science/mission_list [19], Earth Science Decadal missions: <http://www.nap.edu/catalog/11820.html> [6].
- Helio Probes: http://nasascience.nasa.gov/heliophysics/mission_list [20].

Specific technology areas are listed below:

- Significant improvement in wide band gap semiconductor materials, such as AlGaIn, ZnMgO and SiC, individual detectors, and detector arrays for operation at room temperature or higher for missions such as Geo-CAPE, NWO, ATALAST and planetary science composition measurements.
- Highly integrated, low noise (
- Large format UV and X-ray focal plane detector arrays: micro-channel plates, CCDs, and active pixel sensors (>50% QE, 100 Megapixels,
- Advanced Charged Couple Device (CCD) detectors, including improvements in UV quantum efficiency and read noise, to increase the limiting sensitivity in long exposures and improved radiation tolerance. Electron-bombarded CCD and CMOS detectors, including improvements in efficiency, resolution, and global and local count rate capability. In the X-ray, we seek to extend the response to lower energies in some CCDs, and to higher, perhaps up to 50 keV, in others. Possible missions are future GOES missions and International X-ray Observatory.
- Wide band gap semiconductor, radiation hard, visible and solar blind large format imagers for next generation hyperspectral Earth remote sensing experiments. Need larger formats (>1Kx1K), much higher resolution (
- Solar blind, compact, low-noise, radiation hard, EUV and soft X-ray detectors are required. Both single pixels (up to 1cm x 1cm) and large format 1D and 2D arrays are required to span the 0.05nm to 150nm spectral wavelength range. Future GOES missions post-GOES R and T.
- Visible-blind SiC Avalanche Photodiodes (APDs) for EUV photon counting are required. The APDs must show a linear mode gain >1E6 at a breakdown reverse voltage between 80 and 100V. The APD's must demonstrate detection capability of better than 6 photons/pixel/s at near 135nm spectral wavelength. See needs of National Research Council's Earth Science Decadal Survey (NRC, 2007): Tropospheric ozone.

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- Imaging from low-Earth orbit of air fluorescence, UV light generated by giant air showers by ultra-high energy ($E > 10^{19}$ eV) cosmic rays require the development of high sensitivity and efficiency detection of 300-400 nm UV photons to measure signals at the few photon (single photo-electron) level. A secondary goal minimizes the sensitivity to photons with a wavelength greater than 400 nm. High electronic gain ($\sim 10^6$), low noise, fast time response (2 to 10 x 10 mm². Focal plane mass must be minimized (2g/cm² goal). Individual pixel readout is required. The entire focal plane detector can be formed from smaller, individual sub-arrays.
 - Large area (3 m²) photon counting near-UV detectors with 3 mm pixels and able to count at 10 MHz. Array with high active area fraction (>85%), 0.5 Megapixels and readout less than 1 mW/channel. Future instruments are JEM-EUSO and OWL.
 - Large area (m²) X-ray detectors with 85%.
 - Improve beyond CdZnTe detectors using micro-calorimeter arrays at hard X-ray, low gamma-ray bands (above 10 keV and Below 80 keV).
 - Improvement of spatial resolution for the hard x-ray band up to 10 and ultimately to 5 arcsecond resolution.

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

S1.06 Particles and Field Sensors and Instrument Enabling Technologies

Lead Center: GSFC

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

Advanced sensors for the detection of elementary particles (atoms, molecules and their ions) and electric and magnetic fields in space and associated instrument technologies are often critical for enabling transformational science from the study of the sun's outer corona, to the solar wind, to the trapped radiation in Earth's and other planetary magnetic fields, and to the atmospheric composition of the planets and their moons. Improvements in particles and fields sensors and associated instrument technologies enable further scientific advancement for upcoming NASA missions such as Solar Orbiter, Solar Probe Plus, ONEP, SEPAT, INCA, CISR, DGC, HMag and planetary exploration missions. Technology developments that result in a reduction in size, mass, power, and cost will enable these missions to proceed. Of interest are advanced magnetometers, electric field booms, ion/atom/molecule detectors, and associated support electronics and materials. Specific areas of interest include:

- Self-calibrating scalar-vector magnetometer for future Earth and space science missions. Performance goals: dynamic range: $\pm 100,000$ nT, accuracy with self-calibration: 1 nT, sensitivity: 5 pT \times 1/2 (max), max sensor unit size: 6 x 6 x 12 cm, max sensor mass: 0.6 kg, max electronics unit size: 8 x 13 x 5 cm, max electronics mass: 1 kg, and max power: 5 W operation, 0.5 W standby, including, but not limited to \times sensors on a chip \times .
- High-magnetic-field sensor that measures magnetic field magnitudes to 16 Gauss with an accuracy of 1 part in 10⁵.
- Strong, lightweight, thin, compactly-stowed electric field booms possibly using composite materials that

deploy sensors to distances of 10-m or more.

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

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

S1.07 Cryogenic Systems for Sensors and Detectors

Lead Center: GSFC

Participating Center(s): ARC, JPL, MSFC

Cryogenic cooling systems often serve as enabling technologies for detectors and sensors flown on scientific instruments as well as advanced telescopes and observatories. As such, technological improvements to cryogenic systems (as well as components) further advance the mission goals of NASA through enabling performance (and ultimately science gathering) capabilities of flight detectors and sensors. Presently, there are six potential investment areas that NASA is seeking to expand state of the art capabilities in for possible use on future programs such as GEOID, SPICA, WFirst (<http://wfirst.gsfc.nasa.gov/> [21]), Space Infrared Interferometric Telescope (SPIRIT), Submillimeter Probe of the Evolution of Cosmic Structure (SPECS), as well as, the Planetary and Europa

Science missions (<http://www.nasa.gov/multimedia/podcasting/jpl-europa20090218.html> [22]). The topic areas are as follows:

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

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

Lead Center: GSFC

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

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

Novel methods to minimize the operational labor requirements and improve reliability are desired. Long endurance (days/weeks/months) autonomous/unattended instruments with self/remote diagnostics, self/remote maintenance,

capable of maintaining calibration for long periods, and remote control are important. Use of data systems that collect geospatial, inertial, temporal information, and synchronize multiple sensor platforms are also of interest.

Priorities include:

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

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

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

Lead Center: JPL

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

This subtopic solicits development of advanced instrument technologies and components suitable for deployment on planetary and lunar missions. These technologies must be capable of withstanding operation in space and planetary environments, including the expected pressures, radiation levels, launch and impact stresses, and range of survival and operational temperatures. Technologies that reduce mass, power, volume, and data rates for instruments and instrument components without loss of scientific capability are of particular importance. In addition,

technologies that can increase instrument resolution and sensitivity or achieve new & innovative scientific measurements are solicited. For example missions, see <http://science.hq.nasa.gov/missions> [23]. For details of the specific requirements see the National Research Council's, Vision and Voyages for Planetary Science in the Decade 2013-2022 <http://solarsystem.nasa.gov/2013decadal/> [24]. Technologies which support NASA's Planetary Flagship mission candidates (Mars 2018, JEO, & Uranus Orbiter & Probe Mission), New Frontiers Mission candidates (Comet Surface Sample Return, Lunar South Pole-Aitken Basin Sample Return, Saturn Probe, Trojan Tour & Rendezvous, Venus In-Situ Explorer, Io Observer, and the Lunar Geophysical Network) and Discovery missions to various planetary bodies are of top priority.

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

- Mars: Sub-systems relevant to current in situ instrument needs (e.g., lasers and other light sources from UV to microwave, X-ray and ion sources, detectors, mixers, mass analyzers, etc.) or electronics technologies (e.g., FPGA and ASIC implementations, advanced array readouts, miniature high voltage power supplies). Technologies that support high precision in situ measurements of elemental, mineralogical, and organic composition of planetary materials are sought. Conceptually simple, low risk technologies for in situ sample extraction and/or manipulation including fluid and gas storage, pumping, and chemical labeling to support analytical instrumentation. Seismometers, mass analyzers, technologies for heat flow probes, and atmospheric trace gas detectors. Improved robustness and g-force survivability for instrument components, especially for geophysical network sensors, seismometers, and advanced detectors (iCCDs, PMT arrays, etc.). Instruments geared towards rock/sample interrogation prior to sample return are desired.
- Europa & Io: Technologies for high radiation environments, e.g., radiation mitigation strategies, radiation tolerant detectors, and readout electronic components, which enable orbiting instruments to be both radiation-hard and undergo the planetary protection requirements of sterilization (or equivalent) for candidate instruments on the Europa-Jupiter System Mission (JEO) and Io Observer are sought.
- Titan: Low mass and power sensors, mechanisms and concepts for converting terrestrial instruments such as turbidimeters and echo sounders for lake measurements, weather stations, surface (lake and solid) properties packages etc., to cryogenic environments (95K). Mechanical and electrical components and subsystems that work in cryogenic (95K) environments; sample extraction from liquid methane/ethane, sampling from organic 'dunes' at 95K and robust sample preparation and handling mechanisms that feed into mass analyzers are sought. Balloon instruments, such as IR spectrometers, imagers, meteorological instruments, radar sounders, air sampling mechanisms for mass analyzers, and aerosol detectors are also solicited.
- Venus: Sensors, mechanisms, and environmental chamber technologies for operation in Venus's high temperature, high-pressure environment with its unique atmospheric composition. Approaches that can enable precision measurements of surface mineralogy and elemental composition and precision measurements of trace species, noble gases and isotopes in the atmosphere are particularly desired.
- Small Bodies: Technologies that can enable sampling from asteroids and from depth in a comet nucleus, improved in situ analysis of comets. Also, imagers and spectrometers that provide high performance in low light environments.
- Saturn, Uranus and Neptune: Technologies are sought for components, sample acquisition and instrument systems that can enhance mission science return and withstand the low-temperatures/high-pressures of the atmospheric probes during entry.

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

Proposers are strongly encouraged to relate their proposed development to:

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

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

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

S1.10 Atomic Interferometry

Lead Center: GSFC

Participating Center(s): JPL

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

Sensors based on Atom/BEC Interferometry are attractive because:

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

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

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

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

This subtopic seeks concepts and prototypes of devices below:

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

The criteria for evaluations also include:

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

Robustness of the design /prototype to Space environments.

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

Lead Center: JPL

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

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 lightweight 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 as 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/> [25], <http://instrument.jpl.nasa.gov/stellar/> [26]). Also sought are technologies (analysis, algorithms, and test beds) 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:

- 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.
- Development of nanometer to sub-nanometer metrology for measuring inter-spacecraft range and/or bearing for space telescopes and interferometers.
- Control approaches to maintain line-of-sight between two vehicles in inertial space near Sun-Earth L2 to milli-arcsecond levels accuracy.
- 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.
- Swarm modeling, simulation and 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.

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. 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 near infrared wavelengths. The ultimate application of these instruments is to operate in space as part of a future observatory mission. 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 $\sim 1 \mu\text{m}$, 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.

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- Methods to distinguish the coherent and incoherent scatter in a broadband speckle field.
 - Methods of polarization control and polarization apodization.
 - 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 are 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 broadband 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.
- 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: Wide-Field Infrared Survey Telescope (WFIRST) and the New Worlds Technology Development Program (coronagraph, external occulter and interferometer technologies) will push the state of the art in current optomechanical technologies. Mission concepts for New Worlds science would 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. In addition, ground based telescopes such as the Cerro Chajnantor Atacama Telescope (CCAT) require similar technology development.

The desired areal density is 1 - 10 kg/m² with a packaging efficiency of 3-10 deployed/stowed diameter. 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 the Earth-Sun L2.

This subtopic solicits proposals to develop enabling, cost effective component and subsystem technology for deploying large aperture telescopes with low cost. Research areas of interest include:

- Precision deployable structures and metrology for optical telescopes (e.g., innovative active or passive deployable primary or secondary support structures).
- Architectures, packaging and deployment designs for large sunshields and external occulters.

In particular, important subsystem considerations may include:

- Innovative concepts for packaging fully integrated subsystems (e.g., power distribution, sensing, and control components).
- Mechanical, inflatable, or other precision deployable technologies.
- Thermally-stable materials (CTE)
- Innovative systems, which minimize complexity, mass, power and cost.
- Innovative testing and verification methodologies.

The goal for this effort is to mature technologies that can be used to fabricate 16 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. Proposals with system solutions for large sunshields and external occulters will also be accepted. A successful proposal shows a path toward a Phase II delivery of demonstration hardware scalable to 5 meter diameter for ground test characterization.

Proposals should show an understanding of one or more relevant science needs, and present a feasible plan to

fully develop the relevant subsystem technologies and to transition into future NASA program(s).

S2.04 Advanced Optical Component Systems

Lead Center: MSFC

Participating Center(s): GSFC, JPL

The National Academy Astro2010 Decadal Report specifically identifies optical components and coatings as key technologies needed to enable several different future missions, including:

- X-ray imaging mirrors for the International X-Ray Observatory (IXO).
- Active lightweight x-ray imaging mirrors for future very large advanced x-ray observatories.
- Large aperture, lightweight mirrors for future UV/Optical telescopes.
- Broadband high reflectance coatings for future UV/Optical telescopes.

X-ray mirrors are identified by the Decadal as the most important, critical technology needed for IXO. IXO requires 3 m² collecting aperture x-ray imaging mirror with 5 arc-second angular resolution. Mirror areal density depends upon available launch vehicle capacities. Additionally, future x-ray missions require advanced multilayer high-reflectance coating for hard x-ray mirrors (i.e., NuSTAR) and x-ray transmission/reflection gratings.

Future UVOIR missions require 4 to 8 or 16 meter monolithic and/or segmented primary mirrors with 2 for a 5 m fairing EELV vs. 60 kg/m² for a 10 m fairing SLS). Additionally, future UVOIR missions require high-reflectance mirror coatings with spectral coverage from 100 to 2500 nm.

Heliophysics missions also require advanced lightweight, super-polished precision normal and grazing incidence optical components and coatings. Potential missions which could be enabled by these technologies include: Origins of Near-Earth Plasma (ONEP); Ion-Neutral Coupling in the Atmosphere (INCA); Dynamic Geospace Coupling (DGC); Fine-scale Advanced Coronal Transition-Region Spectrograph (FACTS); Reconnection and Micro-scale (RAM); and Solar-C. Heliophysics missions need normal incidence mirror systems ranging from 0.35 meter to 1.5 meters with surface figure errors of 0.1 micro-radians rms slope from 4-mm to 1/2 aperture spatial periods, roughness of 0.2-nm rms and micro-roughness of 0.1-nm rms; and, grazing incidence mirror systems with an effective collecting area of ~3 cm² from 0.1 to 4 nm, 4 meter effective focal length, 0.8 degree angle of incidence and surface roughness of 0.2-nm rms. Additionally, future Heliophysics missions require high-reflectance normal incidence spectral, broadband, dual and even three-band pass multi-layer EUV coatings.

The geosynchronous orbit for GEO-CAPE coastal ecosystem imager requires technology for alternative solar calibration strategies including new materials to reduce weight, and new optical analysis to reduce the size of calibration systems. GEO-CAPE will need a lightweight large aperture (greater than 0.5 m) diffuse solar calibrator, employing multiple diffusers to track on-orbit degradation. Typical materials of interest are PTFE (such as

Spectralon® surface diffuser) or development of new Mie scattering materials for use as volume diffusers in transmission or reflection.

Finally, NASA is developing a heavy lift space launch system (SLS). An SLS with a 10 meter fairing and 100 mt capacity to LEO would enable extremely large 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 all cases, the most important metric for an advanced optical system is affordability or areal cost (cost per square meter of collecting aperture). Currently both x-ray and normal incidence space mirrors 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 subtopic has three objectives:

- Develop and demonstrate technologies to manufacture and test ultra-low-cost precision optical systems for x-ray, UV/optical or infrared telescopes. Potential solutions include, but are not limited to, new mirror materials such as silicon carbide, nanolaminates or carbon-fiber reinforced polymer; or new fabrication processes such as direct precision machining, rapid optical fabrication, roller embossing at optical tolerances, 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). Solutions include reflective, transmissive, diffractive or high order diffractive blazed lens optical components for assembly of large (16 to 32 meter) optical quality primary elements. The EUSO mission requires large-aperture primary segmented refractive, Fresnel or kinoform PMMA or CYTOP lenses with
- Develop and demonstrate optical coatings for EUV and UVOIR telescopes. UVOIR telescopes require broadband (from 100 nm to 2500 nm) high-reflectivity mirror coating with extremely uniform amplitude and polarization properties. Heliophysics missions require high-reflectance (> 90%) normal incidence spectral, broadband, dual and even three-band pass multi-layer coatings over the spectral range from 6 to 200 nm. Studies of improved deposition processes for new UV reflective coatings (e.g., MgF₂), investigations of new coating materials with promising UV performance, and examination of handling processes, contamination control, and safety procedures related to depositing coatings, storing coated optics, integrating coated optics into flight hardware are all areas where progress would be valuable. In all cases, an ability to demonstrate optical performance on 2 to 3 meter class optical surfaces is important.
- Large aperture diffusers (up to 1 meter) for periodic calibration of GeoStationary Earth viewing sensors by viewing the sun either in reflection or transmission off the diffuser.

In regard to large-aperture diffusers material needs to be stable in BTDF/BSDF to 2%/year from 250nm -2.5 microns and highly lambertian (no formal specification for deviation from lambertian).

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:

Dark Energy Mission concepts (e.g., <http://wfirst.gsfc.nasa.gov> [21])

Large X-Ray Mission concepts (e.g., <http://ixo.gsfc.nasa.gov/> [27]),

Gravity Wave Science Mission concepts (e.g., <http://lisa.gsfc.nasa.gov/> [28])

ICESAT (<http://icesat.gsfc.nasa.gov/> [29]), CLARIO, and ACE

ATLAST (<http://www.stsci.edu/institute/atlast/> [30])

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. A new area of interest is large lightweight monolithic metallic aspheres manufactured using innovative mirror substrate materials that can be assembled and welded together from smaller segments.

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 10 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:

- Innovative metal mirror substrate materials or manufacturing methods such as welding component segments into one monolith that produce thin mirror substrates that are stiffer and/or lighter than existing materials or methods.
- 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.

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- 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.
 - Metrology systems useful for measuring large optics with high precision.
 - Metrology systems for measuring optical systems while under cryogenic conditions.

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 the universe 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 spacecraft and platform 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. Science platforms of interest could include unmanned aerial vehicles, sounding rockets, or balloons that carry scientific instruments/payloads, to planetary ascent vehicles or Earth return vehicles that bring samples back to Earth for analysis. 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 2011 are sought in the areas of:

- Command and Data Handling, and Instrument Electronics

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- Thermal Control Systems
 - Power Generation and Conversion
 - Propulsion Systems
 - Power Electronics and Management, and Energy Storage
 - Guidance, Navigation and Control
 - Unmanned Aircraft and Sounding Rocket Technologies
 - Terrestrial and Planetary Balloons

Significant changes to the S3 Topic for 2011 are:

- Merged the 2010 subtopics of S3.08 Planetary Ascent Vehicles and S3.10 Earth Entry Vehicles into a broader "Spacecraft Technology for Sample Return Missions" sub-topic under the S5 Topic.
- Moved power electronics/power processing unit content for electric propulsion systems from S3.04 Propulsion Systems to the revised sub-topic of S3.05 Power Electronics and Management, and Energy Storage.

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

- The Astrophysics Roadmap: <http://nasascience.nasa.gov/about-us/science-strategy> [31].
- Astrophysics Decadal Survey - "New Worlds, New Horizons: in Astronomy and Astrophysics": http://www.nap.edu/catalog.php?record_id=12951 [32].
- The Earth Science Decadal Survey: http://books.nap.edu/catalog.php?record_id=11820 [33].
- The Heliophysics roadmap: "The Solar and Space Physics of a New Era: Recommended Roadmap for Science and Technology 20092030": http://sec.gsfc.nasa.gov/2009_Roadmap.pdf [34].
- The 2011 Planetary Science Decadal Survey was released March 2011. This decadal survey is considering technology needs. http://www.nap.edu/catalog.php?record_id=13117 [35].
- The 2006 Solar System Exploration Roadmap: <http://nasascience.nasa.gov/about-us/science-strategy> [31].
- 2010 Science Plan: <http://science.nasa.gov/about-us/science-strategy/> [36].

Sub Topics:

S3.01 Command, Data Handling, and Electronics

Lead Center: GSFC

Participating Center(s): ARC, JPL, 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.

The subtopic goals are to:

- Develop high-performance processors, memory architectures, and reliable electronic systems.
- 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:

- State what the product is.
- Identify the needs it addresses.
- Identify the improvements over the current state of the art.
- Outline the feasibility of the technical and programmatic approach.
- 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(Si), while some planetary missions can have requirements well in excess of 1 Mrad(Si). For descriptions of radiation effects in electronics, the proposer may visit (<http://radhome.gsfc.nasa.gov/radhome/overview.htm> [37]). 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:

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.

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.

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

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

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.

Power Conversion and Distribution relevant to Command, Data Handling, and Electronics, will be covered in sub-topic S3.05 Power Management and Storage.

S3.02 Thermal Control Systems

Lead Center: GSFC

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

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

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- New generations of electronics used on numerous missions have higher power densities than in the past. High conductivity, vacuum-compatible interface materials that minimize losses across make/break interfaces are needed to reduce interface temperature gradients and facilitate heat removal.
 - Sensitive instruments and electronics drive increased requirements for high electrical conductivity on spacecraft surfaces. This has increased the need for advanced thermal control coatings, particularly those with low absorptance, high emittance, and good electrical conductivity. Also, variable emittance surfaces to modulate heat rejection are needed.
 - Exploration science missions beyond Earth orbit present engineering challenges requiring systems that 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. Systems that incorporate Micro-meteorite and Orbital Debris protection (MMOD) are also of interest.
 - 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.
 - Phase change systems are needed for Mars, Venus, 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 that would provide heat for instrument power-on after the dormant phase.

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

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.

Photovoltaic Energy Conversion

Photovoltaic cell, blanket, and array technologies that lead to significant improvements in overall solar array performance (i.e., conversion efficiency >33%, 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 300 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, MSFC

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 [38]). 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. Propulsion technologies related specifically to Power Processing Units will be sought under S3.05 Power Management and Storage.

Chemical Propulsion Systems

Technology needs include:

- Pump or alternate pressurization technologies that provide for high-pressure operation (chamber pressures > 500 psia) of spacecraft primary propulsion systems (100- to 200-lbf class) using Earth storable or space storable bipropellants.
- Catalytic and non-catalytic ignition technologies that provide reliable ignition of high-performance ($I_{sp} > 240$ sec), nontoxic monopropellants for power-limited spacecraft.

Electric Propulsion Systems

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

- Thrusters with efficiencies > 50% and up to 1 kW of input power that operate with a specific impulse between 1600 to 3500 seconds.
- An efficient (>60 %), dual mode thruster that is capable of operating in both high thrust (>60 mN/kW) and high specific impulse (>3000 sec) modes for a fixed power level.
- High power electric propulsion thrusters (up to 25 kW) and components including cathodes, ion optics, low sputtering materials with long life (> 1×10^8 N-s), high temperature insulators with low secondary electron emission, and high temperature, low electrical resistivity wire.

Proposals should show an understanding of the state of the art, how their technology is superior, and of one or more relevant science needs. The proposals should provide a feasible plan to develop fully 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 Electronics and Management, and Energy Storage

Lead Center: GRC

Participating Center(s): ARC, JPL, JSC

Future NASA science objectives will include missions such as Earth Orbiting, Venus, Europa, Titan/Enceladus Flagship, Lunar Quest and Space Weather missions. 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 high energy density, high power density, long life, high reliability, low mass/volume, radiation tolerance, and wide temperature operation. Other subtopics that could potentially benefit from these technology developments include 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, Management and Distribution (PMAD) for High Power Space Exploration Applications, which is investigating some similar technologies but at a much higher power level. This subtopic is also directly tied to S3.04 - Propulsion Systems for the development of advanced Power Processing Units and associated components.

Power Electronics and Management

The 2009 Heliophysics roadmap (http://sec.gsfc.nasa.gov/2009_Roadmap.pdf [34]), the 2010 SMD Science Plan (<http://science.nasa.gov/about-us/science-strategy/> [36]), the 2010 Planetary Decadal Survey White Papers & Roadmap Inputs (http://sites.nationalacademies.org/SSB/CurrentProjects/ssb_052412 [39]), the 2011 PSD Relevant Technologies document, the 2006 Solar System Exploration (SSE) Roadmap (<http://nasascience.nasa.gov/about-us/science-strategy> [31]), and the 2003 SSE Decadal Survey describe the need for lighter weight, lower power electronics along with radiation hardened, extreme environment electronics for planetary exploration. Radioisotope power systems (RPS) and Power Processing Units (PPUs) for Electric Propulsion (EP) are two programs of interest that would directly benefit from advancements in this technology area. 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. In addition, the Outer Planet Assessment Group has called out high power density/high efficiency power electronics as needs for the Titan/Enceladus Flagship and planetary exploration missions. These types of missions, including Mars Sample Return using Hall thrusters and PPUs, require advancements in radiation hardened power electronics and systems beyond the state-of-the-art. 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 programs with power ranges of a few watts for minimum missions to up to 20 kilowatts for large missions. In addition to electrical component development, RPS has a need for intelligent, fault-tolerant Power Management And Distribution (PMAD) technologies to efficiently manage the system power for these deep space missions.

SMD's In-space Propulsion Technology and Radioisotope Power Systems programs are direct customers of this subtopic, and the solicitation is coordinated with the 2 programs each year.

Overall technologies of interest include:

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- High voltage, radiation hardened, high temperature components, such as capacitors and semiconductors, for EP PPU applications.
 - High power density/high efficiency power electronics.
 - High temperature devices and components/power converters (up to 450°C).
 - Intelligent, fault-tolerant electrical components and PMAD systems.
 - Advanced electronic packaging for thermal control and electromagnetic shielding.

In addition, development is needed in the area of advanced High Voltage Transformer-Rectifier Technology Development for Advanced Cloud and Precipitation Radars, Interferometers, and other Advanced SAR applications where an integrated Transformer-Rectifier Assembly is needed to provide increased stability in the output voltages provided to the Cathode and Collector of a Vacuum Tube (EIK). This would result in increases in the RF phase stability of the output RF Pulse or current approaches. The Transformer-Rectifier Assembly should address using innovative, single-integrated body regulator designs that regulate collector vs. cathode potential, and demonstrate increasing voltage stability over other approaches. The entire Transformer-Rectifier Assembly (Cathode-Collector-Body) should be optimized to achieve maximum energy efficiency and minimum size/mass of the system taking into account necessary high voltage insulation and potting for operation in a space environment (vacuum). Of interest are assemblies that demonstrate:

- Cathode voltages in excess of -12 kV, and Collector voltage in the -3 KV ranges with Beam currents in excess of 340 mA.
- Assemblies for which the primary winding of the transformer is driven through 60VDC (full load) switched at a nominal frequency of 40.5 ± 1.5 kHz, or higher.
- Duty cycles up to 16%.

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° to 500°C for Venus missions, and a span of -230°C to +120°C for Lunar Quest. The Outer Planet Assessment Group and the 2011 PSD Relevant Technologies Document have specifically called out high energy density storage systems as a need for the Titan/Enceladus Flagship and planetary exploration missions. 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 and energy density (>200 Wh/kg for secondary battery systems), 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.

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.

Disclaimer: Technology Available (TAV) subtopics may include an offer to license NASA Intellectual Property (NASA IP) on a non-exclusive, royalty-free basis, for research use under the SBIR award. When included in a TAV subtopic as an available technology, use of the available NASA IP is strictly voluntary. Whether or not a firm uses available NASA IP within their proposal effort will not in any way be a factor in the selection for award.

Patent [6.461.944](#) [40], Methods for growth of relatively large step-free SiC crystal surfaces Neudeck, et al. October 8, 2002

Summary: A method for growing arrays of large-area device-size films of step-free (i.e., atomically flat) SiC surfaces for semiconductor electronic device applications is disclosed. This method utilizes a lateral growth process that better overcomes the effect of extended defects in the seed crystal substrate that limited the obtainable step-free area achievable by prior art processes. The step-free SiC surface is particularly suited for the heteroepitaxial growth of 3C (cubic) SiC, AlN, and GaN films used for the fabrication of both surface-sensitive devices (i.e., surface channel field effect transistors such as HEMT's and MOSFET's) as well as high-electric field devices (pn diodes and other solid-state power switching devices) that are sensitive to extended crystal defects.

S3.06 Guidance, Navigation and Control

Lead Center: GSFC

Participating Center(s): ARC, JPL, JSC

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.

Lightweight 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 bearings. 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

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.

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 that 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 that 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.

Balloon Instrumentation

Devices or methods are desired to accurately measure ambient air temperature, helium gas temperature, balloon

film temperatures, film strain, and tendon load. 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 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.

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), but these techniques 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.

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 keep the condenser section warm. It is desirable to develop a cost-effective method of conducting the heat in this manner while allowing the flow to be reduced/eliminated when conditions warrant. Innovative thermal control techniques and devices developed must be inexpensive to implement. They must function reliably at balloon altitudes of 30-40 km and temperature ranges from -90°C to +40°C. 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 Balloon Technologies

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 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:

Steerable Antenna for Titan and Venus Telecommunications

Many concepts for Titan and Venus balloons require high gain antennas mounted on the balloon gondola to transmit data directly back to Earth. This approach requires that the antenna remain pointed at the Earth despite the motions experienced during balloon flight. A beacon signal from the Earth will be available to facilitate pointing. Innovative concepts are sought for such an antenna and pointing system with the following characteristics: antenna

diameter of 0.8 m, total mass of antenna and pointing system of = 10 kg, power consumption for the steering system = 5 W (avg.), pointing accuracy = 0.5 deg (continuous), hemispheric pointing coverage (2 pi steradians), azimuthal and rotational slew rates (30 deg/sec. It is expected that a Phase I effort will involve a proof-of-concept experiment leading to a plan for full scale prototype fabrication and testing in Phase II. Phase II testing will need to include an Earth atmosphere balloon flight in the troposphere to evaluate the proposed design under real flight conditions.

Long-Life Ballonets for Titan Aerobots

Maintenance of a pressurized balloon shape during large altitude changes requires an internal bladder, or ballonet, that can fill and discharge atmospheric gas and thereby maintain the total gas-filled volume. Ballonets are commonplace in terrestrial blimps and airships; however, the cryogenic 85 K temperature at Titan reduces the flexibility of polymer materials and greatly increases the likelihood of pinhole defect formation over time. Innovative concepts are sought for materials and system designs of a ballonet that can function pinhole-free at 85 K for a minimum of 6 months at Titan while executing repeated altitude excursions from 100 m to 10,000 m. The proposed ballonet design should be scalable across the range of 1 to 50 m³ in volume. Preference will be given to projects that do some cryogenic experimentation in Phase I that builds confidence in the viability of the proposed approach.

S3.08 Unmanned Aircraft and Sounding Rocket Technologies

Lead Center: GSFC

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

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.

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 remote telemetry capabilities and precision flight path control requirements. It is also highly desirable to have UAS ability to perform atmospheric and surface sampling.

Telemetry, Tracking and Control

Low cost over-the-horizon global communications and networks are needed. Efficient and cost effective systems that enable unmanned collaborative multi-platform Earth observation missions are desired.

Avionics and Flight Control

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 conditions (hurricanes, volcanic plumes) can provide needed observations that are otherwise not possible at this time:

- Precision flight path control solutions in smooth atmospheric conditions.
- Attitude and navigation control in highly turbulent atmospheric conditions.
- Low cost, high precision inertial navigation systems (

UA Integrated Vehicle Health Management

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

Guided Dropsondes

NASA Earth Science Research activities can benefit from more capable dropsondes than are currently available. Specifically, dropsondes that can 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 dropsonde dispensing systems on NASA/NOAA P-3's, the NASA Global Hawk, and other unmanned aircraft.
- Guidance schemes, autonomous or active control.
- Cross-range performance and flight path accuracy.
- Operational considerations including airspace utilization and de-confliction.

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 sealed 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.

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Patent [7.431.243](#) [41] Guidance and Control for an Autonomous Soaring UAV, Allen, Michael J., October 7, 2008

Summary: The invention provides a practical method for UAVs to take advantage of thermals in a manner similar to piloted aircrafts and soaring birds. In general, the invention is a method for a UAV to autonomously locate a thermal and be guided to the thermal to greatly improve range and endurance of the aircraft.

Low-Cost Small Spacecraft and Technologies This subtopic is targeted at the development of technologies and systems that 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 Unique Mission Architectures Using Small Spacecraft

Lead Center: ARC

Advancements in space technologies can now enable discussions on how small spacecraft might be used to assemble or form large space structures, which are significantly more capable than the individual spacecraft unit, while exploiting the advantages of small spacecraft such as low unit and launch costs.

This subtopic solicits technologies that include the integration of critical subsystems required to allow small spacecraft to work collaboratively to create sparse arrays, large-scale or synthetic apertures, distributed sensors or clusters of sensors, and robotic technologies which could be used in space to perform novel missions using multiple spacecraft in a coordinated fashion. These technologies could include, but are not limited to: high precision timing systems combined with high precision attitude determination and control systems, satellite-to-satellite communications technologies, autonomous systems, and small, efficient in-space propulsion technologies.

Proposers are asked to build a conceptual system/spacecraft design/operational scenario that details the architecture, components and specifications, as well as existing technology gaps necessary to replace the function of a single large spacecraft with an alternative that uses small spacecraft. Supporting analysis including cost and feasibility should be included. Phase II contract efforts should be used to simulate and prototype to the extent possible the system or further reaching subsystems detailed in Phase I.

For small spacecraft planetary missions, planetary protection requirements vary by planetary destination, and additional backward contamination requirements apply to hardware with the potential to return to Earth (e.g., as part of a sample return mission). Technologies intended for use at/around Mars, Europa (Jupiter), and Enceladus (Saturn) must be developed so as to ensure compliance with relevant planetary protection requirements. Constraints could include surface cleaning with alcohol or water, and/or sterilization treatments such as dry heat (approved specification in NPR 8020.12; exposure of hours at 115C or higher, non-functioning); penetrating radiation (requirements not yet established); or vapor-phase hydrogen peroxide (specification pending).

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> [42]) for mission information. See URL: (<http://marsprogram.jpl.nasa.gov/> [43]) for additional information on Mars Exploration technologies. Planetary protection requirements vary by planetary destination, and additional backward contamination requirements apply to hardware with the potential to return to Earth (e.g., as part of a sample return mission). Technologies intended for use at/around Mars, Europa (Jupiter), and Enceladus (Saturn) must be developed so as to ensure compliance with relevant planetary protection requirements. Constraints could include surface cleaning with alcohol or water, and/or sterilization treatments such as dry heat (approved specification in NPR 8020.12; exposure of hours at 115C or higher, non-functioning); penetrating radiation (requirements not yet established); or vapor-phase hydrogen peroxide (specification pending).

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. This call is not for sensor processing algorithms. Sensing technologies are desired that 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, the rigors of landing on the Martian surface, and planetary protection requirements. Successful candidate sensor technologies can address this call by:

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- 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, altitudes, orientation, localization).
 - 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, craters, slopes), or providing indications of approach velocities and touchdown.
 - Substantially reducing the amount of external processing needed to calculate the measurements.
 - Significantly reducing the impact of incorporating such sensors on the spacecraft in terms of volume, mass, placement, or cost.
 - Providing testbeds (e.g., free-flying vehicles) for closed-loop testing of GNC sensors and technologies used in the powered descent landing phase.

For a sample return mission, monitoring local environmental (weather) conditions on the surface just prior to planetary ascent vehicle launch, via appropriate low-mass sensors.

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.

S5.02 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 [44]). Limited spacecraft resources (power, volume, mass, computational capabilities, and telemetry bandwidth) demand innovative, integrated sampling systems that can survive and operate in challenging environments (e.g., 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), as well as for asteroids and comets. 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, with minimal physical alteration of samples. 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. Asteroid and comet samplers are also of interest.

Sample Manipulation (e.g., 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 (e.g., encapsulation and contamination control)

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, solutions are sought for sample transfer of a payload into a planetary ascent vehicle including automated payload transfer mechanisms and Orbiting Sample (OS) sealing techniques.

Sample Return Facility capabilities

Technologies are needed for terrestrial handling of returned samples, including sample quarantine, biological activity and biohazard assessment, techniques for performing sample science.

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. Technical feasibility should be demonstrated during Phase I and a full capability unit of at least TRL 4 should be delivered in Phase II.

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 Earth, Mars, Jovian and Saturnian systems.

For planetary bodies where gravity dominates, such as the Moon and Mars, 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. Mars is particularly interested in fast traverse capabilities aimed at a fetch rover that would potentially need to travel a long distance to retrieve a sample cache deposited by a prior mission. For small planetary bodies with micro-gravity environments, novel access systems are desired to enable exploration and sample acquisition. Small body missions include Comet Surface Sample Return, Cryogenic Comet Sample Return, and asteroid Trojan Tour and Rendezvous.

For surface and subsurface sampling, advanced manipulation technologies are needed to deploy instruments and tools from spacecraft, landers and rovers. Technologies to enable acquisition of subsurface samples are also needed. 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. For Europa, penetrators and deployment systems 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.

Innovative component technologies for low-mass, low-power, and modular systems tolerant to the in situ environment are of particular interest, e.g., 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.

- Steep terrain adherence for vertical and horizontal mobility.
- Tether play-out and retrieval systems including tension and length sensing.
- Low-mass tether cables with power and communication.
- Sampling system deployment mechanisms such as tethers, booms, and manipulators.
- Low mass/power vision systems and processing capabilities that enable faster surface traverse while maintaining safety over a wide range of surface environments.
- Modular actuators with 1000:1 scale gear ratios.
- Electro-mechanical couplers to enable change out of instruments at the end of a manipulator.s
- Autonomy to enable adaptation of exploration to new conditions.

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

S5.04 Spacecraft Technology for Sample Return Missions

Lead Center: GRC

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

NASA plans to perform sample return missions from a variety of targets including Mars, outer planet moons, and small bodies such as asteroids and comets. In terms of spacecraft technology, these types of targets present a variety of challenges. Some targets, such as Mars and some moons, have relatively large gravity wells and will require ascent propulsion. Other targets are small bodies with very complex geography and very little gravity, which present difficult navigational and maneuvering challenges. In addition, the spacecraft will be subject to extreme environmental conditions including low temperatures (120K or below), dust, and ice particles. Technology innovations should either enhance vehicle capabilities (e.g., increase performance, decrease risk, and improve environmental operational margins) or ease mission implementation (e.g., reduce size, mass, power, cost, increase reliability, or increase autonomy). Specific areas of interest are listed below.

SMD's In-Space Propulsion Technology (ISPT) program is a direct customer of this subtopic, and the solicitation is coordinated with the ISPT program each year. The ISPT program views this subtopic (and the previous Planetary Ascent Vehicle subtopic) as a fertile area for providing possible Phase III efforts. Many of the Planetary Decadal Survey white papers/studies evaluating technologies needed for various planetary, small body, and sample return missions refer to the need for sample return spacecraft technologies.

Small body missions:

- Autonomous operation.
- Terrain based navigation.
- Guidance and control technology for landing and touch-and-go.
- Anchoring concepts for asteroids.
- Propulsion technology for proximity or landed operations.
- Low temperature capable non-contaminating propellants.
- Surface manipulation technologies (e.g., rakes, drills, etc.).
- Concept to obtain a stratified subsurface comet core sample.
- Sample mass, volume, ice content verification.
- Hermetic sample sealing concepts.
- Low power long life cryogenic sample storage.

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- Applicable propulsion technologies for ascent vehicles and for the return to Earth.
 - Erection mechanisms for setting azimuth and elevation of the Mars Ascent Vehicle.

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, CO₂ 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 actuators and gear boxes 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 high-specific-strength for pressure vessel construction, and pressure vessel components compatible with materials such as steel, titanium and beryllium for applications like 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 (-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 and wide-operating-temperature radiation-tolerant /radiation hardened RF electronics, radiation-tolerant/radiation-hardened low-power/ultra-low-power wide-operating-temperature low-noise mixed-signal electronics for space-borne system such as guidance and navigation avionics and instruments, low-temperature radiation-tolerant/radiation-hardened power electronics, low-temperature radiation-tolerant/radiation-hardened high-speed fiber optic transceivers, low-temperature and thermal-cycle-resistant radiation-tolerant/radiation-hardened electronic packaging (including shielding, passives, connectors, wiring harness and materials used in advanced electronics assembly), low to medium power actuators, gear boxes, lubricants 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 wide-temperature electronic/electro-mechanical 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

Technologies intended for use at/around Mars, Europa (Jupiter), and Enceladus (Saturn) must be developed so as to ensure compliance with relevant planetary protection requirements. NASA seeks innovative technologies to facilitate meeting Forward and Backward Contamination Planetary Protection objectives especially for a potential Mars Sample Return (MSR) mission and to facilitate Forward Planetary Protection implementation for a potential mission to Europa.

Backward Contamination Planetary Protection deals with the possibility that Mars (or other planetary) 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.

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

- **Container Design, Sealing, & Verification:** Options for sealing the sample container include (but are not limited to) 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 to support such leak detection technologies. 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 & 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.

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- Meteoroid Protection & Breach Detection: Protection is required for both the sample container and the EEV heat shield. New lightweight shielding techniques are needed. Even with these, there may be a requirement for technology to detect a breach of the shield or damage to the EEV.

Forward Contamination Planetary Protection technologies are desired, particularly for Mars and Europa missions that allow sterilization of previously non-sterilizable flight hardware by either i) dry heat processing or ii) gamma/e-beam 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. Current planning is to facilitate system-level sterilization of spacecraft, so heat tolerant technology solutions for sensors, seals (battery, valve), optical coatings, etc., are highly desired.
- 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 these 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.
- 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:

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.
- Enhanced visualization technologies.
- Improved algorithms for key codes.
- Power-aware "Green" computing technologies and techniques.
- Systems (including both hardware and software) for data-intensive computing.
- Approaches to effectively manage and utilize many-core processors including algorithmic changes, compiler techniques and runtime systems.

User Productivity 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 (e.g., debugging and performance analysis), 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. For operations, potential benefits include: resource virtualization, incremental and transparent provisioning, enhanced resource consolidation and utilization, automated resource management, automated job migration, and increased service availability, and others. For users, potential benefits include: out-sourced operations, on-demand resource availability, increased service reliability, customized software environments, a web user interface, and more. This subtopic element seeks technologies that enable Cloud computing to be used for efficient and effective supercomputing operations and services.

S6.02 Earth Science Applied Research and Decision Support

Lead Center: SSC

Participating Center(s): AFRC, ARC, JPL

The NASA Applied Sciences Program (<http://nasascience.nasa.gov/earth-science/applied-sciences> [45]) 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 responding to natural disasters.

This subtopic seeks proposals for utilities, plug-ins or enhancements to geobrowsers that improve their utility for Earth science research and decision support. Examples of geobrowsers include Google Earth, Microsoft Virtual Earth, NASA World Wind (http://worldwindcentral.com/wiki/Main_page [46]) and COAST (<http://www.coastal.ssc.nasa.gov/coast/COAST.aspx> [47]). Examples include, but are not limited to, the following:

- Visualization of high-resolution imagery in a geobrowser.
- Enhanced geobrowser animation capabilities to provide better visual-analytic displays of time-series and change-detection products.
- Discovery and integration of content from web-enabled sensors.
- Discovery and integration of new datasets based on parameters identified by the user and/or the datasets currently in use.
- Innovative mechanisms for collaboration and data layer sharing.
- Applications that subset, filter, merge, and reformat spatial data.

This subtopic also seeks proposals for advanced information systems and decision environments that take full advantage of multiple data sources and platforms. Special consideration will be given to proposals that provide enhancements to existing, broadly used decision support tools or platforms. Tailored and timely products delivered to a broad range of users are needed to protect vital ecosystems such as coastal marshes, barrier islands and seagrass beds; monitor and manage utilization of critical resources such as water and energy; provide quick and effective response to manmade and natural disasters such as oil spills, earthquakes, hurricanes, floods and wildfires; and promote sustainable, resilient communities and urban environments.

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

S6.03 Algorithms and Tools for Science Data Processing, Discovery and Analysis, in State-of-the-Art Data Environments

Lead Center: GSFC

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

This subtopic seeks technical innovation and unique approaches for the processing, discovery and analysis of data from NASA science missions. Advances in such algorithms will support science data analysis and decision support systems related to current and future missions, and will support mission concepts for:

- All current operational missions (<http://www.nasa.gov/missions/current/index.html> [48]).
- Future Earth Science Decadal Survey missions (<http://science.nasa.gov/earth-science/decadal-surveys> [49]).
- The Landsat Data Continuity Mission (LDCM) (<http://ldcm.nasa.gov/> [50]).
- The Joint Polar Satellite System (JPSS) (<http://www.nesdis.noaa.gov/pdf/jpss.pdf> [51]).
- The Lunar Reconnaissance Orbiter mission (LRO) (<http://lunar.gsfc.nasa.gov/> [52]).
- The Moon Mineralogy Mapper (M3) on Chandrayaan (<http://moonmineralogymapper.jpl.nasa.gov/> [53]).
- The Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) (<http://crism.jhuapl.edu> [54]).
- The Visual Infrared Mapping Spectrometer (VIMS) on Cassini (<http://saturn.jpl.nasa.gov/spacecraft/cassiniorbiterinstruments/instrumentsscassinivims/> [55]).
- The James Webb Space Telescope (JWST) (<http://www.jwst.nasa.gov/> [56]).

Research proposed to this subtopic should demonstrate technical feasibility during Phase I, and in partnership with scientists 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.

In the area of algorithms, innovations are sought in the following areas:

- Optimization of algorithms and computational methods to increase the utility of scientific research data for models, data assimilation, simulations, and visualizations. Success will be measured by both speed improvements and output validation.
- Improvement of data discovery, 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.

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- Techniques for data analysis, that focus on data mining, data search, data fusion and data subsetting that scale to extremely large data sets in cloud, large cluster, or distributed computing environments.

In the area of tools, innovations are sought in the following areas:

- Frameworks and related tools such as open source frameworks or framework components that would enable sharing and validation of tools and algorithms.
- Integrated ecosystem of tools for developing and monitoring 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.
- 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 to allow extensibility for new metrics, and verification of the configuration and health of a system.

Tools and products developed under this subtopic may be used for broad public dissemination or within a narrow scientific community. These tools can be plug-ins or enhancements to existing software, on-line data/computing services, or new stand-alone applications or web services, provided that they promote interoperability and use standard protocols, file formats and Application Programming Interfaces (APIs) or prevalent applications. When appropriate, compliance with the FDGC (Federal Geographic Data Committee) and OGC (Open Geospatial Consortium) is recommended.

S6.04 Integrated Mission Modeling for Opto-mechanical Systems

Lead Center: GSFC

Participating Center(s): ARC

NASA seeks innovative systems engineering modeling methodologies and tools to define, develop and execute future science missions, many of which are likely to feature designs and operational concepts that will pose significant challenges to existing approaches and applications.

Specific areas of interest include the following:

Low-cost Model-Based Systems Engineering (MBSE) methodologies (defined as some combination of tools, methods, and processes - refer to the "INCOSE Survey of MBSE Methodologies") for rapid and agile definition of mission architectures during the conceptual design phase. Here, "low-cost" is intended to capture multiple aspects of the investment in the methodology, including initial purchase, maintenance, and training/learning-curve. These methodologies must support requirements analysis, functional decomposition, definition of verification and

validation methods, and analysis of system behavior and performance. Development of methods and applications based on, or supporting, standards such as UML and SysML is highly encouraged, as is tight integration with Microsoft Office and Microsoft Project.

Interfaces between existing (or proposed) MBSE tools and CAD/CAE/PM applications used to support NASA science mission development, which typically include (but are not limited to): Pro/E, NX, NASTRAN, ANSYS, ABAQUS, ADAMS (for MCAD and structural/mechanical systems analysis); TSS, SINDA, Thermal Desktop, TMG (for thermal systems analysis); Code V, ZEMAX, OSLO (for optical systems analysis); Hyperlynx Analog, Hyperlynx GHZ, System Vision, DxDesigner, ModelSim (for ECAD and electrical systems analysis); Matlab, Simulink, STK (for guidance, navigation and control systems analysis); Excel, MathCAD, Mathematica (for general purpose numerical and symbolic analysis); DOORS (for requirements management); PRICE-H, SEER, SSCM, COSYSMO (for cost modeling)

S6.05 Fault Management Technologies

Lead Center: MSFC

Participating Center(s): ARC, JPL

As science missions are given increasingly complex goals and have more pressure to reduce operations costs, system autonomy increases. Fault Management (FM) is one of the key components of system autonomy. FM consists of the operational mitigations of spacecraft failures. It is implemented with spacecraft hardware, on-board autonomous software that controls hardware, software, information redundancy, and ground-based software and operations procedures.

Many recent Science Mission Directorate (SMD) missions have encountered major cost overruns and schedule slips during test and verification of FM functions. These overruns are due to a lack of understanding of FM functions early in the mission definition cycles, and to FM architectures that do not provide attributes of transparency, verifiability, fault isolation capability, or fault coverage. The NASA FM Handbook is under development to improve the FM design, development, verification & validation and operations processes. FM approaches, architectures, and tools are needed to improve early understanding of needed FM capabilities by project managers and FM engineers, and to improve the efficiency of implementing and testing FM.

Specific objectives are to:

- Improve ability to predict FM system complexity and estimate development and operations costs.
- Enable cost-effective FM design architectures and operations.
- Determine completeness and appropriateness of FM designs and implementations.
- Decrease the labor and time required to develop and test FM models and algorithms.

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- Improve visualization of the full FM design across hardware, software, and operations procedures.
 - Determine extent of testing required, completeness of verification planned, and residual risk resulting from incomplete coverage.
 - Increase data integrity between multi-discipline tools.
 - Standardize metrics and calculations across FM, SE, S&MA and operations disciplines.
 - Increase reliability of FM systems.

Expected outcomes are better estimation and control of FM complexity and development costs, improved FM designs, and accelerated advancement of FM tools and techniques.

The approach of this subtopic is to seek the right balance between sufficient reliability and cost appropriate to the mission type and risk posture. Successful technology development efforts under this subtopic would be considered for follow-on funding by, and infusion into, SMD missions. 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.

Specific technology in the forms listed below is needed to increase delivery of high quality FM systems. These approaches, architectures and tools must be consistent with and enable the NASA FM Handbook concepts and processes.

- FM design tools: System modeling and analyses significantly contributes to the quality of FM design; however, the time it takes to translate system design information into system models often decreases the value of the modeling and analysis results. Examples of enabling techniques and tools are modeling automation, spacecraft modeling libraries, expedited algorithm development, sensor placement analyses, and system model tool integration.
- FM visualization tools: FM systems incorporate hardware, software, and operations mechanisms. The ability to visualize the full FM system and the contribution of each mechanism to protecting mission functions and assets is critical to assessing the completeness and appropriateness of the FM design to the mission attributes (mission type, risk posture, operations concept, etc.). Fault trees and state transition diagrams are examples of visualization tools that could contribute to visualization of the full FM design.
- FM verification and validation tools: As complexity of spacecraft and systems increases, the extensiveness of testing required to verify and validate FM implementations can be resource intensive. Automated test case development, false positive/false negative test tools, model verification and validation tools, and test coverage risk assessments are examples of contributing technologies.
- FM Design Architectures: FM capabilities may be implemented through numerous system, hardware, and software architecture solutions. The FM architecture trade space includes options such as embedded in the flight control software or independent onboard software; on board versus ground-based capabilities; centralized or distributed FM functions; sensor suite implications; integration of multiple FM techniques; innovative software FM architectures implemented on flight processors or on Field Programmable Gate Arrays (FPGAs); and execution in real-time or off-line analysis post-operations. Alternative architecture choices could help control FM system complexity and cost and could offer solutions to transparency,

verifiability, and completeness challenges.

Multi-discipline FM Interoperation: FM designers, Systems Engineering, Safety and Mission Assurance, and Operations perform analyses and assessments of reliabilities, failure modes and effects, sensor coverage, failure probabilities, anomaly detection and response, contingency operations, etc. The relationships between multi-discipline data and analyses are inconsistent and misinterpreted. Resources are expended either in effort to resolve disconnects in data and analyses or worse, reduced mission success due to failure modes that were overlooked. Solutions that address data integrity, identification of metrics, and standardization of data products, techniques and analyses will reduce cost and failures.

Lidar and Laser System Components Topic S1.01

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

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

- Highly efficient solid state laser transmitter operating in the 1.0 μm - 1.7 μm range with wall-plug efficiency of greater than 25%. The proposed laser must show path in maturing to space applications. The laser transmitter must be capable of single frequency with narrow spectral width capable of generating transform-limited pulses, and M2 beam quality 70% are of interest. Although amplifiers such as planar waveguide or grazing incidence have been shown to generate optical efficiencies >50%, much higher efficiency is needed for space applications. Proposed solutions should incorporate electronics packages suitable for use in aircraft demonstration (i.e., small, well packaged, low power).

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- Narrow linewidth laser transmitters and receiver components (seeds, fiber amplifiers, modulators, drivers, etc.) supporting laser absorption spectroscopy applications in the 1.3, 1.5 and 2.0 micron wavelength regimes. The lasers and components should be tunable by several nm, support amplitude modulation at frequencies from 50 KHz to 10 MHz, have frequency stability of less than 3 MHz, and be capable of mixing and simultaneous transmission of multiple lines for differential absorption measurements without introducing non-linear mixing effects. Techniques for cloud and aerosol discrimination are also sought.
 - Efficient and compact single mode solid state or fiber lasers operating at 1.5 and 2.0 micron wavelength regimes suitable for direct detection differential absorption lidar (DIAL) and coherent lidar applications. These lasers must meet the following general requirements: pulse energy 0.5 mJ to 50 mJ, repetition rate 10 Hz to 10 kHz, and pulse duration of either 10 nsec or 200 nsec regimes.
 - Low noise detectors operating in 1.5 to 2.0 micron wavelength for use in differential absorption lidar (DIAL) instruments measuring CO₂ concentration. Large area (>250 micron dia.) detectors with high quantum efficiency (>75%), noise equivalent power of less than 2x 10⁻¹⁴ W/Hz^{1/2}, and bandwidth greater than 50 MHz are being sought. Additionally, arrays of 4x4 PIN detectors for coherent detection and avalanche photodiodes with a minimum gain of 10 are of interest. Other detectors relevant to NASA programs are low-noise, high quantum efficiency devices operating at 355 nm, 532 nm, and 1064 nm with gain greater than or equal to 100. These detectors must be linear or correctable for incident power levels ranging from 0.1 pW to 50 nW and have bandwidths exceeding 200 MHz with excellent transient recovery.
 - Novel compact solid-state UV laser for Ozone DIAL measurements from surface and airborne UAS science platforms that also enables technology demonstrations for future spaceborne measurements are needed. New and novel technology developments that enable solid-state UV lasers operating within the 280 nm - 320 nm wavelength range (305-320 nm for the spaceborne lasers) generating laser pulses of up to 1 KHz rate and average output power greater than 1 Watt. Operation at two distinct wavelengths separated by 10 nm to 15 nm is required for the Ozone measurements. Scalability of the laser design to power levels greater than 10 W for space deployment is important.
 - Novel scanning telescope capable of scanning over 360 degrees in azimuth with nadir angle fixed in the range of 30 to 45 degrees. Clear apertures scalable to 1 m, good optical performance (although diffraction limited performance is not necessary), and high optical efficiency are desired, as is ability to operate at multiple wavelengths from 1064 nm to 355 nm. Optical materials (e.g., substrates and coatings) and components should be space qualifiable. Phase II should result in a prototype unit capable of demonstration in a high-altitude aircraft environment, with aperture on the order 8 inches. Due to issues with spacecraft momentum compensation and previous investments, concepts for large articulating telescopes will not be considered responsive to this request, nor will holographic substrates.
 - Flash Lidar Receiver for planetary landing application with at least 128X128 pixels capable of generating 3-dimensional images and detection of hazardous terrain features, such as rocks, craters and steep slopes from at least 1 km distance. The receiver must include real-time image processing capability with 30 Hz frame rate. Embedded image enhancement and classification algorithms are highly desirable. Proposals for low noise Avalanche Photodiode (APD) arrays with 256x256 pixels format suitable for use in Flash Lidar receiver will be also considered. The detector array must operate in the 1.06 to 1.57 micron region and be able to detect laser pulses with 6 nsec in duration. The array needs to achieve greater than 90% fill factor with a pitch size of 50 to 100 microns with provisions for hybridization with an Integrated Readout Circuit (ROIC).

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

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:

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

- Frequency: 94 GHz.
- Radiation Efficiency: >70%.
- Polarization isolation = 25 dB.
- Interconnect loss:
- No dielectric materials.

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

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

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

Low-Cost mm-wave Beamforming MMIC Receiver

- Frequencies: 35.6, 94 GHz.
- Input Channels: 16.
- Phase shifter: 360 deg.
- 5-bits, Output IF: 1 channel @
- Bandwidth: >100 MHz.

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- Serial phase update rate: >10kHz for all channels.

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

High-Speed Radar Distributed Target Simulator

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

Low-Jitter Programmable Delay/Divide Clock Distribution IC

- Total Jitter:
- Fanout: ≥ 10 .

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

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

L-band Array Antennas

- Compact, lightweight arrays (
- Dual-polarization.

- High polarization isolation (> 25 dB) for airborne and spaceborne radar applications.

- W-band (94 GHz).
- Ka-band (35GHz).

- Low loss (
- High speed (transition time
- Peak power ≥ 1.5 kW.

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- Average power \geq 75 W.
 - Isolation \geq 25 dB.

Fast Turn on and Turn Off Power Amplifiers

To increase solid state radar sensitivity NASA requires compact and high efficiency ($> 50\%$) power amplifiers (> 25 W peak.) in P, L, and X-bands that can be switched off during the receive period to prevent noise leakage. Switch on and switch off times under $1 \mu\text{s}$, stable amplitude (

Small Radar Packaging Concepts for Unmanned Aerial Systems (UAV)

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

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

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

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]):

- High emissivity (>40 dB return loss) surfaces/structures for use as onboard calibration targets that will reduce the weight of aluminum core targets, while reliably improving the uniformity and knowledge of the calibration target temperature. Earth Science Decadal survey missions which apply: SCLP and PATH.
- Room temperature LNAs for 165 to 193 GHz with low $1/f$ noise, and a noise figure of 6.0 dB or better; and cryogenic LNAs for 180 to 270 GHz with noise temperatures of less than 150K. Earth Science Decadal Survey missions that apply: PATH, GACM and future Earth Venture Class low cost millimeter wave instruments.

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- Low noise amplifiers, MMIC or discrete transistor, at frequencies below 2 GHz, operating at room temperature or thermoelectrically cooled, and giving noise figures below 0.25 dB (17K noise temperature). Amplifier should have S11 25 dB, over an octave band, and be stable for any generator impedance at any frequency. For highly red shifted hydrogen spectroscopy for early universe cosmology.
 - Local Oscillator technologies for 2nd generation instruments for SOFIA, next generation HIFI, and suborbital instruments (GUSSTO). This can include: GaN based frequency multipliers that can work in the 200-400 GHz range (output frequency) with input powers up to 1 W. Graphene based devices that can work as frequency multipliers in the frequency range of 1-3 THz.
 - Enabling technology for ultra-stable microwave noise references (three or more) embedded in switched network with reference stability (after temperature correction) to within 0.01K/year. Applies to: PATH, SCLP, GACM, SWOT.
 - RFI mitigation approaches employing channelizers for broadband (>100MHz) radiometers at frequencies between 1 and 40 GHz. These systems should demonstrate both detection and removal approaches for mitigating RFI. Earth Science Decadal Survey missions that apply: SCLP, SWOT.
 - Multi-Frequency and/or multi-Beam Focal Plane Arrays (FPA) as a primary feed for reflector antennas. Earth Science Decadal Survey missions that apply: PATH, SCLP, SWOT.
 - In addition to the technologies listed above, proposals for innovative passive microwave instruments for a wide range of remote sensing applications from measurements of the Earth's surface and atmosphere to cosmic background emission would also be welcome.

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

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]).

The following technologies are of interest for the Scanning Microwave Limb Sounder (<http://mls.jpl.nasa.gov/index-cameo.php> [11]) on the Global Atmospheric Composition Mission, Single Aperture Far Infrared (SAFIR) Observatory (<http://safir.jpl.nasa.gov/technologies.shtml> [12]), the SOFIA (Stratospheric Observatory for Infrared Astronomy) airborne observatory (<http://www.sofia.usra.edu/> [13]), and Inflation Probe (cosmic microwave background, <http://science.gsfc.nasa.gov/660/research/> [8]):

- 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.

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- 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).

Thermal imaging, LANDSAT, all IR Earth observing missions:

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- Development of uncooled or passively cooled detectors with NE \leq 30% in the 6-14 μm infrared wavelength region. Formats ~ 640 x 512 with a goal to exceed 3,000 pixel linear dimension. Also, work in promising new technologies such as InAs/GaSb type-II strain layer superlattices.

The Geo-CAPE Mission

Wide Field 0.26-15 μm and Narrow Field 0.35-2.1 μm . PanFTS 60 μm pixel pitch, 256 X 256 format with in-pixel ADC digitization ROIC, 16-bit precision, 16kHz frame rate.

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

- General Information on Future NASA Missions: <http://www.nasa.gov/missions> [17]
- Specific mission pages: IXO: <http://htxs.gsfc.nasa.gov/index.html> [18], future planetary programs: http://nasascience.nasa.gov/planetary-science/mission_list [19], Earth Science Decadal missions: <http://www.nap.edu/catalog/11820.html> [6].
- Helio Probes: http://nasascience.nasa.gov/heliophysics/mission_list [20].

Specific technology areas are listed below:

- Significant improvement in wide band gap semiconductor materials, such as AlGa N , ZnMgO and SiC, individual detectors, and detector arrays for operation at room temperature or higher for missions such as Geo-CAPE, NWO, ATALAST and planetary science composition measurements.
- Highly integrated, low noise (
- Large format UV and X-ray focal plane detector arrays: micro-channel plates, CCDs, and active pixel sensors (>50% QE, 100 Megapixels,
- Advanced Charged Couple Device (CCD) detectors, including improvements in UV quantum efficiency and read noise, to increase the limiting sensitivity in long exposures and improved radiation tolerance. Electron-bombarded CCD and CMOS detectors, including improvements in efficiency, resolution, and global and

local count rate capability. In the X-ray, we seek to extend the response to lower energies in some CCDs, and to higher, perhaps up to 50 keV, in others. Possible missions are future GOES missions and International X-ray Observatory.

- Wide band gap semiconductor, radiation hard, visible and solar blind large format imagers for next generation hyperspectral Earth remote sensing experiments. Need larger formats (>1Kx1K), much higher resolution (
- Solar blind, compact, low-noise, radiation hard, EUV and soft X-ray detectors are required. Both single pixels (up to 1cm x 1cm) and large format 1D and 2D arrays are required to span the 0.05nm to 150nm spectral wavelength range. Future GOES missions post-GOES R and T.
- Visible-blind SiC Avalanche Photodiodes (APDs) for EUV photon counting are required. The APDs must show a linear mode gain >1E6 at a breakdown reverse voltage between 80 and 100V. The APD's must demonstrate detection capability of better than 6 photons/pixel/s at near 135nm spectral wavelength. See needs of National Research Council's Earth Science Decadal Survey (NRC, 2007): Tropospheric ozone.
- Imaging from low-Earth orbit of air fluorescence, UV light generated by giant air showers by ultra-high energy ($E > 10^{19}$ eV) cosmic rays require the development of high sensitivity and efficiency detection of 300-400 nm UV photons to measure signals at the few photon (single photo-electron) level. A secondary goal minimizes the sensitivity to photons with a wavelength greater than 400 nm. High electronic gain (~106), low noise, fast time response (2 to 10 x 10 mm². Focal plane mass must be minimized (2g/cm² goal). Individual pixel readout is required. The entire focal plane detector can be formed from smaller, individual sub-arrays.
- Large area (3 m²) photon counting near-UV detectors with 3 mm pixels and able to count at 10 MHz. Array with high active area fraction (>85%), 0.5 Megapixels and readout less than 1 mW/channel. Future instruments are JEM-EUSO and OWL.
- Large area (m²) X-ray detectors with 85%).
- Improve beyond CdZnTe detectors using micro-calorimeter arrays at hard X-ray, low gamma-ray bands (above 10 keV and Below 80 keV).
- Improvement of spatial resolution for the hard x-ray band up to 10 and ultimately to 5 arcsecond resolution.

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

Sub Topics:

Particles and Field Sensors and Instrument Enabling Technologies Topic S1.06

Advanced sensors for the detection of elementary particles (atoms, molecules and their ions) and electric and magnetic fields in space and associated instrument technologies are often critical for enabling transformational science from the study of the sun's outer corona, to the solar wind, to the trapped radiation in Earth's and other planetary magnetic fields, and to the atmospheric composition of the planets and their moons. Improvements in particles and fields sensors and associated instrument technologies enable further scientific advancement for upcoming NASA missions such as Solar Orbiter, Solar Probe Plus, ONEP, SEPAT, INCA, CISR, DGC, HMag and planetary exploration missions. Technology developments that result in a reduction in size, mass, power, and cost will enable these missions to proceed. Of interest are advanced magnetometers, electric field booms, ion/atom/molecule detectors, and associated support electronics and materials. Specific areas of interest include:

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- Self-calibrating scalar-vector magnetometer for future Earth and space science missions. Performance goals: dynamic range: $\pm 100,000$ nT, accuracy with self-calibration: 1 nT, sensitivity: 5 pT $\times 1/2$ (max), max sensor unit size: 6 x 6 x 12 cm, max sensor mass: 0.6 kg, max electronics unit size: 8 x 13 x 5 cm, max electronics mass: 1 kg, and max power: 5 W operation, 0.5 W standby, including, but not limited to sensors on a chip.
 - High-magnetic-field sensor that measures magnetic field magnitudes to 16 Gauss with an accuracy of 1 part in 10⁵.
 - Strong, lightweight, thin, compactly-stowed electric field booms possibly using composite materials that deploy sensors to distances of 10-m or more.
 - Cooled (-60°C) solid state ion detector capable of operating at a floating potential of -15 kV relative to ground.
 - Low noise magnetic materials for advanced magnetometer sensors with performance equal to or better than those in the 6-81.3 Mo-Permalloy family.
 - Radiation hardened ASIC spectrum analyzer module that determines mass spectra using fast algorithm deconvolution to produce ion counts for specific ion species.
 - Low-cost, low-power, fast-stepping (= 50- μ s), high-voltage power supplies 5-15 kV.
 - Low-cost, efficient low-power power supplies (5-10 V).
 - Low-power charge sensitive preamplifiers on a chip.
 - High efficiency (5% or greater) conversion surfaces for low energy neutral atom conversion to ions possibly based on nanotechnology.
 - Miniature low-power, high efficiency, thermionic cathodes, capable of 1-mA electron emission per 100-mW heater power with emission surface area of 1-mm² and expected lifetime of 20,000 hours.
 - Long wire boom (= 50 m) deployment systems for the deployment of very lightweight tethers or antennae on spinning spacecraft.
 - Systems to determine the orthogonality of a deployed electric/magnetic field boom system in flight (for use with three-axis rigid 10-m booms) accurate to 0.10° dynamic.
 - Die-level optical interferometer, micro-sized, for measuring Fabry-Perot plate spacing with 0.1-nm accuracy.
 - Diffractive optics (photon sieves) of 0.1-m aperture or larger with micron-sized outer Fresnel zones for high-resolution EUV imaging.

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

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 GEOID, SPICA, WFirst (<http://wfirst.gsfc.nasa.gov/> [21]), Space Infrared Interferometric Telescope (SPIRIT), Submillimeter Probe of the Evolution of Cosmic Structure (SPECs), as well as, the Planetary and Europa Science missions (<http://www.nasa.gov/multimedia/podcasting/jpl-europa20090218.html> [22]). The topic areas are as follows:

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

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:

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

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

Sub Topics:

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

This subtopic solicits development of advanced instrument technologies and components suitable for deployment on planetary and lunar missions. These technologies must be capable of withstanding operation in space and planetary environments, including the expected pressures, radiation levels, launch and impact stresses, and range of survival and operational temperatures. Technologies that reduce mass, power, volume, and data rates for instruments and instrument components without loss of scientific capability are of particular importance. In addition, technologies that can increase instrument resolution and sensitivity or achieve new & innovative scientific measurements are solicited. For example missions, see <http://science.hq.nasa.gov/missions> [23]. For details of the specific requirements see the National Research Council's, Vision and Voyages for Planetary Science in the Decade 2013-2022 <http://solarsystem.nasa.gov/2013decadal/> [24]. Technologies which support NASA's Planetary

Flagship mission candidates (Mars 2018, JEO, & Uranus Orbiter & Probe Mission), New Frontiers Mission candidates (Comet Surface Sample Return, Lunar South Pole-Aitken Basin Sample Return, Saturn Probe, Trojan Tour & Rendezvous, Venus In-Situ Explorer, Io Observer, and the Lunar Geophysical Network) and Discovery missions to various planetary bodies are of top priority.

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

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

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

Proposers are strongly encouraged to relate their proposed development to:

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

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

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

Sub Topics:

Atomic Interferometry Topic S1.10

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

Sensors based on Atom/BEC Interferometry are attractive because:

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

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

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

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

This subtopic seeks concepts and prototypes of devices below:

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

The criteria for evaluations also include:

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

Robustness of the design /prototype to Space environments.

Sub Topics:

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

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/> [25], <http://instrument.jpl.nasa.gov/stellar/> [26]). Also sought are technologies (analysis, algorithms, and test beds) 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:

- 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.
- Development of nanometer to sub-nanometer metrology for measuring inter-spacecraft range and/or bearing for space telescopes and interferometers.
- Control approaches to maintain line-of-sight between two vehicles in inertial space near Sun-Earth L2 to milli-arcsecond levels accuracy.
- 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:

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- 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.
 - Swarm modeling, simulation and 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.

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. 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 near infrared wavelengths. The ultimate application of these instruments is to operate in space as part of a future observatory mission. 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

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- 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 $\sim 1 \mu\text{m}$, 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 broadband speckle field.
 - Methods of polarization control and polarization apodization.
 - 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 are 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 broadband 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.
- 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: Wide-Field Infrared Survey Telescope (WFIRST) and the New Worlds Technology Development Program (coronagraph, external occulter and interferometer technologies) will push the state of the art in current optomechanical technologies. Mission concepts for New Worlds science would 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. In addition, ground based telescopes such as the Cerro Chajnantor Atacama Telescope (CCAT) require similar technology development.

The desired areal density is 1 - 10 kg/m² with a packaging efficiency of 3-10 deployed/stowed diameter. 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 the Earth-Sun L2.

This subtopic solicits proposals to develop enabling, cost effective component and subsystem technology for deploying large aperture telescopes with low cost. Research areas of interest include:

- Precision deployable structures and metrology for optical telescopes (e.g., innovative active or passive deployable primary or secondary support structures).
- Architectures, packaging and deployment designs for large sunshields and external occulters.

In particular, important subsystem considerations may include:

- Innovative concepts for packaging fully integrated subsystems (e.g., power distribution, sensing, and control components).
- Mechanical, inflatable, or other precision deployable technologies.
- Thermally-stable materials (CTE)
- Innovative systems, which minimize complexity, mass, power and cost.

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- Innovative testing and verification methodologies.

The goal for this effort is to mature technologies that can be used to fabricate 16 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. Proposals with system solutions for large sunshields and external occulter will also be accepted. A successful proposal shows a path toward a Phase II delivery of demonstration hardware scalable to 5 meter diameter for ground test characterization.

Proposals should show an understanding of one or more relevant science needs, and present a feasible plan to fully develop the relevant subsystem technologies and to transition into future NASA program(s).

Sub Topics:

Advanced Optical Component Systems Topic S2.04

The National Academy Astro2010 Decadal Report specifically identifies optical components and coatings as key technologies needed to enable several different future missions, including:

- X-ray imaging mirrors for the International X-Ray Observatory (IXO).
- Active lightweight x-ray imaging mirrors for future very large advanced x-ray observatories.
- Large aperture, lightweight mirrors for future UV/Optical telescopes.
- Broadband high reflectance coatings for future UV/Optical telescopes.

X-ray mirrors are identified by the Decadal as the most important, critical technology needed for IXO. IXO requires 3 m² collecting aperture x-ray imaging mirror with 5 arc-second angular resolution. Mirror areal density depends upon available launch vehicle capacities. Additionally, future x-ray missions require advanced multilayer high-reflectance coating for hard x-ray mirrors (i.e., NuSTAR) and x-ray transmission/reflection gratings.

Future UVOIR missions require 4 to 8 or 16 meter monolithic and/or segmented primary mirrors with 2 for a 5 m fairing EELV vs. 60 kg/m² for a 10 m fairing SLS). Additionally, future UVOIR missions require high-reflectance mirror coatings with spectral coverage from 100 to 2500 nm.

Heliophysics missions also require advanced lightweight, super-polished precision normal and grazing incidence optical components and coatings. Potential missions which could be enabled by these technologies include: Origins of Near-Earth Plasma (ONEP); Ion-Neutral Coupling in the Atmosphere (INCA); Dynamic Geospace Coupling (DGC); Fine-scale Advanced Coronal Transition-Region Spectrograph (FACTS); Reconnection and Micro-scale (RAM); and Solar-C. Heliophysics missions need normal incidence mirror systems ranging from 0.35 meter to 1.5 meters with surface figure errors of 0.1 micro-radians rms slope from 4-mm to 1/2 aperture spatial periods,

roughness of 0.2-nm rms and micro-roughness of 0.1-nm rms; and, grazing incidence mirror systems with an effective collecting area of $\sim 3 \text{ cm}^2$ from 0.1 to 4 nm, 4 meter effective focal length, 0.8 degree angle of incidence and surface roughness of 0.2-nm rms. Additionally, future Heliophysics missions require high-reflectance normal incidence spectral, broadband, dual and even three-band pass multi-layer EUV coatings.

The geosynchronous orbit for GEO-CAPE coastal ecosystem imager requires technology for alternative solar calibration strategies including new materials to reduce weight, and new optical analysis to reduce the size of calibration systems. GEO-CAPE will need a lightweight large aperture (greater than 0.5 m) diffuse solar calibrator, employing multiple diffusers to track on-orbit degradation. Typical materials of interest are PTFE (such as Spectralon® surface diffuser) or development of new Mie scattering materials for use as volume diffusers in transmission or reflection.

Finally, NASA is developing a heavy lift space launch system (SLS). An SLS with a 10 meter fairing and 100 mt capacity to LEO would enable extremely large 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 all cases, the most important metric for an advanced optical system is affordability or areal cost (cost per square meter of collecting aperture). Currently both x-ray and normal incidence space mirrors 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 subtopic has three objectives:

- Develop and demonstrate technologies to manufacture and test ultra-low-cost precision optical systems for x-ray, UV/optical or infrared telescopes. Potential solutions include, but are not limited to, new mirror materials such as silicon carbide, nanolaminates or carbon-fiber reinforced polymer; or new fabrication processes such as direct precision machining, rapid optical fabrication, roller embossing at optical tolerances, 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). Solutions include reflective, transmissive, diffractive or high order diffractive blazed lens optical components for assembly of large (16 to 32 meter) optical quality primary elements. The EUSO mission requires large-aperture primary segmented refractive, Fresnel or kinoform PMMA or CYTOP lenses with
- Develop and demonstrate optical coatings for EUV and UVOIR telescopes. UVOIR telescopes require broadband (from 100 nm to 2500 nm) high-reflectivity mirror coating with extremely uniform amplitude and polarization properties. Heliophysics missions require high-reflectance (> 90%) normal incidence spectral, broadband, dual and even three-band pass multi-layer coatings over the spectral range from 6 to 200 nm. Studies of improved deposition processes for new UV reflective coatings (e.g., MgF₂), investigations of new coating materials with promising UV performance, and examination of handling processes, contamination control, and safety procedures related to depositing coatings, storing coated optics, integrating coated optics into flight hardware are all areas where progress would be valuable. In all cases, an ability to demonstrate optical performance on 2 to 3 meter class optical surfaces is important.
- Large aperture diffusers (up to 1 meter) for periodic calibration of GeoStationary Earth viewing sensors by viewing the sun either in reflection or transmission off the diffuser.

In regard to large-aperture diffusers material needs to be stable in BTDF/BSDF to 2%/year from 250nm -2.5 microns and highly lambertian (no formal specification for deviation from lambertian).

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:

Dark Energy Mission concepts (e.g., <http://wfirst.gsfc.nasa.gov> [21])

Large X-Ray Mission concepts (e.g., <http://ixo.gsfc.nasa.gov/> [27]),

Gravity Wave Science Mission concepts (e.g., <http://lisa.gsfc.nasa.gov/> [28])

ICESAT (<http://icesat.gsfc.nasa.gov/> [29]), CLARIO, and ACE

ATLAST (<http://www.stsci.edu/institute/atlast/> [30])

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. A new area of interest is large lightweight monolithic metallic aspheres manufactured using innovative mirror substrate materials that can be assembled and welded together from smaller segments.

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 10 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:

- Innovative metal mirror substrate materials or manufacturing methods such as welding component segments into one monolith that produce thin mirror substrates that are stiffer and/or lighter than existing materials or methods.
- Interferometric nulling optics for very shallow conical optics used in x-ray telescopes.

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- 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.
 - Metrology systems useful for measuring large optics with high precision.
 - Metrology systems for measuring optical systems while under cryogenic conditions.

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.

The subtopic goals are to:

- Develop high-performance processors, memory architectures, and reliable electronic systems.
- 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:

- State what the product is.
- Identify the needs it addresses.
- Identify the improvements over the current state of the art.
- Outline the feasibility of the technical and programmatic approach.
- 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(Si), while some planetary missions can have requirements well in excess of 1 Mrad(Si). For descriptions of radiation effects in electronics, the proposer may visit <http://radhome.gsfc.nasa.gov/radhome/overview.htm> [37]. 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:

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.

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.

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

- Development system design tools that:

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- Take full advantage of rapid prototyping hardware-in-the-loop (HIL) environments for hybrid processing platforms.
 - Automate/accelerate the deployment of data processing and sensor interface design on flight hardware.

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.

Power Conversion and Distribution relevant to Command, Data Handling, and Electronics, will be covered in sub-topic S3.05 Power Management and Storage.

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 crosscutting thermal control discipline are sought in the following areas:

- New generations of electronics used on numerous missions have higher power densities than in the past. High conductivity, vacuum-compatible interface materials that minimize losses across make/break interfaces are needed to reduce interface temperature gradients and facilitate heat removal.
- Sensitive instruments and electronics drive increased requirements for high electrical conductivity on spacecraft surfaces. This has increased the need for advanced thermal control coatings, particularly those with low absorptance, high emittance, and good electrical conductivity. Also, variable emittance surfaces to modulate heat rejection are needed.
- Exploration science missions beyond Earth orbit present engineering challenges requiring systems that 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. Systems that incorporate Micro-meteorite and Orbital Debris protection (MMOD) are also of interest.
- 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.

- Phase change systems are needed for Mars, Venus, 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 that would provide heat for instrument power on after the dormant phase.

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.

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.

Photovoltaic Energy Conversion

Photovoltaic cell, blanket, and array technologies that lead to significant improvements in overall solar array performance (i.e., conversion efficiency >33%, 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 300 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 [38]). 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. Propulsion technologies related specifically to Power Processing Units will be sought under S3.05 Power Management and Storage.

Chemical Propulsion Systems

Technology needs include:

- Pump or alternate pressurization technologies that provide for high-pressure operation (chamber pressures > 500 psia) of spacecraft primary propulsion systems (100- to 200-lbf class) using Earth storable or space storable bipropellants.
- Catalytic and non-catalytic ignition technologies that provide reliable ignition of high-performance (Isp > 240 sec), nontoxic monopropellants for power-limited spacecraft.

Electric Propulsion Systems

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

-
- Thrusters with efficiencies > 50% and up to 1 kW of input power that operate with a specific impulse between 1600 to 3500 seconds.
 - An efficient (>60 %), dual mode thruster that is capable of operating in both high thrust (>60 mN/kW) and high specific impulse (>3000 sec) modes for a fixed power level.
 - High power electric propulsion thrusters (up to 25 kW) and components including cathodes, ion optics, low sputtering materials with long life (>1x10⁸ N-s), high temperature insulators with low secondary electron emission, and high temperature, low electrical resistivity wire.

Proposals should show an understanding of the state of the art, how their technology is superior, and of one or more relevant science needs. The proposals should provide a feasible plan to develop fully 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 Electronics and Management, and Energy Storage Topic S3.05

Future NASA science objectives will include missions such as Earth Orbiting, Venus, Europa, Titan/Enceladus Flagship, Lunar Quest and Space Weather missions. 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 high energy density, high power density, long life, high reliability, low mass/volume, radiation tolerance, and wide temperature operation. Other subtopics that could potentially benefit from these technology developments include 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, Management and Distribution (PMAD) for High Power Space Exploration Applications, which is investigating some similar technologies but at a much higher power level. This subtopic is also directly tied to S3.04 - Propulsion Systems for the development of advanced Power Processing Units and associated components.

Power Electronics and Management

The 2009 Heliophysics roadmap (http://sec.gsfc.nasa.gov/2009_Roadmap.pdf [34]), the 2010 SMD Science Plan (<http://science.nasa.gov/about-us/science-strategy/> [36]), the 2010 Planetary Decadal Survey White Papers & Roadmap Inputs (http://sites.nationalacademies.org/SSB/CurrentProjects/ssb_052412 [39]), the 2011 PSD Relevant Technologies document, the 2006 Solar System Exploration (SSE) Roadmap (<http://nasascience.nasa.gov/about-us/science-strategy> [31]), and the 2003 SSE Decadal Survey describe the need for lighter weight, lower power electronics along with radiation hardened, extreme environment electronics for planetary exploration. Radioisotope power systems (RPS) and Power Processing Units (PPUs) for Electric Propulsion (EP) are two programs of interest that would directly benefit from advancements in this technology area.

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. In addition, the Outer Planet Assessment Group has called out high power density/high efficiency power electronics as needs for the Titan/Enceladus Flagship and planetary exploration missions. These types of missions, including Mars Sample Return using Hall thrusters and PPUs, require advancements in radiation hardened power electronics and systems beyond the state-of-the-art. 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 programs with power ranges of a few watts for minimum missions to up to 20 kilowatts for large missions. In addition to electrical component development, RPS has a need for intelligent, fault-tolerant Power Management And Distribution (PMAD) technologies to efficiently manage the system power for these deep space missions.

SMD's In-space Propulsion Technology and Radioisotope Power Systems programs are direct customers of this subtopic, and the solicitation is coordinated with the 2 programs each year.

Overall technologies of interest include:

- High voltage, radiation hardened, high temperature components, such as capacitors and semiconductors, for EP PPU applications.
- High power density/high efficiency power electronics.
- High temperature devices and components/power converters (up to 450°C).
- Intelligent, fault-tolerant electrical components and PMAD systems.
- Advanced electronic packaging for thermal control and electromagnetic shielding.

In addition, development is needed in the area of advanced High Voltage Transformer-Rectifier Technology Development for Advanced Cloud and Precipitation Radars, Interferometers, and other Advanced SAR applications where an integrated Transformer-Rectifier Assembly is needed to provide increased stability in the output voltages provided to the Cathode and Collector of a Vacuum Tube (EIK). This would result in increases in the RF phase stability of the output RF Pulse or current approaches. The Transformer-Rectifier Assembly should address using innovative, single-integrated body regulator designs that regulate collector vs. cathode potential, and demonstrate increasing voltage stability over other approaches. The entire Transformer-Rectifier Assembly (Cathode-Collector-Body) should be optimized to achieve maximum energy efficiency and minimum size/mass of the system taking into account necessary high voltage insulation and potting for operation in a space environment (vacuum). Of interest are assemblies that demonstrate:

- Cathode voltages in excess of -12 kV, and Collector voltage in the -3 kV ranges with Beam currents in excess of 340 mA.
- Assemblies for which the primary winding of the transformer is driven through 60VDC (full load) switched at a nominal frequency of 40.5±1.5kHz, or higher.
- Duty cycles up to 16%.

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° to 500°C for Venus missions, and a span of -230°C to $+120^{\circ}\text{C}$ for Lunar Quest. The Outer Planet Assessment Group and the 2011 PSD Relevant Technologies Document have specifically called out high energy density storage systems as a need for the Titan/Enceladus Flagship and planetary exploration missions. 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 and energy density (>200 Wh/kg for secondary battery systems), 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.

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.

Disclaimer: Technology Available (TAV) subtopics may include an offer to license NASA Intellectual Property (NASA IP) on a non-exclusive, royalty-free basis, for research use under the SBIR award. When included in a TAV subtopic as an available technology, use of the available NASA IP is strictly voluntary. Whether or not a firm uses available NASA IP within their proposal effort will not in any way be a factor in the selection for award.

Patent [6.461.944 \[40\]](#), Methods for growth of relatively large step-free SiC crystal surfaces Neudeck, et al. October 8, 2002

Summary: A method for growing arrays of large-area device-size films of step-free (i.e., atomically flat) SiC surfaces for semiconductor electronic device applications is disclosed. This method utilizes a lateral growth process that better overcomes the effect of extended defects in the seed crystal substrate that limited the obtainable step-free area achievable by prior art processes. The step-free SiC surface is particularly suited for the heteroepitaxial growth of 3C (cubic) SiC, AlN, and GaN films used for the fabrication of both surface-sensitive devices (i.e., surface channel field effect transistors such as HEMT's and MOSFET's) as well as high-electric field devices (pn diodes and other solid-state power switching devices) that are sensitive to extended crystal defects.

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.

Lightweight 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 bearings. 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

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.

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 that 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 that 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.

Balloon Instrumentation

Devices or methods are desired to accurately measure ambient air temperature, helium gas temperature, balloon film temperatures, film strain, and tendon load. 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 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.

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), but these techniques 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.

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 keep the condenser section warm. It is desirable to develop a cost-effective method of conducting the heat in this manner while allowing the flow to be reduced/eliminated when conditions warrant. Innovative thermal control techniques and devices developed must be inexpensive to implement. They must function reliably at balloon altitudes of 30-40 km and temperature ranges from -90°C to +40°C. 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 Balloon Technologies

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 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:

Steerable Antenna for Titan and Venus Telecommunications

Many concepts for Titan and Venus balloons require high gain antennas mounted on the balloon gondola to transmit data directly back to Earth. This approach requires that the antenna remain pointed at the Earth despite the motions experienced during balloon flight. A beacon signal from the Earth will be available to facilitate pointing. Innovative concepts are sought for such an antenna and pointing system with the following characteristics: antenna diameter of 0.8 m, total mass of antenna and pointing system of = 10 kg, power consumption for the steering system = 5 W (avg.), pointing accuracy = 0.5 deg (continuous), hemispheric pointing coverage (2π steradians), azimuthal and rotational slew rates (30 deg/sec. It is expected that a Phase I effort will involve a proof-of-concept experiment leading to a plan for full scale prototype fabrication and testing in Phase II. Phase II testing will need to include an Earth atmosphere balloon flight in the troposphere to evaluate the proposed design under real flight conditions.

Long-Life Ballonets for Titan Aerobots

Maintenance of a pressurized balloon shape during large altitude changes requires an internal bladder, or ballonet, that can fill and discharge atmospheric gas and thereby maintain the total gas-filled volume. Ballonets are commonplace in terrestrial blimps and airships; however, the cryogenic 85 K temperature at Titan reduces the flexibility of polymer materials and greatly increases the likelihood of pinhole defect formation over time. Innovative concepts are sought for materials and system designs of a ballonet that can function pinhole-free at 85 K for a minimum of 6 months at Titan while executing repeated altitude excursions from 100 m to 10,000 m. The proposed ballonet design should be scalable across the range of 1 to 50 m³ in volume. Preference will be given to projects that do some cryogenic experimentation in Phase I that builds confidence in the viability of the proposed approach.

Sub Topics:

Unmanned Aircraft and Sounding Rocket Technologies Topic S3.08

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.

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 remote telemetry capabilities and precision flight path control requirements. It is also highly desirable to have UAS ability to perform atmospheric and surface sampling.

Telemetry, Tracking and Control

Low cost over-the-horizon global communications and networks are needed. Efficient and cost effective systems that enable unmanned collaborative multi-platform Earth observation missions are desired.

Avionics and Flight Control

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 conditions (hurricanes, volcanic plumes) can provide needed observations that are otherwise not possible at this time:

- Precision flight path control solutions in smooth atmospheric conditions.
- Attitude and navigation control in highly turbulent atmospheric conditions.
- Low cost, high precision inertial navigation systems (

UA Integrated Vehicle Health Management

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

Guided Dropsondes

NASA Earth Science Research activities can benefit from more capable dropsondes than are currently available. Specifically, dropsondes that can 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 dropsonde dispensing systems on NASA/NOAA P-3's, the NASA Global Hawk, and other unmanned aircraft.
- Guidance schemes, autonomous or active control.
- Cross-range performance and flight path accuracy.
- Operational considerations including airspace utilization and de-confliction.

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 sealed 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.

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Patent [7,431,243](#) [41] Guidance and Control for an Autonomous Soaring UAV, Allen, Michael J., October 7, 2008

Summary: The invention provides a practical method for UAVs to take advantage of thermals in a manner similar to piloted aircrafts and soaring birds. In general, the invention is a method for a UAV to autonomously locate a thermal and be guided to the thermal to greatly improve range and endurance of the aircraft.

Sub Topics:

Unique Mission Architectures Using Small Spacecraft Topic S4.01

Advancements in space technologies can now enable discussions on how small spacecraft might be used to assemble or form large space structures, which are significantly more capable than the individual spacecraft unit, while exploiting the advantages of small spacecraft such as low unit and launch costs.

This subtopic solicits technologies that include the integration of critical subsystems required to allow small spacecraft to work collaboratively to create sparse arrays, large-scale or synthetic apertures, distributed sensors or clusters of sensors, and robotic technologies which could be used in space to perform novel missions using multiple spacecraft in a coordinated fashion. These technologies could include, but are not limited to: high precision timing systems combined with high precision attitude determination and control systems, satellite-to-satellite communications technologies, autonomous systems, and small, efficient in-space propulsion technologies.

Proposers are asked to build a conceptual system/spacecraft design/operational scenario that details the architecture, components and specifications, as well as existing technology gaps necessary to replace the function of a single large spacecraft with an alternative that uses small spacecraft. Supporting analysis including cost and feasibility should be included. Phase II contract efforts should be used to simulate and prototype to the extent possible the system or further reaching subsystems detailed in Phase I.

For small spacecraft planetary missions, planetary protection requirements vary by planetary destination, and additional backward contamination requirements apply to hardware with the potential to return to Earth (e.g., as part of a sample return mission). Technologies intended for use at/around Mars, Europa (Jupiter), and Enceladus (Saturn) must be developed so as to ensure compliance with relevant planetary protection requirements. Constraints could include surface cleaning with alcohol or water, and/or sterilization treatments such as dry heat (approved specification in NPR 8020.12; exposure of hours at 115C or higher, non-functioning); penetrating radiation (requirements not yet established); or vapor-phase hydrogen peroxide (specification pending).

Sub Topics:

Planetary Entry, Descent and Landing Technology Topic S5.01

NASA seeks innovative sensor technologies to enhance success for entry, descent and landing (EDL) operations on missions to Mars. This call is not for sensor processing algorithms. Sensing technologies are desired that 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, the rigors of landing on the Martian surface, and planetary protection requirements. 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, altitudes, orientation, localization).
- 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, craters, slopes), or providing indications of approach velocities and touchdown.
- Substantially reducing the amount of external processing needed to calculate the measurements.
- Significantly reducing the impact of incorporating such sensors on the spacecraft in terms of volume, mass, placement, or cost.
- Providing testbeds (e.g., free-flying vehicles) for closed-loop testing of GNC sensors and technologies used in the powered descent landing phase.

For a sample return mission, monitoring local environmental (weather) conditions on the surface just prior to planetary ascent vehicle launch, via appropriate low-mass sensors.

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:

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 [44]). Limited spacecraft resources (power, volume, mass, computational capabilities, and telemetry bandwidth) demand innovative, integrated sampling systems that can survive and operate in challenging environments (e.g., 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), as well as for asteroids and comets. 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, with minimal physical alteration of samples. 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. Asteroid and comet samplers are also of interest.

Sample Manipulation (e.g., 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 (e.g., encapsulation and contamination control)

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, solutions are sought for sample transfer of a payload into a planetary ascent vehicle including automated payload transfer mechanisms and Orbiting Sample (OS) sealing techniques.

Sample Return Facility capabilities

Technologies are needed for terrestrial handling of returned samples, including sample quarantine, biological activity and biohazard assessment, techniques for performing sample science.

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. Technical feasibility should be demonstrated during Phase I and a full capability unit of at least TRL 4 should be delivered in Phase II.

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 Earth, Mars, Jovian and Saturnian systems.

For planetary bodies where gravity dominates, such as the Moon and Mars, 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. Mars is particularly interested in fast traverse capabilities aimed at a fetch rover that would potentially need to travel a long distance to retrieve a sample cache deposited by a prior mission. For small planetary bodies with micro-gravity environments, novel access systems are desired to enable exploration and sample acquisition. Small body missions include Comet Surface Sample Return, Cryogenic Comet Sample Return, and asteroid Trojan Tour and Rendezvous.

For surface and subsurface sampling, advanced manipulation technologies are needed to deploy instruments and tools from spacecraft, landers and rovers. Technologies to enable acquisition of subsurface samples are also needed. 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. For Europa, penetrators and deployment systems 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.

Innovative component technologies for low-mass, low-power, and modular systems tolerant to the in situ environment are of particular interest, e.g., 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.

- Steep terrain adherence for vertical and horizontal mobility.
- Tether play-out and retrieval systems including tension and length sensing.
- Low-mass tether cables with power and communication.
- Sampling system deployment mechanisms such as tethers, booms, and manipulators.
- Low mass/power vision systems and processing capabilities that enable faster surface traverse while maintaining safety over a wide range of surface environments.
- Modular actuators with 1000:1 scale gear ratios.
- Electro-mechanical couplers to enable change out of instruments at the end of a manipulator.s
- Autonomy to enable adaptation of exploration to new conditions.

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

Sub Topics:

Spacecraft Technology for Sample Return Missions Topic S5.04

NASA plans to perform sample return missions from a variety of targets including Mars, outer planet moons, and small bodies such as asteroids and comets. In terms of spacecraft technology, these types of targets present a variety of challenges. Some targets, such as Mars and some moons, have relatively large gravity wells and will require ascent propulsion. Other targets are small bodies with very complex geography and very little gravity, which present difficult navigational and maneuvering challenges. In addition, the spacecraft will be subject to extreme environmental conditions including low temperatures (120K or below), dust, and ice particles. Technology innovations should either enhance vehicle capabilities (e.g., increase performance, decrease risk, and improve environmental operational margins) or ease mission implementation (e.g., reduce size, mass, power, cost, increase reliability, or increase autonomy). Specific areas of interest are listed below.

SMD's In-Space Propulsion Technology (ISPT) program is a direct customer of this subtopic, and the solicitation is coordinated with the ISPT program each year. The ISPT program views this subtopic (and the previous Planetary Ascent Vehicle subtopic) as a fertile area for providing possible Phase III efforts. Many of the Planetary Decadal Survey white papers/studies evaluating technologies needed for various planetary, small body, and sample return missions refer to the need for sample return spacecraft technologies.

Small body missions:

- Autonomous operation.
- Terrain based navigation.
- Guidance and control technology for landing and touch-and-go.
- Anchoring concepts for asteroids.
- Propulsion technology for proximity or landed operations.
- Low temperature capable non-contaminating propellants.
- Surface manipulation technologies (e.g., rakes, drills, etc.).
- Concept to obtain a stratified subsurface comet core sample.
- Sample mass, volume, ice content verification.
- Hermetic sample sealing concepts.
- Low power long life cryogenic sample storage.

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- Applicable propulsion technologies for ascent vehicles and for the return to Earth.
 - Erection mechanisms for setting azimuth and elevation of the Mars Ascent Vehicle.

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, CO₂ 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 actuators and gear boxes 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 high-specific-strength for pressure vessel construction, and pressure vessel components compatible with materials such as steel, titanium and beryllium for applications like 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 (-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 and wide-operating-temperature radiation-tolerant /radiation hardened RF electronics, radiation-tolerant/radiation-hardened low-power/ultra-low-power wide-operating-temperature low-noise mixed-signal electronics for space-borne system such as guidance and navigation avionics and instruments, low-temperature radiation-tolerant/radiation-hardened power electronics, low-temperature radiation-tolerant/radiation-hardened high-speed fiber optic transceivers, low-temperature and thermal-cycle-resistant radiation-tolerant/radiation-hardened electronic packaging (including shielding, passives, connectors, wiring harness and materials used in advanced electronics assembly), low to medium power actuators, gear boxes, lubricants 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 wide-temperature electronic/electro-mechanical 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

Technologies intended for use at/around Mars, Europa (Jupiter), and Enceladus (Saturn) must be developed so as to ensure compliance with relevant planetary protection requirements. NASA seeks innovative technologies to facilitate meeting Forward and Backward Contamination Planetary Protection objectives especially for a potential Mars Sample Return (MSR) mission and to facilitate Forward Planetary Protection implementation for a potential mission to Europa.

Backward Contamination Planetary Protection deals with the possibility that Mars (or other planetary) 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.

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

- **Container Design, Sealing, & Verification:** Options for sealing the sample container include (but are not limited to) 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 to support such leak detection technologies. 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 & 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 & Breach Detection:** Protection is required for both the sample container and the EEV heat shield. New lightweight shielding techniques are needed. Even with these, there may be a requirement for technology to detect a breach of the shield or damage to the EEV.

Forward Contamination Planetary Protection technologies are desired, particularly for Mars and Europa missions that allow sterilization of previously non-sterilizable flight hardware by either i) dry heat processing or ii) gamma/e-beam 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. Current planning is to facilitate system-level sterilization of spacecraft, so heat tolerant technology solutions for sensors, seals (battery, valve), optical coatings, etc., are highly desired.
- **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

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.

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- 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:

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.
- Enhanced visualization technologies.
- Improved algorithms for key codes.
- Power-aware "Green" computing technologies and techniques.
- Systems (including both hardware and software) for data-intensive computing.

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- Approaches to effectively manage and utilize many-core processors including algorithmic changes, compiler techniques and runtime systems.

User Productivity 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 (e.g., debugging and performance analysis), 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. For operations, potential benefits include: resource virtualization, incremental and transparent provisioning, enhanced resource consolidation and utilization, automated resource management, automated job migration, and increased service availability, and others. For users, potential benefits include: out-sourced operations, on-demand resource availability, increased service reliability, customized software environments, a web user interface, and more. This subtopic element seeks technologies that enable Cloud computing to be used for efficient and effective supercomputing operations and services.

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> [45]) 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 responding to natural disasters.

This subtopic seeks proposals for utilities, plug-ins or enhancements to geobrowsers that improve their utility for Earth science research and decision support. Examples of geobrowsers include Google Earth, Microsoft Virtual Earth, NASA World Wind (http://worldwindcentral.com/wiki/Main_page [46]) and COAST (<http://www.coastal.ssc.nasa.gov/coast/COAST.aspx> [47]). Examples include, but are not limited to, the following:

- Visualization of high-resolution imagery in a geobrowser.
- Enhanced geobrowser animation capabilities to provide better visual-analytic displays of time-series and change-detection products.
- Discovery and integration of content from web-enabled sensors.
- Discovery and integration of new datasets based on parameters identified by the user and/or the datasets currently in use.
- Innovative mechanisms for collaboration and data layer sharing.

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- Applications that subset, filter, merge, and reformat spatial data.

This subtopic also seeks proposals for advanced information systems and decision environments that take full advantage of multiple data sources and platforms. Special consideration will be given to proposals that provide enhancements to existing, broadly used decision support tools or platforms. Tailored and timely products delivered to a broad range of users are needed to protect vital ecosystems such as coastal marshes, barrier islands and seagrass beds; monitor and manage utilization of critical resources such as water and energy; provide quick and effective response to manmade and natural disasters such as oil spills, earthquakes, hurricanes, floods and wildfires; and promote sustainable, resilient communities and urban environments.

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

Sub Topics:

Algorithms and Tools for Science Data Processing, Discovery and Analysis, in State-of-the-Art Data Environments
Topic S6.03

This subtopic seeks technical innovation and unique approaches for the processing, discovery and analysis of data from NASA science missions. Advances in such algorithms will support science data analysis and decision support systems related to current and future missions, and will support mission concepts for:

- All current operational missions (<http://www.nasa.gov/missions/current/index.html> [48]).
- Future Earth Science Decadal Survey missions (<http://science.nasa.gov/earth-science/decadal-surveys> [49]).
- The Landsat Data Continuity Mission (LDCM) (<http://ldcm.nasa.gov/> [50]).
- The Joint Polar Satellite System (JPSS) (<http://www.nesdis.noaa.gov/pdf/jpss.pdf> [51]).
- The Lunar Reconnaissance Orbiter mission (LRO) (<http://lunar.gsfc.nasa.gov/> [52]).
- The Moon Mineralogy Mapper (M3) on Chandrayaan (<http://moonmineralogymapper.jpl.nasa.gov/> [53]).
- The Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) (<http://crism.jhuapl.edu> [54]).
- The Visual Infrared Mapping Spectrometer (VIMS) on Cassini (<http://saturn.jpl.nasa.gov/spacecraft/cassiniorbiterinstruments/instrumentsscassinivims/> [55]).
- The James Webb Space Telescope (JWST) (<http://www.jwst.nasa.gov/> [56]).

Research proposed to this subtopic should demonstrate technical feasibility during Phase I, and in partnership with scientists 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.

In the area of algorithms, innovations are sought in the following areas:

- Optimization of algorithms and computational methods to increase the utility of scientific research data for models, data assimilation, simulations, and visualizations. Success will be measured by both speed improvements and output validation.
- Improvement of data discovery, 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.
- Techniques for data analysis, that focus on data mining, data search, data fusion and data subsetting that scale to extremely large data sets in cloud, large cluster, or distributed computing environments.

In the area of tools, innovations are sought in the following areas:

- Frameworks and related tools such as open source frameworks or framework components that would enable sharing and validation of tools and algorithms.
- Integrated ecosystem of tools for developing and monitoring 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.
- 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 to allow extensibility for new metrics, and verification of the configuration and health of a system.

Tools and products developed under this subtopic may be used for broad public dissemination or within a narrow scientific community. These tools can be plug-ins or enhancements to existing software, on-line data/computing services, or new stand-alone applications or web services, provided that they promote interoperability and use standard protocols, file formats and Application Programming Interfaces (APIs) or prevalent applications. When appropriate, compliance with the FDGC (Federal Geographic Data Committee) and OGC (Open Geospatial Consortium) is recommended.

Sub Topics:

Integrated Mission Modeling for Opto-mechanical Systems Topic S6.04

NASA seeks innovative systems engineering modeling methodologies and tools to define, develop and execute future science missions, many of which are likely to feature designs and operational concepts that will pose significant challenges to existing approaches and applications.

Specific areas of interest include the following:

Low-cost Model-Based Systems Engineering (MBSE) methodologies (defined as some combination of tools, methods, and processes - refer to the "INCOSE Survey of MBSE Methodologies") for rapid and agile definition of mission architectures during the conceptual design phase. Here, "low-cost" is intended to capture multiple aspects of the investment in the methodology, including initial purchase, maintenance, and training/learning-curve. These methodologies must support requirements analysis, functional decomposition, definition of verification and validation methods, and analysis of system behavior and performance. Development of methods and applications based on, or supporting, standards such as UML and SysML is highly encouraged, as is tight integration with Microsoft Office and Microsoft Project.

Interfaces between existing (or proposed) MBSE tools and CAD/CAE/PM applications used to support NASA science mission development, which typically include (but are not limited to): Pro/E, NX, NASTRAN, ANSYS, ABAQUS, ADAMS (for MCAD and structural/mechanical systems analysis); TSS, SINDA, Thermal Desktop, TMG (for thermal systems analysis); Code V, ZEMAX, OSLO (for optical systems analysis); Hyperlynx Analog, Hyperlynx GHz, System Vision, DxDesigner, ModelSim (for ECAD and electrical systems analysis); Matlab, Simulink, STK (for guidance, navigation and control systems analysis); Excel, MathCAD, Mathematica (for general purpose numerical and symbolic analysis); DOORS (for requirements management); PRICE-H, SEER, SSCM, COSYSMO (for cost modeling)

Sub Topics:

Fault Management Technologies Topic S6.05

As science missions are given increasingly complex goals and have more pressure to reduce operations costs, system autonomy increases. Fault Management (FM) is one of the key components of system autonomy. FM consists of the operational mitigations of spacecraft failures. It is implemented with spacecraft hardware, on-board autonomous software that controls hardware, software, information redundancy, and ground-based software and operations procedures.

Many recent Science Mission Directorate (SMD) missions have encountered major cost overruns and schedule slips during test and verification of FM functions. These overruns are due to a lack of understanding of FM functions early in the mission definition cycles, and to FM architectures that do not provide attributes of transparency, verifiability, fault isolation capability, or fault coverage. The NASA FM Handbook is under development to improve the FM design, development, verification & validation and operations processes. FM approaches, architectures, and tools are needed to improve early understanding of needed FM capabilities by project managers and FM engineers, and to improve the efficiency of implementing and testing FM.

Specific objectives are to:

- Improve ability to predict FM system complexity and estimate development and operations costs.

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- Enable cost-effective FM design architectures and operations.
 - Determine completeness and appropriateness of FM designs and implementations.
 - Decrease the labor and time required to develop and test FM models and algorithms.
 - Improve visualization of the full FM design across hardware, software, and operations procedures.
 - Determine extent of testing required, completeness of verification planned, and residual risk resulting from incomplete coverage.
 - Increase data integrity between multi-discipline tools.
 - Standardize metrics and calculations across FM, SE, S&MA and operations disciplines.
 - Increase reliability of FM systems.

Expected outcomes are better estimation and control of FM complexity and development costs, improved FM designs, and accelerated advancement of FM tools and techniques.

The approach of this subtopic is to seek the right balance between sufficient reliability and cost appropriate to the mission type and risk posture. Successful technology development efforts under this subtopic would be considered for follow-on funding by, and infusion into, SMD missions. 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.

Specific technology in the forms listed below is needed to increase delivery of high quality FM systems. These approaches, architectures and tools must be consistent with and enable the NASA FM Handbook concepts and processes.

- FM design tools: System modeling and analyses significantly contributes to the quality of FM design; however, the time it takes to translate system design information into system models often decreases the value of the modeling and analysis results. Examples of enabling techniques and tools are modeling automation, spacecraft modeling libraries, expedited algorithm development, sensor placement analyses, and system model tool integration.
- FM visualization tools: FM systems incorporate hardware, software, and operations mechanisms. The ability to visualize the full FM system and the contribution of each mechanism to protecting mission functions and assets is critical to assessing the completeness and appropriateness of the FM design to the mission attributes (mission type, risk posture, operations concept, etc.). Fault trees and state transition diagrams are examples of visualization tools that could contribute to visualization of the full FM design.
- FM verification and validation tools: As complexity of spacecraft and systems increases, the extensiveness of testing required to verify and validate FM implementations can be resource intensive. Automated test case development, false positive/false negative test tools, model verification and validation tools, and test coverage risk assessments are examples of contributing technologies.

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- FM Design Architectures: FM capabilities may be implemented through numerous system, hardware, and software architecture solutions. The FM architecture trade space includes options such as embedded in the flight control software or independent onboard software; on board versus ground-based capabilities; centralized or distributed FM functions; sensor suite implications; integration of multiple FM techniques; innovative software FM architectures implemented on flight processors or on Field Programmable Gate Arrays (FPGAs); and execution in real-time or off-line analysis post-operations. Alternative architecture choices could help control FM system complexity and cost and could offer solutions to transparency, verifiability, and completeness challenges.

Multi-discipline FM Interoperation: FM designers, Systems Engineering, Safety and Mission Assurance, and Operations perform analyses and assessments of reliabilities, failure modes and effects, sensor coverage, failure probabilities, anomaly detection and response, contingency operations, etc. The relationships between multi-discipline data and analyses are inconsistent and misinterpreted. Resources are expended either in effort to resolve disconnects in data and analyses or worse, reduced mission success due to failure modes that were overlooked. Solutions that address data integrity, identification of metrics, and standardization of data products, techniques and analyses will reduce cost and failures.

Sub Topics:
