



NASA SBIR 2009 Phase I Solicitation

Science

Sensors, Detectors and Instruments Topic S1

NASA's Science Mission Directorate (SMD) (<http://nasascience.nasa.gov/> [1]) encompasses research in the areas of Astrophysics (<http://nasascience.nasa.gov/astrophysics> [2]), Earth Science (<http://nasascience.nasa.gov/earth-science> [3]), Heliophysics (<http://nasascience.nasa.gov/heliophysics> [4]), and Planetary Science (<http://nasascience.nasa.gov/planetary-science> [5]). A major objective of SMD instrument development programs is to implement science measurement capabilities with smaller or more affordable spacecraft so development programs can meet multiple mission needs and therefore make the best use of limited resources. The rapid development of small, low-cost remote sensing and in situ instruments is essential to achieving this objective. For Earth Science needs, in particular, the subtopics reflect a focus on instrument development for airborne and Unmanned Aerial Vehicle (UAV) platforms. Astrophysics has a critical need for sensitive detector arrays with imaging, spectroscopy, and polarimetric capabilities which can be demonstrated on ground, airborne, balloon, or suborbital rocket instruments. Heliophysics, which focuses on measurements of the sun and its interaction with the Earth and the other planets in the solar system, needs a significant reduction in the size, mass, power, and cost for instruments to fly on smaller spacecraft. Planetary Science has a critical need for miniaturized instruments with in situ sensors that can be deployed on surface landers, rovers, and airborne platforms. For the 2009 program year, we are actively encouraging proposal submissions for subtopic S1.10 that solicits technology for geodetic instruments and instruments to enable global navigation and very long baseline interferometry. A key objective of this SBIR topic is to develop and demonstrate instrument component and subsystem technologies that reduce the risk, cost, size, and development time of SMD observing instruments and to enable new measurements. Proposals are sought for development components that can be used in planned missions or a current technology program. Research should be conducted to demonstrate feasibility during Phase 1 and show a path towards a Phase 2 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

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 as well as for highly accurate measurements of the distance between spacecraft for gravitational wave astronomy and gravitational field planetary science are among technologies of interest. Innovative technologies that can expand current measurement capabilities to spaceborne or Unmanned Aerial Vehicle (UAV) platforms are particularly desirable. Development of components that can be used in planned missions or current technology programs is highly encouraged. Examples of planned missions and technology programs are: Deformation, Ecosystem Structure and Dynamics of Ice (DESDynI), Laser Interferometer Space Antenna (LISA), Doppler Wind Lidar, Lidar for Surface Topography (LIST), or earth and planetary atmospheric composition (ASCENDS).

Research should be conducted to demonstrate technical feasibility during Phase 1 and show a path toward a Phase 2 prototype demonstration. For the PY09 SBIR Program, we are soliciting only the specific component technologies described below.

- High speed fiber multiplexers for multimode fiber (200 micron core, 0.22 NA) operating at 1 micron wavelength. We require an N by M de-multiplexer (where M is 32 or greater and N is 2) capable of switching at speeds on the order of 10 microseconds with low insertion loss (
- Space-qualifiable high reliability frequency-stabilized CW laser source with 2 W output power at 1064 nm. A master oscillator power amplifier (MOPA) configuration is desirable since the source must be phase-modulated.
- Fiber-coupled pulse compressor device for 1064 nm and 532 nm for reducing 4-6 ns level pulses to sub-ns (0.4 - 0.6 ns) pulses, capable of input pulse energies > 2 mJ.
- Efficient and compact single frequency, near diffraction limited semiconductor lasers (interband cascade laser or quantum cascade lasers) operating in mid-infrared (3 - 4 μm). Requirements include room temperature operation, and pulsed lasers with repetition rates on the order of 10 KHz and pulse energies greater than 0.5 mJ. CW lasers in multiwatt regimes are applicable. Wavelength tunability over 10s of nanometers is desirable for certain applications.
- Efficient and compact single mode solid state or fiber lasers operating at 1.5 and 2.0 micron wavelength regimes suitable for coherent lidar applications. These lasers must meet the following general requirements: pulse energy 0.5 mJ to 50 mJ, repetition rate 10 Hz to 1 kHz, and pulse duration of approximately 200 nsec.
- Single frequency semiconductor or fiber laser generating CW power in 1.5 or 2.0 micron wavelength regions with less than 10 kHz linewidth. Frequency modulation with about 5 GHz bandwidth and wavelength tuning over several nanometers are desirable.
- Development of efficient, compact, and space qualifiable laser absorption spectrometry-related technologies for measuring atmospheric pressure and density. Remote sensing of oxygen in the 1.26 micron or 760 nm spectral region for measuring atmospheric pressure is of particular interest.
- Photon counting detectors (single element and/or multi-element detector array) at near-IR (1 - 1.8 μm) and mid-IR (3 - 4 μm) with single photon sensitivity.

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 (<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. The areas of interest for

this call are listed below:

High-density low-loss millimeter-wave packaging and interconnects for advanced cloud and precipitation radars or Mars landing radars. These packing and interconnect technologies are critical to achieving the density and RF signal performance required for scanning millimeter-wave array radars. Desired performance specifications include:

- Frequency: 35 - 160 GHz
- Performance at 35 GHz:
 - Interconnect loss:
 - Line loss:

High-speed, low-power analog-to-digital converters (ADCs) and digital-to-analog converters (DACs) for advanced SAR, advanced interferometer for surface monitoring, ice topography or hydrology. Digital beam forming (DBF) systems require an array of ADCs. The power consumption of current ADC chips prohibits implementation of large DBF arrays. Furthermore, large arrays require true time delays, which are easily implemented using low-power, high speed ADCs and DACs. Desired performance specifications include:

- Analog Input Bandwidth: 1.3 GHz
- Sampling rate: 500 MS/s
- Resolution 12 bits
- Power consumption: 100 mW

High performance miniature bandpass filters for SMAP, Aquarius follow-on, DESDynI, or Advanced L-band SAR and interferometers. The size of current filters allows for implementation of near-term missions with (with volume and mass penalties) but filter size constrains RF system architectural choices. Desired performance specifications include:

- Center Frequencies: 1.2 - 36 GHz
- Bandwidth: 1%

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- Loss:
 - Isolation: >30 dB

 - Volume: 3

High-performance mm-wave integrated circuits (MMICs) for Advanced SAR, advanced interferometer for surface monitoring, ice topography, hydrology, advanced cloud and precipitation radars or Mars landing radars. Besides packaging, performance of MMICs is the main road block to development of electronically scanned arrays at 94 GHz and higher. Desired specifications/technologies include:

- Frequencies: 94 - 350 GHz
- Device types: Lower Noise Amplifiers, Power Amplifiers, Mixers, Oscillators, Phase Shifters, Switches

Ultra-high efficiency L-band power amplifiers for Advanced SAR/Interferometers or geosynchronous SAR for earthquake monitoring. Using lower efficiency amplifiers in large arrays leads to much higher power system requirements and thermal management challenges. Desired performance specifications include:

- Frequency: 1.2 - 1.3 GHz
- Efficiency: >85%

P-band stretch processing imaging radar antennas and transceivers with bandwidth > 100 MHz for airborne SAR applications for Biomass/ecosystems. Wideband P-band radar systems require low power transmitters with high processing gain to avoid interference with other services. Furthermore, achieving fine range resolution will require novel wideband airborne antennas.

Small radar packaging concepts for Unmanned Aerial Systems (UAS) for Biomass (P), soil moisture and ocean salinity (L, and C), or snow water equivalent (X, Ku, and Ka). Miniaturization of radar and radiometer components while maintaining power and performance is a requirement for UAV science. Desired performance specifications include:

- Mass: 1.5 lb - 35 lb
- Frequency: P-band, L-band, C-band, X-band, Ku -band, and Ka-band
- High Efficiency SSPAs: > 70% efficiency (P, L and C), > 20% (ka)

High power/high efficiency Ka-band and W-band solid state and TWT amplifiers for

Aerosol/Cloud/Ecosystems (ACE) Mission. Spaceborne applications require higher power and efficiency than currently available. Desired performance specifications include:

- SSPA power: > 10 W (Ka-band) and > 2 W (W-band)
- TWT power: > 1kW (Ka-band) and > 200 W (W-band)
- Efficiency: > 20%.
- Phase Linearity:

Simultaneous, multi-frequency U-band transceivers, frequency converters, and amplifiers for airborne/spaceborne applications for barometric pressure measurements in support of NASA/NOAA hurricane science, NWS/aviation weather or decadal survey missions. Currently available airborne and space-qualified U-band (50 - 60 GHz) transceiver and components do not support simultaneous operation at multiple frequencies within the band.

Wide bandwidth, U-band antennas for airborne/spaceborne applications for barometric pressure measurements in support of NASA/NOAA hurricane science, NWS/aviation weather, or decadal survey missions. Currently available antennas do not compensate for wide bandwidth (50 - 60 GHz) operation; consequently, main beam characteristics (e.g., beamwidth, gain, pointing angle, polarization, etc.) vary according to frequency. The need is for a light-weight, aviation/space-qualifiable antenna capable of operating over 50 - 60 GHz without significant variation in main beam characteristics.

Membrane materials for large inflatable membrane antennas for remote sensing applications for earth and planetary science missions. Reflectors manufactured from polymer films could enable greater packaging efficiencies due to their low mass, high packaging efficiencies, solar radiation resistance, and cryogenic flexibility. However, these polymer films must also exhibit near zero CTE and stability in the space environment, as well as be deployable wrinkle free. Innovative intrinsically electroactive polymer membrane actuation mechanisms that can reduce the bulk of traditional active control systems are also of interest. Proposals for remote sensing antenna membrane materials technology are being solicited and should be submitted to subtopic "O1.02 - Antenna Technologies" in the Space Operations portion of this solicitation. Such proposals should indicate that they are applicable to remote sensing antennas.

Composite materials for large deployable antenna reflector structures for remote sensing applications for earth and planetary science missions. These antennas will require high specific stiffness composite materials that can be packed compactly and deployed multiple times for ground evaluation of the antenna structure prior to launch and deployment in space. The deployment of these materials should require low energy. Proposals for remote sensing antenna composite materials technology are being solicited and should be submitted to subtopic "O1.02 - Antenna Technologies" in the Space Operations portion of this solicitation. Such proposals should indicate that they are applicable to remote sensing antennas.

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.

S1.03 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://universe.nasa.gov/program/probes/inflation.html> [8])).

- Low power >200 Mb/s 1-bit A/D converters and cross-correlators for microwave interferometers. Earth Science Decadal survey missions which apply: PATH, SCLP.
- Automated assembly of 180 GHz direct conversion I-Q receiver modules. This technology applies to both the Beyond Einstein Inflation probe and the Decadal Survey PATH concept.
- Low DC power spectrometer (channelizer) covering >500 MHz with 125 kHz resolution for planetary radiometer missions and covering 4 GHz with 1 MHz resolution for Earth observing missions. Also RFI mitigation approaches employing channelizers for broad band radiometers. Earth Science Decadal Survey mission which applies: GACM
- RF (GHz to THz) MEMS switches with low insertion loss (18 dB), capable of switching with speeds of >100 Hz at cryogenic temperatures (below 10 K) for 10^8 or more cycles. Technology applies to Beyond Einstein Probe.
- 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.
- MMIC Low Noise Amplifiers (LNA). Room temperature LNAs for 165 to 193 GHz with low 1/f noise, and a noise figure of 6.0 dB or better; and cryogenic LNAs for 180 to 270 GHz with noise temperatures of less than 150K. Earth Science Decadal Survey missions that apply: PATH and GACM.
- Low loss, low RF power waveguide SPDT diode switches and active noise sources for frequencies above 90 GHz to support calibration of SWOT and other atmospheric temperature and humidity measurements.
- Broad band 180 - 270 GHz radomes for aircraft borne submillimeter remote sensing instruments.

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, 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 specific technologies are of interest for instrument concepts such as Scanning Microwave Limb Sounder (<http://mls.jpl.nasa.gov/index-cameo.php> [11]) on the Global Atmospheric Composition Mission, Climate Absolute Radiance and Refractivity Observatory (http://science.hq.nasa.gov/earth-sun/docs/Vol4_CLARREO.pdf [12]), Methane Trace Gas Sounder, Single Aperture Far Infrared (SAFIR) Observatory (<http://safir.jpl.nasa.gov/technologies.shtml> [13]), and Inflation Probe (cosmic microwave background, <http://universe.nasa.gov/program/probes/inflation.html> [8]):

- New or improved technologies leading to measurement of trace atmospheric species (e.g., CO, CH₄, N₂O) from geostationary and low-Earth orbital platforms. Of particular interest are new techniques in gas filter correlation spectroscopy, Fabry-Perot spectroscopy, or improved component technologies.
- Uncooled or passively cooled detectors with specific detectivity (D^*) $\geq 10^{10}$ cm Hz^{1/2}/W in the operating wavelength ranges 6-14 μ m and 10-100 μ m.
- Efficient, flight qualifiable, spur free, local oscillators for SIS mixers operating in low earth orbit. Two bands: (1) tunable from 200 to 250 GHz, and (2) tunable from 600 to 660 GHz, phase-locked to or derived from an ultra-stable 5 MHz reference.
- Sideband separating SIS mixer with RF band from 580 to 680 GHz, IF band from 6 to 18 GHz, image rejection greater than 10 dB, and receiver noise temperature less than 300 Kelvin. Thermal load on 4 K and 15 K stage must be less than 4 and 30 mW respectively. Application: GACM.
- Quantum cascade laser-based local oscillators for astrophysics applications (2nd generation SOFIA instruments, SAFIR).
- Technologies for calibrating millimeter wave spectrometers for spaceborne missions, including low power, flight qualifiable comb generators and low noise diodes for the bands from 180 to 270 and 600 to 660 GHz; very low return loss (70 dB or better) calibration targets and techniques for quantifying and calibrating out the impact of standing waves in broadband heterodyne submillimeter spectrometers.
- Low power, stable, linear, spectrometers capable of measuring the band from 6-18 GHz with ~120 100 MHz wide channels.

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- Digital spectrometers with ~4 GHz bandwidth and 10 MHz resolution. Components for these digital spectrometers including high speed digitizers, efficient spectrometer firmware, and ASIC implementations.
 - Spatial Filter Array (SFA) consisting of a monolithic array of up to 1200 coherent, polarization preserving, single mode fibers that operate over a large fraction of the spectral range from 0.4 - 1.0 microns and such that each input and output lenslet is mapped to a single fiber. Uniformity of output intensity and high throughput is desired and fiber-to-fiber placement accuracies of http://planetquest.jpl.nasa.gov/TPF/tpf_index.cfm) and Stellar Imager (<http://hires.gsfc.nasa.gov/si/> [14]).
 - High resolution wedged filters with resolving powers of 1,000 to 5,000 in the visible to short wave infrared spectral region. Of particular interest are filters in the 1 to 3.5 micron range.

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.

S1.05 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> [15]

Specific mission pages:

EXIST: <http://exist.gsfc.nasa.gov/> [16]

IXO: <http://htxs.gsfc.nasa.gov/index.html> [17]

Future planetary programs: http://nasascience.nasa.gov/planetary-science/mission_list [18]

Earth Science Decadal missions: <http://www.nap.edu/catalog/11820.html> [6]

Helio Probes: http://nasascience.nasa.gov/heliophysics/mission_list [19]

Specific technology areas are listed below:

- Significant improvement in wide band gap semiconductor materials, individual detectors, and detector arrays for operation at room temperature or higher for missions such as EXIST, Geo-CAPE and planetary science composition measurements.
- Highly integrated, low noise (
- Large format UV and X-ray focal plane detector arrays: microchannel plates, CCDs, and active pixel sensors (>50% QE, 100 Megapixels,
- Advanced Charged Couple Device (CCD) detectors, including improvements in UV quantum efficiency and read noise, to increase the limiting sensitivity in long exposures and improved radiation tolerance. Electron-bombarded CCD detectors, including improvements in efficiency, resolution, and global and local count rate capability. In the X-ray, we seek to extend the response to lower energies in some CCDs, and to higher, perhaps up to 50 keV, in others. Possible missions are future GOES missions and International X-ray Observatory.
- Wide band gap semiconductor, radiation hard, visible and solar blind large format imagers for next generation hyperspectral Earth remote sensing experiments. Need larger formats (>1Kx1K), much higher resolution (
- Solar blind, compact, low-noise, radiation hard, EUV and soft X-ray detectors are required. Both single pixels (up to 1cm x 1cm) and large format 1D and 2D arrays are required to span the 0.05nm to 150nm spectral wavelength range. Future GOES missions post-GOES R and T.
- Visible-blind SiC APDs for EUV photon counting are required. The APDs must show a linear mode gain >1E6 at a breakdown reverse voltage between 80 and 100V. The APD's must demonstrate detection capability of better than 6 photons/pixel/s at near 135nm spectral wavelength. See needs of National Council Decadal Survey (NRC, 2007): Tropospheric ozone.
- Imaging from low-Earth orbit of air fluorescence, UV light generated by giant airshowers by ultra-high energy ($E > 10^{19}$ 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 (2 g/cm² goal). Individual pixel readout. The entire focal plane detector can be formed from smaller, individual sub-arrays.

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.

S1.06 Particles and Field Sensors and Instrument Enabling Technologies

Lead Center: GSFC

Participating Center(s): ARC, JPL, MSFC

Advanced sensors and instrument enabling technologies for the measurement of the physical properties of space plasmas and energetic charged particles, mesospheric - thermospheric neutral species, energetic neutral atoms created at high altitudes by charge exchange, and electric and magnetic fields in space are needed to achieve NASA's transformational science advancements in Heliophysics. The Heliophysics discipline

(<http://sec.gsfc.nasa.gov/> [20]) has as its primary strategic goal the understanding of the physical coupling between the sun's outer corona, the solar wind, the trapped radiation in Earth's and other planetary magnetic fields, and the upper atmospheres of the planets and their moons. This understanding is of national importance not only because of its intrinsic scientific worth, but also because it is the necessary first step toward developing the ability to measure and forecast the "space weather" that affects all human crewed and robotic space assets. Improvements in particles and fields sensors and associated instrument technologies will enable further scientific advancement for upcoming NASA missions such as Solar Probe (<http://solarprobe.gsfc.nasa.gov/> [21]), Solar Sentinels (<http://lws.gsfc.nasa.gov/missions/sentinels/sentinels.htm> [22]), GEC (<http://stp.gsfc.nasa.gov/missions/gec/gec.htm> [23]), Magnetospheric Constellation (<http://stp.gsfc.nasa.gov/missions/mc/mc.htm> [24]), IT-SP and planetary exploration missions. Technology developments that result in expanded measurement capabilities and a reduction in size, mass, power, and cost are necessary in order for some of these missions to proceed. Of special interest are fast high voltage stepping power supplies for charged particle analyzers, electric field booms, self calibrating vector magnetometers, and other supporting sensor electronics.

Specific areas of interest include:

- Low cost, low power, low current, high voltage power supplies which allow ultra-fast stepping (t
- Strong, lightweight, thin, compactly-stowed electric field booms possibly using composite materials that deploy sensors to distances of 10m or more and/or long wire boom (> 50 m) deployment systems for the deployment of very lightweight tethers or antennae on spinning spacecraft.
- Self-calibrating scalar-vector magnetometer for future Earth and space science missions. Performance goals are dynamic range: +/-100,000 nT, accuracy with self-calibration: 1 nT, sensitivity: 5 pT / sqrtHz, Max, max sensor unit size: 6 x 6 x 12 cm, max sensor mass: 0.6 kg, max electronics unit size: 8 x 13 x 5 cm, max electronics mass: 1 kg, and max power: 5 W operation, 0.5 W standby, including, but not limited to "sensors on a chip".
- Low-power cathode for detection of neutral atoms and molecules ionosphere-thermosphere and planetary investigations. Performance goals are thermionic cathodes capable of emitting 1 mA electron current with heater power less than 0.1 W. The largest dimension of the electron emitter surface should not exceed 1 mm; the entire cathode assembly should be small enough so it may be mounted in a shallow channel shaped to match the largest cathode dimension. The assembly should include robust connection leads for heater and cathode surface. Uniformity across the electron beam is not critical.
- A compact electronics box to enable the operation of one Wind Temperature Spectrometer (WTS), one Ion-Drift Spectrometer (IDS), one Neutral Mass Spectrometer (NMS) and one Ion Mass Spectrometer (IMS), all based on the new generation charged-particle spectrometer SDEA. The electronics should be housed in a volume with dimensions not exceeding 3.2x3.2x3.2 inches with power requirement not exceeding 1.1 W. The EB must provide: (a) electronics for MCP detector pulse handling, (b) minimum of 64 detector pulse channels for WTS and IDS, (c) 2 channels devoted to TOF pulse processing with 2 ns time resolution or faster for NMS and IMS, (d) two ion source power supplies (1V/0.1A cathode supply floating at -100VDC) for WTS and NMS, (e) two energy scan supplies (0 to 5 V) for WTS and IMS, (f) two rectangular-wave supplies (0 to 1 V with 1 microsec rise time) for NMS and IMS, (g) ion accelerator optics voltage supplies (3 outputs @ 200 VDC max) for NMS and IMS, (h) MCP voltage supply (one lead/2700VDC max @ 50 microAmp max), and (i) micro-controller with buffer memory and telemetry link.

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.

S1.07 Cryogenic Systems for Sensors and Detectors

Lead Center: GSFC

Participating Center(s): ARC, JPL, MSFC

Cryogenic cooling systems often serve as enabling technologies for detectors and sensors flown on scientific instruments as well as advanced telescopes and observatories. As such, technological improvements to cryogenic systems (as well as components) further advance the mission goals of NASA through enabling performance (and ultimately science gathering) capabilities of flight detectors and sensors. Presently, there are six potential investment areas that NASA is seeking to expand state of the art capabilities in for possible use on future programs such as IXO (<http://ixo.gsfc.nasa.gov/> [25]), Safir (<http://safir.jpl.nasa.gov/> [26]), Spirit, Specs (<http://geons.gsfc.nasa.gov/live/Home/SPECS.html> [27]) and the Europa Science missions (<http://www.nasa.gov/multimedia/podcasting/jpl-europa20090218.html> [28]). The topic areas are as follows:

Extremely Low Vibration Cooling Systems

Examples of such systems include pulse tube coolers and turbo brayton cycles. Desired cooling capabilities sought are on the order of 20 mW at 4K or 1W at 50 K. 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);
- 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

Current heat switches require detailed procedures for operational repeatability. More robust (performance wise) heat switches are currently needed for ease of operation when used with space flight applications.

Highly Efficient Magnetic and Dilution Cooling Technologies

The desired temperature range for proposed systems is

Low Temperature/Power Cooling Systems

Cooling systems providing cooling capacities approximately 0.3W at 35 K with heat rejection capability to temperature sinks upwards of 150 K are of interest. Presently there are no cooling systems operating at this heat rejection temperature. Input powers should be limited to no greater than 10W. Study of passive cooler in tandem with low power, low mass cryocooler satisfying the above mentioned requirements is also of interest.

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.

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

Lead Center: GSFC

Participating Center(s): ARC, JPL, 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, and balloon-based systems (tethered or free). 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: Aerosols, Cloud Particles, Water, and chemical composition: Carbon Dioxide ($^{12}\text{CO}_2$ and $^{13}\text{CO}_2$), Carbon Monoxide, Methane, Reactive and Trace Gases, Radicals, Ozone, 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 phytoplankton, harmful algal blooms, fish or aquatic plants.
- Instrument systems for hazardous environments such as volcanoes and severe storms.

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- Instrument systems for difficult to access areas such as sub-glacial waters.

Instrument systems to support field studies of fundamental processes are of interest, as well as for satellite measurement calibration and validation. Applicability to NASA's Airborne Science, Atmospheric Composition and Radiation Sciences, Ocean Biology and Biogeochemistry, and Applied Sciences programs is a priority. Support of the Integrated Ocean Observing System (IOOS) and regional coastal research is also desired.

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.

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

Lead Center: JPL

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

This subtopic solicits development of advanced instruments and instrument components that are tailored to the demands of planetary instrument deployment on a variety of space platforms (orbiters, flyby spacecraft, landers, rovers, balloon or other aerial vehicles, subsurface penetrators or impactors, etc.) accessing the wide variety of bodies in our solar system (inner and outer planets and their moons, comets, asteroids, etc.). These instruments must be capable of withstanding operation in space and planetary environmental extremes, which include temperature, pressure, radiation, and impact stresses. For example missions see:

http://science.hq.nasa.gov/missions/solar_system.html [29]

Specifically, this subtopic solicits instrument development that provides significant advances in the following areas:

- Improved science return and/or reduced mass, power, volume, data rates for instruments or instrument components (e.g., lasers and other light sources from UV to microwave, X-ray and ion sources, detectors, mixers, seismometers, etc.) or electronics (e.g., FPGA and ASIC implementations, advanced array readouts);
- Instrument technologies for detecting inorganic and organic biomarkers on future Mars missions;
- Improved robustness and g-force survivability for rough landings on planetary bodies;
- Radiation mitigation strategies, radiation tolerant detectors, and readout electronics components for candidate instruments for the Europa-Jupiter System Mission;
- Advanced sample acquisition and processing technologies, including fluid and gas storage, pumping, and manipulation, to support analytical instrumentation, sample return, or planetary protection.
- Sensors, mechanisms, and environmental chamber technologies for operation in Venus's high

temperature, high pressure environment with its unique atmospheric composition. Venus test chambers that can support evaluation of 50 to 100 cm sensors, instruments, and related structures are particularly requested.

Proposers are strongly encouraged to relate their proposed development to (a) future planetary exploration goals of NASA; and (b) existing flight instrument capability to provide a comparison metric for assessing proposed improvements. Proposed instrument architectures should be as simple, robust, and reliable as possible while enabling compelling science.

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

S1.10 Space Geodetic Observatory Components

Lead Center: GSFC

Participating Center(s): JPL

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

- Broadband feeds capable of receiving GNSS signals, Ka-band feeds integrated with broadband feeds, and matching antennas that meet or exceed the slewing and duty cycle requirements of the IVS VLBI2010 specifications.
- VLBI system components including > 4 Gbps recorders, phase/cable calibrators, and frequency standards / distribution systems that meet or exceed the requirements of the IVS VLBI2010 specifications.
- Cost-effective data transmission for e-VLBI from a global network of 30 VLBI stations operating up to 8 Gbps.
- Compact, low mass, space-qualified for MEO, SLR retroreflector arrays with greater than 100 million square meter lidar cross section, with a design that assures the ability to determine the array center to the center of mass of the spacecraft to a millimeter.
- A very high quantum efficiency (>50% at 532nm), low instrument noise, multi-pixelated detector for SLR use in the automated tracking.
- Wide band GNSS antenna and RF front-end technologies accommodating all expected GNSS signals in the next decade, and offering at least an order of magnitude improvements over COTS devices in terms of multipath rejection, and stability of output relative to temperature.

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

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.

S1.11 Lunar Science Instruments and Technology

Lead Center: MSFC

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

NASA lunar robotic science missions support the high-priority goals identified in the 2007 National Research Council report, The Scientific Context for Exploration of the Moon: Final Report (http://www.nap.edu/catalog.php?record_id=11954 [30]). Future missions will characterize the lunar exosphere and surface environment; field test new equipment, technologies, and approaches for performing lunar science; identify landing sites and emplace infrastructure to support robotic and human exploration; demonstrate and validate heritage systems for exploration missions; and provide operational experience in the harsh lunar environment.

Space-qualified instruments are required to perform remote and in situ lunar science investigations, to include measurements of lunar dust composition, reactivity and transport, searching for water ice, assessing the radiation environment, gathering long period measurements of the lunar exosphere, and conducting surface and subsurface geophysical measurements.

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

Geophysical Measurements

Systems, subsystems, and components for seismometers and heat flow sensors capable of long-term continuous operation over multiple lunar day/night cycles with improved sensitivity at lower mass and reduced power consumption compared to the Apollo Lunar Surface Experiments Package (ALSEP) instruments (<http://www.hq.nasa.gov/alsj/frame.html> [31]). Instrument deployment options include robotic deployment from soft Landers, as well as emplacement by hard landers or penetrators. Also of interest are portable surface ground penetrating radars with antenna frequencies of 250-MHz, 500-MHz, and 1000-MHz to characterize the thickness of the lunar regolith. Also of interest are accurate, low mass, thermally stable hollow cubes and retroreflector array assemblies for lunar surface laser ranging.

In Situ Lunar Surface Measurements

Light-weight and power efficient instruments that enable elemental and/or mineralogy analysis using techniques such as high-sensitivity X-ray and UV-fluorescence spectrometers, UV-fluorescence flash lamp/camera systems, scanning electron microscopy with chemical analysis capability; time-of-flight mass spectrometry, gas chromatography and tunable diode laser (TDL) sensors for in situ isotopic and elemental analysis of evolved volatiles, calorimetry, and Laser Induced Breakdown Spectroscopy (LIBS). Instruments shall have the potential to provide isotope ratio measurements and/or hydrogen distributions to ± 10 ppm locally. Characterizing the meteoroid

and subsequent eject flux environment and measurements of surface and deep dielectric charging on the lunar surface should be considered. Also, self calibrating instruments to measure surface and deep dielectric charging on a variety of materials encompassing conductors, semi-conductors, and insulators are another area. Instrument deployment options include robotic deployment from soft Landers, as well as emplacement by hard Landers or penetrators.

Lunar Atmosphere and Dust Environment Measurements

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

Lunar Regolith Particle Analysis

A substantial portion of the particles in the Lunar Regolith are smaller than the integration volume of e-beam analytical equipment, making automated quantitative analysis extremely difficult using available approaches. Therefore, software development is sought 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 cathode luminescence and EDS X-ray. The said software would then use standard image processing tools to resample to common scales, perform appropriate discriminant analysis using the high resolution data, mixed pixel inversion, image segmentation to extract particles, and correlate chemistry with products of the discriminant analysis.

Research should be conducted to demonstrate technical feasibility during Phase 1 and show a path toward a Phase 2 hardware and software demonstration, and when possible, deliver a demonstration unit or software package for NASA testing at the completion of the Phase 2 contract.

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.

Advanced Telescope Systems Topic S2

The NASA Science Missions Directorate seeks technology for cost-effective high-performance advanced space telescopes for astrophysics and Earth science. Astrophysics applications require large aperture light-weight highly

reflecting mirrors, deployable large structures and innovative metrology, control of unwanted radiation for high-contrast optics, precision formation flying for synthetic aperture telescopes, and cryogenic optics to enable far infrared telescopes. A few of the new astrophysics telescopes and their subsystems will require operation at cryogenic temperatures as cold 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://constellation.gsfc.nasa.gov/> [32], <http://lisa.gsfc.nasa.gov/> [33]). Also sought are technologies (analysis, algorithms, and testbeds) to enable detailed analysis, synthesis, modeling, and visualization of such distributed systems.

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

Innovations are solicited for: (a) sensor systems for inertial alignment of multiple vehicles with separations of 10,000 - 100,000 km to accuracy of 1 - 50 milli-arcseconds; (b) development of nanometer to sub-nanometer metrology for measuring inter-spacecraft range and/or bearing for space telescopes and interferometers; (c) control approaches to maintain line-of-sight between two vehicles in inertial space near Sun-Earth L2 to milli-arcsecond levels accuracy; (d) development of combined cm-to-nanometer-level precision formation flying control of numerous spacecraft and their optics to enable large baseline, sparse aperture UV/optical and X-ray telescopes and interferometers for ultra-high angular resolution imagery. Proposals addressing staged-control experiments which combine coarse formation control with fine-level wavefront sensing based control are encouraged.

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

- Distributed, multi-timing, high fidelity simulations;
- Formation modeling techniques;
- Precision guidance and control architectures and design methodologies;
- Centralized and decentralized formation estimation;

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- Distributed sensor fusion;
 - RF and optical precision metrology systems;
 - Formation sensors;
 - Precision microthrusters/actuators;
 - Autonomous reconfigurable formation techniques;
 - Optimal, synchronized, maneuver design methodologies;
 - Collision avoidance mechanisms;
 - Formation management and station keeping.

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

S2.02 Proximity Glare Suppression for Astronomical Coronagraphy

Lead Center: JPL

Participating Center(s): ARC, GSFC

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

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

Starlight Suppression Technologies

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- Advanced starlight canceling coronagraphic instrument concepts;
 - Advanced aperture apodization and aperture shaping techniques;
 - Pupil plane masks for interferometry;
 - 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 in homogeneity, 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;
 - Single mode fiber filtering from visible to $20 \mu\text{m}$ wavelength;
 - Methods of polarization control and polarization apodization; and
 - Components and methods to insure amplitude uniformity in both coronagraphs and interferometers, specifically materials, processes, and metrology to insure coating uniformity.

Wavefront Control Technologies

- Development of small stroke, high precision, deformable mirrors and associated driving electronics scalable to 10^4 or more actuators (both to further the state-of-the-art towards flight-like hardware and to explore novel concepts). Multiple deformable mirror technologies in various phases of development and processes are encouraged to ultimately improve the state-of-the-art in deformable mirror technology. Process improvements are needed to improve repeatability, yield, and performance precision of current devices;
- Development of instruments to perform broad-band sensing of wavefronts and distinguish amplitude and phase in the wavefront;
- Adaptive optics actuators, integrated mirror/actuator programmable deformable mirror;
- Reliability and qualification of actuators and structures in deformable mirrors to eliminate or mitigate single actuator failures;
- Multiplexer development for electrical connection to deformable mirrors that has ultra-low power dissipation;
- High precision wavefront error sensing and control techniques to improve and advance coronagraphic imaging performance; and
- Highly reflecting broadband coatings.

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 the Single Aperture Far-IR (SAFIR) telescope, Terrestrial Planet Finder (TPF, http://planetquest.jpl.nasa.gov/TPF/tpf_index.cfm [34]) missions: Coronagraph, External Occulter and Interferometer, ATLAST, Life Finder, and Submillimeter Probe of the Evolution of Cosmic Structure (SPECS), and the UV Optical Imager (UVOIR) require 10 - 30 m class cost effective telescope observatories that are diffraction limited at wavelengths from the visible to the far IR, and operate at temperatures from 4 - 300 K. The desired areal density is 1 - 10 kg/m². Static and dynamic wavefront error tolerances to thermal and dynamic perturbations may be achieved through passive means (e.g., via a high stiffness system, passive thermal control, jitter isolation or damping) or through active opto-mechanical control. Large deployable multi-layer structures in support of sunshades for passive thermal control and 20m to 50m class planet finding external occulter are also relevant technologies. Potential architecture implementations must package into an existing launch volume, deploy and be self-aligning to the micron level. The target space environment is expected to be L2.

This topic solicits proposals to develop enabling, cost effective component and subsystem technology for these telescopes. Research areas of particular interest include precision deployable structures and metrology (i.e., innovative active or passive deployable primary or secondary support structures); innovative concepts for packaging fully integrated (i.e., including power distribution, sensing, and control components); distributed and localized actuation systems; deployment packaging and mechanisms; active opto-mechanical control distributed on or within the structure; actuator systems for alignment of reflector panels (order of cm stroke actuators, lightweight, nanometer stability); innovative architectures, materials, packaging and deployment of large sunshields and external occulter; mechanical, inflatable, or other deployable technologies; new thermally-stable materials (CTE

Also of interest are innovative metrology systems for direct measurement of the optical elements or their supporting structure; requirements for micron level absolute and subnanometer relative metrology for multiple locations on the primary mirror; measurement of the metering truss; and innovative systems which minimize complexity, mass, power and cost. The goal for this effort is to mature technologies that can be used to fabricate 20 m class or greater, lightweight, ambient or cryogenic flight-qualified observatory systems. Proposals to fabricate demonstration components and subsystems with direct scalability to flight systems through validated models will be given preference. The target launch volume and expected disturbances, along with the estimate of system performance, should be included in the discussion. A successful proposal shows a path toward a Phase 2 delivery of demonstration hardware scalable to 3 m for characterization.

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

S2.04 Advanced Optical Component Systems

Lead Center: MSFC

Participating Center(s): GSFC, JPL

Future launch systems (such as the planned Ares V) will enable extremely large and/or extremely massive space telescopes. Potential systems include 12 to 30 meter class segmented primary mirrors for UV/optical or infrared wavelengths and 8 to 16 meter class segmented x-ray telescope mirrors.

These potential future space telescopes have very specific mirror technology needs. UV/optical telescopes (such as ATLAST-16 and ST-2020) require 1 to 3 meter class mirrors with

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

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

An additional key enabling technology for UV/optical telescopes is a broadband (from 100 nm to 2500 nm) high-reflectivity mirror coating with extremely uniform amplitude and polarization properties which can be deposited on 1 to 3 meter class mirror.

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

An ideal Phase 1 deliverable would be a near UV, visible or x-ray precision mirror, lens or replicating mandrel of at least 0.25 meters. The Phase 2 project would further advance the technology to produce a space-qualifiable precision mirror, lens or mandrel greater than 0.5 meters, with a TRL in the 4 to 5 range. Both deliverables would be accompanied by all necessary documentation, including the optical performance assessment and all data on processing and properties of its substrate materials. The Phase 2 would also include a mechanical and thermal stability analysis.

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

S2.05 Optics Manufacturing and Metrology for Telescope Optical Surfaces

Lead Center: GSFC

Participating Center(s): JPL, MSFC

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

JDEM concepts: <http://universe.nasa.gov/program/probes/jdem.html> [35],

IXO: <http://ixo.gsfc.nasa.gov/> [25],

LISA: <http://lisa.gsfc.nasa.gov/> [33],

ICESAT: <http://icesat.gsfc.nasa.gov/> [36], CLARREO, and ACE.

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

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

By the end of a Phase 2 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:

- 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 (PIAA).

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

Spacecraft and Platform Subsystems Topic S3

The Science Mission Directorate will carry out the scientific exploration of our Earth, the planets, moons, comets, and asteroids of our Solar System and beyond. SMD's future direction will be moving from exploratory missions (orbiters and flybys) into more detailed/specific exploration missions that are at or near the surface of where we want to explore (landers, rovers, and sample returns), that would require new vantage points, or that would need to integrate or distribute capabilities across multiple assets. Future destinations will be more challenging to get to, have more extreme environmental conditions and challenges once you get there, and may be a challenge to get a spacecraft or data back from. A major objective of the NASA science spacecraft systems development programs is to enable science measurement capabilities using smaller and lower cost spacecraft to meet multiple mission requirements thus making the best use of our limited resources. To accomplish this objective, NASA is seeking innovations to significantly improve subsystem capabilities while reducing the mass and cost, that would in turn enable increased scientific return for future NASA missions. Innovations are sought in the areas of: Command, Data Handling, and Electronics; Thermal Control Systems; Power Generation and Conversion; Propulsion Systems; Power Management and Storage; Guidance, Navigation and Control; Sensor and Platform Data Processing & Control; Planetary Ascent Vehicles; Unmanned Aerial Vehicles and Terrestrial Balloons.
Sub Topics:

S3.01 Command, Data Handling, and Electronics

Lead Center: GSFC

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

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

<http://nasascience.nasa.gov/search?SearchableText=missions+under+development> [37]
http://www.nap.edu/catalog.php?record_id=10432 [38]

The subtopic goals are to: (1) develop high-performance processors and memory architectures and reliable electronic systems, and (2) develop an avionics architecture that is flexible, scalable, extensible, adaptable, and reusable. The subtopic objective is to elicit novel architectural concepts and component technologies that are realistic and operate effectively and credibly in environments consistent with the future NASA Science missions.

Successful proposal concepts should significantly advance the state-of-the-art. Proposals should clearly (1) state what the product is; (2) describe how it targets the technical priorities listed below; and (3) outline the feasibility of the technical and programmatic approach. If a Phase 2 proposal is awarded, the combined Phase 1 and Phase 2 developments should produce a prototype that can be characterized by NASA. The technology priorities sought are listed below.

Command and Data Handling

- 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 (>500 MIPS at >100 MIPS/W for general purpose processing platforms, >5 GMACs at >5 GMACS/W for computationally-intensive processing platforms), and tolerance to total dose and single-event radiation effects. Concepts must include tools required to support an integrated hardware/software development flow.
- Radiation-hardened non-volatile low power memories.
- Radiation-hardened physical layer components for onboard data busses (e.g. Ethernet).
- Tunable, scalable, reconfigurable, adaptive fault-tolerant avionics.

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.

The Small Spacecraft Build effort highlighted in Topic S4 (Low-cost Small Spacecraft and Technologies) of the solicitation participates in this subtopic. Offerors are encouraged to take this in consideration as a possible flight opportunity when proposing work to this subtopic.

S3.02 Thermal Control Systems

Lead Center: GSFC

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

Future Spacecraft and instruments for NASA's Science Mission Directorate will require increasingly sophisticated thermal control technology. Some of these requirements include:

1. Optical systems, lasers and detectors require tight temperature control, often to better than $\pm 1^\circ\text{C}$. Some new missions such as LISA require thermal gradients held to even tighter micro-degree levels.
2. Exploration science missions beyond earth orbit present engineering challenges requiring systems which are more self-sufficient and reliable.
3. The introduction of low-cost, small, rapidly configured spacecraft requires the development of new thermal technologies to reduce the time and costs typically required for analysis, design, integration, and testing of the spacecraft.

Innovative proposals for the cross-cutting thermal control discipline are sought in the following areas:

- Methods of precise temperature measurement and control to tight temperature levels.
- High conductivity, vacuum-compatible interface materials to minimize losses across make/break interfaces.
- High conductivity materials to minimize temperature gradients and provide high efficiency light-weight radiators, including interfaces to heat pipes and fluid loops that overcomes issues with CTE mismatch.
- Advanced more efficient thermoelectric coolers capable of providing cooling at ambient and cryogenic temperatures,
- 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.
- Single and two-phase mechanically pumped fluid loop systems which accommodate multiple heat sources and sinks, and long life, lightweight pumps for these systems. Also includes advanced fluid system components such as accumulators, valves, pumps, flow rate sensors, etc. optimized for improved reliability, long life, and low resource needs.
- Phase change systems for Mars or Lunar applications. Reusable phase change systems are desired which can be employed to absorb transient heat dissipations during instrument operations. Technology is sought for phase change systems which can then either store this energy or provide an exothermic process which would provide heat for instrument power-on after the dormant phase.
- Ionic liquids, salts composed of separate cations and anions, have been known but not intensely studied. Because of their tunable and thus extremely favorable solvent and materials properties, ionic liquids are potentially useful for a wide range of space applications, e.g. liquid-mirror telescopes and heat transfer of fluids that could enhance lunar regolith geothermal potential many-fold.
- Efficient, lightweight, oil-less, high lift vapor compression systems or novel new technologies for high performance cooling up to 2 KW.
- Advanced thermal modeling techniques that can be easily integrated into existing codes, emphasizing inclusion of two-phase systems and mechanically pumped system models.
- Integration of standardized formats into existing analytical codes for the representation and exchange of

thermal network models and thermal geometric models and results.

- Analytical codes to automate the generation of reduced thermal models from larger models, including routines to verify the accuracy of the reduced models.

Research should be conducted to demonstrate technical feasibility during Phase 1 and show a path toward a Phase 2 hardware and software demonstration. Phase 2 should deliver a demonstration unit or software package for NASA testing at the completion of the Phase 2 contract.

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.

S3.03 Power Generation and Conversion

Lead Center: GRC

Participating Center(s): 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

Improvements are solicited in component and systems technology relevant to Stirling and thermophotovoltaic power conversion. For Stirling conversion, advances sought, but not limited to, include:

- Novel methods or approaches for radiation-tolerant, sensorless, autonomous control of Stirling converters with very low vibration and having low mass, size, and electromagnetic interference (EMI);
- High-temperature, high-performance regenerators and linear alternators;
- Advances applicable to Venus surface missions including high-temperature heater heads (> 850°C), joining techniques and regenerators (~1200°C), and combined electrical power generation and cooling

systems applicable to Venus surface missions (~1200°C);

- Concepts for Stirling engine power from cold energy lunar regolith down to 2-3 meters below the surface, including Stirling Engines that will provide up to 100 watts with a mass less than 50kg for the surface lunar environment with the hot side operating at about 256 K and a cold side at about 100 degrees lower.

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.

Photovoltaic Energy Conversion

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

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

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.

S3.04 Propulsion Systems

Lead Center: GRC

Participating Center(s): JPL

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

Chemical systems for sample return missions should focus on component technologies for high-pressure (>700 psi) chemical systems such as:

- Lightweight tanks;
- Actuators and regulators;
- Self pressurizing propellants.

This subtopic also seeks proposals that explore uses of technologies that will provide superior performance in electric propulsion systems. These technologies include:

- Hall thruster power processing unit (PPU) capable of 3 ½ kW, 5A, and 700 V with a maximum mass of 5.25 kg;
- High specific impulse/low mass electric propulsion systems for sample return missions;
- Future low cost/low mass electric propulsion systems;
- Thrusters should provide thrust up to 20 mN with a specific impulse between 1600 to 3500 seconds;

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- Corresponding power processing units capable up to 1 kW of input power;
 - The total system mass should not exceed 3 kgs (roughly 1 kg for a thruster and 2 kg for a PPU).

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.

S3.05 Power Management and Storage

Lead Center: GRC

Participating Center(s): JPL

Future NASA science objectives will include missions such as Earth Orbiting, Venus, Europa, Titan and Lunar Quest. Under this subtopic, proposals are solicited to develop energy storage and power electronics to enable or enhance the capabilities of future science missions. The unique requirements for the power systems for these missions can vary greatly, with advancements in components needed above the current State of the Art (SOA) for long life, high reliability, low mass/volume, radiation tolerance, and wide temperature operation. Other subtopics which could potentially benefit from these technology developments include X1.03 Radiation Hardened/Tolerant and Low Temperature Electronics and Processors. Battery development could also be beneficial to X7.01 Advanced Space-rated Batteries which is investigating similar, but different technologies.

Energy Storage

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

Power Management and Distribution (PMAD)

Advanced electrical power technologies are required for the electrical components and systems on future platforms to address the size, mass, efficiency, capacity, durability, and reliability requirements. Of importance are expected improvements in energy density, speed, efficiency, or wide-temperature operation (-125°C to over 450°C) with a number of thermal cycles. Advancements are sought for power electronic devices, components and packaging for Venus type missions with power ranges of a few watts for minimum missions up to a few hundred watts for large missions. In addition, advancements in components or architectures for application to Radioisotope Electric Propulsion (REP) PMAD systems are considered beneficial. Technologies of interest include:

- High temperature devices and components (up to 450°C);

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- Advanced electronic packaging for thermal control and electromagnetic shielding.

Research should be conducted to demonstrate technical feasibility during Phase 1 and show a path toward a Phase 2, and when possible, deliver a demonstration unit for NASA testing at the completion of the Phase 2 contract. Phase 2 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.

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.

S3.06 Guidance, Navigation and Control

Lead Center: GSFC

Participating Center(s): ARC, JPL

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

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

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

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

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

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

S3.07 Sensor and Platform Data Processing and Control

Lead Center: GSFC

Participating Center(s): ARC, JPL

Future NASA's science missions will require high-performance onboard data processing capabilities that far exceed those of today. These capabilities will be leveraged to provide data reduction for missions where sensor bandwidths far exceed downlink bandwidth. Improved onboard data processing will also enable autonomous/collaborative systems, where science operations are autonomously controlled via features extracted from the sensor data. Advances in technologies relevant to sensor and platform data processing and control are sought to support NASA's goals and several missions and projects under development.

<http://nasascience.nasa.gov/search?SearchableText=missions+under+development> [37]

http://www.nap.edu/catalog.php?record_id=10432 [38]

The subtopic goals are to: (1) develop device technologies and architectures that can yield a 10x to 100x improvement in on-board computing power is required to enable the next generation of Earth Science, Space Science and Exploration missions; and (2) develop tool technologies that can enable rapid development of high reliability, high performance onboard data processing applications for these missions.

Successful proposal concepts will significantly exceed the present state-of-the-art. Proposals will clearly (1) state what the product is; (2) describe how it targets the technical priorities listed below; and (3) outline the feasibility of the technical and programmatic approach. If a Phase 2 proposal is awarded, the combined Phase 1 and Phase 2 developments shall produce a prototype that is testable by NASA. The technology priorities sought are listed below.

Device Technologies and Architectures

- Highly reliable, radiation tolerant, special purpose data processing devices (FPGA, multi-core, DSP) that enable accelerated onboard data processing;
- Hybrid onboard processing architectures using multiple heterogeneous processing elements (CPU, FPGA, DSP, multi-core);
- Architectures providing software-based radiation mitigation strategies for commercial processing elements.

Development Tool Technologies

- Hybrid system design tools that (a) take full advantage of hybrid processing platforms, and (b) automate/accelerate the design and verification process.

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.

S3.08 Planetary Ascent Vehicles

Lead Center: GRC

Participating Center(s): AFRC, JPL, MSFC

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

Advanced solid propellant engine system technologies:

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

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

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

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.

S3.09 Technologies for Unmanned Atmospheric Platforms

Lead Center: AFRC

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

Unmanned Aerial Vehicles (UAVs) offer significant potential new capabilities for scientific earth exploration over a large range of mission durations, altitudes, and geographical locations. UAVs can carry earth resources remote sensing and atmospheric sampling instruments on scientific investigations including the Polar Regions. The potential for these robotic systems has just begun to be realized, and to date their earth observation and atmospheric sampling capabilities are in a state of infancy when compared to platform requirements needed to address national concern over global climate and environmental changes. Current UAV operations are restricted from operations in inclement weather particularly when airframe icing or freezing of fuel may become issues. Airframe icing limits both aircraft flight envelope and may affect scientific payload operations.

UAVs must adhere to regulatory requirements for flight operations within the national airspace. These regulatory issues pose challenges to the trade space of potential solutions. UAVs can be roughly categorized into 1) larger/high value assets and 2) smaller/lower value or expendable assets. Such categorization of UAVs may drive different technology solutions to meet the technology needs as described below.

- Precision flight path control for highly repeatable terrain monitoring over daily, seasonal or multi-year cycles;
- Highly accurate UAV platform attitude control with corresponding science payload instrument stability and pointing accuracy;
- Lower-cost over-the-horizon telemetry alternatives for real-time collaborative data sharing and decision-making involving multiple in-flight and ground-based instruments;
- Drop-sonde and surface sampling probes remote from the unmanned aircraft;
- Airframe icing detection and mitigation to enable UAV severe weather flight operations;
- UAV flight systems to enable long endurance inclement weather operations; systems such as fuel anti-freezing thermal management will be needed.

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

S3.10 Terrestrial Balloon Technologies

Lead Center: GSFC

Currently, NASA is developing a Super Pressure terrestrial vehicle targeting 100 day duration missions in mid-latitude. This added capability will greatly enable new science investigations. The design of the current pumpkin shape vehicle utilizes light weight polyethylene film and high strength tendons made of twisted Zylon® yarn. The in-flight performance and health of the vehicle relies on accurate information on a number of environmental, design, and operational parameters. Therefore, NASA is seeking innovations in the following specific areas:

Balloon Instrumentation

Devices or methods to accurately and continuously measure ambient air, helium gas, balloon film temperatures, and film strain. These measurements are needed to accurately model the balloon performance during a typical flight at altitudes of approximately 120,000 feet. The measurements must compensate for the effects of direct solar radiation through shielding or calculation. Minimal mass and volume are highly desired. For film measurements, a non-invasive and non-contact approach is highly desired for the thin polyethylene film used as the balloon envelope, with film thickness ranging from 0.8 to 1.5 mil. The devices of interest 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 telemetry solution be provided.

Device and method to recover a scientific balloon from Antarctica

Scientific balloons are recovered after flight from the interior of Antarctica. These balloons are either loaded onto aircraft used for remote field operation support, or are loaded upon passing overland traverse vehicles to carry back to McMurdo Station for later disposal. Better methods and/or equipment are needed to expedite the operation and reduce the burden on resources used for recovery of scientific balloons in Antarctica. Current methods to recover balloons are resource and time intensive. In these remote locations, resources and available time are limited. Balloons must be cut up into bundles of manageable size and weight in order to fit inside aircraft that are currently used in support of the United States Antarctic Program (USAP). Scientific balloons weigh up to approximately 2000 kg. The balloon is made up of layers of polyethylene film that are 0.8 to 1.5 mil thick. Each balloon is made up of approximately 200 gores that are heat-sealed together. Each gore seal incorporates load tendons that are made of either polyester load tapes or woven Zylon® fibers. Each balloon incorporates metal end-fittings that can be cut out by hand. Folds, twists and binding of material are characteristics of balloons being recovered. The Antarctic operating environment can be -50 degrees Celsius. Environmental sensitivity is also an issue in Antarctica. Existing aircraft recovery assets include ski-equipped Twin Otters and a DC-3 Basler.

Devices or methods to accurately and continuously measure individual axial loading on an array of ~50 or up to 300 separate tendons during a Super Pressure balloon mission

Tendons are the load carrying member in the pumpkin design. During a typical mission, loading on individual tendons should not exceed a critical design limit to ensure structural integrity and survival. Tendons are typically captured at the fitting via individual pins. Loading levels on the tendons can range from ~20 N to ~8,000 N and temperature can vary from room temperature to the troposphere temperatures of -90 degrees Celsius or colder. The devices of interest shall be easily integrated with the tendons or fittings during balloon fabrication and shall have minimal impact on the overall mass of the balloon system. Support telemetry and instrumentation is 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.

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.

Low-Cost Small Spacecraft and Technologies Topic S4

This subtopic is targeted at the development of technologies and systems, which can enable the realization of small spacecraft science and exploration 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 in the areas of avionics, attitude determination and control, and spacecraft integration planning and management. The primary thrust of this topic is directed at reducing the footprint and resources that these bus subsystems require (power, mass, and volume), 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.

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 1 and show a path toward a Phase 2 hardware and/or software demonstration, and when possible, deliver a demonstration unit or software package for NASA testing at the completion of the Phase 2 contract.

Sub Topics:

S4.01 Radiation Hardened High-Density Memory, High Speed Memory Controllers, Data Busses

Lead Center: ARC

There has been considerable progress in the development of low cost high-density memory in the consumer electronics industry. However, spacecraft memory capacities can be orders of magnitude smaller than a desktop computer hard drive. Therefore, NASA has an interest in the development of low cost, high-density memory suitable for spaceflight applications including operations in near and deep space radiation and temperature environments. High-density, radiation-tolerant memory can be beneficial for Astrophysics, Earth Sciences,

Heliophysics and Planetary missions where instruments, such as large-scale imagers and spectrometers can quickly produce large amounts of data.

Proposals are sought for radiation-tolerant high-density memory systems that can address or consider the following performance parameters:

- Storage capabilities of up to 192 Gigabytes of data on single 3U card form factor, suitable for inclusion within integrated avionics units and 3U chassis;
- Units that utilize the Space Plug and Play Architecture (SPA) developed at AFRL (See <http://www.dukeworks.org> [39]);
- Tolerate standard internal spacecraft bus operating temperatures of -25°C to 40°C;
- Tolerate space radiation with Total Ionizing Dose (TID) of 10-400kRad (Si) with an average goal of 100kRad (Si);
- Capable of surviving space launch environments.

Although these are baseline goals, proposals that are able to achieve near comparable values will also be considered.

The proposer to this subtopic is advised that the products proposed may be included in a future small satellite flight opportunity.

S4.02 Radiation Hardened Integrated Unit: GPS/IMU/Time/Processor

Lead Center: ARC

Participating Center(s): GSFC

Many subsystems and components are gaining benefit from miniaturization and reduction in mass and power requirements. Often many different avionic control system components are necessary for small spacecraft missions with stringent pointing requirements. A considerable saving in mass, power, and system complexity can be obtained by integrating components into a single unit. Of particular interest is a GPS, IMU, and timing signal combination in a single unit with an internal low-power processor to perform the internal calculations to provide the spacecraft with the necessary location and attitude knowledge.

Proposals are sought for an integrated GPS, IMU, and timing signal unit coupled with a low power processor to provide the necessary signals to spacecraft components.

The integrated unit should address or consider the following performance parameters:

- Mass less than 2.5kg
- Average power usage less than 15W
- GPS:
 - Position accuracy: 1-5m
 - Velocity accuracy: 1m/s
 - Time to first fix: 1 minute
 - Use L1 signals; desirable to incorporate L2 signals
- IMU:
 - Rate Range: 500 deg/sec
 - Bias repeatability: 0.005 deg/hr
 - Scale Factor Accuracy: 1 to 5 ppm
 - Angle random walk: 0.005 deg/rt-hr
- Timing:
 - 10^{-8} to 10^{-10} Allan deviation
- Able to tolerate an acceleration load of ~25g
- Stable over standard internal spacecraft bus operating temperatures of -25°C to 40°C
- Radiation tolerant with Total Ionizing Dose (TID) of 10 - 400 kRad (Si) with an average goal of 100 kRad (Si)
- Compatible with the Space Plug and Play Architecture (SPA) developed at AFRL (See <http://www.dukeworks.org> [39] for information on SPA)
- Capable of surviving space launch environments

Although these are baseline goals, proposals that are able to achieve near comparable values will also be considered.

The proposer to this subtopic is advised that the products proposed may be included in a future small satellite flight opportunity.

S4.03 Wireless Data and/or Power Connectivity for Small Spacecraft

Lead Center: ARC

Participating Center(s): GSFC, JPL

New advances in wireless connectivity for mobile computing and other electronic devices have opened up the possibilities for wireless spacecraft busses. There are two potential applications, the transfer of data, commands, and signals and delivery of power to components. The use of wireless technology can be beneficial to small spacecraft designs by eliminating the need for data and power connects, thus reducing spacecraft overall mass and volume requirements. Wireless applications for a spacecraft bus must also ensure that the many different signals do not interfere and there is complete transfer of data and power.

The proposed wireless technologies should address or consider the following performance parameters:

- Data transmission capability from 5 - 100 unique devices within the spacecraft;
- Data transfer rates of 500 Megabits per second to 1 Gigabit per second per device;
- Scalable wireless power transfer from ~1mW up to ~20W;
- Overall wireless architecture mass from 3-50kg dependent on the size of the spacecraft bus;
- Both systems (power and data) should be capable of utilizing the Space Plug-and-Play Architecture (SPA) developed by the AFRL. See <http://www.dukeworks.org> [39] for information on SPA;
- Power and data architectures should be tolerant to the space environment including temperatures (25°C to 40°C) and radiation ;
- Capable of surviving space launch environments.

Although these are baseline goals, proposals that are able to achieve near comparable values will also be considered.

The proposer to this subtopic is advised that the products proposed may be included in a future small satellite flight opportunity.

S4.04 Low Cost, High Accuracy Timing Signals

Lead Center: ARC

Participating Center(s): GSFC

Radio science is an important element of many missions, including small spacecraft missions, to planetary bodies and asteroids where mass determination is derived from perturbations of the spacecraft trajectory by the body. Traditionally these missions have required the inclusion of an Ultra Stable Oscillator (USO) with timing signal accuracy on the order of 10^{-12} to 10^{-13} Allan Deviation. Unfortunately these devices are currently prohibitively expensive for low cost missions. Other devices such as precision clocks can provide accuracy on the order of 10^{-8} Allan Deviation. It is envisioned that recent improvements in timing signal devices from other industries or new developments can provide a significant reduction in cost while still providing the necessary accuracy in the timing signal.

Proposals are sought for highly accurate timing signals that address or consider the following performance parameters:

- Provide timing signals with an accuracy of 10^{-10} to 10^{-12} Allan deviation;
- Be capable of utilizing the Space Plug-and-Play Architecture (SPA) developed at AFRL (See <http://www.dukeworks.org> [39]);
- Small enough to fit within a 3U form factor or integrated avionics chassis;
- Mass less than 1kg;
- Power draw less than 5W;
- Stable over standard internal spacecraft bus operating temperatures of -25°C to 40°C;
- Radiation tolerant with Total Ionizing Dose (TID) of 10 - 400 kRad (Si) with an average goal of 100 kRad (Si);
- Capable of surviving space launch environments.

Although these are baseline goals, proposals that are able to achieve near comparable values will also be considered.

The proposer to this subtopic is advised that the products proposed may be included in a future small satellite flight opportunity.

S4.05 High Torque, Low Jitter Reaction Wheels or Control Moment Gyros

Lead Center: ARC

NASA is becoming increasingly interested in using small spacecraft to execute space missions where possible. Many of these missions will require low cost, high torque and low jitter reaction wheels or control moment gyros. Currently there are limited sources of these systems applicable for small spacecraft. Therefore, development of a family of reaction wheels with the appropriate characteristics for nano- and small spacecraft (5 to 100 kg spacecraft mass) with reduced lead times will result in significant benefits to a number of NASA programs and missions.

Proposals are sought for the development of reaction wheels and/or control moment gyros with the following performance parameters:

- Mass less than 2 kg
- Average power usage less than 5W
- Compatible with the Space Plug-and-Play Architecture (SPA) developed at AFRL (See <http://www.dukeworks.org> [39])
- Reaction wheels
 - Angular momentum capacity of 1 to 2 Nms
 - Torque capacity greater than 50mN-m
 - Speed range greater than ± 20000 rpm
- Control Moment Gyros
 - Torques of 0.1 to 5 Nm
- Induced jitter noise TBR:
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- The use of built in control electronics with rate sensor abilities is also desirable
 - Rate sensor should have a range of 500 deg/sec
 - Drift rate 0.5 deg/hr

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- Stable over standard internal spacecraft bus operating temperatures of -25°C to 40°C
 - Radiation tolerant with Total Ionizing Dose (TID) of 10 - 400 kRad (Si) with an average goal of 100 kRad (Si)
 - Capable of surviving space launch environments

Although these are baseline goals, proposals that are able to achieve near comparable values will also be considered.

The proposer to this subtopic is advised that the products proposed may be included in a future small satellite flight opportunity.

S4.06 AI&T Planner and Scheduler

Lead Center: ARC

Proposals are sought for the development of a software tool (or suite of integrated tools) to assist in the planning, scheduling, and operations activities that occur during small spacecraft Assembly, Integration and Test (AI&T). AI&T is a complex period for small spacecraft with many different procedures, dependencies, operations, and tests occurring in parallel. To streamline the process and ensure compliance with mission and science requirements, NASA is interested in a software tool to support planning, scheduling, and management of the small spacecraft AI&T flow. The tool must be scalable for a variety of different mission and spacecraft classes from nanosatellites, which are typically secondary payloads weighing around 5 - 10 kg, up to primary sciences missions, which may weigh more than 100 kg.

Proposals are sought for the development of an AI&T tool with the following capabilities:

- Resource(s) availability determination and planning function
 - Facilities
 - Personnel
 - GSE
- Requirement mapping for qualification tests along with verification and validation functions
- Compatible with NASA proposal development processes to assist in a Phase A schedule and cost generation for the AI&T flow

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- Compatible with NASA NPR 7120.5D Program and Project planning requirements

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> [40] for mission information. See URL: <http://marstech.jpl.nasa.gov/> [41] for additional information on Mars Exploration technologies.

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

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

- Providing critical measurements during the entry phase (e.g., pressure and/or temperature sensors embedded into the aeroshell);
- Improving the accuracy on measurements needed for guidance decisions (e.g., surface relative velocities, altitudes, orientation, localization);

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- 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; and
 - Significantly reducing the impact of incorporating such sensors on the spacecraft in terms of volume, mass, placement, or cost.

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 [42]). Limited spacecraft resources (power, volume, mass, computational capabilities, and telemetry bandwidth) demand innovative, integrated sampling systems that can survive and operate in challenging environments (extremes in temperature, pressure, gravity, vibration and thermal cycling). Special interest lies in sampling systems and components (actuators, gearboxes, etc.) that are suitable for use in the extremely hot high pressure environment at the Venusian surface (460°C, 93 bar). Relevant systems could be integrated on multiple platforms, however of primary interest are samplers that could be mounted on a mobile platform, such as a rover. For reference, current Mars-relevant rovers range in mass from 200 - 800 kg.

Sample Acquisition

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

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

Sample manipulation technologies are needed to enable handling and transfer of structured and unstructured

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

Sample Integrity (encapsulation and contamination)

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

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

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

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

S5.03 Surface and Subsurface Robotic Exploration

Lead Center: JPL

Participating Center(s): ARC, GSFC, JSC

Technologies are needed to enable access and sample acquisition at surface and subsurface sampling sites of scientific interest on Mars or the Moon. Mobility technology is needed to enable access to difficult-to-reach sites such as access through difficult and steep terrain. Manipulation technologies are needed to deploy instruments and sampling tools from vehicles. Many scientifically valuable sites are accessible only via terrain that is too difficult or steep for state-of-the-art planetary rovers to traverse. Sites include crater walls, canyons, and gullies. Tethered systems, non-wheeled systems, and marsupial systems are examples of mobility technologies that are of interest. Tether technology could enable new approaches for deployment, retrieval and mobility. Innovative marsupial systems could allow a pair of vehicles with different mobility characteristics to collaborate to enable access to challenging terrain. Single vehicle systems might utilize a 200 kg class rover and dual vehicle systems might utilize a 500 - 800 kg primary vehicle that provides long traverse to the vicinity of a challenging site and then deployment of a smaller 20 - 50 kg vehicle with steep mobility capability for access and sampling at the site.

Technologies to enable acquisition of subsurface samples are also needed. For Mars in particular, technologies are needed to acquire core samples in the shallow subsurface to about 10cm and to enable subsurface sampling in multiple holes at least 1 - 3 meters deep through rock, regolith or ice compositions. Shallow subsurface sampling systems need to be low mass and deeper subsurface sampling solutions need to be integratable onto 500 - 800 kg stationary landers and mobile platforms. Consideration should be given for potential failure scenarios, such as platform slip and borehole misalignment for integrated systems, and the challenges of dry drilling into mixed media including icy mixtures of rock and regolith. Systems should ensure minimal contamination of samples from Earth-source contaminants and cross-contamination from samples at different locations or depths.

Innovative component technologies for low-mass, low-power, and modular systems are of particular interest. Technical feasibility should be demonstrated during Phase 1 and a full capability unit of at least TRL level 4 - 6 should be delivered in Phase 2. Specific areas of interest include the following:

- Tether play-out and retrieval systems including tension and length sensing;
- Low-mass tether cables with power and communication;
- Steep terrain adherence for vertical and horizontal mobility;
- Modular actuators with 1000:1 scale gear ratios;
- Electro-mechanical couplers to enable change out of instruments on an arm end-effector;
- Drill, core, and boring systems for subsurface sampling to 10cm or 1 to 3 meters.
- High power piezoelectric mechanisms for drilling into Lunar Regolith; must be able to deliver high torque for short impulses to clear any obstacles;
- Shared intelligence allowing systems to collaborate and adapt exploration scenarios to new conditions.

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

S5.04 Rendezvous and Docking Technologies for Orbiting Sample Capture

Lead Center: JPL

Participating Center(s): GSFC, JSC

NASA seeks an innovative suite of products or technologies that will enable and enhance the successful tracking and capture of a sample canister in Mars orbit.

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

Sample capture mechanisms are sought, of very low mass and volume, and of low complexity and extremely high reliability, including detection of contact with the capture mechanism. Appropriate on-sample radio-beacons are sought that are compatible with NASA's radio systems; requirements for these are for long life, and independent initiation of on-orbit operation. Sample capture mechanisms should include close-proximity/contact sensors, including immediate-field imaging.

Command and sequencing software is sought that will robustly operate the onboard GN&C systems, including providing health and safety monitoring of the rendezvous and capture operation, adaptive response to anomalies and abort commanding. Onboard resources can be assumed to be those necessary to perform navigation from images or other data, compute maneuvers, and maintain the spacecraft attitude.

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

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

- Autonomously actuated mechanisms for orbiting sample capture;
 - Mechanical capture mechanisms;
 - Transfer mechanisms from capture device to containment transfer mechanism;
- Optical and contact sensors;
 - Near field imagers (optical or other) (e.g. 10m to 1km);
 - Immediate field imagers (optical) (0.25 to 10m);
 - Detection of orbiting sample for triggering capture mechanism;

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- Near field illuminator;
 - Coherent Radio Doppler and range beacon (high-performance);
 - Low power, low mass and long life beacon for detection aid;
 - 2-way communication for activation, ranging and coherency;
 - Programmable intermittent transmission for power saving and very long dormancy period;
 - Simple Radio beacon (low-performance);
 - Simple 1-way beacon, for long-range detection and 1-way Electra Doppler extraction;
 - Timer activated, multi-year dormant life, and long active life battery;
 - Autonomous Rendezvous GN&C Command and Control system;
 - Utilize existing GN&C computation elements to command and sequence robust and safe rendezvous and capture;
 - Provide self-monitoring, correction and self-abort capability;
 - Provide for high-level Mission scenario design, monitoring and simple implementation;
 - Low-mass, low-cost sample OSC for proximity operations operational readiness tests;
 - A simple, low-cost, low-mass practice sample canister that could be deployed and provide low-risk practice runs, either for a precursor mission, or with the actual sample return mission;
 - The readiness test exercise would not capture the test article in the capture mechanism, but only perform the rendezvous and proximity ops operations.

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.

S5.05 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°C and a surface pressure of about 90 bars. Technologies of interest include high temperature electronics components, high temperature energy storage systems, light mass refrigeration systems, high temperature optical window systems (that are transparent in IR, visible and UV wavelengths) and pressure vessel components compatible with materials such as steel, titanium and beryllium such as low leak rate wide temperature (-50°C to 500°C) seals capable of operating between 0 and 90 bars.

Low Temperature Environments

Low temperature survivability is required for missions to Titan, the surface of Europa and comets. Also Moon equatorial regions experience wide temperature swings from -180°C to +130°C during the lunar day/night cycle, and the sustained temperature at the shadowed regions of lunar poles can be as low as -230°C. Mars diurnal temperature changes from about -120°C to +20°C. Proposals are sought for technologies that enable NASA's long duration missions to low temperature and wide temperature environments. Technologies of interests include low power rad-tolerant RF electronics, mixed signal electronics, power electronics, electronic packaging (including passives, connectors, wiring harness and materials used in advanced electronics assembly), actuators and energy storage sources capable of operating across an ultra-wide temperature range from -230°C to 200°C and computer Aided Design (CAD) tools for modeling and predicting the electrical performance, reliability, and life cycle for low-temperature electronic systems and components.

Research should be conducted to demonstrate technical feasibility during Phase 1 and show a path toward a Phase 2 hardware/software demonstration, and when possible, deliver a demonstration unit for functional and environmental testing at the completion of the Phase 2 contract.

S5.06 Planetary Balloon Technology

Lead Center: JPL

Innovations in materials, structures, and systems concepts have enabled buoyant vehicles to play an expanding role in planning NASA's future Solar System Exploration Program. Balloons and airships are expected to carry scientific payloads on Venus and Titan in order to investigate their atmospheres in situ and their surfaces from close proximity. Their envelopes will be subject to extreme environments and must support missions with a range of durations. Proposals are sought in the following areas:

Metal Balloons for High Temperature Venus Exploration

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

Rapid Buoyancy Modulation System for a Titan Montgolfiere Balloon

Montgolfiere, or hot air, balloons are under development for use on a future mission to Titan. While systems are feasible based on the waste heat from a radioisotope power system (RPS), the large thermal inertias make it dangerous for such balloons to fly near the surface because of their inability to quickly respond to atmospheric turbulence or approach topographic hazards. Proposals are therefore sought for a rapid buoyancy modulation system that can be integrated into a 10 m diameter Titan Montgolfiere balloon operating at 90 K and using a steady-state RPS heat source in the range of 2 - 4 kW. This system needs to be lightweight (less than 10 kg) and consume a small amount of electrical power (less than 5 W average).

Gas Management Systems for Titan Aerobots

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

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.

Information Technologies Topic S6

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

scientific knowledge and technological capabilities, to inspire and motivate the nation's students and teachers, and to engage and educate the public.

Sub Topics:

S6.01 Technologies for Large-Scale Numerical Simulation

Lead Center: ARC

Participating Center(s): GSFC

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

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

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

The approach of this subtopic is to seek novel software and hardware technologies that provide notable benefits to NASA's supercomputing users and facilities, and to infuse these technologies into NASA supercomputing operations. Successful technology development efforts under this subtopic would be considered for follow-on funding by, and infusion into, NASA's high-end computing (HEC) projects (<http://www.hec.nasa.gov/> [43]): 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 1 and show a path toward a Phase 2 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, many applications requiring tight coupling and high concurrency, complex computational workflows and immense datasets, and the need to support hundreds of complex application codes - many of which are frequently updated by the user/developer. As a result, solutions that involve the following must clearly explain how they would work in the NASA environment: Grid computing, web services, client-server models, embarrassingly parallel computations, and technologies that require significant application re-engineering. Projects need not benefit all NASA HEC users or application codes, but demonstrating applicability to an important NASA discipline, or even a key NASA application code, could provide significant value.

Specific technology areas of interest include:

- **Integrated Environments:** The user interface to a supercomputer is typically a command line in a text window. This subtopic element seeks more intuitive, intelligent, user-customized, and integrated interfaces to supercomputing resources, enabling users to more completely leverage the power of HEC to increase their productivity. Such an interface could enhance many essential supercomputing tasks: accessing and managing resources, training, getting services, developing codes, running computations, managing files and data, analyzing and visualizing results, transmitting data, collaborating, etc.
- **Efficient Computing:** In spite of the rapidly increasing capability and efficiency of supercomputers, NASA's HEC facilities cannot purchase, power, and cool sufficient HEC resources to satisfy all user demands. This subtopic element seeks dramatically more efficient and effective supercomputing approaches in terms of their ability to supply increased HEC capability or capacity per dollar and/or per Watt for real NASA applications. Examples include novel computational accelerators and architectures, more capable storage/interconnect/visualization technologies, improved algorithms for key codes, and power-aware "Green" computing technologies and techniques.
- **HEC Ecosystem Modeling:** NASA endeavors to maximize the productivity of its world-class HEC activities. To identify and prioritize improvement initiatives, this subtopic element seeks tools and techniques to routinely monitor and model the productivity of NASA's HEC ecosystem, including modeling change scenarios. The technology should model the workflows of HEC users, facility staff, and resources (supercomputers, storage, networks, etc.), and it should reflect constraints such as budget, power, and space. Offerors should minimize the effort of HEC staff to provide process information.
- **Archive Data Use:** NASA has a vast and rapidly growing wealth of Earth and space observational data, stored in various archives around the U.S. NASA's supercomputers could extract more value from this data and advance NASA's science missions through large-scale data analysis and visualization, and ingest into high-fidelity models. This subtopic element seeks technologies that facilitate efficient, automated use of data in NASA's observational data archives by its HEC centers and users.

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.

S6.02 Earth Science Applied Research and Decision Support

Lead Center: SSC

Participating Center(s): ARC, JPL

The NASA Applied Sciences Program (<http://nasascience.nasa.gov/earth-science/applied-sciences> [44]) seeks innovative and unique approaches to increase the utilization and extend the benefit of Earth Science research data to better meet societal needs. One area of interest is new decision support tools and systems for a variety of ecological applications such as managing coastal environments, natural resources or natural disasters.

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

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

This subtopic is also soliciting proposals for utilities, plug-ins or enhancements to open source geobrowsers that improve their utility for earth science research and decision support. Examples of geobrowsers include NASA World Wind, World Wind Java (http://worldwindcentral.com/wiki/Main_page [45]) and COAST (<http://www.coastal.ssc.nasa.gov/coast/COAST.aspx> [46]). Special consideration will be given to tools for COAST. Examples of specific interest are:

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

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

S6.03 Algorithms for Science Data Processing and Analysis

Lead Center: GSFC

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

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

Current operational missions listed at <http://www.nasa.gov/missions/current/index.html> [47]

- Landsat Data Continuity Mission (LDCM) (<http://ldcm.nasa.gov/> [48]),
- NPOES Preparatory Project (NPP) (<http://jointmission.gsfc.nasa.gov/> [49]),
- Lunar Reconnaissance Orbiter (LRO) (<http://lunar.gsfc.nasa.gov/> [50]),
- Orbiting Carbon Observatory (OCO) (<http://oco.jpl.nasa.gov/> [51]),
- Lunar Atmosphere and Dust Environment Explorer (LADEE) (<http://nasascience.nasa.gov/missions/ladee> [52]),
- Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) (<http://crism.jhuapl.edu> [53]),
- HypSIRI Earth orbiting hyperspectral instrument (<http://hyspirci.jpl.nasa.gov/> [54]),
- Visual Infrared Mapping Spectrometer (VIMS) on Cassini (<http://wwwvims.lpl.arizona.edu/> [55]),
- Moon Mineralogy Mapper (M3) on Chandrayaan (<http://moonmineralogymapper.jpl.nasa.gov/> [56]),
- James Webb Space Telescope (JWST) (<http://www.jwst.nasa.gov/> [57]).

Research proposed to this subtopic should demonstrate technical feasibility during Phase 1, in partnership with scientists, and subsequently show a path toward a Phase 2 prototype demonstration, with significant communication with missions and programs to ensure a successful Phase 3 infusion. Innovations are sought in data processing and analysis algorithms in the following areas:

- Optimization of Algorithms and Computational Methods that increase the utility of scientific research data, models, simulations, and visualizations. Of particular interest are innovative computational methods that will dramatically increase algorithm efficiency as well as the performance of scientific applications. Success will be measured by both speed improvements and output validation.
- Improvement of Data Collection, by identifying data gaps in real-time, and/or derive information through synthesis of data from multiple sources. The ultimate goal is to increase the value of data collected in terms of scientific discovery and application.
- Frameworks and Related Tools for Processing, Analyzing and Fusing image and vector data for the purpose of analyzing NASA's astrophysics, heliophysics, planetary and earth science mission data and therefore enable the advancement of NASA's scientific objectives. Of particular interest are open source

frameworks that would enable sharing and validation of tools and algorithms.

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

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

S6.04 Data Management - Storage, Mining and Visualization

Lead Center: GSFC

Participating Center(s): JPL, LaRC

This subtopic focuses on supporting science analysis through innovative approaches for managing and visualizing collections of science data which are extremely large, complicated, and highly distributed in a networked environment that encompasses large geographic areas. There are specific areas for which proposals are being sought:

- Collaborative visualization tools that enable data exploration, data sharing, and data manipulation among scientists worldwide that make use of innovative hardware and software technologies for data manipulation and display, including the use of large multi-touch input devices or 3 dimensional display devices.
- Social networking tools that enable secure high bandwidth scientific collaboration among scientists worldwide that promote the development of online communities for sharing thoughts and ideas and for arriving at consensus opinions and understanding.
- Tools for science data discovery, data mining, data search, and data subsetting in extremely large data sets in clustered processing and storage environments, cloud computing environments, or shared data and computation environments.
- Storage systems, file systems, and data management systems that promote the secure long term preservation of data in a distributed online storage environment, provide for recovery from system and user errors, and provide dynamically configurable high speed access to data shared over wide area high speed networks.

Research should be conducted to demonstrate technical feasibility during Phase 1 and show a path toward a Phase 2 hardware/software demonstration, and when possible, deliver a demonstration unit for functional and environmental testing at the completion of the Phase 2 contract.

S6.05 Software Engineering Tools for Scientific Models

Lead Center: GSFC

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

Target Programs, Missions and Mission Classes

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

- High-End Computing Program (<http://hec.nasa.gov> [58])
- Modeling, Analysis, and Prediction Program (<http://map.nasa.gov> [59])

Technology Areas

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

- Tools that assist in the construction of fine-grained unit-level software tests based upon existing functionality in a legacy Fortran application. Although tests written by developers are desirable, such tests are exceedingly difficult to create for legacy numerical software. Suites of these tests could provide a significant element of risk-reduction for maintenance and extension of these models, and would be incorporated into some sort of unit-testing framework.
- Tools that enable high-level source code transformations ("refactorings"). Although refactoring support for other programming languages, most notably Java, has shown significant gains in productivity, similar support for Fortran is rather limited. (<http://www.eclipse.org/photran/> [60]).
- Integration of a Fortran unit-testing frameworks within an Integrated Development Environment (IDE). Although multiple Fortran unit-testing frameworks have been developed (<http://sourceforge.net/projects/pfunit> [61]), adoption by the community has been slow in part due to lack of integration within IDE's. Integration of other Fortran capabilities is also encouraged.

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

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

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 as well as for highly accurate measurements of the distance between spacecraft for gravitational wave astronomy and gravitational field planetary science are among technologies of interest. Innovative technologies that can expand current measurement capabilities to spaceborne or Unmanned Aerial Vehicle (UAV) platforms are particularly desirable. Development of components that can be used in planned missions or current technology programs is highly encouraged. Examples of planned missions and technology programs are: Deformation, Ecosystem Structure and Dynamics of Ice (DESDynI), Laser Interferometer Space Antenna (LISA), Doppler Wind Lidar, Lidar for Surface Topography (LIST), or earth and planetary atmospheric composition (ASCENDS).

Research should be conducted to demonstrate technical feasibility during Phase 1 and show a path toward a Phase 2 prototype demonstration. For the PY09 SBIR Program, we are soliciting only the specific component technologies described below.

- High speed fiber multiplexers for multimode fiber (200 micron core, 0.22 NA) operating at 1 micron wavelength. We require an N by M de-multiplexer (where M is 32 or greater and N is 2) capable of switching at speeds on the order of 10 microseconds with low insertion loss (
- Space-qualifiable high reliability frequency-stabilized CW laser source with 2 W output power at 1064 nm. A master oscillator power amplifier (MOPA) configuration is desirable since the source must be phase-modulated.
- Fiber-coupled pulse compressor device for 1064 nm and 532 nm for reducing 4-6 ns level pulses to sub-ns (0.4 - 0.6 ns) pulses, capable of input pulse energies > 2 mJ.

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- Efficient and compact single frequency, near diffraction limited semiconductor lasers (interband cascade laser or quantum cascade lasers) operating in mid-infrared (3 - 4 μm). Requirements include room temperature operation, and pulsed lasers with repetition rates on the order of 10 KHz and pulse energies greater than 0.5 mJ. CW lasers in multiwatt regimes are applicable. Wavelength tunability over 10s of nanometers is desirable for certain applications.
 - Efficient and compact single mode solid state or fiber lasers operating at 1.5 and 2.0 micron wavelength regimes suitable for coherent lidar applications. These lasers must meet the following general requirements: pulse energy 0.5 mJ to 50 mJ, repetition rate 10 Hz to 1 kHz, and pulse duration of approximately 200 nsec.
 - Single frequency semiconductor or fiber laser generating CW power in 1.5 or 2.0 micron wavelength regions with less than 10 kHz linewidth. Frequency modulation with about 5 GHz bandwidth and wavelength tuning over several nanometers are desirable.
 - Development of efficient, compact, and space qualifiable laser absorption spectrometry-related technologies for measuring atmospheric pressure and density. Remote sensing of oxygen in the 1.26 micron or 760 nm spectral region for measuring atmospheric pressure is of particular interest.
 - Photon counting detectors (single element and/or multi-element detector array) at near-IR (1 - 1.8 μm) and mid-IR (3 - 4 μm) with single photon sensitivity.

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:

Active Microwave Technologies Topic S1.02

NASA employs active sensors (radars) for a wide range of remote sensing applications

(<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. The areas of interest for this call are listed below:

High-density low-loss millimeter-wave packaging and interconnects for advanced cloud and precipitation radars or Mars landing radars. These packing and interconnect technologies are critical to achieving the density and RF signal performance required for scanning millimeter-wave array radars. Desired performance specifications include:

- Frequency: 35 - 160 GHz
- Performance at 35 GHz:
 - Interconnect loss:
 - Line loss:

High-speed, low-power analog-to-digital converters (ADCs) and digital-to-analog converters (DACs) for advanced SAR, advanced interferometer for surface monitoring, ice topography or hydrology. Digital beam forming (DBF) systems require an array of ADCs. The power consumption of current ADC chips prohibits implementation of large DBF arrays. Furthermore, large arrays require true time delays, which are easily implemented using low-power, high speed ADCs and DACs. Desired performance specifications include:

- Analog Input Bandwidth: 1.3 GHz
- Sampling rate: 500 MS/s
- Resolution 12 bits
- Power consumption: 100 mW

High performance miniature bandpass filters for SMAP, Aquarius follow-on, DESDynI, or Advanced L-band SAR and interferometers. The size of current filters allows for implementation of near-term missions with (with volume and mass penalties) but filter size constrains RF system architectural choices. Desired performance specifications include:

- Center Frequencies: 1.2 - 36 GHz
- Bandwidth: 1%
- Loss:
- Isolation: >30 dB
- Volume: 3

High-performance mm-wave integrated circuits (MMICs) for Advanced SAR, advanced interferometer for surface monitoring, ice topography, hydrology, advanced cloud and precipitation radars or Mars landing radars. Besides packaging, performance of MMICs is the main road block to development of electronically scanned arrays at 94 GHz and higher. Desired specifications/technologies include:

- Frequencies: 94 - 350 GHz
- Device types: Lower Noise Amplifiers, Power Amplifiers, Mixers, Oscillators, Phase Shifters, Switches

Ultra-high efficiency L-band power amplifiers for Advanced SAR/Interferometers or geosynchronous SAR for earthquake monitoring. Using lower efficiency amplifiers in large arrays leads to much higher power system requirements and thermal management challenges. Desired performance specifications include:

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- Frequency: 1.2 - 1.3 GHz
 - Efficiency: >85%

P-band stretch processing imaging radar antennas and transceivers with bandwidth > 100 MHz for airborne SAR applications for Biomass/ecosystems. Wideband P-band radar systems require low power transmitters with high processing gain to avoid interference with other services. Furthermore, achieving fine range resolution will require novel wideband airborne antennas.

Small radar packaging concepts for Unmanned Aerial Systems (UAS) for Biomass (P), soil moisture and ocean salinity (L, and C), or snow water equivalent (X, Ku, and Ka). Miniaturization of radar and radiometer components while maintaining power and performance is a requirement for UAV science. Desired performance specifications include:

- Mass: 1.5 lb - 35 lb
- Frequency: P-band, L-band, C-band, X-band, Ku -band, and Ka-band
- High Efficiency SSPAs: > 70% efficiency (P, L and C), > 20% (ka)

High power/high efficiency Ka-band and W-band solid state and TWT amplifiers for Aerosol/Cloud/Ecosystems (ACE) Mission. Spaceborne applications require higher power and efficiency than currently available. Desired performance specifications include:

- SSPA power: > 10 W (Ka-band) and > 2 W (W-band)
- TWT power: > 1kW (Ka-band) and > 200 W (W-band)
- Efficiency: > 20%.
- Phase Linearity:

Simultaneous, multi-frequency U-band transceivers, frequency converters, and amplifiers for airborne/spaceborne applications for barometric pressure measurements in support of NASA/NOAA hurricane science, NWS/aviation weather or decadal survey missions. Currently available airborne and space-qualified U-band (50 - 60 GHz) transceiver and components do not support simultaneous operation at multiple frequencies within the band.

Wide bandwidth, U-band antennas for airborne/spaceborne applications for barometric pressure measurements in support of NASA/NOAA hurricane science, NWS/aviation weather, or decadal survey missions. Currently available antennas do not compensate for wide bandwidth (50 - 60 GHz) operation; consequently, main beam characteristics (e.g., beamwidth, gain, pointing angle, polarization, etc.) vary according to frequency. The need is for a light-weight, aviation/space-qualifiable antenna capable of operating over 50 - 60 GHz without significant variation in main beam characteristics.

Membrane materials for large inflatable membrane antennas for remote sensing applications for earth and planetary science missions. Reflectors manufactured from polymer films could enable greater packaging efficiencies due to their low mass, high packaging efficiencies, solar radiation resistance, and cryogenic flexibility. However, these polymer films must also exhibit near zero CTE and stability in the space environment, as well as be deployable wrinkle free. Innovative intrinsically electroactive polymer membrane actuation mechanisms that can reduce the bulk of traditional active control systems are also of interest. Proposals for remote sensing antenna membrane materials technology are being solicited and should be submitted to subtopic "O1.02 - Antenna Technologies" in the Space Operations portion of this solicitation. Such proposals should indicate that they are applicable to remote sensing antennas.

Composite materials for large deployable antenna reflector structures for remote sensing applications for earth and planetary science missions. These antennas will require high specific stiffness composite materials that can be packed compactly and deployed multiple times for ground evaluation of the antenna structure prior to launch and deployment in space. The deployment of these materials should require low energy. Proposals for remote sensing antenna composite materials technology are being solicited and should be submitted to subtopic "O1.02 - Antenna Technologies" in the Space Operations portion of this solicitation. Such proposals should indicate that they are applicable to remote sensing antennas.

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:

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://universe.nasa.gov/program/probes/inflation.html> [8])).

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- Low power >200 Mb/s 1-bit A/D converters and cross-correlators for microwave interferometers. Earth Science Decadal survey missions which apply: PATH, SCLP.
 - Automated assembly of 180 GHz direct conversion I-Q receiver modules. This technology applies to both the Beyond Einstein Inflation probe and the Decadal Survey PATH concept.
 - Low DC power spectrometer (channelizer) covering >500 MHz with 125 kHz resolution for planetary radiometer missions and covering 4 GHz with 1 MHz resolution for Earth observing missions. Also RFI mitigation approaches employing channelizers for broad band radiometers. Earth Science Decadal Survey mission which applies: GACM
 - RF (GHz to THz) MEMS switches with low insertion loss (18 dB), capable of switching with speeds of >100 Hz at cryogenic temperatures (below 10 K) for 10⁸ or more cycles. Technology applies to Beyond Einstein Probe.
 - 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.
 - MMIC Low Noise Amplifiers (LNA). Room temperature LNAs for 165 to 193 GHz with low 1/f noise, and a noise figure of 6.0 dB or better; and cryogenic LNAs for 180 to 270 GHz with noise temperatures of less than 150K. Earth Science Decadal Survey missions that apply: PATH and GACM.
 - Low loss, low RF power waveguide SPDT diode switches and active noise sources for frequencies above 90 GHz to support calibration of SWOT and other atmospheric temperature and humidity measurements.
 - Broad band 180 - 270 GHz radomes for aircraft borne submillimeter remote sensing instruments.

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 specific technologies are of interest for instrument concepts such as Scanning Microwave Limb Sounder (<http://mls.jpl.nasa.gov/index-cameo.php> [11]) on the Global Atmospheric Composition Mission, Climate Absolute Radiance and Refractivity Observatory (http://science.hq.nasa.gov/earth-sun/docs/Volz4_CLARREO.pdf [12]), Methane Trace Gas Sounder, Single Aperture Far Infrared (SAFIR) Observatory (<http://safir.jpl.nasa.gov/technologies.shtml> [13]), and Inflation Probe (cosmic microwave background, <http://universe.nasa.gov/program/probes/inflation.html> [8]):

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- New or improved technologies leading to measurement of trace atmospheric species (e.g., CO, CH₄, N₂O) from geostationary and low-Earth orbital platforms. Of particular interest are new techniques in gas filter correlation spectroscopy, Fabry-Perot spectroscopy, or improved component technologies.
 - Uncooled or passively cooled detectors with specific detectivity (D^*) $\geq 10^{10}$ cm Hz^{1/2}/W in the operating wavelength ranges 6-14 μ m and 10-100 μ m.
 - Efficient, flight qualifiable, spur free, local oscillators for SIS mixers operating in low earth orbit. Two bands: (1) tunable from 200 to 250 GHz, and (2) tunable from 600 to 660 GHz, phase-locked to or derived from an ultra-stable 5 MHz reference.
 - Sideband separating SIS mixer with RF band from 580 to 680 GHz, IF band from 6 to 18 GHz, image rejection greater than 10 dB, and receiver noise temperature less than 300 Kelvin. Thermal load on 4 K and 15 K stage must be less than 4 and 30 mW respectively. Application: GACM.
 - Quantum cascade laser-based local oscillators for astrophysics applications (2nd generation SOFIA instruments, SAFIR).
 - Technologies for calibrating millimeter wave spectrometers for spaceborne missions, including low power, flight qualifiable comb generators and low noise diodes for the bands from 180 to 270 and 600 to 660 GHz; very low return loss (70 dB or better) calibration targets and techniques for quantifying and calibrating out the impact of standing waves in broadband heterodyne submillimeter spectrometers.
 - Low power, stable, linear, spectrometers capable of measuring the band from 6-18 GHz with ~120 100 MHz wide channels.
 - Digital spectrometers with ~4 GHz bandwidth and 10 MHz resolution. Components for these digital spectrometers including high speed digitizers, efficient spectrometer firmware, and ASIC implementations.
 - Spatial Filter Array (SFA) consisting of a monolithic array of up to 1200 coherent, polarization preserving, single mode fibers that operate over a large fraction of the spectral range from 0.4 - 1.0 microns and such that each input and output lenslet is mapped to a single fiber. Uniformity of output intensity and high throughput is desired and fiber-to-fiber placement accuracies of http://planetquest.jpl.nasa.gov/TPF/tpf_index.cfm and Stellar Imager (<http://hires.gsfc.nasa.gov/si/> [14]).
 - High resolution wedged filters with resolving powers of 1,000 to 5,000 in the visible to short wave infrared spectral region. Of particular interest are filters in the 1 to 3.5 micron range.

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:

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> [15]

Specific mission pages:

EXIST: <http://exist.gsfc.nasa.gov/> [16]

IXO: <http://htxs.gsfc.nasa.gov/index.html> [17]

Future planetary programs: http://nasascience.nasa.gov/planetary-science/mission_list [18]

Earth Science Decadal missions: <http://www.nap.edu/catalog/11820.html> [6]

Helio Probes: http://nasascience.nasa.gov/heliophysics/mission_list [19]

Specific technology areas are listed below:

- Significant improvement in wide band gap semiconductor materials, individual detectors, and detector arrays for operation at room temperature or higher for missions such as EXIST, Geo-CAPE and planetary science composition measurements.
- Highly integrated, low noise (
 - Large format UV and X-ray focal plane detector arrays: microchannel plates, CCDs, and active pixel sensors (>50% QE, 100 Megapixels,
 - Advanced Charged Couple Device (CCD) detectors, including improvements in UV quantum efficiency and read noise, to increase the limiting sensitivity in long exposures and improved radiation tolerance. Electron-bombarded CCD detectors, including improvements in efficiency, resolution, and global and local count rate capability. In the X-ray, we seek to extend the response to lower energies in some CCDs, and to higher, perhaps up to 50 keV, in others. Possible missions are future GOES missions and International X-ray Observatory.
- Wide band gap semiconductor, radiation hard, visible and solar blind large format imagers for next generation hyperspectral Earth remote sensing experiments. Need larger formats (>1Kx1K), much higher resolution (
 - Solar blind, compact, low-noise, radiation hard, EUV and soft X-ray detectors are required. Both single pixels (up to 1cm x 1cm) and large format 1D and 2D arrays are required to span the 0.05nm to 150nm spectral wavelength range. Future GOES missions post-GOES R and T.
- Visible-blind SiC APDs for EUV photon counting are required. The APDs must show a linear mode gain >1E6 at a breakdown reverse voltage between 80 and 100V. The APD's must demonstrate detection capability of better than 6 photons/pixel/s at near 135nm spectral wavelength. See needs of National Council Decadal Survey (NRC, 2007): Tropospheric ozone.
- Imaging from low-Earth orbit of air fluorescence, UV light generated by giant airshowers by ultra-high energy ($E > 10^{19}$ 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 (2 g/cm² goal). Individual pixel readout. The entire focal plane detector can be formed from smaller, individual sub-arrays.

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:

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

Advanced sensors and instrument enabling technologies for the measurement of the physical properties of space plasmas and energetic charged particles, mesospheric - thermospheric neutral species, energetic neutral atoms created at high altitudes by charge exchange, and electric and magnetic fields in space are needed to achieve NASA's transformational science advancements in Heliophysics. The Heliophysics discipline (<http://sec.gsfc.nasa.gov/> [20]) has as its primary strategic goal the understanding of the physical coupling between the sun's outer corona, the solar wind, the trapped radiation in Earth's and other planetary magnetic fields, and the upper atmospheres of the planets and their moons. This understanding is of national importance not only because of its intrinsic scientific worth, but also because it is the necessary first step toward developing the ability to measure and forecast the "space weather" that affects all human crewed and robotic space assets. Improvements in particles and fields sensors and associated instrument technologies will enable further scientific advancement for upcoming NASA missions such as Solar Probe (<http://solarprobe.gsfc.nasa.gov/> [21]), Solar Sentinels (<http://lws.gsfc.nasa.gov/missions/sentinels/sentinels.htm> [22]), GEC (<http://stp.gsfc.nasa.gov/missions/gec/gec.htm> [23]), Magnetospheric Constellation (<http://stp.gsfc.nasa.gov/missions/mc/mc.htm> [24]), IT-SP and planetary exploration missions. Technology developments that result in expanded measurement capabilities and a reduction in size, mass, power, and cost are necessary in order for some of these missions to proceed. Of special interest are fast high voltage stepping power supplies for charged particle analyzers, electric field booms, self calibrating vector magnetometers, and other supporting sensor electronics.

Specific areas of interest include:

- Low cost, low power, low current, high voltage power supplies which allow ultra-fast stepping (t
- Strong, lightweight, thin, compactly-stowed electric field booms possibly using composite materials that deploy sensors to distances of 10m or more and/or long wire boom (> 50 m) deployment systems for the deployment of very lightweight tethers or antennae on spinning spacecraft.
- Self-calibrating scalar-vector magnetometer for future Earth and space science missions. Performance goals are dynamic range: +/-100,000 nT, accuracy with self-calibration: 1 nT, sensitivity: 5 pT / sqrtHz, Max, max sensor unit size: 6 x 6 x 12 cm, max sensor mass: 0.6 kg, max electronics unit size: 8 x 13 x 5 cm, max electronics mass: 1 kg, and max power: 5 W operation, 0.5 W standby, including, but not limited to "sensors on a chip".
- Low-power cathode for detection of neutral atoms and molecules ionosphere-thermosphere and planetary investigations. Performance goals are thermionic cathodes capable of emitting 1 mA electron current with heater power less than 0.1 W. The largest dimension of the electron emitter surface should not exceed 1 mm; the entire cathode assembly should be small enough so it may be mounted in a shallow channel shaped to match the largest cathode dimension. The assembly should include robust connection leads for heater and cathode surface. Uniformity across the electron beam is not critical.
- A compact electronics box to enable the operation of one Wind Temperature Spectrometer (WTS), one Ion-Drift Spectrometer (IDS), one Neutral Mass Spectrometer (NMS) and one Ion Mass Spectrometer (IMS), all

based on the new generation charged-particle spectrometer SDEA. The electronics should be housed in a volume with dimensions not exceeding 3.2x3.2x3.2 inches with power requirement not exceeding 1.1 W. The EB must provide: (a) electronics for MCP detector pulse handling, (b) minimum of 64 detector pulse channels for WTS and IDS, (c) 2 channels devoted to TOF pulse processing with 2 ns time resolution or faster for NMS and IMS, (d) two ion source power supplies (1V/0.1A cathode supply floating at -100VDC) for WTS and NMS, (e) two energy scan supplies (0 to 5 V) for WTS and IMS, (f) two rectangular-wave supplies (0 to 1 V with 1 microsec rise time) for NMS and IMS, (g) ion accelerator optics voltage supplies (3 outputs @ 200 VDC max) for NMS and IMS, (h) MCP voltage supply (one lead/2700VDC max @ 50 microAmp max), and (i) micro-controller with buffer memory and telemetry link.

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:

Cryogenic Systems for Sensors and Detectors Topic S1.07

Cryogenic cooling systems often serve as enabling technologies for detectors and sensors flown on scientific instruments as well as advanced telescopes and observatories. As such, technological improvements to cryogenic systems (as well as components) further advance the mission goals of NASA through enabling performance (and ultimately science gathering) capabilities of flight detectors and sensors. Presently, there are six potential investment areas that NASA is seeking to expand state of the art capabilities in for possible use on future programs such as IXO (<http://ixo.gsfc.nasa.gov/> [25]), Safir (<http://safir.jpl.nasa.gov/> [26]), Spirit, Specs (<http://geons.gsfc.nasa.gov/live/Home/SPECS.html> [27]) and the Europa Science missions (<http://www.nasa.gov/multimedia/podcasting/jpl-europa20090218.html> [28]). The topic areas are as follows:

Extremely Low Vibration Cooling Systems

Examples of such systems include pulse tube coolers and turbo brayton cycles. Desired cooling capabilities sought are on the order of 20 mW at 4K or 1W at 50 K. 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);
- 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

Current heat switches require detailed procedures for operational repeatability. More robust (performance wise) heat switches are currently needed for ease of operation when used with space flight applications.

Highly Efficient Magnetic and Dilution Cooling Technologies

The desired temperature range for proposed systems is

Low Temperature/Power Cooling Systems

Cooling systems providing cooling capacities approximately 0.3W at 35 K with heat rejection capability to temperature sinks upwards of 150 K are of interest. Presently there are no cooling systems operating at this heat rejection temperature. Input powers should be limited to no greater than 10W. Study of passive cooler in tandem with low power, low mass cryocooler satisfying the above mentioned requirements is also of interest.

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:

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, and balloon-based systems (tethered or free). 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: Aerosols, Cloud Particles, Water, and chemical composition: Carbon Dioxide ($^{12}\text{CO}_2$ and $^{13}\text{CO}_2$), Carbon Monoxide, Methane, Reactive and Trace Gases, Radicals, Ozone, Three-dimensional Winds and Turbulence.

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- 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 phytoplankton, harmful algal blooms, fish or aquatic plants.
 - Instrument systems for hazardous environments such as volcanoes and severe storms.
 - Instrument systems for difficult to access areas such as sub-glacial waters.

Instrument systems to support field studies of fundamental processes are of interest, as well as for satellite measurement calibration and validation. Applicability to NASA's Airborne Science, Atmospheric Composition and Radiation Sciences, Ocean Biology and Biogeochemistry, and Applied Sciences programs is a priority. Support of the Integrated Ocean Observing System (IOOS) and regional coastal research is also desired.

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:

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

This subtopic solicits development of advanced instruments and instrument components that are tailored to the demands of planetary instrument deployment on a variety of space platforms (orbiters, flyby spacecraft, landers, rovers, balloon or other aerial vehicles, subsurface penetrators or impactors, etc.) accessing the wide variety of bodies in our solar system (inner and outer planets and their moons, comets, asteroids, etc.). These instruments must be capable of withstanding operation in space and planetary environmental extremes, which include temperature, pressure, radiation, and impact stresses. For example missions see:

http://science.hq.nasa.gov/missions/solar_system.html [29]

Specifically, this subtopic solicits instrument development that provides significant advances in the following areas:

- Improved science return and/or reduced mass, power, volume, data rates for instruments or instrument components (e.g., lasers and other light sources from UV to microwave, X-ray and ion sources, detectors, mixers, seismometers, etc.) or electronics (e.g., FPGA and ASIC implementations, advanced array readouts);
- Instrument technologies for detecting inorganic and organic biomarkers on future Mars missions;
- Improved robustness and g-force survivability for rough landings on planetary bodies;
- Radiation mitigation strategies, radiation tolerant detectors, and readout electronics components for candidate instruments for the Europa-Jupiter System Mission;
- Advanced sample acquisition and processing technologies, including fluid and gas storage, pumping, and manipulation, to support analytical instrumentation, sample return, or planetary protection.

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- Sensors, mechanisms, and environmental chamber technologies for operation in Venus's high temperature, high pressure environment with its unique atmospheric composition. Venus test chambers that can support evaluation of 50 to 100 cm sensors, instruments, and related structures are particularly requested.

Proposers are strongly encouraged to relate their proposed development to (a) future planetary exploration goals of NASA; and (b) existing flight instrument capability to provide a comparison metric for assessing proposed improvements. Proposed instrument architectures should be as simple, robust, and reliable as possible while enabling compelling science.

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

Sub Topics:

Space Geodetic Observatory Components Topic S1.10

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

- Broadband feeds capable of receiving GNSS signals, Ka-band feeds integrated with broadband feeds, and matching antennas that meet or exceed the slewing and duty cycle requirements of the IVS VLBI2010 specifications.
- VLBI system components including > 4 Gbps recorders, phase/cable calibrators, and frequency standards / distribution systems that meet or exceed the requirements of the IVS VLBI2010 specifications.
- Cost-effective data transmission for e-VLBI from a global network of 30 VLBI stations operating up to 8 Gbps.
- Compact, low mass, space-qualified for MEO, SLR retroreflector arrays with greater than 100 million square meter lidar cross section, with a design that assures the ability to determine the array center to the center of mass of the spacecraft to a millimeter.
- A very high quantum efficiency (>50% at 532nm), low instrument noise, multi-pixelated detector for SLR use in the automated tracking.
- Wide band GNSS antenna and RF front-end technologies accommodating all expected GNSS signals in the next decade, and offering at least an order of magnitude improvements over COTS devices in terms of multipath rejection, and stability of output relative to temperature.
- Continuous, reliable co-location monitoring and control system for the relative 3-D displacement of geodetic instruments within a geodetic observatory to better than 1 mm.

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

Sub Topics:

Lunar Science Instruments and Technology Topic S1.11

NASA lunar robotic science missions support the high-priority goals identified in the 2007 National Research Council report, The Scientific Context for Exploration of the Moon: Final Report (http://www.nap.edu/catalog.php?record_id=11954 [30]). Future missions will characterize the lunar exosphere and surface environment; field test new equipment, technologies, and approaches for performing lunar science; identify landing sites and emplace infrastructure to support robotic and human exploration; demonstrate and validate heritage systems for exploration missions; and provide operational experience in the harsh lunar environment.

Space-qualified instruments are required to perform remote and in situ lunar science investigations, to include measurements of lunar dust composition, reactivity and transport, searching for water ice, assessing the radiation environment, gathering long period measurements of the lunar exosphere, and conducting surface and subsurface geophysical measurements.

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

Geophysical Measurements

Systems, subsystems, and components for seismometers and heat flow sensors capable of long-term continuous operation over multiple lunar day/night cycles with improved sensitivity at lower mass and reduced power consumption compared to the Apollo Lunar Surface Experiments Package (ALSEP) instruments (<http://www.hq.nasa.gov/alsj/frame.html> [31]). Instrument deployment options include robotic deployment from soft Landers, as well as emplacement by hard landers or penetrators. Also of interest are portable surface ground penetrating radars with antenna frequencies of 250-MHz, 500-MHz, and 1000-MHz to characterize the thickness of the lunar regolith. Also of interest are accurate, low mass, thermally stable hollow cubes and retroreflector array assemblies for lunar surface laser ranging.

In Situ Lunar Surface Measurements

Light-weight and power efficient instruments that enable elemental and/or mineralogy analysis using techniques such as high-sensitivity X-ray and UV-fluorescence spectrometers, UV/fluorescence flash lamp/camera systems, scanning electron microscopy with chemical analysis capability; time-of-flight mass spectrometry, gas chromatography and tunable diode laser (TDL) sensors for in situ isotopic and elemental analysis of evolved volatiles, calorimetry, and Laser Induced Breakdown Spectroscopy (LIBS). Instruments shall have the potential to provide isotope ratio measurements and/or hydrogen distributions to ± 10 ppm locally. Characterizing the meteoroid and subsequent eject flux environment and measurements of surface and deep dielectric charging on the lunar surface should be considered. Also, self calibrating instruments to measure surface and deep dielectric charging on a variety of materials encompassing conductors, semi-conductors, and insulators are another area. Instrument deployment options include robotic deployment from soft Landers, as well as emplacement by hard Landers or penetrators.

Lunar Atmosphere and Dust Environment Measurements

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

Lunar Regolith Particle Analysis

A substantial portion of the particles in the Lunar Regolith are smaller than the integration volume of e-beam analytical equipment, making automated quantitative analysis extremely difficult using available approaches. Therefore, software development is sought 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 cathode luminescence and EDS X-ray. The said software would then use standard image processing tools to resample to common scales, perform appropriate discriminant analysis using the high resolution data, mixed pixel inversion, image segmentation to extract particles, and correlate chemistry with products of the discriminant analysis.

Research should be conducted to demonstrate technical feasibility during Phase 1 and show a path toward a Phase 2 hardware and software demonstration, and when possible, deliver a demonstration unit or software package for NASA testing at the completion of the Phase 2 contract.

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 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://constellation.gsfc.nasa.gov/> [32], <http://lisa.gsfc.nasa.gov/> [33]). Also sought are technologies (analysis, algorithms, and testbeds) to enable detailed analysis, synthesis, modeling, and visualization of such distributed systems.

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

Innovations are solicited for: (a) sensor systems for inertial alignment of multiple vehicles with separations of 10,000 - 100,000 km to accuracy of 1 - 50 milli-arcseconds; (b) development of nanometer to sub-nanometer metrology for measuring inter-spacecraft range and/or bearing for space telescopes and interferometers; (c) control approaches to maintain line-of-sight between two vehicles in inertial space near Sun-Earth L2 to milli-arcsecond levels accuracy; (d) development of combined cm-to-nanometer-level precision formation flying control of numerous spacecraft and their optics to enable large baseline, sparse aperture UV/optical and X-ray telescopes and interferometers for ultra-high angular resolution imagery. Proposals addressing staged-control experiments which combine coarse formation control with fine-level wavefront sensing based control are encouraged.

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

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

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

Sub Topics:

Proximity Glare Suppression for Astronomical Coronagraphy Topic S2.02

This subtopic addresses the unique problem of imaging and spectroscopic characterization of faint astrophysical objects that are located within the obscuring glare of much brighter stellar sources and innovative advanced wavefront sensing and control for cost-effective space telescopes. Examples include planetary systems beyond our own, the detailed inner structure of galaxies with very bright nuclei, binary star formation, and stellar evolution.

Contrast ratios of one million to ten billion over an angular spatial scale of 0.05-1.5 arcsec are typical of these objects. Achieving a very low background requires control of both scattered and diffracted light. The failure to control either amplitude or phase fluctuations in the optical train severely reduces the effectiveness of starlight cancellation schemes.

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

Starlight Suppression Technologies

- Advanced starlight canceling coronagraphic instrument concepts;
- Advanced aperture apodization and aperture shaping techniques;
- Pupil plane masks for interferometry;
- 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 in homogeneity, 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;
- Single mode fiber filtering from visible to $20 \mu\text{m}$ wavelength;
- Methods of polarization control and polarization apodization; and
- Components and methods to insure amplitude uniformity in both coronagraphs and interferometers, specifically materials, processes, and metrology to insure coating uniformity.

Wavefront Control Technologies

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

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- Development of instruments to perform broad-band sensing of wavefronts and distinguish amplitude and phase in the wavefront;
 - Adaptive optics actuators, integrated mirror/actuator programmable deformable mirror;
 - Reliability and qualification of actuators and structures in deformable mirrors to eliminate or mitigate single actuator failures;
 - Multiplexer development for electrical connection to deformable mirrors that has ultra-low power dissipation;
 - High precision wavefront error sensing and control techniques to improve and advance coronagraphic imaging performance; and
 - Highly reflecting broadband coatings.

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 the Single Aperture Far-IR (SAFIR) telescope, Terrestrial Planet Finder (TPF, http://planetquest.jpl.nasa.gov/TPF/tpf_index.cfm [34]) missions: Coronagraph, External Occulter and Interferometer, ATLAST, Life Finder, and Submillimeter Probe of the Evolution of Cosmic Structure (SPECs), and the UV Optical Imager (UVOIR) require 10 - 30 m class cost effective telescope observatories that are diffraction limited at wavelengths from the visible to the far IR, and operate at temperatures from 4 - 300 K. The desired areal density is 1 - 10 kg/m². Static and dynamic wavefront error tolerances to thermal and dynamic perturbations may be achieved through passive means (e.g., via a high stiffness system, passive thermal control, jitter isolation or damping) or through active opto-mechanical control. Large deployable multi-layer structures in support of sunshades for passive thermal control and 20m to 50m class planet finding external occulter are also relevant technologies. Potential architecture implementations must package into an existing launch volume, deploy and be self-aligning to the micron level. The target space environment is expected to be L2.

This topic solicits proposals to develop enabling, cost effective component and subsystem technology for these telescopes. Research areas of particular interest include precision deployable structures and metrology (i.e., innovative active or passive deployable primary or secondary support structures); innovative concepts for packaging fully integrated (i.e., including power distribution, sensing, and control components); distributed and localized actuation systems; deployment packaging and mechanisms; active opto-mechanical control distributed on or within the structure; actuator systems for alignment of reflector panels (order of cm stroke actuators, lightweight, nanometer stability); innovative architectures, materials, packaging and deployment of large sunshields and external occulter; mechanical, inflatable, or other deployable technologies; new thermally-stable materials (CTE

Also of interest are innovative metrology systems for direct measurement of the optical elements or their supporting structure; requirements for micron level absolute and subnanometer relative metrology for multiple locations on the primary mirror; measurement of the metering truss; and innovative systems which minimize complexity, mass, power and cost. The goal for this effort is to mature technologies that can be used to fabricate 20 m class or greater, lightweight, ambient or cryogenic flight-qualified observatory systems. Proposals to fabricate demonstration components and subsystems with direct scalability to flight systems through validated models will be given preference. The target launch volume and expected disturbances, along with the estimate of system

performance, should be included in the discussion. A successful proposal shows a path toward a Phase 2 delivery of demonstration hardware scalable to 3 m for characterization.

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

Sub Topics:

Advanced Optical Component Systems Topic S2.04

Future launch systems (such as the planned Ares V) will enable extremely large and/or extremely massive space telescopes. Potential systems include 12 to 30 meter class segmented primary mirrors for UV/optical or infrared wavelengths and 8 to 16 meter class segmented x-ray telescope mirrors.

These potential future space telescopes have very specific mirror technology needs. UV/optical telescopes (such as ATLAST-16 and ST-2020) require 1 to 3 meter class mirrors with

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

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

An additional key enabling technology for UV/optical telescopes is a broadband (from 100 nm to 2500 nm) high-reflectivity mirror coating with extremely uniform amplitude and polarization properties which can be deposited on 1 to 3 meter class mirror.

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

An ideal Phase 1 deliverable would be a near UV, visible or x-ray precision mirror, lens or replicating mandrel of at least 0.25 meters. The Phase 2 project would further advance the technology to produce a space-qualified precision mirror, lens or mandrel greater than 0.5 meters, with a TRL in the 4 to 5 range. Both deliverables would be accompanied by all necessary documentation, including the optical performance assessment and all data on

processing and properties of its substrate materials. The Phase 2 would also include a mechanical and thermal stability analysis.

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

Sub Topics:

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

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

JDEM concepts: <http://universe.nasa.gov/program/probes/jdem.html> [35],

IXO: <http://ixo.gsfc.nasa.gov/> [25],

LISA: <http://lisa.gsfc.nasa.gov/> [33],

ICESAT: <http://icesat.gsfc.nasa.gov/> [36], CLARREO, and ACE.

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

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

By the end of a Phase 2 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:

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

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

Sub Topics:

Command, Data Handling, and Electronics Topic S3.01

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

<http://nasascience.nasa.gov/search?SearchableText=missions+under+development> [37]

http://www.nap.edu/catalog.php?record_id=10432 [38]

The subtopic goals are to: (1) develop high-performance processors and memory architectures and reliable electronic systems, and (2) develop an avionics architecture that is flexible, scalable, extensible, adaptable, and reusable. The subtopic objective is to elicit novel architectural concepts and component technologies that are realistic and operate effectively and credibly in environments consistent with the future NASA Science missions.

Successful proposal concepts should significantly advance the state-of-the-art. Proposals should clearly (1) state what the product is; (2) describe how it targets the technical priorities listed below; and (3) outline the feasibility of the technical and programmatic approach. If a Phase 2 proposal is awarded, the combined Phase 1 and Phase 2

developments should produce a prototype that can be characterized by NASA. The technology priorities sought are listed below.

Command and Data Handling

- 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 (>500 MIPS at >100 MIPS/W for general purpose processing platforms, >5 GMACs at >5 GMACS/W for computationally-intensive processing platforms), and tolerance to total dose and single-event radiation effects. Concepts must include tools required to support an integrated hardware/software development flow.
- Radiation-hardened non-volatile low power memories.
- Radiation-hardened physical layer components for onboard data busses (e.g. Ethernet).
- Tunable, scalable, reconfigurable, adaptive fault-tolerant avionics.

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.

The Small Spacecraft Build effort highlighted in Topic S4 (Low-cost Small Spacecraft and Technologies) of the solicitation participates in this subtopic. Offerors are encouraged to take this in consideration as a possible flight opportunity when proposing work to this subtopic.

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. Some of these requirements include:

1. Optical systems, lasers and detectors require tight temperature control, often to better than +/- 1°C. Some new missions such as LISA require thermal gradients held to even tighter micro-degree levels.
2. Exploration science missions beyond earth orbit present engineering challenges requiring systems which are more self-sufficient and reliable.
3. The introduction of low-cost, small, rapidly configured spacecraft requires the development of new thermal technologies to reduce the time and costs typically required for analysis, design, integration, and testing of the spacecraft.

Innovative proposals for the cross-cutting thermal control discipline are sought in the following areas:

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- Methods of precise temperature measurement and control to tight temperature levels.
 - High conductivity, vacuum-compatible interface materials to minimize losses across make/break interfaces.
 - High conductivity materials to minimize temperature gradients and provide high efficiency light-weight radiators, including interfaces to heat pipes and fluid loops that overcomes issues with CTE mismatch.
 - Advanced more efficient thermoelectric coolers capable of providing cooling at ambient and cryogenic temperatures,
 - 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.
 - Single and two-phase mechanically pumped fluid loop systems which accommodate multiple heat sources and sinks, and long life, lightweight pumps for these systems. Also includes advanced fluid system components such as accumulators, valves, pumps, flow rate sensors, etc. optimized for improved reliability, long life, and low resource needs.
 - Phase change systems for Mars or Lunar applications. Reusable phase change systems are desired which can be employed to absorb transient heat dissipations during instrument operations. Technology is sought for phase change systems which can then either store this energy or provide an exothermic process which would provide heat for instrument power-on after the dormant phase.
 - Ionic liquids, salts composed of separate cations and anions, have been known but not intensely studied. Because of their tunable and thus extremely favorable solvent and materials properties, ionic liquids are potentially useful for a wide range of space applications, e.g. liquid-mirror telescopes and heat transfer of fluids that could enhance lunar regolith geothermal potential many-fold.
 - Efficient, lightweight, oil-less, high lift vapor compression systems or novel new technologies for high performance cooling up to 2 KW.
 - Advanced thermal modeling techniques that can be easily integrated into existing codes, emphasizing inclusion of two-phase systems and mechanically pumped system models.
 - Integration of standardized formats into existing analytical codes for the representation and exchange of thermal network models and thermal geometric models and results.
 - Analytical codes to automate the generation of reduced thermal models from larger models, including routines to verify the accuracy of the reduced models.

Research should be conducted to demonstrate technical feasibility during Phase 1 and show a path toward a Phase 2 hardware and software demonstration. Phase 2 should deliver a demonstration unit or software package for NASA testing at the completion of the Phase 2 contract.

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:

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

Improvements are solicited in component and systems technology relevant to Sterling and thermophotovoltaic power conversion. For Stirling conversion, advances sought, but not limited to, include:

- Novel methods or approaches for radiation-tolerant, sensorless, autonomous control of Stirling converters with very low vibration and having low mass, size, and electromagnetic interference (EMI);
- High-temperature, high-performance regenerators and linear alternators;
- Advances applicable to Venus surface missions including high-temperature heater heads (> 850°C), joining techniques and regenerators (~1200°C), and combined electrical power generation and cooling systems applicable to Venus surface missions (~1200°C);
- Concepts for Stirling engine power from cold energy lunar regolith down to 2-3 meters below the surface, including Stirling Engines that will provide up to 100 watts with a mass less than 50kg for the surface lunar environment with the hot side operating at about 256 K and a cold side at about 100 degrees lower.

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.

Photovoltaic Energy Conversion

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

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

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:

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.

Chemical systems for sample return missions should focus on component technologies for high-pressure (>700

psi) chemical systems such as:

- Lightweight tanks;
- Actuators and regulators;
- Self pressurizing propellants.

This subtopic also seeks proposals that explore uses of technologies that will provide superior performance in electric propulsion systems. These technologies include:

- Hall thruster power processing unit (PPU) capable of 3 ½ kW, 5A, and 700 V with a maximum mass of 5.25 kg;
- High specific impulse/low mass electric propulsion systems for sample return missions;
- Future low cost/low mass electric propulsion systems;
- Thrusters should provide thrust up to 20 mN with a specific impulse between 1600 to 3500 seconds;
- Corresponding power processing units capable up to 1 kW of input power;
- The total system mass should not exceed 3 kgs (roughly 1 kg for a thruster and 2 kg for a PPU).

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:

Power Management and Storage Topic S3.05

Future NASA science objectives will include missions such as Earth Orbiting, Venus, Europa, Titan and Lunar Quest. Under this subtopic, proposals are solicited to develop energy storage and power electronics to enable or enhance the capabilities of future science missions. The unique requirements for the power systems for these missions can vary greatly, with advancements in components needed above the current State of the Art (SOA) for long life, high reliability, low mass/volume, radiation tolerance, and wide temperature operation. Other subtopics which could potentially benefit from these technology developments include X1.03 Radiation Hardened/Tolerant and Low Temperature Electronics and Processors. Battery development could also be beneficial to X7.01 Advanced Space-rated Batteries which is investigating similar, but different technologies.

Energy Storage

Future science missions will require advanced primary and secondary battery systems capable of operating at temperature extremes from -100°C for Titan missions to 400°C to 500°C for Venus missions, and a span of

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

Power Management and Distribution (PMAD)

Advanced electrical power technologies are required for the electrical components and systems on future platforms to address the size, mass, efficiency, capacity, durability, and reliability requirements. Of importance are expected improvements in energy density, speed, efficiency, or wide-temperature operation (-125°C to over 450°C) with a number of thermal cycles. Advancements are sought for power electronic devices, components and packaging for Venus type missions with power ranges of a few watts for minimum missions up to a few hundred watts for large missions. In addition, advancements in components or architectures for application to Radioisotope Electric Propulsion (REP) PMAD systems are considered beneficial. Technologies of interest include:

- High temperature devices and components (up to 450°C);
- Advanced electronic packaging for thermal control and electromagnetic shielding.

Research should be conducted to demonstrate technical feasibility during Phase 1 and show a path toward a Phase 2, and when possible, deliver a demonstration unit for NASA testing at the completion of the Phase 2 contract. Phase 2 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.

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:

Guidance, Navigation and Control Topic S3.06

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

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

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

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

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

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

Sub Topics:

Sensor and Platform Data Processing and Control Topic S3.07

Future NASA's science missions will require high-performance onboard data processing capabilities that far exceed those of today. These capabilities will be leveraged to provide data reduction for missions where sensor bandwidths far exceed downlink bandwidth. Improved onboard data processing will also enable autonomous/collaborative systems, where science operations are autonomously controlled via features extracted from the sensor data. Advances in technologies relevant to sensor and platform data processing and control are sought to support NASA's goals and several missions and projects under development.

<http://nasascience.nasa.gov/search?SearchableText=missions+under+development> [37]

http://www.nap.edu/catalog.php?record_id=10432 [38]

The subtopic goals are to: (1) develop device technologies and architectures that can yield a 10x to 100x improvement in on-board computing power is required to enable the next generation of Earth Science, Space Science and Exploration missions; and (2) develop tool technologies that can enable rapid development of high reliability, high performance onboard data processing applications for these missions.

Successful proposal concepts will significantly exceed the present state-of-the-art. Proposals will clearly (1) state what the product is; (2) describe how it targets the technical priorities listed below; and (3) outline the feasibility of the technical and programmatic approach. If a Phase 2 proposal is awarded, the combined Phase 1 and Phase 2 developments shall produce a prototype that is testable by NASA. The technology priorities sought are listed below.

Device Technologies and Architectures

- Highly reliable, radiation tolerant, special purpose data processing devices (FPGA, multi-core, DSP) that enable accelerated onboard data processing;

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- Hybrid onboard processing architectures using multiple heterogeneous processing elements (CPU, FPGA, DSP, multi-core);
 - Architectures providing software-based radiation mitigation strategies for commercial processing elements.

Development Tool Technologies

- Hybrid system design tools that (a) take full advantage of hybrid processing platforms, and (b) automate/accelerate the design and verification process.

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:

Planetary Ascent Vehicles Topic S3.08

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

Advanced solid propellant engine system technologies:

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

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

- Higher performing monopropellants with specific impulse >240 secs;

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- High chamber pressure thrusters > 500 psia;
 - Pressurization component technologies to reduce system mass (filters, solenoid valves, latch valves, tanks, fill and drain and check valves);
 - Small lightweight pump technologies to operate at >500 psi output pressure;
 - Non-pyrotechnic isolation valves.

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:

Technologies for Unmanned Atmospheric Platforms Topic S3.09

Unmanned Aerial Vehicles (UAVs) offer significant potential new capabilities for scientific earth exploration over a large range of mission durations, altitudes, and geographical locations. UAVs can carry earth resources remote sensing and atmospheric sampling instruments on scientific investigations including the Polar Regions. The potential for these robotic systems has just begun to be realized, and to date their earth observation and atmospheric sampling capabilities are in a state of infancy when compared to platform requirements needed to address national concern over global climate and environmental changes. Current UAV operations are restricted from operations in inclement weather particularly when airframe icing or freezing of fuel may become issues. Airframe icing limits both aircraft flight envelope and may affect scientific payload operations.

UAVs must adhere to regulatory requirements for flight operations within the national airspace. These regulatory issues pose challenges to the trade space of potential solutions. UAVs can be roughly categorized into 1) larger/high value assets and 2) smaller/lower value or expendable assets. Such categorization of UAVs may drive different technology solutions to meet the technology needs as described below.

- Precision flight path control for highly repeatable terrain monitoring over daily, seasonal or multi-year cycles;
- Highly accurate UAV platform attitude control with corresponding science payload instrument stability and pointing accuracy;
- Lower-cost over-the-horizon telemetry alternatives for real-time collaborative data sharing and decision-making involving multiple in-flight and ground-based instruments;
- Drop-sonde and surface sampling probes remote from the unmanned aircraft;
- Airframe icing detection and mitigation to enable UAV severe weather flight operations;
- UAV flight systems to enable long endurance inclement weather operations; systems such as fuel anti-freezing thermal management will be needed.

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 Balloon Technologies Topic S3.10

Currently, NASA is developing a Super Pressure terrestrial vehicle targeting 100 day duration missions in mid-latitude. This added capability will greatly enable new science investigations. The design of the current pumpkin shape vehicle utilizes light weight polyethylene film and high strength tendons made of twisted Zylon® yarn. The in-flight performance and health of the vehicle relies on accurate information on a number of environmental, design, and operational parameters. Therefore, NASA is seeking innovations in the following specific areas:

Balloon Instrumentation

Devices or methods to accurately and continuously measure ambient air, helium gas, balloon film temperatures, and film strain. These measurements are needed to accurately model the balloon performance during a typical flight at altitudes of approximately 120,000 feet. The measurements must compensate for the effects of direct solar radiation through shielding or calculation. Minimal mass and volume are highly desired. For film measurements, a non-invasive and non-contact approach is highly desired for the thin polyethylene film used as the balloon envelope, with film thickness ranging from 0.8 to 1.5 mil. The devices of interest 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 telemetry solution be provided.

Device and method to recover a scientific balloon from Antarctica

Scientific balloons are recovered after flight from the interior of Antarctica. These balloons are either loaded onto aircraft used for remote field operation support, or are loaded upon passing overland traverse vehicles to carry back to McMurdo Station for later disposal. Better methods and/or equipment are needed to expedite the operation and reduce the burden on resources used for recovery of scientific balloons in Antarctica. Current methods to recover balloons are resource and time intensive. In these remote locations, resources and available time are limited. Balloons must be cut up into bundles of manageable size and weight in order to fit inside aircraft that are currently used in support of the United States Antarctic Program (USAP). Scientific balloons weigh up to approximately 2000 kg. The balloon is made up of layers of polyethylene film that are 0.8 to 1.5 mil thick. Each balloon is made up of approximately 200 gores that are heat-sealed together. Each gore seal incorporates load tendons that are made of either polyester load tapes or woven Zylon® fibers. Each balloon incorporates metal end-fittings that can be cut out by hand. Folds, twists and binding of material are characteristics of balloons being recovered. The Antarctic operating environment can be -50 degrees Celsius. Environmental sensitivity is also an issue in Antarctica. Existing aircraft recovery assets include ski-equipped Twin Otters and a DC-3 Basler.

Devices or methods to accurately and continuously measure individual axial loading on an array of ~50 or up to 300 separate tendons during a Super Pressure balloon mission

Tendons are the load carrying member in the pumpkin design. During a typical mission, loading on individual tendons should not exceed a critical design limit to ensure structural integrity and survival. Tendons are typically captured at the fitting via individual pins. Loading levels on the tendons can range from ~20 N to ~8,000 N and temperature can vary from room temperature to the troposphere temperatures of -90 degrees Celsius or colder. The devices of interest shall be easily integrated with the tendons or fittings during balloon fabrication and shall have minimal impact on the overall mass of the balloon system. Support telemetry and instrumentation is 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.

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:

Radiation Hardened High-Density Memory, High Speed Memory Controllers, Data Busses Topic S4.01
There has been considerable progress in the development of low cost high-density memory in the consumer electronics industry. However, spacecraft memory capacities can be orders of magnitude smaller than a desktop computer hard drive. Therefore, NASA has an interest in the development of low cost, high-density memory suitable for spaceflight applications including operations in near and deep space radiation and temperature environments. High-density, radiation-tolerant memory can be beneficial for Astrophysics, Earth Sciences, Heliophysics and Planetary missions where instruments, such as large-scale imagers and spectrometers can quickly produce large amounts of data.

Proposals are sought for radiation-tolerant high-density memory systems that can address or consider the following performance parameters:

- Storage capabilities of up to 192 Gigabytes of data on single 3U card form factor, suitable for inclusion within integrated avionics units and 3U chassis;
- Units that utilize the Space Plug and Play Architecture (SPA) developed at AFRL (See <http://www.dukeworks.org> [39]);
- Tolerate standard internal spacecraft bus operating temperatures of -25°C to 40°C;
- Tolerate space radiation with Total Ionizing Dose (TID) of 10-400kRad (Si) with an average goal of 100kRad (Si);
- Capable of surviving space launch environments.

Although these are baseline goals, proposals that are able to achieve near comparable values will also be considered.

The proposer to this subtopic is advised that the products proposed may be included in a future small satellite

flight opportunity.

Sub Topics:

Radiation Hardened Integrated Unit: GPS/IMU/Time/Processor Topic S4.02

Many subsystems and components are gaining benefit from miniaturization and reduction in mass and power requirements. Often many different avionic control system components are necessary for small spacecraft missions with stringent pointing requirements. A considerable saving in mass, power, and system complexity can be obtained by integrating components into a single unit. Of particular interest is a GPS, IMU, and timing signal combination in a single unit with an internal low-power processor to perform the internal calculations to provide the spacecraft with the necessary location and attitude knowledge.

Proposals are sought for an integrated GPS, IMU, and timing signal unit coupled with a low power processor to provide the necessary signals to spacecraft components.

The integrated unit should address or consider the following performance parameters:

- Mass less than 2.5kg
- Average power usage less than 15W
- GPS:
 - Position accuracy: 1-5m
 - Velocity accuracy: 1m/s
 - Time to first fix: 1 minute
 - Use L1 signals; desirable to incorporate L2 signals
- IMU:
 - Rate Range: 500 deg/sec
 - Bias repeatability: 0.005 deg/hr
 - Scale Factor Accuracy: 1 to 5 ppm
 - Angle random walk: 0.005 deg/rt-hr
- Timing:

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- 10^{-8} to 10^{-10} Allan deviation
 - Able to tolerate an acceleration load of ~25g
 - Stable over standard internal spacecraft bus operating temperatures of -25°C to 40°C
 - Radiation tolerant with Total Ionizing Dose (TID) of 10 - 400 kRad (Si) with an average goal of 100 kRad (Si)
 - Compatible with the Space Plug and Play Architecture (SPA) developed at AFRL (See <http://www.dukeworks.org> [39] for information on SPA)
 - Capable of surviving space launch environments

Although these are baseline goals, proposals that are able to achieve near comparable values will also be considered.

The proposer to this subtopic is advised that the products proposed may be included in a future small satellite flight opportunity.

Sub Topics:

Wireless Data and/or Power Connectivity for Small Spacecraft Topic S4.03

New advances in wireless connectivity for mobile computing and other electronic devices have opened up the possibilities for wireless spacecraft busses. There are two potential applications, the transfer of data, commands, and signals and delivery of power to components. The use of wireless technology can be beneficial to small spacecraft designs by eliminating the need for data and power connects, thus reducing spacecraft overall mass and volume requirements. Wireless applications for a spacecraft bus must also ensure that the many different signals do not interfere and there is complete transfer of data and power.

The proposed wireless technologies should address or consider the following performance parameters:

- Data transmission capability from 5 - 100 unique devices within the spacecraft;
- Data transfer rates of 500 Megabits per second to 1 Gigabit per second per device;
- Scalable wireless power transfer from ~1mW up to ~20W;
- Overall wireless architecture mass from 3-50kg dependent on the size of the spacecraft bus;
- Both systems (power and data) should be capable of utilizing the Space Plug-and-Play Architecture (SPA) developed by the AFRL. See <http://www.dukeworks.org> [39] for information on SPA;
- Power and data architectures should be tolerant to the space environment including temperatures (25°C to

40°C) and radiation ;

- Capable of surviving space launch environments.

Although these are baseline goals, proposals that are able to achieve near comparable values will also be considered.

The proposer to this subtopic is advised that the products proposed may be included in a future small satellite flight opportunity.

Sub Topics:

Low Cost, High Accuracy Timing Signals Topic S4.04

Radio science is an important element of many missions, including small spacecraft missions, to planetary bodies and asteroids where mass determination is derived from perturbations of the spacecraft trajectory by the body. Traditionally these missions have required the inclusion of an Ultra Stable Oscillator (USO) with timing signal accuracy on the order of 10^{-12} to 10^{-13} Allan Deviation. Unfortunately these devices are currently prohibitively expensive for low cost missions. Other devices such as precision clocks can provide accuracy on the order of 10^{-8} Allan Deviation. It is envisioned that recent improvements in timing signal devices from other industries or new developments can provide a significant reduction in cost while still providing the necessary accuracy in the timing signal.

Proposals are sought for highly accurate timing signals that address or consider the following performance parameters:

- Provide timing signals with an accuracy of 10^{-10} to 10^{-12} Allan deviation;
- Be capable of utilizing the Space Plug-and-Play Architecture (SPA) developed at AFRL (See <http://www.dukeworks.org> [39]);
- Small enough to fit within a 3U form factor or integrated avionics chassis;
- Mass less than 1kg;
- Power draw less than 5W;
- Stable over standard internal spacecraft bus operating temperatures of -25°C to 40°C;
- Radiation tolerant with Total Ionizing Dose (TID) of 10 - 400 kRad (Si) with an average goal of 100 kRad (Si);
- Capable of surviving space launch environments.

Although these are baseline goals, proposals that are able to achieve near comparable values will also be considered.

The proposer to this subtopic is advised that the products proposed may be included in a future small satellite flight opportunity.

Sub Topics:

High Torque, Low Jitter Reaction Wheels or Control Moment Gyros Topic S4.05

NASA is becoming increasingly interested in using small spacecraft to execute space missions where possible. Many of these missions will require low cost, high torque and low jitter reaction wheels or control moment gyros. Currently there are limited sources of these systems applicable for small spacecraft. Therefore, development of a family of reaction wheels with the appropriate characteristics for nano- and small spacecraft (5 to 100 kg spacecraft mass) with reduced lead times will result in significant benefits to a number of NASA programs and missions.

Proposals are sought for the development of reaction wheels and/or control moment gyros with the following performance parameters:

- Mass less than 2 kg
- Average power usage less than 5W
- Compatible with the Space Plug-and-Play Architecture (SPA) developed at AFRL (See <http://www.dukeworks.org> [39])
- Reaction wheels
 - Angular momentum capacity of 1 to 2 Nms
 - Torque capacity greater than 50mN-m
 - Speed range greater than ± 20000 rpm
- Control Moment Gyros
 - Torques of 0.1 to 5 Nm
- Induced jitter noise TBR:
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- The use of built in control electronics with rate sensor abilities is also desirable
 - Rate sensor should have a range of 500 deg/sec
 - Drift rate 0.5 deg/hr
 - Stable over standard internal spacecraft bus operating temperatures of -25°C to 40°C
 - Radiation tolerant with Total Ionizing Dose (TID) of 10 - 400 kRad (Si) with an average goal of 100 kRad (Si)
 - Capable of surviving space launch environments

Although these are baseline goals, proposals that are able to achieve near comparable values will also be considered.

The proposer to this subtopic is advised that the products proposed may be included in a future small satellite flight opportunity.

Sub Topics:

AI&T Planner and Scheduler Topic S4.06

Proposals are sought for the development of a software tool (or suite of integrated tools) to assist in the planning, scheduling, and operations activities that occur during small spacecraft Assembly, Integration and Test (AI&T). AI&T is a complex period for small spacecraft with many different procedures, dependencies, operations, and tests occurring in parallel. To streamline the process and ensure compliance with mission and science requirements, NASA is interested in a software tool to support planning, scheduling, and management of the small spacecraft AI&T flow. The tool must be scalable for a variety of different mission and spacecraft classes from nanosatellites, which are typically secondary payloads weighing around 5 - 10 kg, up to primary sciences missions, which may weigh more than 100 kg.

Proposals are sought for the development of an AI&T tool with the following capabilities:

- Resource(s) availability determination and planning function
 - Facilities
 - Personnel
 - GSE
- Requirement mapping for qualification tests along with verification and validation functions

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- Compatible with NASA proposal development processes to assist in a Phase A schedule and cost generation for the AI&T flow
 - Compatible with NASA NPR 7120.5D Program and Project planning requirements

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

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

- Providing critical measurements during the entry phase (e.g., pressure and/or temperature sensors embedded into the aeroshell);
- Improving the accuracy on measurements needed for guidance decisions (e.g., surface relative velocities, 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; and
- Significantly reducing the impact of incorporating such sensors on the spacecraft in terms of volume, mass, placement, or cost.

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 [42]). Limited spacecraft resources (power, volume, mass, computational capabilities, and telemetry bandwidth) demand innovative, integrated sampling systems that can survive and operate in challenging environments (extremes in temperature, pressure, gravity, vibration and thermal cycling). Special interest lies in sampling systems and components (actuators, gearboxes, etc.) that are suitable for use in the extremely hot high pressure environment at the Venusian surface (460°C, 93 bar). Relevant systems could be integrated on multiple platforms, however of primary interest are samplers that could be mounted on a mobile platform, such as a rover. For reference, current Mars-relevant rovers range in mass from 200 - 800 kg.

Sample Acquisition

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

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

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

Sample Integrity (encapsulation and contamination)

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

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

well as innovative mechanical or system solutions - e.g., single-use sample "sleeves," or fully-integrated sample acquisition and encapsulation systems.

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

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

Sub Topics:

Surface and Subsurface Robotic Exploration Topic S5.03

Technologies are needed to enable access and sample acquisition at surface and subsurface sampling sites of scientific interest on Mars or the Moon. Mobility technology is needed to enable access to difficult-to-reach sites such as access through difficult and steep terrain. Manipulation technologies are needed to deploy instruments and sampling tools from vehicles. Many scientifically valuable sites are accessible only via terrain that is too difficult or steep for state-of-the-art planetary rovers to traverse. Sites include crater walls, canyons, and gullies. Tethered systems, non-wheeled systems, and marsupial systems are examples of mobility technologies that are of interest. Tether technology could enable new approaches for deployment, retrieval and mobility. Innovative marsupial systems could allow a pair of vehicles with different mobility characteristics to collaborate to enable access to challenging terrain. Single vehicle systems might utilize a 200 kg class rover and dual vehicle systems might utilize a 500 - 800 kg primary vehicle that provides long traverse to the vicinity of a challenging site and then deployment of a smaller 20 - 50 kg vehicle with steep mobility capability for access and sampling at the site.

Technologies to enable acquisition of subsurface samples are also needed. For Mars in particular, technologies are needed to acquire core samples in the shallow subsurface to about 10cm and to enable subsurface sampling in multiple holes at least 1 - 3 meters deep through rock, regolith or ice compositions. Shallow subsurface sampling systems need to be low mass and deeper subsurface sampling solutions need to be integratable onto 500 - 800 kg stationary landers and mobile platforms. Consideration should be given for potential failure scenarios, such as platform slip and borehole misalignment for integrated systems, and the challenges of dry drilling into mixed media including icy mixtures of rock and regolith. Systems should ensure minimal contamination of samples from Earth-source contaminants and cross-contamination from samples at different locations or depths.

Innovative component technologies for low-mass, low-power, and modular systems are of particular interest. Technical feasibility should be demonstrated during Phase 1 and a full capability unit of at least TRL level 4 - 6 should be delivered in Phase 2. Specific areas of interest include the following:

- Tether play-out and retrieval systems including tension and length sensing;
- Low-mass tether cables with power and communication;
- Steep terrain adherence for vertical and horizontal mobility;

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- Modular actuators with 1000:1 scale gear ratios;
 - Electro-mechanical couplers to enable change out of instruments on an arm end-effector;
 - Drill, core, and boring systems for subsurface sampling to 10cm or 1 to 3 meters.
 - High power piezoelectric mechanisms for drilling into Lunar Regolith; must be able to deliver high torque for short impulses to clear any obstacles;
 - Shared intelligence allowing systems to collaborate and adapt exploration scenarios to new conditions.

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

Sub Topics:

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

NASA seeks an innovative suite of products or technologies that will enable and enhance the successful tracking and capture of a sample canister in Mars orbit.

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

Sample capture mechanisms are sought, of very low mass and volume, and of low complexity and extremely high reliability, including detection of contact with the capture mechanism. Appropriate on-sample radio-beacons are sought that are compatible with NASA's radio systems; requirements for these are for long life, and independent initiation of on-orbit operation. Sample capture mechanisms should include close-proximity/contact sensors, including immediate-field imaging.

Command and sequencing software is sought that will robustly operate the onboard GN&C systems, including providing health and safety monitoring of the rendezvous and capture operation, adaptive response to anomalies and abort commanding. Onboard resources can be assumed to be those necessary to perform navigation from images or other data, compute maneuvers, and maintain the spacecraft attitude.

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

Products or technologies are sought that can be made compatible with the environmental conditions of

interplanetary spaceflight and the rigors normal Mars orbits. Proposals should show an understanding of one or more relevant science needs, and present a feasible plan to fully develop a technology and infuse it into a NASA program. Successful candidate products or technologies can address this call by providing one or more of the following functions, and giving estimated expected performance capabilities of the approach, including, but not limited to, accuracies, ranges, limits of operation, references to previous or related flight experience:

- Autonomously actuated mechanisms for orbiting sample capture;
 - Mechanical capture mechanisms;
 - Transfer mechanisms from capture device to containment transfer mechanism;
- Optical and contact sensors;
 - Near field imagers (optical or other) (e.g. 10m to 1km);
 - Immediate field imagers (optical) (0.25 to 10m);
 - Detection of orbiting sample for triggering capture mechanism;
 - Near field illuminator;
- Coherent Radio Doppler and range beacon (high-performance);
 - Low power, low mass and long life beacon for detection aid;
 - 2-way communication for activation, ranging and coherency;
 - Programmable intermittent transmission for power saving and very long dormancy period;
- Simple Radio beacon (low-performance);
 - Simple 1-way beacon, for long-range detection and 1-way Electra Doppler extraction;
 - Timer activated, multi-year dormant life, and long active life battery;
- Autonomous Rendezvous GN&C Command and Control system;
 - Utilize existing GN&C computation elements to command and sequence robust and safe rendezvous and capture;
 - Provide self-monitoring, correction and self-abort capability;
 - Provide for high-level Mission scenario design, monitoring and simple implementation;

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- Low-mass, low-cost sample OSC for proximity operations operational readiness tests;
 - A simple, low-cost, low-mass practice sample canister that could be deployed and provide low-risk practice runs, either for a precursor mission, or with the actual sample return mission;
 - The readiness test exercise would not capture the test article in the capture mechanism, but only perform the rendezvous and proximity ops operations.

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:

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°C and a surface pressure of about 90 bars. Technologies of interest include high temperature electronics components, high temperature energy storage systems, light mass refrigeration systems, high temperature optical window systems (that are transparent in IR, visible and UV wavelengths) and pressure vessel components compatible with materials such as steel, titanium and beryllium such as low leak rate wide temperature (-50°C to 500°C) seals capable of operating between 0 and 90 bars.

Low Temperature Environments

Low temperature survivability is required for missions to Titan, the surface of Europa and comets. Also Moon equatorial regions experience wide temperature swings from -180°C to +130°C during the lunar day/night cycle, and the sustained temperature at the shadowed regions of lunar poles can be as low as -230°C. Mars diurnal temperature changes from about -120°C to +20°C. Proposals are sought for technologies that enable NASA's long duration missions to low temperature and wide temperature environments. Technologies of interests include low power rad-tolerant RF electronics, mixed signal electronics, power electronics, electronic packaging (including passives, connectors, wiring harness and materials used in advanced electronics assembly), actuators and energy storage sources capable of operating across an ultra-wide temperature range from -230°C to 200°C and computer Aided Design (CAD) tools for modeling and predicting the electrical performance, reliability, and life cycle for low-temperature electronic systems and components.

Research should be conducted to demonstrate technical feasibility during Phase 1 and show a path toward a Phase 2 hardware/software demonstration, and when possible, deliver a demonstration unit for functional and environmental testing at the completion of the Phase 2 contract.

Sub Topics:

Planetary Balloon Technology Topic S5.06

Innovations in materials, structures, and systems concepts have enabled buoyant vehicles to play an expanding role in planning NASA's future Solar System Exploration Program. Balloons and airships are expected to carry scientific payloads on Venus and Titan in order to investigate their atmospheres in situ and their surfaces from close proximity. Their envelopes will be subject to extreme environments and must support missions with a range of durations. Proposals are sought in the following areas:

Metal Balloons for High Temperature Venus Exploration

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

Rapid Buoyancy Modulation System for a Titan Montgolfiere Balloon

Montgolfiere, or hot air, balloons are under development for use on a future mission to Titan. While systems are feasible based on the waste heat from a radioisotope power system (RPS), the large thermal inertias make it dangerous for such balloons to fly near the surface because of their inability to quickly respond to atmospheric turbulence or approach topographic hazards. Proposals are therefore sought for a rapid buoyancy modulation system that can be integrated into a 10 m diameter Titan Montgolfiere balloon operating at 90 K and using a steady-state RPS heat source in the range of 2 - 4 kW. This system needs to be lightweight (less than 10 kg) and consume a small amount of electrical power (less than 5 W average).

Gas Management Systems for Titan Aerobots

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

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:

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; and
- Enhance the efficiency and effectiveness of NASA's supercomputing operations and services.

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

The approach of this subtopic is to seek novel software and hardware technologies that provide notable benefits to NASA's supercomputing users and facilities, and to infuse these technologies into NASA supercomputing operations. Successful technology development efforts under this subtopic would be considered for follow-on funding by, and infusion into, NASA's high-end computing (HEC) projects (<http://www.hec.nasa.gov/> [43]): 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 1 and show a path toward a Phase 2 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, many applications requiring tight coupling and high concurrency, complex computational workflows and immense datasets, and the need to support hundreds of complex application codes - many of which are frequently updated by the user/developer. As a result, solutions that involve the following must clearly explain how they would work in the NASA environment: Grid computing, web services, client-server models, embarrassingly parallel computations, and technologies that require significant application re-engineering. Projects need not benefit all NASA HEC users or application codes, but demonstrating applicability to an important NASA discipline, or even a key NASA application code, could provide significant value.

Specific technology areas of interest include:

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- **Integrated Environments:** The user interface to a supercomputer is typically a command line in a text window. This subtopic element seeks more intuitive, intelligent, user-customized, and integrated interfaces to supercomputing resources, enabling users to more completely leverage the power of HEC to increase their productivity. Such an interface could enhance many essential supercomputing tasks: accessing and managing resources, training, getting services, developing codes, running computations, managing files and data, analyzing and visualizing results, transmitting data, collaborating, etc.
 - **Efficient Computing:** In spite of the rapidly increasing capability and efficiency of supercomputers, NASA's HEC facilities cannot purchase, power, and cool sufficient HEC resources to satisfy all user demands. This subtopic element seeks dramatically more efficient and effective supercomputing approaches in terms of their ability to supply increased HEC capability or capacity per dollar and/or per Watt for real NASA applications. Examples include novel computational accelerators and architectures, more capable storage/interconnect/visualization technologies, improved algorithms for key codes, and power-aware "Green" computing technologies and techniques.
 - **HEC Ecosystem Modeling:** NASA endeavors to maximize the productivity of its world-class HEC activities. To identify and prioritize improvement initiatives, this subtopic element seeks tools and techniques to routinely monitor and model the productivity of NASA's HEC ecosystem, including modeling change scenarios. The technology should model the workflows of HEC users, facility staff, and resources (supercomputers, storage, networks, etc.), and it should reflect constraints such as budget, power, and space. Offerors should minimize the effort of HEC staff to provide process information.
 - **Archive Data Use:** NASA has a vast and rapidly growing wealth of Earth and space observational data, stored in various archives around the U.S. NASA's supercomputers could extract more value from this data and advance NASA's science missions through large-scale data analysis and visualization, and ingest into high-fidelity models. This subtopic element seeks technologies that facilitate efficient, automated use of data in NASA's observational data archives by its HEC centers and users.

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

Sub Topics:

Earth Science Applied Research and Decision Support Topic S6.02

The NASA Applied Sciences Program (<http://nasascience.nasa.gov/earth-science/applied-sciences> [44]) seeks innovative and unique approaches to increase the utilization and extend the benefit of Earth Science research data to better meet societal needs. One area of interest is new decision support tools and systems for a variety of ecological applications such as managing coastal environments, natural resources or natural disasters.

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

- Development of new integrated multiple user requirements knowledge data bases and archival library

tools to support researchers and promote infusion of successful technologies into existing processes.

- Development of new decision support strategies and presentation methodologies for applied earth science applications to reduce risk, cost, and time.

This subtopic is also soliciting proposals for utilities, plug-ins or enhancements to open source geobrowsers that improve their utility for earth science research and decision support. Examples of geobrowsers include NASA World Wind, World Wind Java (http://worldwindcentral.com/wiki/Main_page [45]) and COAST (<http://www.coastal.ssc.nasa.gov/coast/COAST.aspx> [46]). Special consideration will be given to tools for COAST. Examples of specific interest are:

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

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

Sub Topics:

Algorithms for Science Data Processing and Analysis Topic S6.03

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

Current operational missions listed at <http://www.nasa.gov/missions/current/index.html> [47]

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- Landsat Data Continuity Mission (LDCM) (<http://ldcm.nasa.gov/> [48]),
 - NPOES Preparatory Project (NPP) (<http://jointmission.gsfc.nasa.gov/> [49]),
 - Lunar Reconnaissance Orbiter (LRO) (<http://lunar.gsfc.nasa.gov/> [50]),
 - Orbiting Carbon Observatory (OCO) (<http://oco.jpl.nasa.gov/> [51]),
 - Lunar Atmosphere and Dust Environment Explorer (LADEE) (<http://nasascience.nasa.gov/missions/ladee> [52]),
 - Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) (<http://crism.jhuapl.edu> [53]),
 - HypIRI Earth orbiting hyperspectral instrument (<http://hyspiri.jpl.nasa.gov/> [54]),
 - Visual Infrared Mapping Spectrometer (VIMS) on Cassini (<http://wwwvims.lpl.arizona.edu/> [55]),
 - Moon Mineralogy Mapper (M3) on Chandrayaan (<http://moonmineralogymapper.jpl.nasa.gov/> [56]),
 - James Webb Space Telescope (JWST) (<http://www.jwst.nasa.gov/> [57]).

Research proposed to this subtopic should demonstrate technical feasibility during Phase 1, in partnership with scientists, and subsequently show a path toward a Phase 2 prototype demonstration, with significant communication with missions and programs to ensure a successful Phase 3 infusion. Innovations are sought in data processing and analysis algorithms in the following areas:

- Optimization of Algorithms and Computational Methods that increase the utility of scientific research data, models, simulations, and visualizations. Of particular interest are innovative computational methods that will dramatically increase algorithm efficiency as well as the performance of scientific applications. Success will be measured by both speed improvements and output validation.
- Improvement of Data Collection, by identifying data gaps in real-time, and/or derive information through synthesis of data from multiple sources. The ultimate goal is to increase the value of data collected in terms of scientific discovery and application.
- Frameworks and Related Tools for Processing, Analyzing and Fusing image and vector data for the purpose of analyzing NASA's astrophysics, heliophysics, planetary and earth science mission data and therefore enable the advancement of NASA's scientific objectives. Of particular interest are open source frameworks that would enable sharing and validation of tools and algorithms.

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

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

Sub Topics:

Data Management - Storage, Mining and Visualization Topic S6.04

This subtopic focuses on supporting science analysis through innovative approaches for managing and visualizing collections of science data which are extremely large, complicated, and highly distributed in a networked environment that encompasses large geographic areas. There are specific areas for which proposals are being sought:

- Collaborative visualization tools that enable data exploration, data sharing, and data manipulation among scientists worldwide that make use of innovative hardware and software technologies for data manipulation and display, including the use of large multi-touch input devices or 3 dimensional display devices.
- Social networking tools that enable secure high bandwidth scientific collaboration among scientists worldwide that promote the development of online communities for sharing thoughts and ideas and for arriving at consensus opinions and understanding.
- Tools for science data discovery, data mining, data search, and data subsetting in extremely large data sets in clustered processing and storage environments, cloud computing environments, or shared data and computation environments.
- Storage systems, file systems, and data management systems that promote the secure long term preservation of data in a distributed online storage environment, provide for recovery from system and user errors, and provide dynamically configurable high speed access to data shared over wide area high speed networks.

Research should be conducted to demonstrate technical feasibility during Phase 1 and show a path toward a Phase 2 hardware/software demonstration, and when possible, deliver a demonstration unit for functional and environmental testing at the completion of the Phase 2 contract.

Sub Topics:

Software Engineering Tools for Scientific Models Topic S6.05

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

Target Programs, Missions and Mission Classes

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

- High-End Computing Program (<http://hec.nasa.gov> [58])
- Modeling, Analysis, and Prediction Program (<http://map.nasa.gov> [59])

Technology Areas

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

- Tools that assist in the construction of fine-grained unit-level software tests based upon existing functionality in a legacy Fortran application. Although tests written by developers are desirable, such tests are exceedingly difficult to create for legacy numerical software. Suites of these tests could provide a significant element of risk-reduction for maintenance and extension of these models, and would be incorporated into some sort of unit-testing framework.
- Tools that enable high-level source code transformations ("refactorings"). Although refactoring support for other programming languages, most notably Java, has shown significant gains in productivity, similar support for Fortran is rather limited. (<http://www.eclipse.org/photran/> [60]).
- Integration of a Fortran unit-testing frameworks within an Integrated Development Environment (IDE). Although multiple Fortran unit-testing frameworks have been developed (<http://sourceforge.net/projects/pfunit> [61]), adoption by the community has been slow in part due to lack of integration within IDE's. Integration of other Fortran capabilities is also encouraged.

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

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

Sub Topics:
