NASA SBIR 2014 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, Earth Science, Heliophysics and Planetary Science. The National Academy of Science has provided NASA with recently updated Decadal surveys that are useful to identify technologies that are of interest to the above science divisions. Those documents are available at the following locations:

- Astrophysics - (http://sites.nationalacademies.org/bpa/BPA_049810 [2]).
- Planetary - (http://solarsystem.nasa.gov/2013decadal/index.cfm [3]).
- Earth Science - (http://science.nasa.gov/earth-science/decadal-surveys/ [4]).
- Heliophysics - The 2009 technology roadmap can be downloaded at (http://science.nasa.gov/heliophysics/ [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.

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 of components, subsystems and systems that can be used in planned missions or a current technology program. Research should be conducted to demonstrate feasibility during Phase I and show a path towards a Phase II prototype demonstration. The following subtopics are concomitant with these objectives and are organized by technology.
Sub Topics:

S1.01 Lidar Remote Sensing Technologies

Lead Center: LaRC

Participating Center(s): GSFC, JPL

NASA recognizes the potential of lidar technology in meeting many of its science objectives by providing new capabilities or offering enhancements over current measurements of atmospheric and topographic parameters from ground, airborne, and space-based platforms. To meet NASA's requirements, advances are needed in state-of-the-art lidar technology with an emphasis on compactness, efficiency, reliability, lifetime, and high performance. Innovative lidar subsystem and component technologies systems that directly address the measurement of atmospheric constituents and surface topography of the Earth, Mars, the Moon, and other planetary bodies will be considered under this subtopic.

Proposals relevant to the development of lidar instruments that can be used in planned missions or current technology programs are highly encouraged. Examples of planned missions and technology programs are:

- Active Sensing of CO_2 Emissions over Nights, Days, and Seasons (ASCENDS).
- Aerosols-Clouds-Ecosystems (ACE).
- Doppler Wind Lidar (3D-WINDS).
- Laser Interferometer Space Antenna (LISA).
- Ozone Lidar.
- Lidar for Surface Topography (LIST).
- Mars atmospheric sensing, atmospheric entry and descent sensors for Mars and Earth, and tracking large-scale water movement (GRACE-II).

In addition, innovative technologies relevant to the NASA sub-orbital programs, such as Unmanned Aircraft Systems (UAS) and Venture-class focusing on the studies of the Earth climate, carbon cycle, weather, and atmospheric composition, are being sought. Compact, high efficiency lidar instruments for deployment on unconventional platforms, such as balloon, small sat, and cube sat, are also considered and encouraged.

The proposals should target advancement of lidar technologies for eventual space utilization. Phase I research should demonstrate the technical feasibility and show a path toward a Phase II prototype unit. Phase II prototypes should be capable of laboratory demonstration and preferably suitable for operation in the field from a ground-based station, an aircraft platform, or any science platform amply defended by the proposer. For the 2014 SBIR Program, we are soliciting the component and subsystem technologies described below.

Solid state, single frequency, pulsed, laser transmitters operating in the 1.0 µm to1.7 µm range with a wall-plug efficiency of greater than 25% suitable for CO_2 measurement, and free-space laser communication applications. The laser transmitters must be capable of generating frequency transform-limited pulses with a quality beam M^2 of less than 1.5 with an approximately 20 W of average power. We are interested in two different regimes of repetition rates: from 5 kHz to 20 kHz, and from 20 Hz to 100 Hz. In addition, development of non-traditional optical amplifier architectures that yield optical efficiency of >70% are of interest.

Compact and rugged single-frequency CW laser systems operating at 1.06 mm, 1.57 mm, 1.651 mm and 2.05 mm wavelengths suitable for precision space interferometry applications such as LISA, GRACE-II, and coherent detection lidars. The lasers must be developed with space environment considerations and demonstrate a clear path to space. Proposed lasers must be able to generate at least 20 mW of power with less than 10 kHz linewidth over a tunable range of about 50 nm. Systems must be highly wavelength stable and come with full supporting electronic systems for thermal and power control.

Long wavelength solid state laser transmitter technology (e 10 µm) is needed for atmospheric lidar and possible terrain altimeter instruments for Venus. The highly dense atmosphere, volatile clouds, and thick scattering layers make this measurement a low probability event, but should be possible with significant pulse energies at long wavelengths. In combination of large, lightweight receiver, we can maximize the possibility of achieving a round trip remote sensing link from low Venus orbit. Minimum pulse energies of e 100 mJ are needed to reach the surface in the best conditions, such as with periodic holes and gaps in the clouds. Repetition rates of e 10Hz are desired for reasonable footprint spacing should a link be achieved.

Ultra-low noise photo receiver modules, operating either at 1.6 or 2.0 micron wavelengths for measuring CO_2 concentration, comprising of the detection device, complete Dewar/cooling systems, and associated amplifiers. General requirements are: large active detection diameter (>200 micron), high quantum efficiency (>85%), noise equivalent power of the order of 10-14 W/sqrt(Hz), and bandwidth greater than 20 MHz.

Lightweight scanning telescopes capable of a conical pattern with nadir angle fixed in the range of 30 to 45 degrees. The lightweight scanning telescopes are sought for both direct and heterodyne detection wind lidars and tropospheric ozone lidars. For winds, the direct detection lidar operates in 355 nm to 1064 nm wavelength region and the heterodyne detection lidar in 1550 nm to 2050 nm. For ozone, these systems should operate between 280-300 nm. The ozone systems are designed to support NASA's TOLNet network providing data for satellite validation and the study of anthropogenic pollution. High optical efficiency and near diffraction-limited performance are among major considerations. The proposer must show a clear path to space by addressing scalability to apertures greater than 1 m, materials (e.g., substrates and coatings) selection compatible with a space environment, and thermally-stable design. Phase II should result in a prototype unit capable of demonstration in a high-altitude aircraft environment, with aperture of at least 10 inches in diameter.

S1.02 Microwave Technologies for Remote Sensing

Lead Center: GSFC

Participating Center(s): JPL, LaRC

NASA employs active (radar) and passive (radiometer) microwave sensors for a wide range of remote sensing applications (for example, see: http://www.nap.edu/catalog/11820.html [6]). These sensors include low frequency (less than 10 MHz) sounders to G-band (160 GHz) radars for measuring precipitation and clouds, for planetary landing, upper atmospheric monitoring, and global snow coverage (SCLP). We are seeking proposals for the development of innovative technologies to support these future radar and radiometer missions and applications. The areas of interest for this call are listed below:

- W-band Solid State Power Amplifier: Freq: 94 GHz +/- 500 MHz, Peak power: > 50 W, Duty cycle: > 20 % , Gain: > 40 dB, Gain flatness within band: <+/- 1 dB, Phase linearity within band:< +/- 1 degree, On/off switching speed: < 1 ?s, Noise figure: < 15 dB, Spurious: < -60 dBc, Harmonic: < -25 dBc.
- 640 GHz Polarimeter I, Q, U Channels, Polarimetric measurements to provide microphysical parameterization of ice clouds applicable to ACE.
- Broadband low noise cryogenic amplifier operating between 1 and 6 GHz.
- G-band (140-220 GHz) Components: 3-port strip line/CPW based switch (20 dB isolation, 1 dB loss, 1 kHz switching frequency), G-band (140-220 GHz) Components: Isolator with isolation > 15 dB, Insertion loss < 1.2 dB.
- High power Solid-State Ka-band Transmitter: Psat > 200W, Duty Cycle > 20%, DC to RF Efficiency > 30%, Gain > 50 dB.
- Very high-efficiency VHF Power Amplifier for CubeSats: Center frequency range: 40MHz to 100MHz, Fractional bandwidth: 20%, Psat >25W, Gain > 40 dB, Efficiency > 90%.
- Technology for low-power, rad-tolerant broad band spectrometer back ends for microwave radiometers. Includes: digitizers with 20 Gsps, 20 GHz bandwidth, 4 or more EOB and a simple interface to FPGA; ASIC implementations of polyphase spectrometer digital signal processing with ~1 watt/GHz.
- Back ends for microwave radiometers and sounders including compact low power RFI mitigation hardware for upgrading existing systems and low-power, low-mass filter back ends with >5 GHz spectral coverage, 200 MHz resolution, and less than one watt.

S1.03 Sensor and Detector Technology for Visible, IR, Far IR and Submillimeter

Lead Center: JPL

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 [7]), and astronomy and astrophysics (http://www.nap.edu/books/0309070317/html/ [8]).

- Development of un-cooled or cooled infrared detectors (hybridized or designed to be hybridized to an appropriate read-out integrated circuit) with NE?T<20mK, QE>30% and dark currents <1.5x10-6 A/cm^2 in the 5-14 µm infrared wavelength region. Array formats may be variable, 640 x 512 typical, with a goal to meet or exceed 2k X 2k pixel arrays. Evolve new technologies such as InAs/GaSb type-II strained layer super-lattices to meet these specifications.
- New or improved technologies leading to measurement of trace atmospheric species (e.g., CO, CH_4, N_2O) or broadband energy balance in the IR and far-IR from geostationary and low-Earth orbital platforms. Of particular interest are new direct, nanowire or heterodyne detector technologies made using high temperature superconducting films (YBCO, MgB_2) or engineered semiconductor materials, especially 2-Dimensional Electron Gas (2-DEG) and Quantum Wells (QW) that operate at temperatures achieved by standard 1 or 2 stage flight qualified cryocoolers and do not require cooling to liquid helium temperatures.

Candidate missions are thermal imaging, LANDSAT Thermal InfraRed Sensor (TIRS), Climate Absolute Radiance and Refractivity Observatory (CLARREO), BOReal Ecosystem Atmosphere Study (BOREAS), Methane Trace Gas Sounder or other infrared earth observing missions.
- 1k x 1k or larger format MCT detector arrays with cutoff wavelength extended to 12 microns for use in missions to NEOs, comets and the outer planets.
- Compact, low power, readout electronics for KID arrays. Enables mega pixel arrays for mm to Far IR telescopes and spectrometers for astrophysics and earth observation.
- Development of a robust wafer-level integration technology that will allow high-frequency capable interconnects and allow two dis-similar substrates (i.e., silicon and GaAs) to be aligned and mechanically 'welded' together. Specially develop ball grid and/or Through Silicon Via (TSV) technology that can support submillimeter-wave arrays. Initially the technology can be demonstrated at the '1-inch' die level but should be do-able at the 4-inch wafer level.

S1.04 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 [9]).

Specific mission pages:

- IXO - (http://htxs.gsfc.nasa.gov/index.html [10]).
- Future planetary programs - (http://nasascience.nasa.gov/planetary-science/mission_list [11]).
- Earth Science Decadal missions - (http://www.nap.edu/catalog/11820.html [6]).
- Helio Probes - (http://nasascience.nasa.gov/heliophysics/mission_list [12]).

Specific technology areas are:

- Significant improvement in wide band gap semiconductor materials, such as AlGaN, ZnMgO and SiC, individual detectors, and detector arrays for operation at room temperature or higher for missions such as Geo-CAPE, NWO, ATALAST and planetary science composition measurements.
- Highly integrated, low noise (< 300 electrons rms with interconnects), low power (< 100 uW/channel) mixed signal ASIC readout electronics as well as charge amplifier ASIC readouts with tunable capacitive inputs to match detector pixel capacitance. See needs of National Research Council's Earth Science Decadal Survey (NRC, 2007): Future Missions include GEOCape, HyspIRI, GACM, future GOES and SOHO programs and planetary science composition measurements.
- Visible-blind SiC Avalanche Photodiodes (APDs) for EUV photon counting are required. The APDs must show a linear mode gain >10E6 at a breakdown reverse voltage between 80 and 100V. The APD's must demonstrate detection capability of better than 6 photons/pixel/s down to 135nm wavelength. See needs of National Research Council's Earth Science Decadal Survey (NRC, 2007): Tropospheric ozone.
- Large area (3 m^2) photon counting near-UV detectors with 3 mm pixels and able to count at 10 MHz. Array with high active area fraction (>85%), 0.5 megapixels and readout less than 1 mW/channel. Future instruments are focal planes for JEM-EUSO and OWL ultra-high energy cosmic ray instruments and ground Cherenkov telescope arrays such as CTA, and ring-imaging Cherenkov detectors for cosmic ray instruments such as BESS-ISO. As an example (JEM-EUSO and OWL), imaging from low-Earth orbit of air

fluorescence, UV light generated by giant air showers by ultra-high energy (E >10E19 eV) cosmic rays require the development of high sensitivity and efficiency detection of 300-400 nm UV photons to measure signals at the few photon (single photo-electron) level. A secondary goal minimizes the sensitivity to photons with a wavelength greater than 400 nm. High electronic gain (10E4 to 10E6), low noise, fast time response (<10 ns), minimal dead time (<5% dead time at 10 ns response time), high segmentation with low dead area (<20% nominal, <5% goal), and the ability to tailor pixel size to match that dictated by the imaging optics. Optical designs under consideration dictate a pixel size ranging from approximately 2 x 2 mm^2 to 10 x 10 mm^2. Focal plane mass must be minimized (2g/cm^2 goal). Individual pixel readout is required. The entire focal plane detector can be formed from smaller, individual sub-arrays.

S1.05 Particles and Field Sensors and Instrument Enabling Technologies

Lead Center: GSFC

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

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

- Self-calibrating scalar-vector magnetometer for future Earth and space science missions. Performance goals: dynamic range: ±100,000 nT, accuracy with self-calibration: 1 nT, sensitivity: 5 pT - Hz-1/2 (max), max sensor unit size: 6 x 6 x 12 cm, max sensor mass: 0.6 kg, max electronics unit size: 8 x 13 x 5 cm, max electronics mass: 1 kg, and max power: 5 W operation, 0.5 W standby, including, but not limited to "sensors on a chip".
- High magnetic-field sensor that measures magnetic field magnitudes to 16 Gauss with an accuracy of 1 part in 105.
- Strong, lightweight, thin, compactly stowed electric field booms possibly using composite materials that deploy sensors to distances of 10-m or more.
- Low-noise magnetic materials for advanced magnetometer sensors with performance equal to or better than those in the 6-81.3 Mo-Permalloy family.
- Radiation-hardened ASICs including Low-power multi-channel ADCs, DACs, and spectrum analyzer modules that determine mass spectra using fast algorithm deconvolution to produce ion counts for specific ion species.
- Low-cost, low-power, fast-stepping (?; 50-µs), high-voltage power supplies 5-15 kV. Low-cost, efficient low-power power supplies (5-10 V).
- High efficiency (5% or greater) conversion surfaces for low-energy neutral atom conversion to ions.
- Miniature low-power, high-efficiency, thermionic cathodes, and cold cathodes, capable of 1-mA electron emission per 100-mW heater power with emission surface area of 1-mm^2 and expected lifetime of 20,000 hours.
- Long wire boom (?; 50 m) deployment systems for the deployment of very lightweight tethers or antennae on spinning spacecraft.
- Systems to determine the orthogonality of a deployed electric/magnetic field boom system in flight (for use with three-axis rigid 10-m booms) accurate to 0.10° dynamic.
- APDs in single pixel and multi-pixel. The APDs, typically used for photons, should be optimized for particles including thin dead layer, increased energy range, gain stability and radiation hardness, but with much higher energy resolution (<0.5KeV) compared to SSDs.
- Solar Blind particle detectors less sensitive to light such as silicon carbide based.
- Developing near real-time data-assimilative models and tools, for both solar quiet and active times, which allow for precise specification and forecasts of the space environment, beginning with solar eruptions and

propagation, and including ionospheric electron density specification.

S1.06 In Situ Sensors and Sensor Systems for Lunar and Planetary Science

Lead Center: JPL

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

This subtopic solicits development of advanced instrument technologies and components suitable for deployment on planetary and lunar missions. These technologies must be capable of withstanding operation in space and planetary environments, including the expected pressures, radiation levels, launch and impact stresses, and range of survival and operational temperatures. Technologies that reduce mass, power, volume, and data rates for instruments and instrument components without loss of scientific capability are of particular importance. In addition, technologies that can increase instrument resolution and sensitivity or achieve new and innovative scientific measurements are solicited. For example missions, see (http://science.hq.nasa.gov/missions [13]). For details of the specific requirements see the National Research Council's, Vision and Voyages for Planetary Science in the Decade 2013-2022 (http://solarsystem.nasa.gov/2013decadal/ [14]). Technologies that support NASA's New Frontiers and Discovery missions to various planetary bodies are of top priority.

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

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

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

Proposers are strongly encouraged to relate their proposed development to NASA's future planetary exploration goals and existing flight instrument capability, to provide a comparison metric for assessing proposed improvements.

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

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

S1.07 Airborne Measurement Systems

Lead Center: GSFC

Measurement system miniaturization and/or increased performance is needed to support for NASA's airborne science missions, particularly those utilizing the Global Hawk, SIERRA, Dragon Eye or other unmanned aircraft. The subject airborne instruments are intended as calibration/validation systems - the proposers should demonstrate an understanding of the measurement requirements and be able to link those to instrument performance. Linkages to other subtopics such as S3.04 Unmanned Aircraft and Sounding Rocket Technologies are encouraged. Complete instrument systems are desired, including features such as remote/unattended operation and data acquisition, low power consumption, and minimum size and weight. Desired sensors include:

- Precipitation- multiphase (0.1 mm to 20 mm with 5 % accuracy in three dimensions).
- Surface snow thickness (5 cm resolution).
- Aerosols and cloud particles (0.01 micron to 200 micron with 10 % accuracy).
- Volcanic ash (0.25 to 100 micron with 10 % accuracy).
- Sulfur dioxide (4 ppb resolution).

- Carbon dioxide (1 ppm accuracy).
- Methane (5 ppm accuracy, 10 ppm precision).
- Three-dimensional wind measurement (1 mps accuracy/resolution at 10 Hz sampling).

S1.08 Surface and Sub-surface Measurement Systems

Lead Center: GSFC

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

Relevance to future space missions such as Active Sensing of CO_2 Emissions over Nights, Days, and Seasons (ASCENDS), Orbiting Carbon Observatory – 2 (OCO-2), Global Precipitation Measurement (GPM), Geostationary Coastal and Air Pollution Events (GEO-CAPE), Hyperspectral InfraRed Imager (HyspIRI), Aerosol, Cloud, Ecosystems (ACE, including Pre-ACE/PACE), etc., is important, yet early adoption for alternative uses by NASA, other agencies, or industry is recognized as a viable path towards full maturity. Additionally, sensor system innovations with significant near-term commercial potential that may be suitable for NASA's research after full development are of interest:

- Precipitation (e.g., motion stabilized disdrometer for shipboard deployments).
- Suspended particle concentrations and spectra of mineral and biogenic (phytoplankton and detritus) components.
- Gases - carbon dioxide, methane, etc.
- Miniaturized air-dropped sensors, suitable for Global Hawk deployment, for ocean surface and subsurface measurements such as conductivity, temperature, and depth. Miniature systems suitable for penetration of thin ice are highly desirable.
- Multi-wavelength, LIDAR-based, atmospheric ozone and aerosol profilers for continuous, simultaneous observations from multiple sites. Examples include three-band ozone measurement systems operating in the UV spectrum (e.g., 280-316 nm, possibly tunable), combined with visible or infrared systems for aerosols. Remote/untended operation, minimum eye-hazards, and portability are desired.
- Miniaturized and novel instrumentation for measuring inherent and apparent optical properties (specifically to support vicarious calibration and validation of ocean color satellites, i.e., reflectance, absorption, scattering), in situ biogeochemical measurements of marine and aquatic components and rates including but not limited to nutrients, phytoplankton and their functional groups, and floating and submerged aquatic plants.

Novel geophysical and diagnostic instruments suitable for ecosystem monitoring. Fielding for NASA's Applications and Earth Science Research activities is a primary goal. Innovations with future utility for other NASA programs (for example, Planetary Research) that can be matured in an Earth science role are also encouraged.

S1.09 Atomic Interferometry

Lead Center: JPL

Participating Center(s): GSFC

Recent developments of laser control and manipulation of atoms have led to a new type of precision inertial force and gravity sensors based on atom interferometry. Atom interferometers exploit the quantum mechanical wave nature of atomic particles and quantum gases for sensitive interferometric measurements. Ground-based laboratory experiments and instruments have already demonstrated beyond the state of the art performances of accelerometer, gyroscope, and gravity measurements. Microgravity environment in space provides opportunities for further drastic improvements in sensitivity and precision. Such inertial sensors will have great potential to provide new capabilities for NASA Earth and planetary gravity measurements, for spacecraft inertial navigation and guidance, and for gravitational wave detection and test of properties of gravity in space.

Currently the most mature development of atom interferometers as measurement instruments are those based on light pulsed atom interferometers with freefall cold atoms. There remain a number of technical challenges to infuse this technology in space applications. Some of the identified key challenges are (but not limited to):

- Compact high flux ultra-cold atom sources for free space atom interferometers ($>1x10^6$ total useful free-space atoms, <1 nK, Rb, K, Cs, Yb, Sr, and Hg are example candidates but others can be justified by the offeror).
- Ultra-high vacuum seal technologies that allow completely sealed, non-magnetic enclosures with high quality optical access (base pressure maintained $<1x10^{-9}$ torr, consideration should be given to the inclusion of cold atom sources of interest).
- Beyond the state-of-the-art photonic components at wavelengths for atomic species of interest, particularly at NIR and visible: efficient acousto-optic modulators (low rf power ~ 200 mW or less, low thermal distortion, ~80$ or greater diffraction efficiency); efficient electro-optic modulators (low bias drift, residual AM, and return loss, fiber-coupled preferred), miniature optical isolators (~30 dB isolation or greater, ~ -2 dB loss or less), robust high-speed high-extinction shutters (switching time < 1 ms, extinction > 60 dB are highly desired).
- Flight qualifiable lasers of narrow linewidth and higher power for clock and cooling transitions of atomic species of interest. Clock lasers: 1 $Hz/s^{1/2}$ at 1 s, ~ 1W output power or greater; Cooling and trapping lasers: 10 kHz linewidth and ~ 1 W or greater.
- Analysis and simulation tool of cold atom system in trapped and freefall states relevant to atom interferometer and clock measurements in space.

The subsystem technology development proposals should clearly state the relevance, define requirements, relevant atomic species and working laser wavelengths, and indicate its path to a space-borne instrument.

Recognizing the fact that the field of atom interferometry is an active research field and there are potential breakthrough approaches still being investigated in research laboratories, NASA is also interested in new ideas of atom interferometry that will lead to better and smaller inertial sensors for rotational sensors, accelerometers, and gravity measurement instruments and will benefit and enable future NASA space missions. Therefore, this subtopic call is also soliciting practical approaches to new sensor ideas that may have high risk but can have high payoffs. Some of the known examples are:

- Bose Einstein condensate based sensors.
- Sensors using large momentum transfer.
- Guided atom wave sensors.
- Non-classical atom interferometers.
- Any other cold atom-based sensor technology such as optical clocks.

Advanced Telescope Systems Topic S2

The NASA Science Missions Directorate seeks technology for cost-effective high-performance advanced space telescopes for astrophysics and Earth science. Astrophysics applications require large aperture light-weight highly reflecting mirrors, deployable large structures and innovative metrology, control of unwanted radiation for high-contrast optics, precision formation flying for synthetic aperture telescopes, and cryogenic optics to enable far infrared telescopes. A few of the new astrophysics telescopes and their subsystems will require operation at cryogenic temperatures as cold a 4 °K. 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 telescopes for Earth science.
Sub Topics:

S2.01 Proximity Glare Suppression for Astronomical Coronagraphy

Lead Center: JPL

Participating Center(s): ARC, GSFC

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

This innovative research focuses on advances in coronagraphic instruments, starlight cancellation instruments, and potential occulting technologies that operate at visible and near infrared wavelengths. The ultimate application of these instruments is to operate in space as part of a future observatory mission. Measurement techniques include imaging, photometry, spectroscopy, and polarimetry. There is interest in component development and innovative instrument design, as well as in the fabrication of subsystem devices to include, but not limited to, the following areas:

Starlight Suppression Technologies

- Image plane hybrid metal/dielectric, and polarization apodization masks in linear and circular patterns.
- Transmissive holographic masks for diffraction control and PSF apodization.
- Sharp-edged, low-scatter pupil plane masks.
- Low-scatter, low-reflectivity, sharp, flexible edges for control of scatter in starshades.
- Systems to measure spatial optical density, phase inhomogeneity, scattering, spectral dispersion, thermal variations, and to otherwise estimate the accuracy of high-dynamic range apodizing masks.
- Pupil remapping technologies to achieve beam apodization.
- Techniques to characterize highly aspheric optics.
- Methods to distinguish the coherent and incoherent scatter in a broad band speckle field.
- Coherent fiber bundles consisting of up to 10,000 fibers with lenslets on both input and output side, such that both spatial and temporal coherence is maintained across the fiber bundle for possible wavefront/amplitude control through the fiber bundle.

Wavefront Measurement and Control Technologies

- Small stroke, high precision, deformable mirrors and associated driving electronics scalable to 10,000 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.
- Instruments to perform broad-band sensing of wavefronts and distinguish amplitude and phase in the wavefront.
- Integrated mirror/actuator programmable deformable mirror.
- Multiplexers with ultra-low power dissipation for electrical connection to deformable mirrors.
- Low-order wavefront sensors for measuring wavefront instabilities to enable real-time control and post-processing of aberrations.
- Thermally and mechanically insensitive optical benches and systems.

Optical Coating and Measurement Technologies

- Instruments capable of measuring polarization cross-talk and birefringence to parts per million.
- Highly reflecting, uniform, broadband coatings for large (> 1 m diameter) optics.
- Polarization-insensitive coatings for large optics.
- Methods to measure the spectral reflectivity and polarization uniformity across large optics.

Other

- Methods to fabricate diffractive patterns on large optics to generate astrometric reference frames.
- Artificial star and planet point sources, with 1e10 dynamic range and uniform illumination of an f/25 optical system, working in the visible and near infrared.
- Deformable, calibrated, collimating source to simulate the telescope front end of a coronagraphic system undergoing thermal deformations.
- Technologies for high contrast integral field spectroscopy, in particular for microlens arrays with or without accompanying mask arrays, working in the visible and NIR (0.4 - 1.8 microns), with lenslet separations in the 0.1 -0.4 mm range, in formats of ~140x140 lenslets.

S2.02 Precision Deployable Optical Structures and Metrology

Lead Center: JPL

Participating Center(s): GSFC, LaRC

Planned future NASA Missions in astrophysics, such as the Wide-Field Infrared Survey Telescope (WFIRST) and the New Worlds Technology Development Program (coronagraph, external occulter and interferometer technologies) will push the state of the art in current optomechanical technologies. Mission concepts for New Worlds science would require 10 - 30 m class, cost-effective telescope observatories that are diffraction limited at wavelengths from the visible to the far IR, and operate at temperatures from 4 - 300 K. In addition, ground based telescopes such as the Cerro Chajnantor Atacama Telescope (CCAT) requires similar technology development.

The desired areal density is 1 - 10 kg/m^2 with a packaging efficiency of 3-10 deployed/stowed diameter. Static and dynamic wavefront error tolerances to thermal and dynamic perturbations may be achieved through passive means (e.g., via a high stiffness system, passive thermal control, jitter isolation or damping) or through active opto-mechanical control. Large deployable multi-layer structures in support of sunshades for passive thermal control and 20m to 50m class planet finding external occulters are also relevant technologies. Potential architecture implementations must package into an existing launch volume, deploy and be self-aligning to the micron level. The target space environment is expected to be the Earth-Sun L2.

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

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

In particular, important subsystem considerations may include:

- Innovative concepts for packaging fully integrated subsystems (e.g., power distribution, sensing, and control components).
- Mechanical, inflatable, or other precision deployable technologies.
- Thermally-stable materials (CTE < 1ppm) for deployable structures.
- Innovative systems, which minimize complexity, mass, power and cost.
- Innovative testing and verification methodologies.

The goal for this effort is to mature technologies that can be used to fabricate 16 m class or greater, lightweight, ambient or cryogenic flight-qualified observatory systems. Proposals to fabricate demonstration components and subsystems with direct scalability to flight systems through validated models will be given preference. The target launch volume and expected disturbances, along with the estimate of system performance, should be included in the discussion. Proposals with system solutions for large sunshields and external occulters will also be accepted. A successful proposal shows a path toward a Phase II delivery of demonstration hardware scalable to 5 meter diameter for ground test characterization.

Before embarking on the design and fabrication of complex space-based deployable telescopes, additional risk reduction in operating an actively controlled telescope in orbit is desired. To be cost effective, deployable apertures that conform to a cubesat (up to 3-U) or ESPA format are desired. Consequently, deployment hinge and latching concepts, buildable for these missions and scaleable to larger systems are desired. Such a system should allow <25 micron deployment repeatability and sub-micron stability for both thermal and mechanical on-orbit disturbances. A successful proposal would deliver a full-scale cubesat or ESPA ring compatible deployable aperture with mock optical elements.

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

S2.03 Advanced Optical Systems

Lead Center: MSFC

Participating Center(s): GSFC, JPL

his subtopic solicits solutions in the following areas:

- Optical Components, Coatings and Systems for potential x-ray missions.
- Optical Components, Coatings and Systems for potential UV/Optical missions.

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 primary emphasis of this subtopic is to mature technologies needed to manufacture, test or operate complete mirror systems or telescope assemblies. Section 3 contains a detailed discussion on specific technologies which need developing for each area.

The 2010 National Academy Astro2010 Decadal Report specifically identifies optical components and coatings as key technologies needed to enable several different future missions, including:

- Light-weight x-ray imaging mirrors for future large advanced x-ray observatories.
- Large aperture, light-weight mirrors for future UV/Optical telescopes.
- Broadband high reflectance coatings for future UV/Optical telescopes.

The 2012 National Academy report “NASA Space Technology Roadmaps and Priorities” states that one of the top technical challenges in which NASA should invest over the next five years is developing a new generation of larger effective aperture, lower-cost astronomical telescopes that enable discovery of habitable planets, facilitate advances in solar physics, and enable the study of faint structures around bright objects. To enable this capability requires low-cost, ultra-stable, large-aperture, normal and grazing incidence mirrors with low mass-to-collecting area ratios. To enable these new astronomical telescopes, the report identifies three specific optical systems technologies:

- Active align/control of grazing-incidence imaging systems to achieve < 1 arc-second angular resolution.
- Active align/control of normal-incidence imaging systems to achieve 500 nm diffraction limit (40 nm rms wavefront error, WFE) performance.
- Normal incidence 4-meter (or larger) diameter 5 nm rms WFE (300 nm system diffraction limit) mirrors.

Finally, impacting potential space telescopes, NASA is developing a heavy lift space launch system (SLS). An SLS with an 8 to 10 meter fairing and 80 to 100 mt capacity to LEO would enable extremely large space telescopes. Potential systems include 12 to 30 meter class segmented primary mirrors for UV/optical or infrared wavelengths and 8 to 16 meter class segmented x-ray telescope mirrors. These potential future space telescopes have very specific mirror technology needs. UV/optical telescopes (such as ATLAST-9 or ATLAST-16) require 1 to 3 meter class mirrors with < 5 nm rms surface figures. IR telescopes (such as SAFIR/CALISTO) require 2 to 3 to 8 meter class mirrors with cryo-deformations < 100 nm rms. X-ray telescopes (such as GenX) require 1 to 2 meter long grazing incidence segments with angular resolution < 0.5 arc-sec and surface micro-roughness < 0.5-nm rms.

Technical Challenges:

In all cases, the most important metric for an advanced optical system (after performance) is affordability or areal cost (cost per square meter of collecting aperture). Currently both x-ray and normal incidence space mirrors cost $4 million to $6 million per square meter of optical surface area. This research effort seeks a cost reduction for precision optical components by 5 to 50 times, to less than $1M to $100K/m^2.

Successful proposals shall provide a scale-up roadmap (including processing and infrastructure issues) for full scale space qualifiable flight optics systems. Material behavior, process control, active and/or passive optical performance, and mounting/deploying issues should be resolved and demonstrated.

Optical Components, Coatings and Systems for Potential X-ray Missions

Potential x-ray missions require:

- X-ray imaging telescopes with <1 arc-sec angular resolution and > 1 to 5 m^2 collecting area.
- Multilayer high-reflectance coatings for hard x-ray mirrors (similar to NuSTAR).
- X-ray transmission and/or reflection gratings.

Regarding x-ray telescope, multiple technologies are needed to enable < 1 arc-sec x-ray observatories. These include, but are not limited to: new materials such as silicon carbide, porous silicon, beryllium; improved techniques to manufacture (such as direct precision machining, rapid optical fabrication, slumping or replication technologies) 0.3 to 2 meter diameter mirror shells or segments; improved metrology, performance prediction and testing techniques; active control of mirror shape; new structures for holding and actively aligning of mirrors in a telescope assembly.

For example, the Wide-Field X-Ray Telescope (WFXT) requires a 6 meter focal length x-ray mirror with 1 arc-sec resolution and 1 m^2 of collecting area. One implementation of this mirror has 71 concentric full shell hyperbola/parabola pairs whose diameters range from 0.3 to 1.0 meter and whose length is 150 to 240 mm (this length is split between the H/P pair). Total mass for the integrated mirror system (shells and structure) is < 1000 kg. For individual mirror shells, axial slope errors should be ~ 1 arc-sec rms (~100 nm rms figure error for 20 mm spatial frequencies) and surface finish should be < 0.5 nm rms.

Additionally, potential Heliophysics missions require a grazing incidence telescope with an effective collecting area of ~3 cm^2 for 0.1 to 4 nm wavelengths, 4 meter effective focal length, 0.8 degree angle of incidence and surface roughness of 0.2 nm rms.

Regarding x-ray coatings, future x-ray missions require multilayer depth gradient coatings with high broadband reflectivity for 5 to 80 keV energy photons.

Regarding improved metrology and performance prediction, technology is needed to fully characterize x-ray mirrors (and mandrels) and predict their angular resolution performance. Potential solutions include (but are not limited to): both sub-aperture stitching (in the lateral direction) to acquire data over the entire optical surface, and merging/interpolating data with different spatial frequency domains. This can be done using different surface measuring instruments with different fields of view and resolutions.

Successful proposals will demonstrate an ability to manufacture, test and control a prototype 0.25 to 0.5 meter diameter x-ray mirror assembly; or, to coat a 0.25 to 0.5 meter class representative optical component; or, to characterize and performance predict a 0.5 to 1.0 meter class x-ray mirror or mandrel. An ideal Phase I project would deliver a sub-scale component such as a 0.25 meter x-ray precision mirror; or demonstrate a prototype metrology system capable of characterizing the optical surface morphology of an x-ray component and predicting its angular performance. An ideal Phase II project would further advance the technology to produce a space-qualifiable 0.5 meter mirror, with a TRL in the 4 to 5 range; or deliver a metrology system capable of characterizing 0.5 to 1.0 meter class x-ray mirrors (or mandrels) and predicting their angular resolution performance. Both Phase I and Phase II deliverables would be accompanied by all necessary documentation, including the optical performance assessment and all data on processing and properties of its substrate materials. The Phase II would also include a mechanical and thermal stability analysis.

Optical Components, Coatings and Systems for Potential UV/Optical Missions

Potential UV/Optical missions require:

- Large aperture, light-weight mirrors.
- Broadband high reflectance coatings.

Regarding large aperture mirrors, future UVOIR missions require 4 to 8 or 16 meter monolithic or segmented primary mirrors with < 10 nm rms surface figures. Mirror areal density depends upon available launch vehicle capacities to Sun-Earth L2 (i.e., 15 kg/m^2 for a 5 m fairing EELV vs. 60 kg/m^2 for a 10 m fairing SLS).

Regarding broadband reflectance coating, future UVOIR missions require coatings with broadband reflectivity > 60% and uniform polarization from 90 nm to 2500 nm which can be deposited onto a 2 to 4 to 8 meter mirror substrate. Additionally, the coatings need to have > 90% reflectivity from 450 nm to 2500 nm. Future EUV missions require coatings with reflectivity > 90% from 6 nm to 200 nm which can be deposited onto mirror substrates as large as 2.4 meters in diameter.

Successful proposals will demonstrate an ability to manufacture, test and control ultra-low-cost precision 0.25 to 0.5 meter optical systems; or to coat a 0.25 to 0.5 meter representative optical component. Potential solutions include, but are not limited to, new mirror materials such as silicon carbide, nanolaminates or carbon-fiber reinforced polymer; new fabrication processes such as direct precision machining, rapid optical fabrication, roller embossing at optical tolerances, slumping or replication technologies to manufacture 1 to 2 meter (or larger) precision quality mirrors or lens segments. Solutions include reflective, transmissive, diffractive or high order diffractive blazed lens optical components for assembly of large (16 to 32 meter) optical quality primary elements.

Potential solutions to improve UV reflective coatings include, but are not limited to, investigations of new coating materials with promising UV performance; new deposition processes; and examination of handling processes, contamination control, and safety procedures related to depositing coatings, storing coated optics, and integrating coated optics into flight hardware. An ability to demonstrate optical performance on 2 to 3 meter class optical surfaces is important.

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

S2.04 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:

- WFIRST concepts (http://wfirst.gsfc.nasa.gov/ [15]).
- NGXO (http://ixo.gsfc.nasa.gov/ [16]).
- SGO (http://lisa.gsfc.nasa.gov/ [17]).

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. Also, novel metrological solutions that can measure figure errors over a large fraction of the PSD range are desired, especially techniques and instrumentation that can perform measurements while the optic is mounted to the figuring/polishing machine. Large lightweight monolithic metallic aspheres manufactured using innovative mirror substrate materials that can be assembled and welded together from smaller segments are sought. Also of interest is analytical software to process, fit, and model large optics surface metrology data with the goals to characterize surface morphology over spatial frequency bandwidths determined by the desired angular resolution performance; to provide stitched metrology capabilities obtained with different surface measuring instruments with different fields of view and resolution; to provide a data analysis tool for defining the optical surface fabrication tolerances based on the desired x-ray optics angular resolution performance; to allow forecasting of the surface morphological properties of optics.

By the end of a Phase II program, technologies must be developed to the point where the technique or instrument can dovetail into an existing optics manufacturing facility producing optics at the R&D stage. Metrology instruments should have 10 nm or better surface height resolution and span at least 3 orders of magnitude in lateral spatial frequency. Examples of technologies and instruments of interest include:

- Innovative metal mirror substrate materials or manufacturing methods such as welding component segments into one monolith that produce thin mirror substrates that are stiffer and/or lighter than existing materials or methods.
- Interferometric nulling optics for very shallow conical optics used in x-ray telescopes.
- Segmented systems commonly span 60 degrees in azimuth and 200 mm axial length and cone angles vary from 0.1 to 1 degree.
- Low stress metrology mounts that can hold optics without introducing mounting distortion.
- Low normal force figuring/polishing systems operating in the 1 mm to 50 mm period range with minimal impact at significantly smaller and larger period ranges.
- In-situ metrology systems that can measure optics and provide feedback to figuring/polishing instruments without removing the part from the spindle.
- Innovative mirror substrate materials or manufacturing methods that produce thin mirror substrates that are stiffer and/or lighter than existing materials or methods.
- Extreme aspheric and/or anamorphic optics for pupil intensity amplitude apodization.
- Metrology systems useful for measuring large optics with high precision.
- Innovative method of bonding extremely lightweight (less than 1 kg/m^2 areal density) and thin (less than 1 mm) mirrors to a housing structure, preserving both alignment and figure.
- Innovative method of improving the figure of extremely lightweight and thin mirrors without polishing, such as using the coating stress.
- Manufacturing technology and wavefront sensing and control as applied to coronagraph applications for exoplanet detection.

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

Spacecraft and Platform Subsystems Topic S3

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

and control; transmitters/antenna; computers/on-board processing/software; and structural elements. Science platforms of interest could include unmanned aerial vehicles, sounding rockets, or balloons that carry scientific instruments/payloads, to planetary ascent vehicles or Earth return vehicles that bring samples back to Earth for analysis. This topic area addresses the future needs in many of these sub-system areas, as well as their application to specific spacecraft and platform needs. Innovations for 2014 are sought in the areas of:

- Command and Data Handling, and Instrument Electronics.
- Power Generation and Conversion.
- Propulsion Systems for Robotic Science Missions.
- Power Electronics and Management, and Energy Storage.
- Unmanned Aircraft and Sounding Rocket Technologies.
- Thermal Control Systems.
- Guidance, Navigation and Control.
- Terrestrial and Planetary Balloons.

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

- The Astrophysics Roadmap - (http://nasascience.nasa.gov/about-us/science-strategy [18]).
- Astrophysics Decadal Survey - "New Worlds, New Horizons: in Astronomy and Astrophysics" (http://www.nap.edu/catalog.php?record_id=12951 [19]).
- The Earth Science Decadal Survey - (http://books.nap.edu/catalog.php?record_id=11820 [20]).
- The Heliophysics roadmap - "The Solar and Space Physics of a New Era: Recommended Roadmap for Science and Technology 20092030" (http://sec.gsfc.nasa.gov/2009_Roadmap.pdf [21]).
- The 2011 Planetary Science Decadal Survey was released March 2011. This decadal survey is considering technology needs. (http://www.nap.edu/catalog.php?record_id=13117 [22]).

Sub Topics:

S3.01 Power Generation and Conversion

Lead Center: GRC

Participating Center(s): ARC, JPL, JSC

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

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

Radioisotope Power Conversion

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

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

- System specific mass greater than 10 We/kg.
- Highly reliable autonomous control.

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

- Advanced bulk materials enabling demonstration of high efficiency thermoelectric energy conversion (>15%) when using high grade space-qualified heat sources (> 1000 K).
- Advanced thermoelectric couple and module component technologies that will facilitate integration of new high performance materials into high reliability, high temperature long life systems, such as: thermally stable, low resistance and mechanically compliant interface structures, advanced lightweight thermal insulation materials and stable thermoelectric material encapsulation coatings.
- Advanced concepts capable of taking advantage of miniature space-qualified heat sources (~ 1Wth class) and compatible with very high g loadings at the system level (> 10,000 g) as well as operation in extreme environments (temperature, radiation).

Photovoltaic Energy Conversion

Photovoltaic cell, blanket, and array technologies that lead to significant improvements in overall solar array performance (i.e., conversion efficiency >33%, array mass specific power >300watts/kilogram, decreased stowed volume, reduced initial and recurring cost, long-term operation in high radiation environments, high power arrays, and a wide range of space environmental operating conditions) are solicited. Photovoltaic technologies that provide enhancing and/or enabling capabilities for a wide range of aerospace mission applications will be considered. Technologies that address specific NASA Science mission needs include:

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

S3.02 Propulsion Systems for Robotic Science Missions

Lead Center: GRC

Participating Center(s): JPL, MSFC

The Science Mission Directorate (SMD) needs spacecraft with more demanding propulsive performance and flexibility for more ambitious missions requiring high duty cycles, more challenging environmental conditions, and extended operation. Planetary spacecraft need the ability to rendezvous with, orbit, and conduct in situ exploration of planets, moons, and other small bodies in the solar system (http://solarsystem.nasa.gov/multimedia/download-detail.cfm?DL_ID=742 [23]). 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 and low-power, nuclear electric propulsion (NEP) missions. Roadmaps for propulsion technologies can be found from the National Research Council (http://www.nap.edu/openbook.php?record_id=13354&page=168 [24]) and NASA's Office of the Chief Technologist (http://www.nasa.gov/pdf/501329main_TA02-InSpaceProp-DRAFT-Nov2010-A.pdf [25]).

The focus of this solicitation is for next generation propulsion systems and components, including micropropulsion rocket technologies, and low cost/low mass electric propulsion technologies. Propulsion technologies related specifically to Power Processing Units will be sought under S3.03 Power Electronics and Management, and Energy Storage and should not be submitted to this subtopic.

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

Electric Propulsion Systems

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

- Long-life thrusters and related system components with efficiencies > 55% and up to 1 kW of input power that operate with a specific impulse between 1600 to 3500 seconds to enable radioisotope electric propulsion.
- Any long-life, electric propulsion technology between 1 to 10 kW/thruster that would enable a low-power nuclear electric propulsion system based on a kilopower nuclear reactor.

Mini-satellite Propulsion Systems

This subtopic also seeks proposals that address the propulsion for spacecraft 180-1000 kg. It is desired that the capability of plane-changing or de-orbiting in a timely manner be achieved. These system or component technologies would likely be:

- Low mass and low volume fractions.
- Wide range of delta-V capability to provide 100-1000s of m/s.
- Wide range of specific impulses up to 1000s of seconds.
- Precise thrust vectoring and low vibration for precision maneuvering.
- Efficient use of onboard resources (i.e., high power efficiency and simplified thermal and propellant management).
- Affordability.
- Safety for users and primary payloads.

Small Satellite/CubeSat Propulsion

The small satellite (<180kg) market shows significant promise to enable low cost science missions. Launch vehicle providers, like SLS, are considering a large number of secondary payload opportunities. The majority of small satellite missions flown are often selected for concept or component demonstration activities as the primary objectives. Opportunities are anticipated to select future small satellite missions based on application goals (i.e., science return). However, several technology limitations prevent high value science from low-cost small spacecraft, such as post deployment propulsion capabilities. Additionally, propulsion systems often place constraints on handling, storage, operations, etc., that may limit secondary payload consideration.

Specifically, proposals are sought for propulsion systems capable of full scale flight demonstration on 12U CubeSats or smaller; to enable science through secondary payloads carried by SLS or other launch vehicles. Mission applications can be extended up to ESPA based or up to 180kg spacecraft.

Proposals are sought that can deliver hardware products and proof-of-concept demonstrations in Phase I. Proposals are sought that can deliver hardware at or greater than TRL 6 suitable for flight demonstration within the

Phase II resources provided. Propulsion systems requiring Phase II-E or II-X funding will be considered if justified through enabling mission capabilities.

Specific propulsion technologies of interest to interplanetary small satellites include:

- Moderate to high specific impulse propulsion systems.
- High specific impulse - density solutions.
- Systems that require no pressurization prior to operations.
- Systems that place no demanding storage requirements prior to launch.
- Systems than can remain quiescent under ambient conditions for extended durations (>6 months) prior to launch.

In addressing technology requirements, proposers should identify potential mission applications and quantify the expected advancement over state-of-the-art alternatives.

Note to Proposer: Topic H2 under the Human Exploration and Operations Directorate also addresses advanced propulsion. Proposals more aligned with exploration mission requirements should be proposed in H2.

S3.03 Power Electronics and Management, and Energy Storage

Lead Center: GRC

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

Future NASA science objectives will include missions such as Earth Orbiting, Venus, Europa, Titan/Enceladus Flagship, Lunar Quest and Space Weather. Under this subtopic, proposals are solicited to develop energy storage and power electronics to enable or enhance the capabilities of future science missions. The unique requirements for the power systems for these missions can vary greatly, with advancements in components needed above the current State of the Art (SOA) for high energy density, high power density, long life, high reliability, low mass/volume, radiation tolerance, and wide temperature operation. Other subtopics which could potentially benefit from these technology developments include S4.04 Extreme Environments Technology, and S4.01 Planetary Entry, Descent and Landing Technology. This subtopic is also directly tied to S3.02 Power Electronics and Management, and Energy Storage for the development of advanced Power Processing Units and associated components.

Power Electronics and Management

The 2009 Heliophysics roadmap (http://sec.gsfc.nasa.gov/2009_Roadmap.pdf [21]), the 2010 SMD Science Plan (http://science.nasa.gov/about-us/science-strategy/ [26]), the 2010 Planetary Decadal Survey White Papers & Roadmap Inputs (http://www8.nationalacademies.org/ssbsurvey/publicview.aspx [27]), the 2011 PSD Relevant Technologies document, the 2006 Solar System Exploration (SSE) Roadmap (http://nasascience.nasa.gov/about-us/science-strategy [18]), and the 2003 SSE Decadal Survey describe the need for lighter weight, lower power electronics along with radiation hardened, extreme environment electronics for planetary exploration. Radioisotope power systems (RPS) and Power Processing Units (PPUs) for Electric Propulsion (EP) are two programs of interest which would directly benefit from advancements in this technology area. Advances in electrical power technologies are required for the electrical components and systems for these future platforms to address program size, mass, efficiency, capacity, durability, and reliability requirements. In addition, the Outer Planet Assessment Group has called out high power density/high efficiency power electronics as needs for the Titan/Enceladus Flagship and planetary exploration missions. These types of missions, including Mars Sample Return using Hall thrusters and PPUs, require advancements in radiation hardened power electronics and systems beyond the state-of-the-art. Of importance are expected improvements in energy density, speed, efficiency, or wide-temperature operation (-125 °C to over 450 °C) with a number of thermal cycles. Novel approaches to minimizing the weight of advanced PPUs are also of interest. Advancements are sought for power electronic devices, components, packaging and cabling for programs with power ranges of a few watts for minimum missions to up to 20 kilowatts for large missions. In addition to electrical component development, RPS has a need for intelligent, fault-tolerant Power Management And Distribution (PMAD) technologies to efficiently manage the system power for these deep space missions.

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

Overall technologies of interest include:

- High voltage, radiation hardened, high temperature components.
- High power density/high efficiency power electronics and associated drivers for switching elements.
- Lightweight, highly conductive power cables and/or cables integrated with vehicle structures.
- Intelligent management and fault-tolerant electrical components and PMAD systems.
- Advanced electronic packaging for thermal control and electromagnetic shielding; integrated packaging technology for modularity.

Energy Storage

Future science missions will require advanced primary and secondary battery systems capable of operating at temperature extremes from -100 °C for Titan missions to 400 to 500 °C for Venus missions, and a span of -230 °C to +120 °C for Lunar Quest. The Outer Planet Assessment Group and the 2011 PSD Relevant Technologies Document have specifically called out high energy density storage systems as a need for the Titan/Enceladus Flagship and planetary exploration missions. In addition, high energy-density rechargeable electrochemical battery systems that offer greater than 50,000 charge/discharge cycles (10 year operating life) for low-earth-orbiting spacecraft, 20 year life for geosynchronous (GEO) spacecraft, are desired. Advancements to battery energy storage capabilities that address one or more of the above requirements for the stated missions combined with very high specific energy and energy density (>200 Wh/kg for secondary battery systems), along with radiation tolerance are of interest.

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

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

Patent 6,461,944, Methods for growth of relatively large step-free SiC crystal surfaces Neudeck, et al., October 8, 2002.

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

S3.04 Unmanned Aircraft and Sounding Rocket Technologies

Lead Center: GSFC

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

Unmanned Aircraft Systems

Breakthrough technologies that will enhance performance and utility of NASA's Airborne Science fleet with expanded use of unmanned aircraft systems (UAS) are sought. Desired performance envelope expansion over existing capabilities includes lower and higher altitudes, longer range and endurance, and flight in hazardous conditions (hurricanes, tornadoes, and volcano plumes, for example). Novel airborne platforms incorporating tailored sensors and instrumentation suitable for supporting NASA's Earth science research goals are encouraged. Additionally, innovative subsystem elements that will support existing or future UAS are desired. Potential concepts include:

- Coordinated (Matrixed) Platforms: Systems that enable multiple measurements from several vantage points to increase spatial and temporal coverage.
- Optical or radio frequency system networks that will enable multiple unmanned aircraft systems to communicate with a global communication systems.
- Sense and avoid systems that enable flights in the National Airspace System.
- Attitude and navigation control for highly turbulent conditions.
- Low cost, high precision inertial navigation systems (< 0.10 degree accuracy, resolution).
- Small, easily transportable systems requiring a crew of one or two.
- Novel propulsion approaches targeting increased range and endurance, flight in adverse conditions, reduced operating costs, and/or minimum sampling contamination (NASA's SIERRA requires 25 to 40 hp, for example).
- Guided Dropsondes.

Sounding Rockets

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

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

- High data rate telemetry and on board recording (greater than 20Mb/s).
- High-accuracy, small, and affordable attitude, acceleration, and rate sensors for guidance, navigation and control systems.
- High capacity, small, light-weight, operationally safe, and affordable batteries for on-board power systems.
- Autonomous vehicle environmental diagnostics system capable of monitoring flight loading (thermal, acceleration, stress/strain) for solid rocket vehicle systems.
- Location determination systems to provide over-the-horizon position of buoyant payloads to facilitate expedient location and retrieval from the ocean.
- Flotation systems, ranging from tethered flotation devices to self-encapsulation systems, for augmenting buoyancy of sealed payload systems launched from water-based launch ranges.

S3.05 Guidance, Navigation and Control

Lead Center: GSFC

Participating Center(s): ARC, JPL, JSC

NASA seeks innovative, ground breaking, and high impact developments in spacecraft guidance, navigation, and control technologies in support of future science and exploration mission requirements. This subtopic covers the technologies enabling significant performance improvements over the state of the art in the areas of positioning, navigation, timing, attitude determination, and attitude control. Component technology developments are sought for the range of flight sensors, actuators, and associated algorithms and software required to provide these improved capabilities. Technologies that apply to a range of spacecraft platform sizes, from large, to mid-size, to emerging smallsat-cubesat class spacecraft are desired.

Advances in the following areas are sought:

- Navigation systems: Autonomous onboard flight navigation sensors and algorithms incorporating a range of measurements from GNSS measurements, ground-based optical and RF tracking, and celestial navigation. Also relative navigation sensors enabling precision formation flying and astrometric alignment of a formation of vehicles relative to a background starfield.
- Attitude Determination and Control Systems: Sensors and actuators that enable milli-arcsecond class pointing capabilities for large space telescopes, with improvements in size, weight, and power requirements. Also lightweight, compact sensors and actuators that will enable pointing performance comparable to large platforms on lower cost, small spacecraft.

Proposals should address the following specific technology needs:

- Precision attitude reference sensors, incorporating optical, inertial, and x-ray measurements, leading to significant increase in accuracy and performance over the current state of the art.
- Autononomous navigation sensors and algorithms applicable to missions in HEO orbits, cis-lunar orbits, and beyond earth orbit. Techniques using above the constellation GNSS measurements, as well as measurements from celestial objects.
- Compact, low power attitude determination and control systems for small satellite platforms, including ESPA (EELV Secondary Payload Adapter) class spacecraft and smaller, university standard cubesat form factors.
- Relative navigation sensors for spacecraft formation flying and autonomous rendezvous with asteroids. Technologies applicable to laser beam steering and pulsed lasers for LIDAR.

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

S3.06 Terrestrial and Planetary Balloons

Lead Center: GSFC

Participating Center(s): JPL

Terrestrial Balloons

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

- *Power Storage* - Improved devices to store electrical energy onboard balloon payloads are needed. Long duration balloon flights can experience 12 hours or more of darkness, and excess electrical power generated during the day from solar panels needs to be stored and used. Improvements are needed over the current state of the art in power density, energy density, overall size, overall mass and/or cost. Typical parameters for balloon are 28 VDC and 100 to 1000 watts power consumption. Rechargeable batteries are presently used for balloon payload applications. Lithium Ion rechargeable batteries with energy densities of 60 watt-hours per kilogram are the current state of the art.
- *Satellite Communications* - Improved downlink bitrates using satellite relay communications from balloon payloads are needed. Long duration balloon flights currently utilize satellite communication systems to relay science and operations data from the balloon to ground based control centers. The current maximum downlink bit rate is 150 kilobits per second operating continuously during the balloon flight. Future requirements are for bit rates of 1 megabit per second or more. Improvements in bit rate performance, reduction in size and mass of existing systems, or reductions in cost of high bit rate systems are needed. TDRSS and Iridium satellite communications are currently used for balloon payload applications. A

commercial S-band TDRSS transceiver and mechanically steered 18 dBi gain antenna provide 150 kbps continuous downlink. TDRSS K-band transceivers are available but are currently cost prohibitive. Open port Iridium service is under development, but the operational cost is prohibitive.

Planetary Balloons

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

- *Steerable Antenna for Titan and Venus Telecommunications* - Many concepts for Titan and Venus balloons require high gain antennas mounted on the balloon gondola to transmit data directly back to Earth. This approach requires that the antenna remain mechanically or electronically pointed at the Earth despite the motions experienced during balloon flight. A beacon signal from the Earth will be available to facilitate pointing. Innovative concepts are sought for such an antenna and pointing system with the following characteristics: dish antenna diameter of 0.8 m (or equivalent non-dish gain), total mass of antenna and pointing system of ? 10 kg, power consumption for the steering system ? 5 W (avg.), pointing accuracy ? 0.5 deg (continuous), hemispheric pointing coverage (2 pi steradians), azimuthal and rotational slew rates ? 30 deg/sec. It is expected that a Phase I effort will involve a proof-of-concept experiment leading to a plan for full scale prototype fabrication and testing in Phase II. Phase II testing will need to include an Earth atmosphere balloon flight in the troposphere to evaluate the proposed design under real flight conditions.
- *Altitude-Cycling Balloons for Venus* - NASA is interested in Venus balloons that continuously cycle across a wide altitude range without the use of ballast drops. Such balloons not only enable scientific measurements at different altitudes, they also enable the periodic cooling of the payload during the time spent at the highest altitude. Innovative concepts and system-level solutions are sought for such an altitude cycling Venus balloon with the following characteristics: a minimum cycling altitude of 45 km or lower, a maximum cycling altitude of 58 km or higher, a balloon large enough to carry a 100 kg payload, and a flight duration of at least 14 (Earth) days comprising both day and night conditions. It is expected that a Phase I effort will consist of a complete system-level design and a proof-of-concept experiment on one or more key components.

S3.07 Thermal Control Systems

Lead Center: GSFC

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

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

- Future highly integrated electronics for CubeSat/SmallSat will drastically increase the performance per unit volume, mass and power of electronics systems. High flux heat acquisition and transport devices are required. In addition, high conductivity, vacuum-compatible interface materials are needed in order to reduce interface temperature gradients and facilitate efficient heat removal.
- Components of advanced small spacecraft such as CubeSat/SmallSat will have very small masses (i.e., small thermal capacitance), and their temperatures are highly sensitive to variations in the component power output and spacecraft environmental temperature. Advanced thermal devices capable of maintaining components within their specified temperature ranges are needed. Some examples are:
    - Phase change systems with high thermal capacity, low volume and low mass for endothermic/exothermal thermal management and conditioning.
    - Durable thermal coatings with low absorptance, variable emmittance, and good electrical conductivity.

    - High performance, low cost insulation systems for diverse environments.
    - Passive radiator turn-down devices to enable variation of heat rejection rates.
- Advanced thermal control systems with easily adaptable/reconfigurable thermal management architectures are needed in order to accommodate multiple heat sources and multiple heat sinks, particularly a thermal system that can facilitate heat sharing among on and off components and heat dissipation among multiple radiators placed on various locations on the spacecraft surface. Also needed are improved design and analysis tools for rapid design, integration and testing, and flight operations.
- Thermal control systems for long duration operation are needed, including long life pumps, single-phase and two-phase mechanically pumped fluid systems, components adaptable to distributed heat acquisition and rejection in diverse environments such as high radiation doses (Europa, etc.), and novel heat lift capabilities that enable operation in warm environments.
- Advanced detectors and optical systems at infrared wavelengths require efficient cooling methods to low temperatures. Advanced cryogenic thermal devices for precision temperature measurement and control over much larger sensor areas than currently possible are needed.

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

Note to Proposer: Subtopic H3.01 Thermal Control for Future Human Exploration Vehicles, under the Human Exploration and Operations Mission Directorate, also addresses thermal control technologies. Proposals more aligned with exploration mission requirements should be proposed in H3.01.

Robotic Exploration Technologies Topic S4

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 [28]) for mission information. See URL: (http://mars.nasa.gov/msl/mission/technology [29]/) for additional information on Mars Exploration technologies. Planetary protection requirements vary by planetary destination, and additional backward contamination requirements apply to hardware with the potential to return to Earth (e.g., as part of a sample return mission). Technologies intended for use at/around Mars, Europa (Jupiter), and Enceladus (Saturn) must be developed so as to ensure compliance with relevant planetary protection requirements. Constraints could include surface cleaning with alcohol or water, and/or sterilization treatments such as dry heat (approved specification in NPR 8020.12; exposure of hours at 115 °C or higher, non-functioning); penetrating radiation (requirements not yet established); or vapor-phase hydrogen peroxide (specification pending).
Sub Topics:

S4.01 Planetary Entry, Descent and Landing Technology

Lead Center: JPL

Participating Center(s): ARC, JSC, LaRC

NASA seeks innovative sensor technologies to enhance success for entry, descent and landing (EDL) operations on missions to Mars. This call is not for sensor processing algorithms. Sensing technologies are desired that determine the entry point of the spacecraft in the Mars atmosphere; provide inputs to systems that control spacecraft trajectory, speed, and orientation to the surface; locate the spacecraft relative to the Martian surface; evaluate potential hazards at the landing site; and determine when the spacecraft has touched down. Appropriate sensing technologies for this subtopic should provide measurements of physical forces or properties that support some aspect of EDL operations. NASA also seeks to use measurements made during EDL to better characterize the Martian atmosphere, providing data for improving atmospheric modeling for future landers. Proposals are invited for innovative sensor technologies that improve the reliability of EDL operations.

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

- Providing critical measurements during the entry phase (e.g., pressure and/or temperature sensors embedded into the aeroshell).
- Improving the accuracy of 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 situational awareness during landing by identifying hazards (rocks, craters, slopes) and/or providing indications of approach velocities and touchdown.
- Substantially reducing the amount of external processing needed to calculate the measurements.
- Significantly reducing the impact of incorporating such sensors on the spacecraft in terms of volume, mass, placement, or cost.
- For a sample-return mission, monitoring local environmental (weather) conditions on the surface prior to landing of a "fetch" rover or launch of a planetary ascent vehicle, 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.

S4.02 Robotic Mobility, Manipulation and Sampling

Lead Center: JPL

Participating Center(s): ARC, GSFC, JSC

Technologies for robotic mobility, manipulation, and sampling are needed to enable access to sites of interest and acquisition and handling of samples for in-situ analysis or return to Earth from planetary and solar system small bodies including Mars, Venus, comets, asteroids, and planetary moons.

Mobility technologies are needed to enable access to crater walls, canyons, gullies, sand dunes, and high rock density regions for planetary bodies where gravity dominates, such as the Moon and Mars. Trafficability challenges include steep terrain, obstacle size, and low soil cohesion. Tethered systems, non-wheeled systems, and marsupial systems are examples of mobility technologies that are of interest. Technologies to enable mobility on small bodies in micro-gravity environments are also of interest.

Manipulation technologies are needed to enable deployment of sampling tools and handling of samples. Mars mission sample-handling technologies are needed to enable transfer and storage of a range of rock and regolith cores approximately 1cm long and up to about 10cm long. Small-body mission manipulation technologies are needed to deploy sampling tools to the surface and transfer samples to in-situ instruments and sample storage containers.

Sample acquisition tools are needed to acquire samples on planetary and small bodies. For Mars, a coring tool is needed to acquire rock and regolith cores approximately 1cm diameter and up to 10cm long which also supports transfer of the samples to a sample handling system. Abrading bits for the tool are needed to provide rock-surface abrasion capability to better than 0.2mm scale roughness. A deep drill is needed to enable sample acquisition from the subsurface including rock cores to 3m depth and icy samples from deeper locations. Tools for sampling from asteroids and comets are needed which support transfer of the sample for in-situ analysis or sample return. Tools for acquisition and transfer of icy samples on Europa are also of interest. Minimization of mass and ability to work reliably in the harsh mission environment are important characteristics for the tools. Example environmental conditions include microgravity for small-body missions, high temperature and pressure (460 °C, 93bar) on Venus, and at Europa the radiation environment is estimated at 2.9 Mrad total ionizing dose (TID) behind 100 mil thick aluminum.

Contamination control and planetary protection are important considerations for sample acquisition and handling technologies. Contamination may include Earth-source contaminants produced by the sampling tool, handling system, or deposited on the sampling location from another source on the rover. "Cleaning to sterility" technologies are needed that will be compatible with spacecraft materials and processes. Surface cleaning validation methods are needed that can be used routinely to quantify trace amounts (~ng/cm^2) of organic contamination and submicron particle (~100nm size) contamination. Priority will be given to cleaning and sterilization methods that have potential for in-situ applications.

Component technologies for low-mass and low-power systems tolerant to the in-situ environment are of particular interest. Technical feasibility should be demonstrated during Phase I and a full capability unit of at least TRL 4 should be delivered in Phase II. Proposals should show an understanding of relevant science needs and engineering constraints and present a feasible plan to fully develop a technology and infuse it into a NASA program. Specific areas of interest include the following:

- Six-axis force-torque sensors for 100g and 35kg payloads.
- Steep terrain adherence.
- Tether play-out and retrieval systems including tension and length sensing.
- Low-mass tether cables with power and communication.
- Sampling system deployment mechanisms.
- Low mass/power vision systems and processing capabilities that enable faster surface traverse.
- Modular actuators and actuators for harsh environments.
- Abrading bit providing smooth surface preparation.
- Small body sampling tool.
- Cleaning to sterility technologies that will be compatible with spacecraft materials and processes.
- Surface cleaning validation technology to quantify trace amount (~ng/cm^2) of organic contamination and submicron particle (~100nm size) contamination.
- Sample handling technologies that minimize cross contamination and preserve mechanical integrity of samples.

S4.03 Spacecraft Technology for Sample Return Missions

Lead Center: JPL

Participating Center(s): GRC

NASA plans to perform sample return missions from a variety of scientifically important targets including Mars, small bodies such as asteroids and comets, and outer planet moons. These types of targets present a variety of spacecraft technology challenges.

Some targets, such as Mars and some moons, have relatively large gravity wells and will require ascent propulsion. Includes propellants that are transported along with the mission or propellants that can be generated using local resources.

Other targets are small bodies with very complex geography and very little gravity, which present difficult navigational and maneuvering challenges.

In addition, the spacecraft will be subject to extreme environmental conditions including low temperatures (-270 °C), dust, and ice particles.

Technology innovations should either enhance vehicle capabilities (e.g., increase performance, decrease risk, and improve environmental operational margins) or ease sample return mission implementation (e.g., reduce size, mass, power, cost, increase reliability, or increase autonomy).

S4.04 Extreme Environments Technology

Lead Center: JPL

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

NASA is interested in expanding its ability to explore the deep atmosphere and surface of giant planets, asteroids, and comets 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 planets. Proposals are sought for technologies that are suitable for remote sensing applications at cryogenic temperatures, and in-situ atmospheric and surface explorations in the high-temperature high-pressure environment at the Venusians surface (485 ?C, 93 atmospheres), or in low-temperature environments such as Titan (-180 ?C), Europa (-220 ?C), Ganymede (-200 ?C), Mars, the Moon, asteroids, comets and other small bodies. Also Europa-Jupiter missions may have a mission life of 10 years and the radiation environment is estimated at 2.9 Mega-rad total ionizing dose (TID) behind 0.1 inch thick aluminum. Proposals are sought for technologies that enable NASA's long duration missions to extreme wide-temperature and cosmic radiation environments. High reliability, ease of maintenance, low volume, low mass, and low out-gassing characteristics are highly desirable. Special interest lies in development of following technologies that are suitable for the environments discussed above.

- Wide temperature range precision mechanisms i.e., beam steering, scanner, linear and tilting multi-axis mechanisms.
- Radiation-tolerant/radiation hardened low-power low-noise mixed-signal mechanism control electronics for precision actuators and sensors.
- Wide temperature range feedback sensors with sub-arc-second/nanometer precision.
- Long life, long stroke, low power, and high torque/force actuators with sub-arc-second/nanometer precision.
- Long life Bearings/tribological surfaces/lubricants.
- High temperature energy storage systems.
- High-temperature actuators and gear boxes for robotic arms and other mechanisms.
- Low-power and wide-operating-temperature radiation-tolerant /radiation hardened RF electronics.
- Radiation-tolerant/radiation-hardened low-power/ultra-low-powerwide-operating-temperature low-noise mixed-signal electronics for space-borne system such as guidance and navigation avionics and instruments.
- Radiation-tolerant/radiation-hardened power electronics.
- Radiation-tolerant/ radiation-hardened electronic packaging (including, shielding, passives, connectors, wiring harness and materials used in advanced electronics assembly).

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

Information Technologies Topic S5

NASA Missions and Programs create a wealth of science data and information that are essential to understanding our earth, our solar system and the universe. Advancements in information technology will allow many people within and beyond the Agency to more effectively analyze and apply these data and information to create knowledge. For example, 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, provide visualizations of datasets that are extremely large and complicated, and aid in the design of systems and missions. 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 data and science information are 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:

S5.01 Technologies for Large-Scale Numerical Simulation

Lead Center: ARC

Participating Center(s): GSFC

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

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

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

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

Offerors should demonstrate awareness of the state-of-the-art of their proposed technology, and should leverage existing commercial capabilities and research efforts where appropriate. Open source software and open standards are strongly preferred. Note that the NASA supercomputing environment is characterized by:

- HEC systems operating behind a firewall to meet strict IT security requirements.
- Communication-intensive applications.
- Massive computations requiring high concurrency.
- Complex computational workflows and immense datasets.
- 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.
- Technologies that require significant application re-engineering.

Projects need not benefit all NASA HEC users or application codes, but demonstrating applicability to an important NASA discipline, or even a key NASA application code, could provide significant value.

Specific technology areas of interest:

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

    - Cloud supercomputing with high performance interconnects (e.g., InfiniBand).
    - Enhanced visualization technologies.
    - Improved algorithms for key codes.
    - Power-aware "Green" computing technologies and techniques.
    - Approaches to effectively manage and utilize many-core processors including algorithmic changes, compiler techniques and runtime systems.
- User Productivity Environments - The user interface to a supercomputer is typically a command line in a text window. This subtopic element seeks more intuitive, intelligent, user-customizable, and integrated interfaces to supercomputing resources, enabling users to more completely leverage the power of HEC to increase their productivity. Such an interface could enhance many essential supercomputing tasks: accessing and managing resources, training, getting services, developing and porting codes (e.g., debugging and performance analysis), running computations, managing files and data, analyzing and visualizing results, transmitting data, collaborating, etc.
- Ultra-Scale Computing - Over the next decade, the HEC community faces great challenges in enabling its users to effectively exploit next-generation supercomputers featuring massive concurrency to the tune of millions of cores. To overcome these challenges, this subtopic element seeks ultra-scale computing technologies that enable resiliency/fault-tolerance in extreme-scale (unreliable) systems both at job startup and during execution. Also of interest are system and software co-design methodologies, to achieve performance and efficiency synergies. Finally, tools are sought that facilitate verification and validation of ultra-scale applications and systems.

S5.02 Earth Science Applied Research and Decision Support

Lead Center: SSC

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

The NASA Applied Sciences Program (http://nasascience.nasa.gov/earth-science/applied-sciences [30]) seeks innovative and unique approaches to increase the utilization and extend the benefit of Earth Science research data to better meet societal needs. One area of interest is new decision support tools and systems for a variety of ecological applications such as managing coastal environments, natural resources or responding to natural disasters.

Currently, creating decision support tools (DST) that effectively utilize remote sensing data requires significant efforts by experts in multiple domains. This creates a barrier to the widespread use of Earth observations by state and local governments, businesses, and the public. This subtopic aims to democratize the creation of Earth science driven decision support tools and to unleash a creative explosion of DST development that significantly increases the return on investment for Earth science missions.

Specifically, this subtopic develops core capabilities that can be integrated to build multiple remote sensing driven DSTs customized to the requirements of different users in varied fields. Proven development and commercialization strategies will be used to meet these objectives. Similar to Eclipse, this subtopic will create an open-source DST development framework that enables components from multiple providers to be seamlessly integrated. This subtopic will also create software components that plug into the framework and open source tools that help users create new components. The components will provide functionality ranging from basic operations, such as retrieval of data meeting user-specified criteria from online repositories and visualization, to sophisticated data processing and analysis algorithms, such as atmospheric correction, data fusion, computational model interfaces, and machine learning based quality control.

To expedite DST development and deployment by knowledgeable users, this subtopic seeks an open source graphical workflow tool, similar to Labview or Simulink, which enables well informed users to quickly create a functional DST from a catalog of software components. Ultimately, a more sophisticated graphical workflow development tool, similar to MIT’s Scratch would enforce functionally, but not necessarily logically, “correct by construction” rules that would enable a broad population of people to successfully create DSTs. Open source and commercial components, as well as services, will be available through an online “store” similar to iTunes or Google Play.

The framework, components and resulting DSTs should be able to run in a commercial cloud such as Amazon EC2 or Google Compute Engine. Cloud enabled components and DSTs, those that can intelligently take advantage of flexible computing resources for processing, analysis, visualization, optimization, etc. are highly desired.

Ideally, users should be able to create, configure deploy DSTs, and view outputs such as status, reports, alerts, plots, maps, etc. via desktop computers (Windows 7 and OS X) as well as tablet and smart phones running recent versions of Android (4.0 and later) and iOS (5.0 and later). An HTML5 web application in a standards compliant browser, such as Chrome, can provide the required level of interoperability and capability. Due to serious security issues, Java and Flash based approaches will not be considered.

S5.03 Algorithms and Tools for Science Data Processing, Discovery and Analysis, in State-of-the-Art Data Environments

Lead Center: GSFC

The size of NASA's observational data sets is growing dramatically as new missions come on line. In addition, NASA scientists continue to generate new models that regularly produce data sets of hundreds of terabytes or more. It is growing ever increasingly difficult to manage all of the data through its full lifecycle, as well as provide effective data analytical methods to analyze the large amount of data. For example, the HyspIRI mission is expected to produce an average science data rate of 800 million bits per second (Mbps), JPSS-1 will be 300 Mbps and NPP is already producing 300 Mbps, compared to 150 Mbps for the EOS-Terra, Aqua and Aura missions. Other examples are SDO with a rate of 150 Mbps and 16.4 Gigabits for a single image from the HiRise camera on the Mars Reconnaissance Orbiter (MRO).

This subtopic area seeks innovation and unique approaches to solve issues associated around the use of "Big Data" within NASA. The emphasis of this subtopic is on tools that leverage existing systems, interfaces, and infrastructure, where it exists and where appropriate. Reuse of existing NASA assets is strongly encouraged.

Specifically, innovations are being sought in the following areas:

- *Parallel Processing for Data Analytics* - Open source tools like the Hadoop Distributed File Systems (HDFS) have shown promise for use in simple MapReduce operations to analyze model and observation data. In addition to HDFS, there is a rapid emergence and adoption of cloud software packages integrated with object stores, such as OpenStack and Swift. The goal is to accelerate these types of open source tools for use with binary structured data from observations and model output using MapReduce or a similar paradigm.
- *High Performance File System Abstractions* - NASA scientists currently use a large number of existing applications for data analysis, such as GrADS, python scripts, and more, that are not compatible with an object storage environment. If data were stored within an object storage environment, these applications would not be able to access the data. Many of these applications would require a substantial amount of investment to enable them to use object storage file systems. Therefore, a file system abstraction, such as FUSE (file system in user space) is needed to facilitate the use of existing data analysis applications with an object storage environment. The goal is to make a FUSE-like file system abstraction robust, reliable, and highly performing for use with large NASA data sets.
- *Data Management of Large-Scale Scientific Repositories* - With increasing size of scientific repositories comes an increasing demand for using the data in ways that may never have been imagined when the repository was conceived. The goal is to provide capabilities for the flexible repurposing of scientific data, including large-scale data integration, aggregation, representation, and distribution to emerging user communities and applications.
- *Server Side Data Processing* - Large data repositories make it necessary for analytical codes to migrate to where the data are stored. Hadoop does that at the level of a single HDFS. In a densely networked world of geographically distributed repositories, tiered intermediation is needed. The goal is to provide support for migratable codes and analytical outputs as first class objects within a provenance-oriented data management cyberinfrastructure.
- *Techniques for Data Analysis and Visualization* - New methods for data analytics that scale to extremely large data sets are necessary for data mining, searching, fusion, subsetting, discovery, visualization, and more. In addition, new algorithms and methods are needed to look for unknown correlations across large,

distributed scientific data sets. The goal is to increase the scientific value of model and observation data by making analysis easier and higher performing. Among others, some of the topics of interest are:
    - Techniques for automated derivation of analysis products such as machine learning for extraction of features in large image datasets (e.g., volcanic thermal measurement, plume measurement, automated flood mapping, disturbance mapping, change detection, etc.).
    - Workflows for automated data processing, interpretation, and distribution.
- *Accelerated Large Scale Data Movement* - There are a multitude of large distributed data stores across NASA that includes both observation and model data. The movement of data across the network must be optimized to take full advantage of large-scale data analytics, especially when comparing model to observation data. The goal is to optimize data movement in the following ways:
    - Accelerate and make it easier to move data over the wide area to facilitate large-scale data management and analysis.
    - Optimize the movement of data within more local environments, such as the usage of Remote Direct Memory Access (RDMA) within HDFS.
    - Virtualization of high-speed network interfaces for use within cloud environments.

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

Tools and products developed under this subtopic may be used for broad public dissemination or within a narrow scientific community. These tools can be plug-ins or enhancements to existing software, on-line data/computing services, or new stand-alone applications or web services, provided that they promote interoperability and use standard protocols, file formats and Application Programming Interfaces (APIs) or prevalent applications.

S5.04 Integrated Science Mission Modeling

Lead Center: GSFC

Participating Center(s): ARC, JPL

NASA seeks innovative systems modeling methods and tools to:

- Define, develop and execute future science missions, many of which are likely to feature designs and operational concepts that will pose significant challenges to existing approaches and applications.
- Enable disciplined system analysis for the ongoing management and decision support of the space science technology portfolio, particularly with regard to understanding technology alternatives, relationships, priorities, timing, availability, down-selection, maturation, investment needs, system engineering considerations, and cost-to-benefit ratios; to examine "what-if" scenarios; and to facilitate multidisciplinary assessment, coordination, and integration of the technology roadmaps as a whole.

Use of System Modeling Language (SysML) is encouraged but not required. SysML is a general purpose graphical modeling language for analyzing, designing and verifying complex systems that may include hardware, software, information, personnel, procedures and facilities. As a language, SysML represents requirements, structure, behavior, and equations in nine different diagram types, and can represent both hardware and software models. The language can be extended to provide metamodels for different disciplines, and is supported by multiple commercial tools. SysML is finding increased use throughout the agency to support systems engineering and analysis.

Specific areas of interest include the following:

- Integration of system and mission modeling tools with high-fidelity multidisciplinary design and modeling tools, supporting efficient analysis methods that accommodate uncertainty, multiple objectives, and large-scale systems - This requires the development of robust interfaces between SysML and other tools, including CAD/CAE/PDM/PLM applications, used to support NASA science mission development, implementation and operations. The objective is to produce a unified environment supporting mixed systems-level and detailed analysis during any lifecycle phase, and rapid analysis of widely varying concepts/configurations using mixed-fidelity models, including geometry/mesh-based models when required. The human interface for such a system could be a "dashboard" (web-based is highly desirable) which initially allows for monitoring of the dataflow across a heterogeneous set of tools and finally allows for control of the data flow between the variety of applications.

- Modeling and rapid integration of programmatic, operational, and risk elements - Fully integrated system model representations must include non-physics based constructs such as cost, schedule, risk, operations, and organizational model elements. Novel methods and tools to model these system attributes are critical. In addition, approaches to integrate these in a meaningful way with other system model elements are needed. Methods that consider the development of these models as by-products of a collaborative and/or concurrent design process are particularly valuable.
- Library of SysML models of NASA related systems - Using a library of SysML models, engineers will be able to design their systems by reusing a set of existing models. Too often, these engineers have to begin from scratch the design of the systems. A library of verified and validated models would provide a way for the engineers to design a new spacecraft by assembling existing models that are domain specific, and therefore easy to adapt to the target system. In order to provide for seamless integration between SysML models each model must identify its level of abstraction both in terms of the modeling of time (progression: no ordering of events, qualitative ordering of events, metric time ordering of events) and the modeling of space (progression: lumped parameters models, distributed parameter models). Such levels of abstraction "certificates" for SysML will help determine integration interface requirements between any two models.
- Profiles for spacecraft, space robotics, and scientific instruments - Profiles provide a means of tailoring SysML for particular purposes. Extensions of the language can be inserted. This allows an organization to create domain specific constructs which extend existing SysML modeling elements. By developing profiles for NASA domains such as Spacecraft, Space Robotics and Scientific Instruments, powerful mechanisms will be available to NASA systems engineers for designing future space systems.
- Requirements Modeling - SysML offers requirements modeling capabilities, thus providing ways to visualize important requirements relationships. There is a need to combine traditional requirements management, supported by tools including but not limited to DOORS and CRADLE, and SysML requirements modeling in a standardized and sustainable way.
- Functional Modeling - The intermediate data products between requirements and specification are detailed functional models that identify all of the functions required to achieve the mission profile(s). There is a critical need to model this layer as it is a key data product to provide traceability between requirements and implementation.
- Model and Modeling Process Synthesis - As model-based design broadens and integrates larger and more complex models, methods for how to sequence and operate the design synthesis, evaluation (e.g., V&V) and elaboration process will become more important, as will considerations of how model-based processes are made compatible with existing review and development cycles.

S5.05 Fault Management Technologies

Lead Center: MSFC

Participating Center(s): ARC, JPL

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

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

Specific objectives are to:

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

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

The approach of this subtopic is to seek the right balance between sufficient reliability and cost appropriate to the mission type and risk posture. Successful technology development efforts under this subtopic would be considered for follow-on funding by, and infusion into, SMD missions. Research should be conducted to demonstrate technical feasibility and NASA relevance during Phase I and show a path toward a Phase II prototype demonstration.

Offerors should demonstrate awareness of the state-of-the-art of their proposed technology, and should leverage existing commercial capabilities and research efforts where appropriate.

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

- *FM Design Tools* - System modeling and analyses significantly contributes to the quality of FM design; however, the time it takes to translate system design information into system models often decreases the value of the modeling and analysis results. Examples of enabling techniques and tools are modeling automation, spacecraft modeling libraries, expedited algorithm development, sensor placement analyses, and system model tool integration.
- *FM Visualization Tools* - FM systems incorporate hardware, software, and operations mechanisms. The ability to visualize the full FM system and the contribution of each mechanism to protecting mission functions and assets is critical to assessing the completeness and appropriateness of the FM design to the mission attributes (mission type, risk posture, operations concept, etc.). Fault trees and state transition diagrams are examples of visualization tools that could contribute to visualization of the full FM design.
- *FM Verification and Validation Tools* - As complexity of spacecraft and systems increases, the extensiveness of testing required to verify and validate FM implementations can be resource intensive. Automated test case development, false positive/false negative test tools, model verification and validation tools, and test coverage risk assessments are examples of contributing technologies.
- *FM Design Architectures* - FM capabilities may be implemented through numerous system, hardware, and software architecture solutions. The FM architecture trade space includes options such as embedded in the flight control software or independent onboard software; on board versus ground-based capabilities; centralized or distributed FM functions; sensor suite implications; integration of multiple FM techniques; innovative software FM architectures implemented on flight processors or on Field Programmable Gate Arrays (FPGAs); and execution in real-time or off-line analysis post-operations. Alternative architecture choices could help control FM system complexity and cost and could offer solutions to transparency, verifiability, and completeness challenges.
- *Multi-discipline FM Interoperation* - FM designers, Systems Engineering, Safety and Mission Assurance, and Operations perform analyses and assessments of reliabilities, failure modes and effects, sensor coverage, failure probabilities, anomaly detection and response, contingency operations, etc. The relationships between multi-discipline data and analyses are inconsistent and misinterpreted. Resources are expended either in effort to resolve disconnects in data and analyses or worse, reduced mission success due to failure modes that were overlooked. Solutions that address data integrity, identification of

metrics, and standardization of data products, techniques and analyses will reduce cost and failures.

Lidar Remote Sensing Technologies Topic S1.01

NASA recognizes the potential of lidar technology in meeting many of its science objectives by providing new capabilities or offering enhancements over current measurements of atmospheric and topographic parameters from ground, airborne, and space-based platforms. To meet NASA's requirements, advances are needed in state-of-the-art lidar technology with an emphasis on compactness, efficiency, reliability, lifetime, and high performance. Innovative lidar subsystem and component technologies systems that directly address the measurement of atmospheric constituents and surface topography of the Earth, Mars, the Moon, and other planetary bodies will be considered under this subtopic.

Proposals relevant to the development of lidar instruments that can be used in planned missions or current technology programs are highly encouraged. Examples of planned missions and technology programs are:

- Active Sensing of CO_2 Emissions over Nights, Days, and Seasons (ASCENDS).
- Aerosols-Clouds-Ecosystems (ACE).
- Doppler Wind Lidar (3D-WINDS).
- Laser Interferometer Space Antenna (LISA).
- Ozone Lidar.
- Lidar for Surface Topography (LIST).
- Mars atmospheric sensing, atmospheric entry and descent sensors for Mars and Earth, and tracking large-scale water movement (GRACE-II).

In addition, innovative technologies relevant to the NASA sub-orbital programs, such as Unmanned Aircraft Systems (UAS) and Venture-class focusing on the studies of the Earth climate, carbon cycle, weather, and atmospheric composition, are being sought. Compact, high efficiency lidar instruments for deployment on unconventional platforms, such as balloon, small sat, and cube sat, are also considered and encouraged.

The proposals should target advancement of lidar technologies for eventual space utilization. Phase I research should demonstrate the technical feasibility and show a path toward a Phase II prototype unit. Phase II prototypes should be capable of laboratory demonstration and preferably suitable for operation in the field from a ground-based station, an aircraft platform, or any science platform amply defended by the proposer. For the 2014 SBIR Program, we are soliciting the component and subsystem technologies described below.

Solid state, single frequency, pulsed, laser transmitters operating in the 1.0 µm to1.7 µm range with a wall-plug efficiency of greater than 25% suitable for CO_2 measurement, and free-space laser communication applications. The laser transmitters must be capable of generating frequency transform-limited pulses with a quality beam M^2 of less than 1.5 with an approximately 20 W of average power. We are interested in two different regimes of repetition rates: from 5 kHz to 20 kHz, and from 20 Hz to 100 Hz. In addition, development of non-traditional optical amplifier architectures that yield optical efficiency of >70% are of interest.

Compact and rugged single-frequency CW laser systems operating at 1.06 mm, 1.57 mm, 1.651 mm and 2.05 mm wavelengths suitable for precision space interferometry applications such as LISA, GRACE-II, and coherent detection lidars. The lasers must be developed with space environment considerations and demonstrate a clear path to space. Proposed lasers must be able to generate at least 20 mW of power with less than 10 kHz linewidth over a tunable range of about 50 nm. Systems must be highly wavelength stable and come with full supporting electronic systems for thermal and power control.

Long wavelength solid state laser transmitter technology (e 10 µm) is needed for atmospheric lidar and possible terrain altimeter instruments for Venus. The highly dense atmosphere, volatile clouds, and thick scattering layers make this measurement a low probability event, but should be possible with significant pulse energies at long wavelengths. In combination of large, lightweight receiver, we can maximize the possibility of achieving a round trip remote sensing link from low Venus orbit. Minimum pulse energies of e 100 mJ are needed to reach the surface in the best conditions, such as with periodic holes and gaps in the clouds. Repetition rates of e 10Hz are desired for reasonable footprint spacing should a link be achieved.

Ultra-low noise photo receiver modules, operating either at 1.6 or 2.0 micron wavelengths for measuring CO_2 concentration, comprising of the detection device, complete Dewar/cooling systems, and associated amplifiers. General requirements are: large active detection diameter (>200 micron), high quantum efficiency (>85%), noise equivalent power of the order of 10-14 W/sqrt(Hz), and bandwidth greater than 20 MHz.

Lightweight scanning telescopes capable of a conical pattern with nadir angle fixed in the range of 30 to 45 degrees. The lightweight scanning telescopes are sought for both direct and heterodyne detection wind lidars and tropospheric ozone lidars. For winds, the direct detection lidar operates in 355 nm to 1064 nm wavelength region and the heterodyne detection lidar in 1550 nm to 2050 nm. For ozone, these systems should operate between 280-300 nm. The ozone systems are designed to support NASA's TOLNet network providing data for satellite validation and the study of anthropogenic pollution. High optical efficiency and near diffraction-limited performance are among major considerations. The proposer must show a clear path to space by addressing scalability to apertures greater than 1 m, materials (e.g., substrates and coatings) selection compatible with a space environment, and thermally-stable design. Phase II should result in a prototype unit capable of demonstration in a high-altitude aircraft environment, with aperture of at least 10 inches in diameter.
Sub Topics:
 Microwave Technologies for Remote Sensing Topic S1.02
NASA employs active (radar) and passive (radiometer) microwave sensors for a wide range of remote sensing applications (for example, see: http://www.nap.edu/catalog/11820.html [6]). These sensors include low frequency (less than 10 MHz) sounders to G-band (160 GHz) radars for measuring precipitation and clouds, for planetary landing, upper atmospheric monitoring, and global snow coverage (SCLP). We are seeking proposals for the development of innovative technologies to support these future radar and radiometer missions and applications. The areas of interest for this call are listed below:

- W-band Solid State Power Amplifier: Freq: 94 GHz +/- 500 MHz, Peak power: > 50 W, Duty cycle: > 20 % , Gain: > 40 dB, Gain flatness within band: <+/- 1 dB, Phase linearity within band:< +/- 1 degree, On/off switching speed: < 1 ?s, Noise figure: < 15 dB, Spurious: < -60 dBc, Harmonic: < -25 dBc.
- 640 GHz Polarimeter I, Q, U Channels, Polarimetric measurements to provide microphysical parameterization of ice clouds applicable to ACE.
- Broadband low noise cryogenic amplifier operating between 1 and 6 GHz.
- G-band (140-220 GHz) Components: 3-port strip line/CPW based switch (20 dB isolation, 1 dB loss, 1 kHz switching frequency), G-band (140-220 GHz) Components: Isolator with isolation > 15 dB, Insertion loss < 1.2 dB.
- High power Solid-State Ka-band Transmitter: Psat > 200W, Duty Cycle > 20%, DC to RF Efficiency > 30%, Gain > 50 dB.
- Very high-efficiency VHF Power Amplifier for CubeSats: Center frequency range: 40MHz to 100MHz, Fractional bandwidth: 20%, Psat >25W, Gain > 40 dB, Efficiency > 90%.
- Technology for low-power, rad-tolerant broad band spectrometer back ends for microwave radiometers. Includes: digitizers with 20 Gsps, 20 GHz bandwidth, 4 or more EOB and a simple interface to FPGA; ASIC implementations of polyphase spectrometer digital signal processing with ~1 watt/GHz.
- Back ends for microwave radiometers and sounders including compact low power RFI mitigation hardware for upgrading existing systems and low-power, low-mass filter back ends with >5 GHz spectral coverage, 200 MHz resolution, and less than one watt.

Sub Topics:
 Sensor and Detector Technology for Visible, IR, Far IR and Submillimeter Topic S1.03
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 [7]), and astronomy and astrophysics (http://www.nap.edu/books/0309070317/html/ [8]).

- Development of un-cooled or cooled infrared detectors (hybridized or designed to be hybridized to an appropriate read-out integrated circuit) with NE?T<20mK, QE>30% and dark currents <1.5x10-6 A/cm^2 in the 5-14 µm infrared wavelength region. Array formats may be variable, 640 x 512 typical, with a goal to meet or exceed 2k X 2k pixel arrays. Evolve new technologies such as InAs/GaSb type-II strained layer super-lattices to meet these specifications.
- New or improved technologies leading to measurement of trace atmospheric species (e.g., CO, CH_4, N_2O)

or broadband energy balance in the IR and far-IR from geostationary and low-Earth orbital platforms. Of particular interest are new direct, nanowire or heterodyne detector technologies made using high temperature superconducting films (YBCO, MgB_2) or engineered semiconductor materials, especially 2-Dimensional Electron Gas (2-DEG) and Quantum Wells (QW) that operate at temperatures achieved by standard 1 or 2 stage flight qualified cryocoolers and do not require cooling to liquid helium temperatures. Candidate missions are thermal imaging, LANDSAT Thermal InfraRed Sensor (TIRS), Climate Absolute Radiance and Refractivity Observatory (CLARREO), BOReal Ecosystem Atmosphere Study (BOREAS), Methane Trace Gas Sounder or other infrared earth observing missions.
- 1k x 1k or larger format MCT detector arrays with cutoff wavelength extended to 12 microns for use in missions to NEOs, comets and the outer planets.
- Compact, low power, readout electronics for KID arrays. Enables mega pixel arrays for mm to Far IR telescopes and spectrometers for astrophysics and earth observation.
- Development of a robust wafer-level integration technology that will allow high-frequency capable interconnects and allow two dis-similar substrates (i.e., silicon and GaAs) to be aligned and mechanically 'welded' together. Specially develop ball grid and/or Through Silicon Via (TSV) technology that can support submillimeter-wave arrays. Initially the technology can be demonstrated at the '1-inch' die level but should be do-able at the 4-inch wafer level.

Sub Topics:
Detector Technologies for UV, X-Ray, Gamma-Ray and Cosmic-Ray Instruments Topic S1.04
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 [9]).

Specific mission pages:

- IXO - (http://htxs.gsfc.nasa.gov/index.html [10]).
- Future planetary programs - (http://nasascience.nasa.gov/planetary-science/mission_list [11]).
- Earth Science Decadal missions - (http://www.nap.edu/catalog/11820.html [6]).
- Helio Probes - (http://nasascience.nasa.gov/heliophysics/mission_list [12]).

Specific technology areas are:

- Significant improvement in wide band gap semiconductor materials, such as AlGaN, ZnMgO and SiC, individual detectors, and detector arrays for operation at room temperature or higher for missions such as Geo-CAPE, NWO, ATALAST and planetary science composition measurements.
- Highly integrated, low noise (< 300 electrons rms with interconnects), low power (< 100 uW/channel) mixed signal ASIC readout electronics as well as charge amplifier ASIC readouts with tunable capacitive inputs to match detector pixel capacitance. See needs of National Research Council's Earth Science Decadal Survey (NRC, 2007): Future Missions include GEOCape, HyspIRI, GACM, future GOES and SOHO programs and planetary science composition measurements.
- Visible-blind SiC Avalanche Photodiodes (APDs) for EUV photon counting are required. The APDs must show a linear mode gain >10E6 at a breakdown reverse voltage between 80 and 100V. The APD's must demonstrate detection capability of better than 6 photons/pixel/s down to 135nm wavelength. See needs of National Research Council's Earth Science Decadal Survey (NRC, 2007): Tropospheric ozone.
- Large area (3 m^2) photon counting near-UV detectors with 3 mm pixels and able to count at 10 MHz. Array with high active area fraction (>85%), 0.5 megapixels and readout less than 1 mW/channel. Future instruments are focal planes for JEM-EUSO and OWL ultra-high energy cosmic ray instruments and ground Cherenkov telescope arrays such as CTA, and ring-imaging Cherenkov detectors for cosmic ray instruments such as BESS-ISO. As an example (JEM-EUSO and OWL), imaging from low-Earth orbit of air

fluorescence, UV light generated by giant air showers by ultra-high energy (E >10E19 eV) cosmic rays require the development of high sensitivity and efficiency detection of 300-400 nm UV photons to measure signals at the few photon (single photo-electron) level. A secondary goal minimizes the sensitivity to photons with a wavelength greater than 400 nm. High electronic gain (10E4 to 10E6), low noise, fast time response (<10 ns), minimal dead time (<5% dead time at 10 ns response time), high segmentation with low dead area (<20% nominal, <5% goal), and the ability to tailor pixel size to match that dictated by the imaging optics. Optical designs under consideration dictate a pixel size ranging from approximately 2 x 2 mm^2 to 10 x 10 mm^2. Focal plane mass must be minimized (2g/cm^2 goal). Individual pixel readout is required. The entire focal plane detector can be formed from smaller, individual sub-arrays.

Sub Topics:
Particles and Field Sensors and Instrument Enabling Technologies Topic S1.05
Advanced sensors for the detection of elementary particles (atoms, molecules and their ions) and electric and magnetic fields in space and associated instrument technologies are often critical for enabling transformational science from the study of the sun's outer corona, to the solar wind, to the trapped radiation in Earth's and other planetary magnetic fields, and to the atmospheric composition of the planets and their moons. Improvements in particles and fields sensors and associated instrument technologies enable further scientific advancement for upcoming NASA missions such as CubeSats, ICON, GOLD, Solar Orbiter, Solar Probe Plus, ONEP, SEPAT, INCA, CISR, DGC, HMag and planetary exploration missions. Technology developments that result in a reduction in size, mass, power, and cost will enable these missions to proceed. Of interest are advanced magnetometers, electric field booms, ion/atom/molecule detectors, and associated support electronics and materials. Specific areas of interest include:

- Self-calibrating scalar-vector magnetometer for future Earth and space science missions. Performance goals: dynamic range: ±100,000 nT, accuracy with self-calibration: 1 nT, sensitivity: 5 pT - Hz-1/2 (max), max sensor unit size: 6 x 6 x 12 cm, max sensor mass: 0.6 kg, max electronics unit size: 8 x 13 x 5 cm, max electronics mass: 1 kg, and max power: 5 W operation, 0.5 W standby, including, but not limited to "sensors on a chip".
- High magnetic-field sensor that measures magnetic field magnitudes to 16 Gauss with an accuracy of 1 part in 105.
- Strong, lightweight, thin, compactly stowed electric field booms possibly using composite materials that deploy sensors to distances of 10-m or more.
- Low-noise magnetic materials for advanced magnetometer sensors with performance equal to or better than those in the 6-81.3 Mo-Permalloy family.
- Radiation-hardened ASICs including Low-power multi-channel ADCs, DACs, and spectrum analyzer modules that determine mass spectra using fast algorithm deconvolution to produce ion counts for specific ion species.
- Low-cost, low-power, fast-stepping (?; 50-µs), high-voltage power supplies 5-15 kV. Low-cost, efficient low-power power supplies (5-10 V).
- High efficiency (5% or greater) conversion surfaces for low-energy neutral atom conversion to ions.
- Miniature low-power, high-efficiency, thermionic cathodes, and cold cathodes, capable of 1-mA electron emission per 100-mW heater power with emission surface area of 1-mm^2 and expected lifetime of 20,000 hours.
- Long wire boom (?; 50 m) deployment systems for the deployment of very lightweight tethers or antennae on spinning spacecraft.
- Systems to determine the orthogonality of a deployed electric/magnetic field boom system in flight (for use with three-axis rigid 10-m booms) accurate to 0.10° dynamic.
- APDs in single pixel and multi-pixel. The APDs, typically used for photons, should be optimized for particles including thin dead layer, increased energy range, gain stability and radiation hardness, but with much higher energy resolution (<0.5KeV) compared to SSDs.
- Solar Blind particle detectors less sensitive to light such as silicon carbide based.
- Developing near real-time data-assimilative models and tools, for both solar quiet and active times, which allow for precise specification and forecasts of the space environment, beginning with solar eruptions and propagation, and including ionospheric electron density specification.

Sub Topics:
In Situ Sensors and Sensor Systems for Lunar and Planetary Science Topic S1.06
This subtopic solicits development of advanced instrument technologies and components suitable for deployment

on planetary and lunar missions. These technologies must be capable of withstanding operation in space and planetary environments, including the expected pressures, radiation levels, launch and impact stresses, and range of survival and operational temperatures. Technologies that reduce mass, power, volume, and data rates for instruments and instrument components without loss of scientific capability are of particular importance. In addition, technologies that can increase instrument resolution and sensitivity or achieve new and innovative scientific measurements are solicited. For example missions, see (http://science.hq.nasa.gov/missions [13]). For details of the specific requirements see the National Research Council's, Vision and Voyages for Planetary Science in the Decade 2013-2022 (http://solarsystem.nasa.gov/2013decadal/ [14]). Technologies that support NASA's New Frontiers and Discovery missions to various planetary bodies are of top priority.

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

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

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

Proposers are strongly encouraged to relate their proposed development to NASA's future planetary exploration goals and existing flight instrument capability, to provide a comparison metric for assessing proposed improvements.

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

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

Sub Topics:

Airborne Measurement Systems Topic S1.07

Measurement system miniaturization and/or increased performance is needed to support for NASA's airborne science missions, particularly those utilizing the Global Hawk, SIERRA, Dragon Eye or other unmanned aircraft. The subject airborne instruments are intended as calibration/validation systems - the proposers should demonstrate an understanding of the measurement requirements and be able to link those to instrument performance. Linkages to other subtopics such as S3.04 Unmanned Aircraft and Sounding Rocket Technologies are encouraged. Complete instrument systems are desired, including features such as remote/unattended operation and data acquisition, low power consumption, and minimum size and weight. Desired sensors include:

- Precipitation- multiphase (0.1 mm to 20 mm with 5 % accuracy in three dimensions).
- Surface snow thickness (5 cm resolution).
- Aerosols and cloud particles (0.01 micron to 200 micron with 10 % accuracy).
- Volcanic ash (0.25 to 100 micron with 10 % accuracy).
- Sulfur dioxide (4 ppb resolution).
- Carbon dioxide (1 ppm accuracy).
- Methane (5 ppm accuracy, 10 ppm precision).
- Three-dimensional wind measurement (1 mps accuracy/resolution at 10 Hz sampling).

Sub Topics:

Surface and Sub-surface Measurement Systems Topic S1.08

Relevance to future space missions such as Active Sensing of CO_2 Emissions over Nights, Days, and Seasons (ASCENDS), Orbiting Carbon Observatory – 2 (OCO-2), Global Precipitation Measurement (GPM), Geostationary Coastal and Air Pollution Events (GEO-CAPE), Hyperspectral InfraRed Imager (HyspIRI), Aerosol, Cloud, Ecosystems (ACE, including Pre-ACE/PACE), etc., is important, yet early adoption for alternative uses by NASA, other agencies, or industry is recognized as a viable path towards full maturity. Additionally, sensor system innovations with significant near-term commercial potential that may be suitable for NASA’s research after full development are of interest:

- Precipitation (e.g., motion stabilized disdrometer for shipboard deployments).
- Suspended particle concentrations and spectra of mineral and biogenic (phytoplankton and detritus) components.
- Gases - carbon dioxide, methane, etc.
- Miniaturized air-dropped sensors, suitable for Global Hawk deployment, for ocean surface and subsurface measurements such as conductivity, temperature, and depth. Miniature systems suitable for penetration of thin ice are highly desirable.
- Multi-wavelength, LIDAR-based, atmospheric ozone and aerosol profilers for continuous, simultaneous observations from multiple sites. Examples include three-band ozone measurement systems operating in the UV spectrum (e.g., 280-316 nm, possibly tunable), combined with visible or infrared systems for aerosols. Remote/untended operation, minimum eye-hazards, and portability are desired.
- Miniaturized and novel instrumentation for measuring inherent and apparent optical properties (specifically to support vicarious calibration and validation of ocean color satellites, i.e., reflectance, absorption, scattering), in situ biogeochemical measurements of marine and aquatic components and rates including but not limited to nutrients, phytoplankton and their functional groups, and floating and submerged aquatic plants.

Novel geophysical and diagnostic instruments suitable for ecosystem monitoring. Fielding for NASA's Applications and Earth Science Research activities is a primary goal. Innovations with future utility for other NASA programs (for example, Planetary Research) that can be matured in an Earth science role are also encouraged.
Sub Topics:
Atomic Interferometry Topic S1.09
Recent developments of laser control and manipulation of atoms have led to a new type of precision inertial force and gravity sensors based on atom interferometry. Atom interferometers exploit the quantum mechanical wave nature of atomic particles and quantum gases for sensitive interferometric measurements. Ground-based laboratory experiments and instruments have already demonstrated beyond the state of the art performances of accelerometer, gyroscope, and gravity measurements. Microgravity environment in space provides opportunities for further drastic improvements in sensitivity and precision. Such inertial sensors will have great potential to provide new capabilities for NASA Earth and planetary gravity measurements, for spacecraft inertial navigation and guidance, and for gravitational wave detection and test of properties of gravity in space.

Currently the most mature development of atom interferometers as measurement instruments are those based on light pulsed atom interferometers with freefall cold atoms. There remain a number of technical challenges to infuse this technology in space applications. Some of the identified key challenges are (but not limited to):

- Compact high flux ultra-cold atom sources for free space atom interferometers ($>1\times10^6$ total useful free-space atoms, <1 nK, Rb, K, Cs, Yb, Sr, and Hg are example candidates but others can be justified by the offeror).
- Ultra-high vacuum seal technologies that allow completely sealed, non-magnetic enclosures with high quality optical access (base pressure maintained $<1\times10^{-9}$ torr, consideration should be given to the inclusion of cold atom sources of interest).
- Beyond the state-of-the-art photonic components at wavelengths for atomic species of interest, particularly at NIR and visible: efficient acousto-optic modulators (low rf power ~ 200 mW or less, low thermal distortion, ~80$ or greater diffraction efficiency); efficient electro-optic modulators (low bias drift, residual AM, and return loss, fiber-coupled preferred), miniature optical isolators (~30 dB isolation or greater, ~ -2 dB loss or less), robust high-speed high-extinction shutters (switching time < 1 ms, extinction > 60 dB are highly desired).
- Flight qualifiable lasers of narrow linewidth and higher power for clock and cooling transitions of atomic species of interest. Clock lasers: 1 $Hz/s^{1/2}$ at 1 s, ~ 1W output power or greater; Cooling and trapping lasers: 10 kHz linewidth and ~ 1 W or greater.
- Analysis and simulation tool of cold atom system in trapped and freefall states relevant to atom interferometer and clock measurements in space.

The subsystem technology development proposals should clearly state the relevance, define requirements, relevant atomic species and working laser wavelengths, and indicate its path to a space-borne instrument.

Recognizing the fact that the field of atom interferometry is an active research field and there are potential breakthrough approaches still being investigated in research laboratories, NASA is also interested in new ideas of atom interferometry that will lead to better and smaller inertial sensors for rotational sensors, accelerometers, and gravity measurement instruments and will benefit and enable future NASA space missions. Therefore, this subtopic call is also soliciting practical approaches to new sensor ideas that may have high risk but can have high payoffs. Some of the known examples are:

- Bose Einstein condensate based sensors.
- Sensors using large momentum transfer.
- Guided atom wave sensors.
- Non-classical atom interferometers.
- Any other cold atom-based sensor technology such as optical clocks.

Sub Topics:
Proximity Glare Suppression for Astronomical Coronagraphy Topic S2.01
This subtopic addresses the unique problem of imaging and spectroscopic characterization of faint astrophysical objects that are located within the obscuring glare of much brighter stellar sources. Examples include planetary systems beyond our own, the detailed inner structure of galaxies with very bright nuclei, binary star formation, and stellar evolution. Contrast ratios of one million to ten billion over an angular spatial scale of 0.05-1.5 arcsec are typical of these objects. Achieving a very low background requires control of both scattered and diffracted light. The failure to control either amplitude or phase fluctuations in the optical train severely reduces the effectiveness of starlight cancellation schemes.

This innovative research focuses on advances in coronagraphic instruments, starlight cancellation instruments, and potential occulting technologies that operate at visible and near infrared wavelengths. The ultimate application of these instruments is to operate in space as part of a future observatory mission. Measurement techniques include imaging, photometry, spectroscopy, and polarimetry. There is interest in component development and innovative instrument design, as well as in the fabrication of subsystem devices to include, but not limited to, the following areas:

Starlight Suppression Technologies

- Image plane hybrid metal/dielectric, and polarization apodization masks in linear and circular patterns.
- Transmissive holographic masks for diffraction control and PSF apodization.
- Sharp-edged, low-scatter pupil plane masks.
- Low-scatter, low-reflectivity, sharp, flexible edges for control of scatter in starshades.
- Systems to measure spatial optical density, phase inhomogeneity, scattering, spectral dispersion, thermal variations, and to otherwise estimate the accuracy of high-dynamic range apodizing masks.
- Pupil remapping technologies to achieve beam apodization.
- Techniques to characterize highly aspheric optics.
- Methods to distinguish the coherent and incoherent scatter in a broad band speckle field.
- Coherent fiber bundles consisting of up to 10,000 fibers with lenslets on both input and output side, such that both spatial and temporal coherence is maintained across the fiber bundle for possible wavefront/amplitude control through the fiber bundle.

Wavefront Measurement and Control Technologies

- Small stroke, high precision, deformable mirrors and associated driving electronics scalable to 10,000 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.
- Instruments to perform broad-band sensing of wavefronts and distinguish amplitude and phase in the wavefront.
- Integrated mirror/actuator programmable deformable mirror.
- Multiplexers with ultra-low power dissipation for electrical connection to deformable mirrors.
- Low-order wavefront sensors for measuring wavefront instabilities to enable real-time control and post-

processing of aberrations.
- Thermally and mechanically insensitive optical benches and systems.

Optical Coating and Measurement Technologies

- Instruments capable of measuring polarization cross-talk and birefringence to parts per million.
- Highly reflecting, uniform, broadband coatings for large (> 1 m diameter) optics.
- Polarization-insensitive coatings for large optics.
- Methods to measure the spectral reflectivity and polarization uniformity across large optics.

Other

- Methods to fabricate diffractive patterns on large optics to generate astrometric reference frames.
- Artificial star and planet point sources, with 1e10 dynamic range and uniform illumination of an f/25 optical system, working in the visible and near infrared.
- Deformable, calibrated, collimating source to simulate the telescope front end of a coronagraphic system undergoing thermal deformations.
- Technologies for high contrast integral field spectroscopy, in particular for microlens arrays with or without accompanying mask arrays, working in the visible and NIR (0.4 - 1.8 microns), with lenslet separations in the 0.1 -0.4 mm range, in formats of ~140x140 lenslets.

Sub Topics:
Precision Deployable Optical Structures and Metrology Topic S2.02
Planned future NASA Missions in astrophysics, such as the Wide-Field Infrared Survey Telescope (WFIRST) and the New Worlds Technology Development Program (coronagraph, external occulter and interferometer technologies) will push the state of the art in current optomechanical technologies. Mission concepts for New Worlds science would require 10 - 30 m class, cost-effective telescope observatories that are diffraction limited at wavelengths from the visible to the far IR, and operate at temperatures from 4 - 300 K. In addition, ground based telescopes such as the Cerro Chajnantor Atacama Telescope (CCAT) requires similar technology development.

The desired areal density is 1 - 10 kg/m^2 with a packaging efficiency of 3-10 deployed/stowed diameter. Static and dynamic wavefront error tolerances to thermal and dynamic perturbations may be achieved through passive means (e.g., via a high stiffness system, passive thermal control, jitter isolation or damping) or through active opto-mechanical control. Large deployable multi-layer structures in support of sunshades for passive thermal control and 20m to 50m class planet finding external occulters are also relevant technologies. Potential architecture implementations must package into an existing launch volume, deploy and be self-aligning to the micron level. The target space environment is expected to be the Earth-Sun L2.

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

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

In particular, important subsystem considerations may include:

- Innovative concepts for packaging fully integrated subsystems (e.g., power distribution, sensing, and control components).
- Mechanical, inflatable, or other precision deployable technologies.
- Thermally-stable materials (CTE < 1ppm) for deployable structures.
- Innovative systems, which minimize complexity, mass, power and cost.
- Innovative testing and verification methodologies.

The goal for this effort is to mature technologies that can be used to fabricate 16 m class or greater, lightweight, ambient or cryogenic flight-qualified observatory systems. Proposals to fabricate demonstration components and subsystems with direct scalability to flight systems through validated models will be given preference. The target launch volume and expected disturbances, along with the estimate of system performance, should be included in the discussion. Proposals with system solutions for large sunshields and external occulters will also be accepted. A successful proposal shows a path toward a Phase II delivery of demonstration hardware scalable to 5 meter diameter for ground test characterization.

Before embarking on the design and fabrication of complex space-based deployable telescopes, additional risk reduction in operating an actively controlled telescope in orbit is desired. To be cost effective, deployable apertures that conform to a cubesat (up to 3-U) or ESPA format are desired. Consequently, deployment hinge and latching concepts, buildable for these missions and scaleable to larger systems are desired. Such a system should allow <25 micron deployment repeatability and sub-micron stability for both thermal and mechanical on-orbit disturbances. A successful proposal would deliver a full-scale cubesat or ESPA ring compatible deployable aperture with mock optical elements.

Proposals should show an understanding of one or more relevant science needs, and present a feasible plan to fully develop the relevant subsystem technologies and to transition into future NASA program(s).
Sub Topics:
Advanced Optical Systems Topic S2.03
his subtopic solicits solutions in the following areas:

- Optical Components, Coatings and Systems for potential x-ray missions.
- Optical Components, Coatings and Systems for potential UV/Optical missions.

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 primary emphasis of this subtopic is to mature technologies needed to manufacture, test or operate complete mirror systems or telescope assemblies. Section 3 contains a detailed discussion on specific technologies which need developing for each area.

The 2010 National Academy Astro2010 Decadal Report specifically identifies optical components and coatings as key technologies needed to enable several different future missions, including:

- Light-weight x-ray imaging mirrors for future large advanced x-ray observatories.
- Large aperture, light-weight mirrors for future UV/Optical telescopes.
- Broadband high reflectance coatings for future UV/Optical telescopes.

The 2012 National Academy report “NASA Space Technology Roadmaps and Priorities” states that one of the top technical challenges in which NASA should invest over the next five years is developing a new generation of larger effective aperture, lower-cost astronomical telescopes that enable discovery of habitable planets, facilitate advances in solar physics, and enable the study of faint structures around bright objects. To enable this capability requires low-cost, ultra-stable, large-aperture, normal and grazing incidence mirrors with low mass-to-collecting area ratios. To enable these new astronomical telescopes, the report identifies three specific optical systems technologies:

- Active align/control of grazing-incidence imaging systems to achieve < 1 arc-second angular resolution.
- Active align/control of normal-incidence imaging systems to achieve 500 nm diffraction limit (40 nm rms wavefront error, WFE) performance.
- Normal incidence 4-meter (or larger) diameter 5 nm rms WFE (300 nm system diffraction limit) mirrors.

Finally, impacting potential space telescopes, NASA is developing a heavy lift space launch system (SLS). An SLS with an 8 to 10 meter fairing and 80 to 100 mt capacity to LEO would enable extremely large space telescopes. Potential systems include 12 to 30 meter class segmented primary mirrors for UV/optical or infrared wavelengths and 8 to 16 meter class segmented x-ray telescope mirrors. These potential future space telescopes have very specific mirror technology needs. UV/optical telescopes (such as ATLAST-9 or ATLAST-16) require 1 to 3 meter class mirrors with < 5 nm rms surface figures. IR telescopes (such as SAFIR/CALISTO) require 2 to 3 to 8 meter class mirrors with cryo-deformations < 100 nm rms. X-ray telescopes (such as GenX) require 1 to 2 meter long grazing incidence segments with angular resolution < 0.5 arc-sec and surface micro-roughness < 0.5-nm rms.

Technical Challenges:

In all cases, the most important metric for an advanced optical system (after performance) is affordability or areal cost (cost per square meter of collecting aperture). Currently both x-ray and normal incidence space mirrors cost $4 million to $6 million per square meter of optical surface area. This research effort seeks a cost reduction for precision optical components by 5 to 50 times, to less than $1M to $100K/m^2.

Successful proposals shall provide a scale-up roadmap (including processing and infrastructure issues) for full scale space qualifiable flight optics systems. Material behavior, process control, active and/or passive optical performance, and mounting/deploying issues should be resolved and demonstrated.

Optical Components, Coatings and Systems for Potential X-ray Missions

Potential x-ray missions require:

- X-ray imaging telescopes with <1 arc-sec angular resolution and > 1 to 5 m^2 collecting area.
- Multilayer high-reflectance coatings for hard x-ray mirrors (similar to NuSTAR).
- X-ray transmission and/or reflection gratings.

Regarding x-ray telescope, multiple technologies are needed to enable < 1 arc-sec x-ray observatories. These include, but are not limited to: new materials such as silicon carbide, porous silicon, beryllium; improved techniques to manufacture (such as direct precision machining, rapid optical fabrication, slumping or replication technologies) 0.3 to 2 meter diameter mirror shells or segments; improved metrology, performance prediction and testing techniques; active control of mirror shape; new structures for holding and actively aligning of mirrors in a telescope assembly.

For example, the Wide-Field X-Ray Telescope (WFXT) requires a 6 meter focal length x-ray mirror with 1 arc-sec resolution and 1 m^2 of collecting area. One implementation of this mirror has 71 concentric full shell hyperbola/parabola pairs whose diameters range from 0.3 to 1.0 meter and whose length is 150 to 240 mm (this length is split between the H/P pair). Total mass for the integrated mirror system (shells and structure) is < 1000 kg. For individual mirror shells, axial slope errors should be ~ 1 arc-sec rms (~100 nm rms figure error for 20 mm spatial frequencies) and surface finish should be < 0.5 nm rms.

Additionally, potential Heliophysics missions require a grazing incidence telescope with an effective collecting area of ~3 cm^2 for 0.1 to 4 nm wavelengths, 4 meter effective focal length, 0.8 degree angle of incidence and surface roughness of 0.2 nm rms.

Regarding x-ray coatings, future x-ray missions require multilayer depth gradient coatings with high broadband reflectivity for 5 to 80 keV energy photons.

Regarding improved metrology and performance prediction, technology is needed to fully characterize x-ray mirrors (and mandrels) and predict their angular resolution performance. Potential solutions include (but are not limited to): both sub-aperture stitching (in the lateral direction) to acquire data over the entire optical surface, and merging/interpolating data with different spatial frequency domains. This can be done using different surface measuring instruments with different fields of view and resolutions.

Successful proposals will demonstrate an ability to manufacture, test and control a prototype 0.25 to 0.5 meter diameter x-ray mirror assembly; or, to coat a 0.25 to 0.5 meter class representative optical component; or, to characterize and performance predict a 0.5 to 1.0 meter class x-ray mirror or mandrel. An ideal Phase I project would deliver a sub-scale component such as a 0.25 meter x-ray precision mirror; or demonstrate a prototype metrology system capable of characterizing the optical surface morphology of an x-ray component and predicting its angular performance. An ideal Phase II project would further advance the technology to produce a space-qualifiable 0.5 meter mirror, with a TRL in the 4 to 5 range; or deliver a metrology system capable of characterizing 0.5 to 1.0 meter class x-ray mirrors (or mandrels) and predicting their angular resolution performance. Both Phase I and Phase II deliverables would be accompanied by all necessary documentation, including the optical performance assessment and all data on processing and properties of its substrate materials. The Phase II would also include a mechanical and thermal stability analysis.

Optical Components, Coatings and Systems for Potential UV/Optical Missions

Potential UV/Optical missions require:

- Large aperture, light-weight mirrors.
- Broadband high reflectance coatings.

Regarding large aperture mirrors, future UVOIR missions require 4 to 8 or 16 meter monolithic or segmented primary mirrors with < 10 nm rms surface figures. Mirror areal density depends upon available launch vehicle capacities to Sun-Earth L2 (i.e., 15 kg/m^2 for a 5 m fairing EELV vs. 60 kg/m^2 for a 10 m fairing SLS).

Regarding broadband reflectance coating, future UVOIR missions require coatings with broadband reflectivity > 60% and uniform polarization from 90 nm to 2500 nm which can be deposited onto a 2 to 4 to 8 meter mirror substrate. Additionally, the coatings need to have > 90% reflectivity from 450 nm to 2500 nm. Future EUV missions require coatings with reflectivity > 90% from 6 nm to 200 nm which can be deposited onto mirror substrates as large as 2.4 meters in diameter.

Successful proposals will demonstrate an ability to manufacture, test and control ultra-low-cost precision 0.25 to 0.5 meter optical systems; or to coat a 0.25 to 0.5 meter representative optical component. Potential solutions include, but are not limited to, new mirror materials such as silicon carbide, nanolaminates or carbon-fiber reinforced polymer; new fabrication processes such as direct precision machining, rapid optical fabrication, roller embossing at optical tolerances, slumping or replication technologies to manufacture 1 to 2 meter (or larger) precision quality mirrors or lens segments. Solutions include reflective, transmissive, diffractive or high order diffractive blazed lens optical components for assembly of large (16 to 32 meter) optical quality primary elements.

Potential solutions to improve UV reflective coatings include, but are not limited to, investigations of new coating materials with promising UV performance; new deposition processes; and examination of handling processes, contamination control, and safety procedures related to depositing coatings, storing coated optics, and integrating coated optics into flight hardware. An ability to demonstrate optical performance on 2 to 3 meter class optical surfaces is important.

An ideal Phase I deliverable would be a precision mirror of at least 0.25 meters; or a coated mirror of at least 0.25 meters. An ideal Phase II project would further advance the technology to produce a space-qualifiable mirror greater than 0.5 meters, with a TRL in the 4 to 5 range. Both Phase I and Phase II deliverables would be accompanied by all necessary documentation, including the optical performance assessment and all data on processing and properties of its substrate materials. The Phase II would also include a mechanical and thermal stability analysis.
Sub Topics:
Optics Manufacturing and Metrology for Telescope Optical Surfaces Topic S2.04
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:

- WFIRST concepts (http://wfirst.gsfc.nasa.gov/ [15]).
- NGXO (http://ixo.gsfc.nasa.gov/ [16]).
- SGO (http://lisa.gsfc.nasa.gov/ [17]).

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. Also, novel metrological solutions that can measure figure errors over a large fraction of the PSD range are desired, especially techniques and instrumentation that can perform measurements while the optic is mounted to the figuring/polishing machine.

Large lightweight monolithic metallic aspheres manufactured using innovative mirror substrate materials that can be assembled and welded together from smaller segments are sought. Also of interest is analytical software to process, fit, and model large optics surface metrology data with the goals to characterize surface morphology over spatial frequency bandwidths determined by the desired angular resolution performance; to provide stitched metrology capabilities obtained with different surface measuring instruments with different fields of view and resolution; to provide a data analysis tool for defining the optical surface fabrication tolerances based on the desired x-ray optics angular resolution performance; to allow forecasting of the surface morphological properties of optics.

By the end of a Phase II program, technologies must be developed to the point where the technique or instrument can dovetail into an existing optics manufacturing facility producing optics at the R&D stage. Metrology instruments should have 10 nm or better surface height resolution and span at least 3 orders of magnitude in lateral spatial frequency. Examples of technologies and instruments of interest include:

- Innovative metal mirror substrate materials or manufacturing methods such as welding component segments into one monolith that produce thin mirror substrates that are stiffer and/or lighter than existing materials or methods.
- Interferometric nulling optics for very shallow conical optics used in x-ray telescopes.
- Segmented systems commonly span 60 degrees in azimuth and 200 mm axial length and cone angles vary from 0.1 to 1 degree.
- Low stress metrology mounts that can hold optics without introducing mounting distortion.
- Low normal force figuring/polishing systems operating in the 1 mm to 50 mm period range with minimal impact at significantly smaller and larger period ranges.
- In-situ metrology systems that can measure optics and provide feedback to figuring/polishing instruments without removing the part from the spindle.
- Innovative mirror substrate materials or manufacturing methods that produce thin mirror substrates that are stiffer and/or lighter than existing materials or methods.
- Extreme aspheric and/or anamorphic optics for pupil intensity amplitude apodization.
- Metrology systems useful for measuring large optics with high precision.
- Innovative method of bonding extremely lightweight (less than 1 kg/m^2 areal density) and thin (less than 1 mm) mirrors to a housing structure, preserving both alignment and figure.
- Innovative method of improving the figure of extremely lightweight and thin mirrors without polishing, such as using the coating stress.
- Manufacturing technology and wavefront sensing and control as applied to coronagraph applications for exoplanet detection.

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 S3.01
Future NASA science missions will employ Earth orbiting spacecraft, planetary spacecraft, balloons, aircraft, surface assets, and marine craft as observation platforms. Proposals are solicited to develop advanced power-generation and conversion technologies to enable or enhance the capabilities of future science missions. Requirements for these missions are varied and include long life, high reliability, significantly lower mass and volume, higher mass specific power, and improved efficiency over the state of practice for components and systems. Other desired capabilities are high radiation tolerance and the ability to operate in extreme environments (high and low temperatures and over wide temperature ranges).

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

Radioisotope Power Conversion

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

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

- System specific mass greater than 10 We/kg.
- Highly reliable autonomous control.

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

- Advanced bulk materials enabling demonstration of high efficiency thermoelectric energy conversion (>15%) when using high grade space-qualified heat sources (> 1000 K).
- Advanced thermoelectric couple and module component technologies that will facilitate integration of new high performance materials into high reliability, high temperature long life systems, such as: thermally stable, low resistance and mechanically compliant interface structures, advanced lightweight thermal insulation materials and stable thermoelectric material encapsulation coatings.
- Advanced concepts capable of taking advantage of miniature space-qualified heat sources (~ 1Wth class) and compatible with very high g loadings at the system level (> 10,000 g) as well as operation in extreme environments (temperature, radiation).

Photovoltaic Energy Conversion

Photovoltaic cell, blanket, and array technologies that lead to significant improvements in overall solar array performance (i.e., conversion efficiency >33%, array mass specific power >300watts/kilogram, decreased stowed volume, reduced initial and recurring cost, long-term operation in high radiation environments, high power arrays, and a wide range of space environmental operating conditions) are solicited. Photovoltaic technologies that provide enhancing and/or enabling capabilities for a wide range of aerospace mission applications will be considered. Technologies that address specific NASA Science mission needs include:

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

Sub Topics:
 Propulsion Systems for Robotic Science Missions Topic S3.02
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://solarsystem.nasa.gov/multimedia/download-detail.cfm?DL_ID=742 [23]). 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 and low-power, nuclear electric propulsion (NEP) missions. Roadmaps for propulsion technologies can be found from the National Research Council (http://www.nap.edu/openbook.php?record_id=13354&page=168 [24]) and NASA’s Office of the Chief Technologist (http://www.nasa.gov/pdf/501329main_TA02-InSpaceProp-DRAFT-Nov2010-A.pdf [25]).

The focus of this solicitation is for next generation propulsion systems and components, including micropropulsion rocket technologies, and low cost/low mass electric propulsion technologies. Propulsion technologies related specifically to Power Processing Units will be sought under S3.03 Power Electronics and Management, and Energy Storage and should not be submitted to this subtopic.

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

Electric Propulsion Systems

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

- Long-life thrusters and related system components with efficiencies > 55% and up to 1 kW of input power that operate with a specific impulse between 1600 to 3500 seconds to enable radioisotope electric propulsion.
- Any long-life, electric propulsion technology between 1 to 10 kW/thruster that would enable a low-power nuclear electric propulsion system based on a kilopower nuclear reactor.

Mini-satellite Propulsion Systems

This subtopic also seeks proposals that address the propulsion for spacecraft 180-1000 kg. It is desired that the capability of plane-changing or de-orbiting in a timely manner be achieved. These system or component technologies would likely be:

- Low mass and low volume fractions.
- Wide range of delta-V capability to provide 100-1000s of m/s.
- Wide range of specific impulses up to 1000s of seconds.
- Precise thrust vectoring and low vibration for precision maneuvering.
- Efficient use of onboard resources (i.e., high power efficiency and simplified thermal and propellant management).
- Affordability.
- Safety for users and primary payloads.

Small Satellite/CubeSat Propulsion

The small satellite (<180kg) market shows significant promise to enable low cost science missions. Launch vehicle providers, like SLS, are considering a large number of secondary payload opportunities. The majority of small satellite missions flown are often selected for concept or component demonstration activities as the primary objectives. Opportunities are anticipated to select future small satellite missions based on application goals (i.e., science return). However, several technology limitations prevent high value science from low-cost small spacecraft, such as post deployment propulsion capabilities. Additionally, propulsion systems often place constraints on handling, storage, operations, etc., that may limit secondary payload consideration.

Specifically, proposals are sought for propulsion systems capable of full scale flight demonstration on 12U CubeSats or smaller; to enable science through secondary payloads carried by SLS or other launch vehicles. Mission applications can be extended up to ESPA based or up to 180kg spacecraft.

Proposals are sought that can deliver hardware products and proof-of-concept demonstrations in Phase I. Proposals are sought that can deliver hardware at or greater than TRL 6 suitable for flight demonstration within the Phase II resources provided. Propulsion systems requiring Phase II-E or II-X funding will be considered if justified through enabling mission capabilities.

Specific propulsion technologies of interest to interplanetary small satellites include:

- Moderate to high specific impulse propulsion systems.
- High specific impulse - density solutions.
- Systems that require no pressurization prior to operations.
- Systems that place no demanding storage requirements prior to launch.
- Systems than can remain quiescent under ambient conditions for extended durations (>6 months) prior to launch.

In addressing technology requirements, proposers should identify potential mission applications and quantify the expected advancement over state-of-the-art alternatives.

Note to Proposer: Topic H2 under the Human Exploration and Operations Directorate also addresses advanced propulsion. Proposals more aligned with exploration mission requirements should be proposed in H2.
Sub Topics:
Power Electronics and Management, and Energy Storage Topic S3.03
Future NASA science objectives will include missions such as Earth Orbiting, Venus, Europa, Titan/Enceladus Flagship, Lunar Quest and Space Weather. Under this subtopic, proposals are solicited to develop energy storage and power electronics to enable or enhance the capabilities of future science missions. The unique requirements for the power systems for these missions can vary greatly, with advancements in components needed above the current State of the Art (SOA) for high energy density, high power density, long life, high reliability, low mass/volume, radiation tolerance, and wide temperature operation. Other subtopics which could potentially benefit from these technology developments include S4.04 Extreme Environments Technology, and S4.01 Planetary Entry, Descent and Landing Technology. This subtopic is also directly tied to S3.02 Power Electronics and Management, and Energy Storage for the development of advanced Power Processing Units and associated components.

Power Electronics and Management

The 2009 Heliophysics roadmap (http://sec.gsfc.nasa.gov/2009_Roadmap.pdf [21]), the 2010 SMD Science Plan (http://science.nasa.gov/about-us/science-strategy/ [26]), the 2010 Planetary Decadal Survey White Papers & Roadmap Inputs (http://www8.nationalacademies.org/ssbsurvey/publicview.aspx [27]), the 2011 PSD Relevant Technologies document, the 2006 Solar System Exploration (SSE) Roadmap (http://nasascience.nasa.gov/about-us/science-strategy [18]), and the 2003 SSE Decadal Survey describe the need for lighter weight, lower power electronics along with radiation hardened, extreme environment electronics for planetary exploration. Radioisotope power systems (RPS) and Power Processing Units (PPUs) for Electric Propulsion (EP) are two programs of interest which would directly benefit from advancements in this technology area. Advances in electrical power technologies are required for the electrical components and systems for these future platforms to address program size, mass, efficiency, capacity, durability, and reliability requirements. In addition, the Outer Planet Assessment Group has called out high power density/high efficiency power electronics as needs for the Titan/Enceladus Flagship and planetary exploration missions. These types of missions, including Mars Sample Return using Hall thrusters and PPUs, require advancements in radiation hardened power electronics and systems beyond the state-of-the-art. Of importance are expected improvements in energy density, speed, efficiency, or wide-temperature operation (-125 °C to over 450 °C) with a number of thermal cycles. Novel approaches to minimizing the weight of advanced PPUs are also of interest. Advancements are sought for power electronic devices, components, packaging and cabling for programs with power ranges of a few watts for minimum missions to up to 20 kilowatts for large missions. In addition to electrical component development, RPS has a need for intelligent, fault-tolerant Power Management And Distribution (PMAD) technologies to efficiently manage the system power for these deep space missions.

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

Overall technologies of interest include:

- High voltage, radiation hardened, high temperature components.
- High power density/high efficiency power electronics and associated drivers for switching elements.
- Lightweight, highly conductive power cables and/or cables integrated with vehicle structures.
- Intelligent management and fault-tolerant electrical components and PMAD systems.
- Advanced electronic packaging for thermal control and electromagnetic shielding; integrated packaging

technology for modularity.

Energy Storage

Future science missions will require advanced primary and secondary battery systems capable of operating at temperature extremes from -100 °C for Titan missions to 400 to 500 °C for Venus missions, and a span of -230 °C to +120 °C for Lunar Quest. The Outer Planet Assessment Group and the 2011 PSD Relevant Technologies Document have specifically called out high energy density storage systems as a need for the Titan/Enceladus Flagship and planetary exploration missions. In addition, high energy-density rechargeable electrochemical battery systems that offer greater than 50,000 charge/discharge cycles (10 year operating life) for low-earth-orbiting spacecraft, 20 year life for geosynchronous (GEO) spacecraft, are desired. Advancements to battery energy storage capabilities that address one or more of the above requirements for the stated missions combined with very high specific energy and energy density (>200 Wh/kg for secondary battery systems), along with radiation tolerance are of interest.

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

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

Patent 6,461,944, Methods for growth of relatively large step-free SiC crystal surfaces Neudeck, et al., October 8, 2002.

A method for growing arrays of large-area device-size films of step-free (i.e., atomically flat) SiC surfaces for semiconductor electronic device applications is disclosed. This method utilizes a lateral growth process that better overcomes the effect of extended defects in the seed crystal substrate that limited the obtainable step-free area achievable by prior art processes. The step-free SiC surface is particularly suited for the heteroepitaxial growth of 3C (cubic) SiC, AlN, and GaN films used for the fabrication of both surface-sensitive devices (i.e., surface channel field effect transistors such as HEMT's and MOSFET's) as well as high-electric field devices (pn diodes and other solid-state power switching devices) that are sensitive to extended crystal defects.
Sub Topics:
Guidance, Navigation and Control Topic S3.05
NASA seeks innovative, ground breaking, and high impact developments in spacecraft guidance, navigation, and control technologies in support of future science and exploration mission requirements. This subtopic covers the technologies enabling significant performance improvements over the state of the art in the areas of positioning, navigation, timing, attitude determination, and attitude control. Component technology developments are sought for the range of flight sensors, actuators, and associated algorithms and software required to provide these improved capabilities. Technologies that apply to a range of spacecraft platform sizes, from large, to mid-size, to emerging smallsat-cubesat class spacecraft are desired.

Advances in the following areas are sought:

- Navigation systems: Autonomous onboard flight navigation sensors and algorithms incorporating a range of measurements from GNSS measurements, ground-based optical and RF tracking, and celestial navigation. Also relative navigation sensors enabling precision formation flying and astrometric alignment of a formation of vehicles relative to a background starfield.
- Attitude Determination and Control Systems: Sensors and actuators that enable milli-arcsecond class pointing capabilities for large space telescopes, with improvements in size, weight, and power requirements. Also lightweight, compact sensors and actuators that will enable pointing performance comparable to large platforms on lower cost, small spacecraft.

Proposals should address the following specific technology needs:

- Precision attitude reference sensors, incorporating optical, inertial, and x-ray measurements, leading to significant increase in accuracy and performance over the current state of the art.
- Autononomous navigation sensors and algorithms applicable to missions in HEO orbits, cis-lunar orbits, and beyond earth orbit. Techniques using above the constellation GNSS measurements, as well as measurements from celestial objects.
- Compact, low power attitude determination and control systems for small satellite platforms, including ESPA (EELV Secondary Payload Adapter) class spacecraft and smaller, university standard cubesat form factors.
- Relative navigation sensors for spacecraft formation flying and autonomous rendezvous with asteroids. Technologies applicable to laser beam steering and pulsed lasers for LIDAR.

Proposals should show an understanding of one or more relevant science or exploration needs, and present a feasible plan to fully develop a technology and infuse it into a NASA program.
Sub Topics:
Terrestrial and Planetary Balloons Topic S3.06

Terrestrial Balloons

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

- *Power Storage* - Improved devices to store electrical energy onboard balloon payloads are needed. Long duration balloon flights can experience 12 hours or more of darkness, and excess electrical power generated during the day from solar panels needs to be stored and used. Improvements are needed over the current state of the art in power density, energy density, overall size, overall mass and/or cost. Typical parameters for balloon are 28 VDC and 100 to 1000 watts power consumption. Rechargeable batteries are presently used for balloon payload applications. Lithium Ion rechargeable batteries with energy densities of 60 watt-hours per kilogram are the current state of the art.
- *Satellite Communications* - Improved downlink bitrates using satellite relay communications from balloon payloads are needed. Long duration balloon flights currently utilize satellite communication systems to relay science and operations data from the balloon to ground based control centers. The current maximum downlink bit rate is 150 kilobits per second operating continuously during the balloon flight. Future requirements are for bit rates of 1 megabit per second or more. Improvements in bit rate performance, reduction in size and mass of existing systems, or reductions in cost of high bit rate systems are needed. TDRSS and Iridium satellite communications are currently used for balloon payload applications. A commercial S-band TDRSS transceiver and mechanically steered 18 dBi gain antenna provide 150 kbps continuous downlink. TDRSS K-band transceivers are available but are currently cost prohibitive. Open port Iridium service is under development, but the operational cost is prohibitive.

Planetary Balloons

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

- *Steerable Antenna for Titan and Venus Telecommunications* - Many concepts for Titan and Venus balloons require high gain antennas mounted on the balloon gondola to transmit data directly back to Earth. This approach requires that the antenna remain mechanically or electronically pointed at the Earth despite the motions experienced during balloon flight. A beacon signal from the Earth will be available to facilitate pointing. Innovative concepts are sought for such an antenna and pointing system with the following characteristics: dish antenna diameter of 0.8 m (or equivalent non-dish gain), total mass of antenna and

pointing system of ? 10 kg, power consumption for the steering system ? 5 W (avg.), pointing accuracy ? 0.5 deg (continuous), hemispheric pointing coverage (2 pi steradians), azimuthal and rotational slew rates ? 30 deg/sec. It is expected that a Phase I effort will involve a proof-of-concept experiment leading to a plan for full scale prototype fabrication and testing in Phase II. Phase II testing will need to include an Earth atmosphere balloon flight in the troposphere to evaluate the proposed design under real flight conditions.
- *Altitude-Cycling Balloons for Venus* - NASA is interested in Venus balloons that continuously cycle across a wide altitude range without the use of ballast drops. Such balloons not only enable scientific measurements at different altitudes, they also enable the periodic cooling of the payload during the time spent at the highest altitude. Innovative concepts and system-level solutions are sought for such an altitude cycling Venus balloon with the following characteristics: a minimum cycling altitude of 45 km or lower, a maximum cycling altitude of 58 km or higher, a balloon large enough to carry a 100 kg payload, and a flight duration of at least 14 (Earth) days comprising both day and night conditions. It is expected that a Phase I effort will consist of a complete system-level design and a proof-of-concept experiment on one or more key components.

Sub Topics:
  Thermal Control Systems Topic S3.07
Future Spacecraft and instruments for NASA's Science Mission Directorate will require increasingly sophisticated thermal control technology. Innovative proposals for the cross-cutting thermal control discipline are sought in the following areas:

- Future highly integrated electronics for CubeSat/SmallSat will drastically increase the performance per unit volume, mass and power of electronics systems. High flux heat acquisition and transport devices are required. In addition, high conductivity, vacuum-compatible interface materials are needed in order to reduce interface temperature gradients and facilitate efficient heat removal.
- Components of advanced small spacecraft such as CubeSat/SmallSat will have very small masses (i.e., small thermal capacitance), and their temperatures are highly sensitive to variations in the component power output and spacecraft environmental temperature. Advanced thermal devices capable of maintaining components within their specified temperature ranges are needed. Some examples are:
    - Phase change systems with high thermal capacity, low volume and low mass for endothermic/exothermal thermal management and conditioning.
    - Durable thermal coatings with low absorptance, variable emmittance, and good electrical conductivity.
    - High performance, low cost insulation systems for diverse environments.
    - Passive radiator turn-down devices to enable variation of heat rejection rates.
- Advanced thermal control systems with easily adaptable/reconfigurable thermal management architectures are needed in order to accommodate multiple heat sources and multiple heat sinks, particularly a thermal system that can facilitate heat sharing among on and off components and heat dissipation among multiple radiators placed on various locations on the spacecraft surface. Also needed are improved design and analysis tools for rapid design, integration and testing, and flight operations.
- Thermal control systems for long duration operation are needed, including long life pumps, single-phase and two-phase mechanically pumped fluid systems, components adaptable to distributed heat acquisition and rejection in diverse environments such as high radiation doses (Europa, etc.), and novel heat lift capabilities that enable operation in warm environments.
- Advanced detectors and optical systems at infrared wavelengths require efficient cooling methods to low temperatures. Advanced cryogenic thermal devices for precision temperature measurement and control over much larger sensor areas than currently possible are needed.

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

Note to Proposer: Subtopic H3.01 Thermal Control for Future Human Exploration Vehicles, under the Human Exploration and Operations Mission Directorate, also addresses thermal control technologies. Proposals more aligned with exploration mission requirements should be proposed in H3.01.
Sub Topics:
  Planetary Entry, Descent and Landing Technology Topic S4.01
NASA seeks innovative sensor technologies to enhance success for entry, descent and landing (EDL) operations

on missions to Mars. This call is not for sensor processing algorithms. Sensing technologies are desired that determine the entry point of the spacecraft in the Mars atmosphere; provide inputs to systems that control spacecraft trajectory, speed, and orientation to the surface; locate the spacecraft relative to the Martian surface; evaluate potential hazards at the landing site; and determine when the spacecraft has touched down. Appropriate sensing technologies for this subtopic should provide measurements of physical forces or properties that support some aspect of EDL operations. NASA also seeks to use measurements made during EDL to better characterize the Martian atmosphere, providing data for improving atmospheric modeling for future landers. Proposals are invited for innovative sensor technologies that improve the reliability of EDL operations.

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

- Providing critical measurements during the entry phase (e.g., pressure and/or temperature sensors embedded into the aeroshell).
- Improving the accuracy of 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 situational awareness during landing by identifying hazards (rocks, craters, slopes) and/or providing indications of approach velocities and touchdown.
- Substantially reducing the amount of external processing needed to calculate the measurements.
- Significantly reducing the impact of incorporating such sensors on the spacecraft in terms of volume, mass, placement, or cost.
- For a sample-return mission, monitoring local environmental (weather) conditions on the surface prior to landing of a "fetch" rover or launch of a planetary ascent vehicle, 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:
Robotic Mobility, Manipulation and Sampling Topic S4.02
Technologies for robotic mobility, manipulation, and sampling are needed to enable access to sites of interest and acquisition and handling of samples for in-situ analysis or return to Earth from planetary and solar system small bodies including Mars, Venus, comets, asteroids, and planetary moons.

Mobility technologies are needed to enable access to crater walls, canyons, gullies, sand dunes, and high rock density regions for planetary bodies where gravity dominates, such as the Moon and Mars. Trafficability challenges include steep terrain, obstacle size, and low soil cohesion. Tethered systems, non-wheeled systems, and marsupial systems are examples of mobility technologies that are of interest. Technologies to enable mobility on small bodies in micro-gravity environments are also of interest.

Manipulation technologies are needed to enable deployment of sampling tools and handling of samples. Mars mission sample-handling technologies are needed to enable transfer and storage of a range of rock and regolith cores approximately 1cm long and up to about 10cm long. Small-body mission manipulation technologies are needed to deploy sampling tools to the surface and transfer samples to in-situ instruments and sample storage containers.

Sample acquisition tools are needed to acquire samples on planetary and small bodies. For Mars, a coring tool is needed to acquire rock and regolith cores approximately 1cm diameter and up to 10cm long which also supports transfer of the samples to a sample handling system. Abrading bits for the tool are needed to provide rock-surface abrasion capability to better than 0.2mm scale roughness. A deep drill is needed to enable sample acquisition from the subsurface including rock cores to 3m depth and icy samples from deeper locations. Tools for sampling from asteroids and comets are needed which support transfer of the sample for in-situ analysis or sample return. Tools for acquisition and transfer of icy samples on Europa are also of interest. Minimization of mass and ability to work reliably in the harsh mission environment are important characteristics for the tools. Example environmental conditions include microgravity for small-body missions, high temperature and pressure (460 °C, 93bar) on Venus, and at Europa the radiation environment is estimated at 2.9 Mrad total ionizing dose (TID) behind 100 mil thick aluminum.

Contamination control and planetary protection are important considerations for sample acquisition and handling technologies. Contamination may include Earth-source contaminants produced by the sampling tool, handling system, or deposited on the sampling location from another source on the rover. "Cleaning to sterility" technologies are needed that will be compatible with spacecraft materials and processes. Surface cleaning validation methods are needed that can be used routinely to quantify trace amounts (~ng/cm^2) of organic contamination and submicron particle (~100nm size) contamination. Priority will be given to cleaning and sterilization methods that have potential for in-situ applications.

Component technologies for low-mass and low-power systems tolerant to the in-situ environment are of particular interest. Technical feasibility should be demonstrated during Phase I and a full capability unit of at least TRL 4 should be delivered in Phase II. Proposals should show an understanding of relevant science needs and engineering constraints and present a feasible plan to fully develop a technology and infuse it into a NASA program. Specific areas of interest include the following:

- Six-axis force-torque sensors for 100g and 35kg payloads.
- Steep terrain adherence.
- Tether play-out and retrieval systems including tension and length sensing.
- Low-mass tether cables with power and communication.
- Sampling system deployment mechanisms.
- Low mass/power vision systems and processing capabilities that enable faster surface traverse.
- Modular actuators and actuators for harsh environments.
- Abrading bit providing smooth surface preparation.
- Small body sampling tool.
- Cleaning to sterility technologies that will be compatible with spacecraft materials and processes.
- Surface cleaning validation technology to quantify trace amount (~ng/cm^2) of organic contamination and submicron particle (~100nm size) contamination.
- Sample handling technologies that minimize cross contamination and preserve mechanical integrity of samples.

Sub Topics:
  Spacecraft Technology for Sample Return Missions Topic S4.03
NASA plans to perform sample return missions from a variety of scientifically important targets including Mars, small bodies such as asteroids and comets, and outer planet moons. These types of targets present a variety of spacecraft technology challenges.

Some targets, such as Mars and some moons, have relatively large gravity wells and will require ascent propulsion. Includes propellants that are transported along with the mission or propellants that can be generated using local resources.

Other targets are small bodies with very complex geography and very little gravity, which present difficult navigational and maneuvering challenges.

In addition, the spacecraft will be subject to extreme environmental conditions including low temperatures (-270 °C), dust, and ice particles.

Technology innovations should either enhance vehicle capabilities (e.g., increase performance, decrease risk, and improve environmental operational margins) or ease sample return mission implementation (e.g., reduce size, mass, power, cost, increase reliability, or increase autonomy).
Sub Topics:
  Extreme Environments Technology Topic S4.04
NASA is interested in expanding its ability to explore the deep atmosphere and surface of giant planets, asteroids, and comets 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 planets. Proposals are sought for technologies that are suitable for remote sensing applications at cryogenic temperatures, and in-situ atmospheric and surface explorations in the high-temperature high-pressure environment at the Venusians surface (485 ?C, 93 atmospheres), or in low-temperature environments such as Titan (-180 ?C), Europa (-220 ?C), Ganymede (-200 ?C), Mars, the Moon, asteroids, comets and other small bodies. Also Europa-Jupiter missions may have a mission

life of 10 years and the radiation environment is estimated at 2.9 Mega-rad total ionizing dose (TID) behind 0.1 inch thick aluminum. Proposals are sought for technologies that enable NASA's long duration missions to extreme wide-temperature and cosmic radiation environments. High reliability, ease of maintenance, low volume, low mass, and low out-gassing characteristics are highly desirable. Special interest lies in development of following technologies that are suitable for the environments discussed above.

- Wide temperature range precision mechanisms i.e., beam steering, scanner, linear and tilting multi-axis mechanisms.
- Radiation-tolerant/radiation hardened low-power low-noise mixed-signal mechanism control electronics for precision actuators and sensors.
- Wide temperature range feedback sensors with sub-arc-second/nanometer precision.
- Long life, long stroke, low power, and high torque/force actuators with sub-arc-second/nanometer precision.
- Long life Bearings/tribological surfaces/lubricants.
- High temperature energy storage systems.
- High-temperature actuators and gear boxes for robotic arms and other mechanisms.
- Low-power and wide-operating-temperature radiation-tolerant /radiation hardened RF electronics.
- Radiation-tolerant/radiation-hardened low-power/ultra-low-powerwide-operating-temperature low-noise mixed-signal electronics for space-borne system such as guidance and navigation avionics and instruments.
- Radiation-tolerant/radiation-hardened power electronics.
- Radiation-tolerant/ radiation-hardened electronic packaging (including, shielding, passives, connectors, wiring harness and materials used in advanced electronics assembly).

Research should be conducted to demonstrate technical feasibility during Phase I and show a path toward a Phase II hardware demonstration, and when possible, deliver a demonstration unit for functional and environmental testing at the completion of the Phase II contract.
Sub Topics:
Technologies for Large-Scale Numerical Simulation Topic S5.01
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.
- Enhance the efficiency and effectiveness of NASA's supercomputing operations and services.

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

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

Offerors should demonstrate awareness of the state-of-the-art of their proposed technology, and should leverage existing commercial capabilities and research efforts where appropriate. Open source software and open standards are strongly preferred. Note that the NASA supercomputing environment is characterized by:

- HEC systems operating behind a firewall to meet strict IT security requirements.
- Communication-intensive applications.
- Massive computations requiring high concurrency.
- Complex computational workflows and immense datasets.
- 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.
- Technologies that require significant application re-engineering.

Projects need not benefit all NASA HEC users or application codes, but demonstrating applicability to an important NASA discipline, or even a key NASA application code, could provide significant value.

Specific technology areas of interest:

- Efficient Computing - In spite of the rapidly increasing capability and efficiency of supercomputers, NASA's HEC facilities cannot purchase, power, and cool sufficient HEC resources to satisfy all user demands. This subtopic element seeks dramatically more efficient and effective supercomputing approaches in terms of their ability to supply increased HEC capability or capacity per dollar and/or per Watt for real NASA applications. Examples include:
    - Novel computational accelerators and architectures.
    - Cloud supercomputing with high performance interconnects (e.g., InfiniBand).
    - Enhanced visualization technologies.
    - Improved algorithms for key codes.
    - Power-aware "Green" computing technologies and techniques.
    - Approaches to effectively manage and utilize many-core processors including algorithmic changes, compiler techniques and runtime systems.
- User Productivity Environments - The user interface to a supercomputer is typically a command line in a text window. This subtopic element seeks more intuitive, intelligent, user-customizable, and integrated interfaces to supercomputing resources, enabling users to more completely leverage the power of HEC to increase their productivity. Such an interface could enhance many essential supercomputing tasks: accessing and managing resources, training, getting services, developing and porting codes (e.g., debugging and performance analysis), running computations, managing files and data, analyzing and visualizing results, transmitting data, collaborating, etc.
- Ultra-Scale Computing - Over the next decade, the HEC community faces great challenges in enabling its users to effectively exploit next-generation supercomputers featuring massive concurrency to the tune of millions of cores. To overcome these challenges, this subtopic element seeks ultra-scale computing technologies that enable resiliency/fault-tolerance in extreme-scale (unreliable) systems both at job startup and during execution. Also of interest are system and software co-design methodologies, to achieve performance and efficiency synergies. Finally, tools are sought that facilitate verification and validation of ultra-scale applications and systems.

Sub Topics:
Earth Science Applied Research and Decision Support Topic S5.02
The NASA Applied Sciences Program (http://nasascience.nasa.gov/earth-science/applied-sciences [30]) seeks innovative and unique approaches to increase the utilization and extend the benefit of Earth Science research data to better meet societal needs. One area of interest is new decision support tools and systems for a variety of ecological applications such as managing coastal environments, natural resources or responding to natural disasters.

Currently, creating decision support tools (DST) that effectively utilize remote sensing data requires significant efforts by experts in multiple domains. This creates a barrier to the widespread use of Earth observations by state and local governments, businesses, and the public. This subtopic aims to democratize the creation of Earth science driven decision support tools and to unleash a creative explosion of DST development that significantly increases the return on investment for Earth science missions.

Specifically, this subtopic develops core capabilities that can be integrated to build multiple remote sensing driven DSTs customized to the requirements of different users in varied fields. Proven development and commercialization strategies will be used to meet these objectives. Similar to Eclipse, this subtopic will create an open-source DST development framework that enables components from multiple providers to be seamlessly integrated. This subtopic will also create software components that plug into the framework and open source tools that help users create new components. The components will provide functionality ranging from basic operations, such as retrieval of data meeting user-specified criteria from online repositories and visualization, to sophisticated data processing and analysis algorithms, such as atmospheric correction, data fusion, computational model interfaces, and machine learning based quality control.

To expedite DST development and deployment by knowledgeable users, this subtopic seeks an open source graphical workflow tool, similar to Labview or Simulink, which enables well informed users to quickly create a functional DST from a catalog of software components. Ultimately, a more sophisticated graphical workflow development tool, similar to MIT’s Scratch would enforce functionally, but not necessarily logically, “correct by construction” rules that would enable a broad population of people to successfully create DSTs. Open source and commercial components, as well as services, will be available through an online “store” similar to iTunes or Google Play.

The framework, components and resulting DSTs should be able to run in a commercial cloud such as Amazon EC2 or Google Compute Engine. Cloud enabled components and DSTs, those that can intelligently take advantage of flexible computing resources for processing, analysis, visualization, optimization, etc. are highly desired.

Ideally, users should be able to create, configure deploy DSTs, and view outputs such as status, reports, alerts, plots, maps, etc. via desktop computers (Windows 7 and OS X) as well as tablet and smart phones running recent versions of Android (4.0 and later) and iOS (5.0 and later). An HTML5 web application in a standards compliant browser, such as Chrome, can provide the required level of interoperability and capability. Due to serious security issues, Java and Flash based approaches will not be considered.
Sub Topics:
Algorithms and Tools for Science Data Processing, Discovery and Analysis, in State-of-the-Art Data Environments
Topic S5.03
The size of NASA's observational data sets is growing dramatically as new missions come on line. In addition, NASA scientists continue to generate new models that regularly produce data sets of hundreds of terabytes or more. It is growing ever increasingly difficult to manage all of the data through its full lifecycle, as well as provide effective data analytical methods to analyze the large amount of data. For example, the HyspIRI mission is expected to produce an average science data rate of 800 million bits per second (Mbps), JPSS-1 will be 300 Mbps and NPP is already producing 300 Mbps, compared to 150 Mbps for the EOS-Terra, Aqua and Aura missions. Other examples are SDO with a rate of 150 Mbps and 16.4 Gigabits for a single image from the HiRise camera on the Mars Reconnaissance Orbiter (MRO).

This subtopic area seeks innovation and unique approaches to solve issues associated around the use of "Big Data" within NASA. The emphasis of this subtopic is on tools that leverage existing systems, interfaces, and infrastructure, where it exists and where appropriate. Reuse of existing NASA assets is strongly encouraged.

Specifically, innovations are being sought in the following areas:

- *Parallel Processing for Data Analytics* - Open source tools like the Hadoop Distributed File Systems (HDFS) have shown promise for use in simple MapReduce operations to analyze model and observation data. In addition to HDFS, there is a rapid emergence and adoption of cloud software packages integrated with object stores, such as OpenStack and Swift. The goal is to accelerate these types of open source tools for use with binary structured data from observations and model output using MapReduce or a similar paradigm.
- *High Performance File System Abstractions* - NASA scientists currently use a large number of existing

applications for data analysis, such as GrADS, python scripts, and more, that are not compatible with an object storage environment. If data were stored within an object storage environment, these applications would not be able to access the data. Many of these applications would require a substantial amount of investment to enable them to use object storage file systems. Therefore, a file system abstraction, such as FUSE (file system in user space) is needed to facilitate the use of existing data analysis applications with an object storage environment. The goal is to make a FUSE-like file system abstraction robust, reliable, and highly performing for use with large NASA data sets.

- *Data Management of Large-Scale Scientific Repositories* - With increasing size of scientific repositories comes an increasing demand for using the data in ways that may never have been imagined when the repository was conceived. The goal is to provide capabilities for the flexible repurposing of scientific data, including large-scale data integration, aggregation, representation, and distribution to emerging user communities and applications.
- *Server Side Data Processing* - Large data repositories make it necessary for analytical codes to migrate to where the data are stored. Hadoop does that at the level of a single HDFS. In a densely networked world of geographically distributed repositories, tiered intermediation is needed. The goal is to provide support for migratable codes and analytical outputs as first class objects within a provenance-oriented data management cyberinfrastructure.
- *Techniques for Data Analysis and Visualization* - New methods for data analytics that scale to extremely large data sets are necessary for data mining, searching, fusion, subsetting, discovery, visualization, and more. In addition, new algorithms and methods are needed to look for unknown correlations across large, distributed scientific data sets. The goal is to increase the scientific value of model and observation data by making analysis easier and higher performing. Among others, some of the topics of interest are:
  - Techniques for automated derivation of analysis products such as machine learning for extraction of features in large image datasets (e.g., volcanic thermal measurement, plume measurement, automated flood mapping, disturbance mapping, change detection, etc.).
  - Workflows for automated data processing, interpretation, and distribution.
- *Accelerated Large Scale Data Movement* - There are a multitude of large distributed data stores across NASA that includes both observation and model data. The movement of data across the network must be optimized to take full advantage of large-scale data analytics, especially when comparing model to observation data. The goal is to optimize data movement in the following ways:
  - Accelerate and make it easier to move data over the wide area to facilitate large-scale data management and analysis.
  - Optimize the movement of data within more local environments, such as the usage of Remote Direct Memory Access (RDMA) within HDFS.
  - Virtualization of high-speed network interfaces for use within cloud environments.

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

Tools and products developed under this subtopic may be used for broad public dissemination or within a narrow scientific community. These tools can be plug-ins or enhancements to existing software, on-line data/computing services, or new stand-alone applications or web services, provided that they promote interoperability and use standard protocols, file formats and Application Programming Interfaces (APIs) or prevalent applications.
Sub Topics:
Integrated Science Mission Modeling Topic S5.04
NASA seeks innovative systems modeling methods and tools to:

- Define, develop and execute future science missions, many of which are likely to feature designs and operational concepts that will pose significant challenges to existing approaches and applications.
- Enable disciplined system analysis for the ongoing management and decision support of the space science technology portfolio, particularly with regard to understanding technology alternatives, relationships, priorities, timing, availability, down-selection, maturation, investment needs, system engineering considerations, and cost-to-benefit ratios; to examine "what-if" scenarios; and to facilitate multidisciplinary assessment, coordination, and integration of the technology roadmaps as a whole.

Use of System Modeling Language (SysML) is encouraged but not required. SysML is a general purpose graphical modeling language for analyzing, designing and verifying complex systems that may include hardware, software, information, personnel, procedures and facilities. As a language, SysML represents requirements, structure, behavior, and equations in nine different diagram types, and can represent both hardware and software models. The language can be extended to provide metamodels for different disciplines, and is supported by multiple commercial tools. SysML is finding increased use throughout the agency to support systems engineering and analysis.

Specific areas of interest include the following:

- Integration of system and mission modeling tools with high-fidelity multidisciplinary design and modeling tools, supporting efficient analysis methods that accommodate uncertainty, multiple objectives, and large-scale systems - This requires the development of robust interfaces between SysML and other tools, including CAD/CAE/PDM/PLM applications, used to support NASA science mission development, implementation and operations. The objective is to produce a unified environment supporting mixed systems-level and detailed analysis during any lifecycle phase, and rapid analysis of widely varying concepts/configurations using mixed-fidelity models, including geometry/mesh-based models when required. The human interface for such a system could be a "dashboard" (web-based is highly desirable) which initially allows for monitoring of the dataflow across a heterogeneous set of tools and finally allows for control of the data flow between the variety of applications.
- Modeling and rapid integration of programmatic, operational, and risk elements - Fully integrated system model representations must include non-physics based constructs such as cost, schedule, risk, operations, and organizational model elements. Novel methods and tools to model these system attributes are critical. In addition, approaches to integrate these in a meaningful way with other system model elements are needed. Methods that consider the development of these models as by-products of a collaborative and/or concurrent design process are particularly valuable.
- Library of SysML models of NASA related systems - Using a library of SysML models, engineers will be able to design their systems by reusing a set of existing models. Too often, these engineers have to begin from scratch the design of the systems. A library of verified and validated models would provide a way for the engineers to design a new spacecraft by assembling existing models that are domain specific, and therefore easy to adapt to the target system. In order to provide for seamless integration between SysML models each model must identify its level of abstraction both in terms of the modeling of time (progression: no ordering of events, qualitative ordering of events, metric time ordering of events) and the modeling of space (progression: lumped parameters models, distributed parameter models). Such levels of abstraction "certificates" for SysML will help determine integration interface requirements between any two models.
- Profiles for spacecraft, space robotics, and scientific instruments - Profiles provide a means of tailoring SysML for particular purposes. Extensions of the language can be inserted. This allows an organization to create domain specific constructs which extend existing SysML modeling elements. By developing profiles for NASA domains such as Spacecraft, Space Robotics and Scientific Instruments, powerful mechanisms will be available to NASA systems engineers for designing future space systems.
- Requirements Modeling - SysML offers requirements modeling capabilities, thus providing ways to visualize important requirements relationships. There is a need to combine traditional requirements management, supported by tools including but not limited to DOORS and CRADLE, and SysML requirements modeling in a standardized and sustainable way.
- Functional Modeling - The intermediate data products between requirements and specification are detailed functional models that identify all of the functions required to achieve the mission profile(s). There is a critical need to model this layer as it is a key data product to provide traceability between requirements and implementation.
- Model and Modeling Process Synthesis - As model-based design broadens and integrates larger and more complex models, methods for how to sequence and operate the design synthesis, evaluation (e.g., V&V) and elaboration process will become more important, as will considerations of how model-based processes are made compatible with existing review and development cycles.

Sub Topics:

Fault Management Technologies Topic S5.05

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

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

Specific objectives are to:

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

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

The approach of this subtopic is to seek the right balance between sufficient reliability and cost appropriate to the mission type and risk posture. Successful technology development efforts under this subtopic would be considered for follow-on funding by, and infusion into, SMD missions. Research should be conducted to demonstrate technical feasibility and NASA relevance during Phase I and show a path toward a Phase II prototype demonstration.

Offerors should demonstrate awareness of the state-of-the-art of their proposed technology, and should leverage existing commercial capabilities and research efforts where appropriate.

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

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

Arrays (FPGAs); and execution in real-time or off-line analysis post-operations. Alternative architecture choices could help control FM system complexity and cost and could offer solutions to transparency, verifiability, and completeness challenges.
- *Multi-discipline FM Interoperation* - FM designers, Systems Engineering, Safety and Mission Assurance, and Operations perform analyses and assessments of reliabilities, failure modes and effects, sensor coverage, failure probabilities, anomaly detection and response, contingency operations, etc. The relationships between multi-discipline data and analyses are inconsistent and misinterpreted. Resources are expended either in effort to resolve disconnects in data and analyses or worse, reduced mission success due to failure modes that were overlooked. Solutions that address data integrity, identification of metrics, and standardization of data products, techniques and analyses will reduce cost and failures.

Sub Topics: