NASA SBIR 2012 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 here (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. For the 2012 program year, we are restructuring the Sensors, Detectors and Instruments Topic, rotating out, combining and retiring some of the subtopics. Please read each subtopic of interest carefully. One new subtopic, S1.09 Surface and Sub-surface Measurement Systems was added this year. This new subtopic solicits proposals that are for ground-based surface vehicles, and submerged systems. Systems that will provide near-term benefit in a ground-based application but that are ultimately intended for flight or mobile platforms are in scope. 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
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 emphasis on compactness, efficiency, reliability, lifetime, and high performance. Innovative lidar subsystem and component technologies systems that directly address the measurements of the atmosphere and surface topography of the Earth, Mars, the Moon, and other planetary bodies will be considered under this subtopic.

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: Laser Interferometer Space Antenna (LISA), Doppler Wind Lidar (3D-WINDS), Ozone Lidar, Lidar for Surface Topography (LIST), Mars atmospheric sensing, Mars and earth re-entry atmospheric entry and descent, Active Sensing of CO₂ Emissions over Nights, Days, and Seasons (ASCENDS), and Aerosols-Clouds-Ecosystems (ACE). In addition, innovative technologies relevant to the NASA sub-orbital programs, such as Unmanned Aircraft Systems (UAS) and Venture-class focusing on the studies of the Earth climate, carbon cycle, weather, and atmospheric composition, are being sought.

The proposals should target components and subsystems development 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 or an aircraft platform. For the PY12 SBIR Program, we are soliciting the component and subsystem technologies described below.

Solid state, single frequency, pulsed, laser transmitter operating in the 1.0 µm - 1.7 µm range with wall-plug efficiency of greater than 25% suitable for CO₂ measurement, interferometry, and free-space laser communication applications. The laser transmitter must be capable of generating frequency transform-limited pulses with a quality beam M² of less than 1.5. We are interested in two different regimes of repetition rate and output energy: in one case, repetition rate from 5 KHz to 20 kHz with pulse energy from 1 - 4 mJ, and in the second case, repetition rate 20 Hz to 2 kHz with pulse energy from 30 - 300 mJ. In addition, development of non-traditional optical amplifier architectures that yield optical efficiency of >70% are of interest. Attention to the compact and rugged designs for possible aircraft flight tests is highly desirable.

Single-frequency solid-state crystal, planar waveguide or fiber amplifiers/lasers operating at 1.5 and 2.0 micron wavelength regimes suitable for direct detection differential absorption lidar (DIAL) and coherent lidar applications. These lasers must meet one of the two general requirements:

- Pulse energy 0.5 mJ to 2 mJ, repetition rate 2 kHz to 10 kHz, and pulse duration of 10 nsec for direct detection lidars.
- 5 mJ to 50 mJ , 20 Hz to 2 kHz, 200 nsec for coherent detection lidars.

2-micron single frequency laser system generating at least 30 mW of power with a precision frequency locking mechanism suitable for measurements of atmospheric CO₂. The laser must be locked to a CO₂ absorption line peak via a fiber gas cell with accuracy better than 200 kHz. The frequency locked laser shall be modulated to generate two preset offset frequencies from the center frequency alternatively, one at 3-4 GHz, and the other at
15-20GHz range. The frequency stability at these off-center frequencies shall be better than 500 KHz.

Pulsed, single frequency, solid state laser operating in the 450-500 nm range serving as a transmitter for an oceanography lidar. The laser must be able to produce bandwidth-limited pulses with 10 nsec or shorter duration. The proposed design must be scalable to at least 10 W of average power, preferably generating 100 mJ at 100-200 Hz, but will consider lower pulse energies with higher repletion rates. Pulse energies can be less than the above stated goals by a factor of 10 for the Phase II delivered unit.

S1.02 Microwave Technologies for Remote Sensing

**Lead Center:** JPL

**Participating Center(s):** GSFC, 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](http://www.nap.edu/catalog/11820.html) [6]). These sensors include low frequency (less than 10) 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:

- Space qualifiable, High power and efficiency P-band power amplifiers: Center Frequency: 420-450, Gain: > 40 dB, Efficiency: >80%, Duty Cycle: 10%, Mass
- Space-qualifiable Single-Board Digital Radar Transceiver in PC-104e form factor. Frequency bands: 400-500, 1200-1300, with arbitrary waveform generator (100 us pulselength, 30 BW), 2-channel ADC, FPGA, PCIe bus , Size: Approx 9cm x 9.6cm x 3.1cm
- Cryogenic LNAs for 180 to 270 GHz with noise temperatures of less than 100K. Earth Science Decadal Survey missions that apply: PATH, GACM and future Earth Venture Class low cost millimeter wave instruments.
- Receiver technologies for the PATH mission including: low noise (Local Oscillator technologies for 2nd generation instruments for SOFIA, next generation HIFI, and suborbital instruments (GUSSTO). This can include: GaN based frequency multipliers that can work in the 200-400 GHz range (output frequency) with input powers up to 1 W. Graphene-based (or other suitable technology) devices that can work as frequency multipliers in the frequency range of 1-3 THz.
- Compact, light-weight array antennas with 50 - 60% bandwidth using electronic frequency hopping and tuning capabilities, dual-polarization, high cross-polarization isolation (> 25 dB) for airborne and spaceborne radar applications
- P-, L-, C-, X band MMIC pulsed radar transceivers with dynamic load matching, wideband (> 50) high power efficiency (> 30%), high T/R isolation (> 90 dB)
- Large (~5m) deployable parabolic cylindrical antennas, F=35, 94 GHz
- G-Band Microwave Components: For measurement of microphysical properties of clouds and upper atmospheric constituents (particles of less than mm sizes):
  - G-band Noise Source (ENR> 10dB).
  - W-band LO (6 dBm, Freq. Stability 5-10 (-20 C - 40 C) DC Power
  - G-band isolator (Isolation > 15 dB, Insertion Loss
  - G-band switching circulator (Isolation > 15 dB Insertion Loss
  - Integration and packaging G-band receiver for cubesat and microsat platforms.
- Multi-Frequency and/or multi-Beam Focal Plane Arrays (FPA) as a primary feed for reflector antennas. In
NASA’s SCLP mission, it is required to collect Earth science data at high spatial and as well as temporal resolutions simultaneously. In addition to high spatial and temporal resolutions, the proposed antenna system must offer ways to suppress RFI and control antenna illumination. NASA is looking for a small (3 x 3) focal plane array system to be used as a feed for its main reflector. Wideband array element covering 19, and 37 GHz must be used as a basic element of the proposed FPA.

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

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

NASA is seeking new technologies or improvements to existing technologies to meet the detector needs of future missions, as described in the most recent decadal surveys for Earth science (http://www.nap.edu/catalog/11820.html [6]), planetary science (http://www.nap.edu/catalog/10432.html [7]), and astronomy and astrophysics (http://www.nap.edu/books/0309070317/html/ [8]).

The following technologies are of interest for the Scanning Microwave Limb Sounder (http://mls.jpl.nasa.gov/index-cameo.php [9]) on the Global Atmospheric Composition Mission and the SOFIA (Stratospheric Observatory for Infrared Astronomy) airborne observatory:

- Radiation tolerant digital polyphase filterbank back ends for sideband separating microwave spectrometers. Requirements are >5GHz instantaneous bandwidth per sideband, 2 MHz resolution, low power.
- Improved submillimeter mixers for frequencies >2 THz are needed for heterodyne receivers to fly on SOFIA. Minimum noise temperatures for cryogenic operation and instantaneous bandwidths >5 GHz are key parameters.
- Efficient, flight qualifyable, spur free, local oscillators for SIS mixers operating in low earth orbit. Two bands:
  - Tunable from 200 to 250 GHz.
  - Tunable from 610 to 650 GHz, phase-locked to or derived from an ultra-stable 5 MHz reference.
- Quantum cascade laser-based local oscillators >2THz for astrophysics applications

Thermal imaging, LANDSAT Thermal InfraRed Sensor (TIRS), Climate Absolute Radiance and Refractivity Observatory (CLARREO), BOREal Ecosystem Atmosphere Study (BOREAS), other infrared earth observing missions, Trojan Tour, Europa Jupiter System Mission (EJSM) such as a descoped Jupiter Europa Orbiter (JEO), Io Observer, or Jupiter Io Callisto Europa (JuICE) missions (see the Jupiter Europa Orbiter Mission Study 2008: Final Report, (http://opfm.jpl.nasa.gov/library/ [10]) and future planetary missions:

- Development of un-cooled or cooled Infrared detectors (hybridized or designed to be hybridized to an appropriate read-out integrated circuit) with NE?T30% and dark currents 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 strain layer super-lattices to meet these specifications.
- 2-D arrays of thermopile detectors (wavelength range 20-100 µm; Detectivity = 4x10^9; operating temp 100-200 K).
1kx1k MCT detector arrays with cutoff wavelength extended to =12 µm for use in missions to NEOs, comets and the outer planets.

New or improved technologies leading to measurement of trace atmospheric species (e.g., CO, CH\textsubscript{4}, N\textsubscript{2}O) from geostationary and low-Earth orbital platforms; see Methane Trace Gas Sounder. Of particular interest are new techniques in gas filter correlation spectroscopy, Fabry-Perot spectroscopy, or improved component technologies. Technologies are needed for active and passive wave front and amplitude control, and relevant missions include Extra solar Planetary Imaging Coronagraph (EPIC), and other coronagraphic missions such as Terrestrial Planet Finder (http://exep.jpl.nasa.gov/TPF-C/tpf-C_index.cfm [11]) and Stellar Imager (http://hires.gsfc.nasa.gov/si/ [12]):

- MEMS based segmented deformable mirrors consisting of arrays of up to 1200 hexagonal packed segments with strokes over the range of 0 to 1.0 microns, quantized with 16-bit electronics with segment level stabilities of 0.015 nm rms (1-bit) over 1 hour intervals. Segments should be flat to 2 nm rms or better and the substrate flat to 125 nm or better and high uniformity of coatings (1% rms).
- 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 0.2 -0.5 mm range, with contrast between neighboring spectra of ~10^-4. and uniform focal lengths to
- Spatial Filter Array (SFA) consisting of a monolithic array of up to 1200 coherent, polarization preserving, single mode fibers, or custom waveguides, that operate with minimal coupling losses over a large fraction of the spectral range from 0.4 - 1.0 microns. The SFA should have input and output lenslet with each pair mapped to a single fiber or waveguide and such that the lenslets maintain path length uniformity to

Blazed, holographic optical gratings on convex surfaces: The Offner spectrometer design uses a symmetric optical layout to balance aberrations, producing good imaging performance and spectral images with little or no distortion. Both of these attributes improve the measurement capability of the spectrometer by eliminating the spatial-spectral information mixing that other spectrometer forms typically produce. The key element in an Offner spectrometer is the convex spherical grating that is used to disperse the light spectrally. While such gratings can be made holographically, these gratings suffer from low efficiency due to their lack of signal-enhancing blazed groove structure. Development is needed for production of holographically-generated convex gratings that have a continuously-varying blaze angle to provide high efficiency diffraction into a chosen wavelength range and diffraction order (415 nm to 695 nm in first order and 290 nm to 390 nm in the second order). Such gratings also should have less scattered light than similar mechanically-ruled gratings, improving spectrometer performance.

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 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](http://www.nasa.gov/missions [13]).

Specific technology areas are listed below:

- 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 (Large format UV and X-ray focal plane detector arrays: micro-channel plates, CCDs, and active pixel sensors (>50% QE, 100 Megapixels).
- Advanced Charged Couple Device (CCD) detectors, including improvements in UV quantum efficiency and read noise, to increase the limiting sensitivity in long exposures and improved radiation tolerance. Electron-bombarded CCD and CMOS detectors, including improvements in efficiency, resolution, and global and local count rate capability. In the X-ray, we seek to extend the response to lower energies in some CCDs, and to higher, perhaps up to 50 keV, in others. Possible missions are future GOES missions and International X-ray Observatory.
- Wide band gap semiconductor, radiation hard, visible and solar blind large format imagers for next generation hyperspectral Earth remote sensing experiments. Need larger formats (>1Kx1K), much higher resolution (Solar blind, compact, low-noise, radiation hard, EUV and soft X-ray detectors are required. Both single pixels (up to 1cm x 1cm) and large format 1D and 2D arrays are required to span the 0.05nm to 150nm spectral wavelength range. Future missions include GOES post R and T.
- Visible-blind SiC Avalanche Photodiodes (APDs) for EUV photon counting are required. The APDs must show a linear mode gain >1E6 at a breakdown reverse voltage between 80 and 100V. The APD's must demonstrate detection capability of better than 6 photons/pixel/s down to 135nm wavelength. See needs of National Research Council's Earth Science Decadal Survey (NRC, 2007): Tropospheric ozone.
- Large format 1D (1 x 2k) and 2D (2k x 2k) SiC arrays (operating temp 170-300K; D* = 3x1015) including Schottky diodes, PINs and APDs for instruments on future outer planets missions.
- 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 (~106), low noise, fast time response (2. Focus plane mass must be minimized (2g/cm² goal). Individual pixel readout is required. The entire focal plane detector can be formed from smaller, individual sub-arrays.
- Large area (3 m²) photon counting near-UV detectors with 3 mm pixels and able to count at 10 MHz. Array with high active area fraction (>85%), 0.5 Megapixels and readout less than 1 mW/channel. Future instruments are JEM-EUSO and OWL.
- Large area (m²) X-ray detectors with 85%. Future instrument is a Phased-Fresnel X-ray Imager.
- Improve beyond CdZnTe detectors using micro-calorimeter arrays at hard X-ray, low gamma-ray bands (above 10 keV and Below 80 keV).
- Technologies to improve spatial resolution for the hard X-ray band to 10 and ultimately to 5 arc-second resolution.
- High-density, low-temperature electrical interfaces: In microcalorimeter and cryogenic IR detector assemblies, the large number of electrical connections required on the low-temperature stage (below 4 Kelvin) requires high-density, miniaturized cryogenic connectors. NASA needs suitable nano-miniature connectors that can connect to superconducting wires (Nb or Al) deposited on a high density flex cable. The metal traces will likely be layered into a stripline configuration to minimize cross-talk, leading to pads onto
which the connector is attached. This type of flex cable has extremely low thermal conductivity. A modular connector, easily integrated into or removed from the superconducting flex cable, is sought.

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 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.
- Cooled (-60 ºC) solid-state ion detector capable of operating at a floating potential of -15 kV relative to ground.
- Low-noise magnetic materials for advanced magnetometer sensors with performance equal to or better than those in the 6-81.3 Mo-Permalloy family.
- Radiation-hardened ASICs including 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).
- Low-power, charge-sensitive preamplifiers on a chip.
- High efficiency (5% or greater) conversion surfaces for low-energy neutral atom conversion to ions possibly based on nanotechnology.
- Miniature low-power, high-efficiency, thermionic cathodes, capable of 1-mA electron emission per 100-mW heater power with emission surface area of 1-mm² and expected lifetime of 20,000 hours.
- Long wire boom (? 50 m) deployment systems for the deployment of very lightweight tethers or antennae on spinning spacecraft.
- Systems to determine the orthogonality of a deployed electric/magnetic field boom system in flight (for use with three-axis rigid 10-m booms) accurate to 0.10° dynamic.
- Die-level optical interferometer, micro-sized, for measuring Fabry-Perot plate spacing with 0.1-nm accuracy.
- Diffractive optics (photon sieves) of 0.1-m aperture or larger with micron-sized outer Fresnel zones for high-resolution EUV imaging.
- Avalanche Photodiode Detectors (APDs), in single pixel and multi-pixel form, to make a breakthrough in particle detection by taking advantage of their inherent gain compared to the unity gain SSDs. 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.

- 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 Cryogenic Systems for Sensors and Detectors

Lead Center: GSFC

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

Cryogenic cooling systems often serve as enabling technologies for detectors and sensors flown on scientific instruments as well as advanced telescopes and observatories. As such, technological improvements to cryogenic systems (as well as components) further advance the mission goals of NASA through enabling performance (and ultimately science gathering) capabilities of flight detectors and sensors. Presently, there are six potential investment areas that NASA is seeking to expand state of the art capabilities in for possible use on future programs such as GEOID, SPICA, WFirst (http://wfirst.gsfc.nasa.gov/ [17]), Spirit, Specs (http://nmdb.gsfc.nasa.gov/geons [18]) and the Europa Science missions (http://www.nasa.gov/multimedia/podcasting/jpl-europa20090218.html [19]). The topic areas are as follows:

- **Extremely Low Vibration Cooling Systems** - Examples of such systems include pulse tube coolers and turbo brayton cycles. Desired cooling capabilities sought are on the order of 20 mW at 4K or 1W at 50K. Present state of the art capabilities display

- **Advanced Magnetic Cooler Components** - An example of an advanced magnetic cooler might be Adiabatic Demagnetization Refrigeration systems. Specific components sought include:
  - Low current superconducting magnets.
  - Active/Passive magnetic shielding (3-4 Tesla magnets).
  - Superconducting leads (10K - 90K) capable of 10 amp operation with 1 mW conduction.
  - 10 mK scale thermometry.

- **Continuous Flow Distributed Cooling Systems** - Distributed cooling provides increased lifetime of cryogen fluids for applications on both the ground and spaceborne platforms. This has impacts on payload mass and volume for flight systems which translate into costs (either on the ground, during launch or in flight). Cooling systems that provide continuous distributed flow are a cost effective alternative to present techniques/methodologies. Cooling systems that can be used with large loads and/or deployable structures are presently being sought after.

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

- **Highly Efficient Magnetic and Dilution Cooling Technologies** - The desired temperature range for proposed systems is

- **Low Temperature/Input Power Cooling Systems** - Cooling systems providing cooling capacities approximately 0.3W at 35K with heat rejection capability to temperature sinks upwards of 150K are of interest. Presently there are no cooling systems operating at this heat rejection temperature. Input powers should be limited to no greater than 20W. Study of passive cooler in tandem with low power, low mass cryocooler satisfying the above mentioned requirements is also of interest.
S1.07 In Situ Sensors and Sensor Systems for Lunar and Planetary Science

Lead Center: JPL

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

This subtopic solicits development of advanced instrument technologies and components suitable for deployment on planetary and lunar missions. These technologies must be capable of withstanding operation in space and planetary environments, including the expected pressures, radiation levels, launch and impact stresses, and range of survival and operational temperatures. Technologies that reduce mass, power, volume, and data rates for instruments and instrument components without loss of scientific capability are of particular importance. In addition, technologies that can increase instrument resolution and sensitivity or achieve new & innovative scientific measurements are solicited. For example missions, see (http://science.hq.nasa.gov/missions [20]). 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/ [21]). 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.

- **Saturn, Uranus and Neptune** - Technologies are sought for components, sample acquisition and instrument systems that can enhance mission science return and withstand the low-temperatures/high-pressures of the atmospheric probes during entry.

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

Proposers are strongly encouraged to relate their proposed development to:

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

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

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

**S1.08 Airborne Measurement Systems**

*Lead Center: GSFC*

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

A focus is on miniaturization and increased sensitivity/performance needed to support for NASA's airborne science missions. Linkage to other subtopics such as S3.05 Unmanned Aircraft and Sounding Rocket Technologies is
encouraged. Complete instrument systems are desired, including features such as remote/unattended operation and data acquisition, low power consumption, and minimum size and weight.

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), 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 (multiphase).
- Surface snow thickness (5 cm resolution is desired), and potentially, snow density.
- Aerosols and cloud particles.
- Volcanic ash and gases.
- Gases: Reactive and tracers of source emissions. Examples include (but are not limited to) carbon dioxide, carbon monoxide, methane, water vapor.
- High quality three-dimensional wind instruments suitable for gas flux measurements, as well as advanced temperature and pressure systems.

### S1.09 Surface & Sub-surface Measurement Systems

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

For ground-based surface vehicles, and submerged systems. Systems that are ultimately intended for flight or mobile platforms that will provide near-term benefit in a ground-based application are in scope, as this step will aid in maturation of new concepts.

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), 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., stabilized disdrometer).
- Particles: mineral, biogenic, nutrients.
- Gases – carbon dioxide, methane, etc.
- Air and water quality.
- Water and ice flow rates.
- Seismic monitoring.
- Autonomous sample collection and/or analysis systems.
• Air-dropped sensors for 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.
• Oceanic, coastal, and fresh water measurements including inherent and apparent optical properties for calibration and validation of satellite ocean color radiometric data, temperature, salinity, currents, in situ biogeochemical and chemical particle composition, sediments, and biological or ecological properties of aquatic environments including but not limited to nutrients, phytoplankton and their functional groups, harmful algal blooms, fish or aquatic plants and animals.
• 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 a Earth science role are also encouraged.

Advanced Telescope Systems Topic S2

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

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

**Wavefront Control Technologies**

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

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

• Development of techniques to improve the wavefront stability of the telescope beam, and/or to mitigate the residual instability. These include but are not limited to: the development of low order wavefront sensors, improved pointing techniques, as well as model-based software algorithms that predict and subtract the instabilities in post-processing.

**Optical Coating and Measurement Technologies**

• Instruments capable of measuring polarization cross-talk and birefringence to parts per million.

• Highly reflecting broadband coatings for large (> 1 m diameter) optics.

• Polarization-insensitive coatings for large optics.

**Other**

• 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.

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

**S2.02 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/m² with a packaging efficiency of 3-10 deployed/stowed diameter. Static and dynamic wavefront error tolerances to thermal and dynamic perturbations may be achieved through passive means (e.g., via a high stiffness system, passive thermal control, jitter isolation or damping) or through active opto-mechanical control. Large deployable multi-layer structures in support of sunshades for passive thermal control and 20m to 50m class planet finding external occulters are also relevant technologies. Potential architecture implementations must package into an existing launch volume, deploy and be self-aligning to the micron level. The target space environment is expected to be the Earth-Sun L2.

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

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

In particular, important subsystem considerations may include:

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

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

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

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 Component Systems

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

This 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.
- Large aperture diffusers (up to 1 meter) to calibrate GeoStationary Earth viewing sensors.

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
- 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, effecting 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

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

Technical Challenges

In all cases, the most important metric for an advanced optical system is affordability or areal cost (cost per square meter of collecting aperture). Currently both X-ray and normal incidence space mirrors cost $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/m².

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 to 5 m² collecting area.
- Multilayer high-reflectance coatings for hard X-ray mirrors (similar to NuSTAR).
- X-ray transmission and/or reflection gratings.

Multiple technologies are needed to enable

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 m² 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

Successful proposals will demonstrate an ability to manufacture, test and control a prototype X-ray mirror assembly in the 0.25 to 0.5 meter class; or to coat a 0.25 to 0.5 meter class representative optical component. An ideal Phase I deliverable would deliver a sub-scale component such as a 0.25 meter X-ray precision mirror. 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. Both deliverables would be accompanied by all necessary documentation, including the optical performance assessment and all data on processing and properties of its substrate materials. The Phase II would also include a mechanical and thermal stability analysis.

Optical Components, Coatings and Systems for potential UV/Optical missions
Potential UV/Optical missions require:

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

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

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 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.

**Large aperture diffusers (up to 1 meter) to calibrate GeoStationary Earth viewing sensors**

The geosynchronous orbit for GEO-CAPE coastal ecosystem imager requires technology for alternative periodic solar calibration strategies including new materials to reduce weight, and new optical analysis to reduce the size of calibration systems. GEO-CAPE will need a light-weight large aperture (greater than 0.5 m) diffuse solar calibrator, employing multiple diffusers to track on-orbit degradation. Typical materials of interest are PTFE (such as Spectralon® surface diffuser) or development of new Mie scattering materials for use as volume diffusers in transmission or reflection. Material needs to be stable in BTDF/BSDF to 2%/year from 250 to 2500 nm and highly lambertian (no formal specification for deviation from lambertian).
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][17].
- NGXO [http://ixo.gsfc.nasa.gov][22].
- ATLAST [http://www.stsci.edu/institute/atlast][24].

Optical systems currently being researched for these missions are large area aspheres, requiring accurate figuring and polishing across six orders of magnitude in period. Technologies are sought that will enhance the figure quality of optics in any range as long as the process does not introduce artifacts in other ranges. For example, mm-period polishing should not introduce waviness errors at the 20 mm or 0.05 mm periods in the power spectral density. Also, novel metrological solutions that can measure figure errors over a large fraction of the PSD range are sought, especially techniques and instrumentation that can perform measurements while the optic is mounted to the figuring/polishing machine. Large lightweight monolithic metallic aspheres manufactured using innovative mirror substrate materials that can be assembled and welded together from smaller segments are sought. Also, optical system design and tolerancing requires software analysis tools capable of accurately ray tracing a broader range of materials and effects than are currently treated with conventional optical software. Updated software algorithms code is a technology of interest.

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° in azimuth and 200 mm axial length and cone angles vary from 0.1 to 1°.
- Low stress metrology mounts that can hold very thin optics without introducing mounting distortion.
- Low normal force figuring/polishing systems operating in the 1 mm to 50 mm period range with minimal impact at significantly smaller and larger period ranges.
• In-situ metrology systems that can measure optics and provide feedback to figuring/polishing instruments without removing the part from the spindle.

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

• Extreme aspheric and/or anamorphic optics for pupil intensity amplitude apodization.

• Metrology systems useful for measuring large optics with high precision.

• 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.

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, which 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.
• 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. 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). Innovations for 2012 are sought in the areas of:

• Command and Data Handling, and Instrument Electronics.
• Power Generation and Conversion - Propulsion Systems.
• Power Electronics and Management, and Energy Storage.
• Unmanned Aircraft and Sounding Rocket Technologies.

Significant changes to the S3 Topic for 2011 are that the following areas will not be solicited in 2012, but may be solicited again in the 2013:

• Thermal Control Systems - Guidance, Navigation and Control.
• Terrestrial and Planetary Balloons.

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

• The Astrophysics Roadmap: (http://nasascience.nasa.gov/about-us/science-strategy [25]).
• Astrophysics Decadal Survey - "New Worlds, New Horizons: in Astronomy and Astrophysics": (http://www.nap.edu/catalog.php?record_id=12951 [26]).
• The Earth Science Decadal Survey: (http://books.nap.edu/catalog.php?record_id=11820 [27]).
• The 2011 Planetary Science Decadal Survey was released March 2011. This decadal survey is considering technology needs. (http://sites.nationalacademies.org/SSB/currentprojects/SSB_052412 [29]).

Sub Topics:

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

Lead Center: GSFC

Participating Center(s): JPL, LaRC

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

- Develop high-performance processors, memory architectures, and reliable electronic systems.
- Develop tools and technologies that would enable rapid deployment of high-reliability, high-performance onboard processing applications and would interface to external sensors on flight hardware.

The subtopic objective is to elicit novel architectural concepts and component technologies that are realistic and operate effectively and credibly in environments consistent with the future NASA science missions.

However, it is also expected that some commercial non-radiation hardened, higher performance capabilities should also be leveraged to meet performance, fault tolerance and recovery, power management, or other unique requirements.

Successful proposal concepts should significantly advance the state-of-the-art. Proposals should clearly:

- State what the product is.
- Identify the needs it addresses.
- Identify the improvements over the current state-of-the-art.
- Outline the feasibility of the technical and programmatic approach.
- Present how it could be infused into a NASA program.

Furthermore, proposals should indicate an understanding of the intended operating environment, including temperature and radiation. It should be noted that environmental requirements will vary significantly from mission to mission. For example, some low Earth orbit missions have a total ionizing dose (TID) radiation requirement of less than 10 krad(Si), while some planetary missions can have requirements well in excess of 1 Mrad(Si). For descriptions of radiation effects in electronics, the proposer may visit:

(http://radhome.gsfc.nasa.gov/radhome/overview.htm [30]).

If a Phase II proposal is awarded, the combined Phase I and Phase II developments should produce a prototype that can be characterized by NASA.

The technology priorities sought are listed below:

- Novel, ruggedized packaging/Interconnect for high-density packaging (enclosures, printed wiring boards) enabling miniaturization.
- Miniaturization of C&DH subsystem components that enable reduced power computing.
- Innovative approaches for single event effects mitigation technologies leveraging non-RHBD (Radiation Hardened By Design) devices for performance (speed, power, mass) that is capable of exceeding
traditional RHBD devices and/or capabilities that are not yet available with RHBD devices. Area of interest for this year is to focus on processors.

Power Conversion and Distribution relevant to Command, Data Handling, and Electronics, will be covered in sub-topic S3.04 Power Electronics and Management, and Energy Storage.

S3.02 Power Generation and Conversion

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

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

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

Radioisotope Power Conversion

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

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

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

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

- High temperature, high efficiency conversion greater than 10%.
- Long life, minimal degradation.

**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 >300 watts/kilogram, decreased stowed volume, reduced initial and recurring cost, long-term operation in high radiation environments, high power arrays, and a wide range of space environmental operating conditions) are solicited. Technologies specifically addressing the following mission needs are highly sought:

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

Note to Proposer: Topic H8 under the Human Exploration and Operations Mission Directorate also addresses power. Proposals more aligned with very high power or with exploration mission requirements should be proposed in H8.

**S3.03 Propulsion Systems**

**Lead Center:** GRC

**Participating Center(s):** JPL, MSFC

The Science Mission Directorate (SMD) needs spacecraft with more demanding propulsive performance and flexibility for more ambitious missions requiring high duty cycles, more challenging environmental conditions, and extended operation. Planetary spacecraft need the ability to rendezvous with, orbit, and conduct in situ exploration of planets, moons, and other small bodies in the solar system (http://solarsystem.nasa.gov/multimedia/download-detail.cfm?DL_ID=742 [31]). Future spacecraft and constellations of spacecraft will have high-precision propulsion requirements, usually in volume- and power-limited envelopes.

This subtopic seeks innovations to meet SMD propulsion requirements, which are reflected in the goals of NASA's In-Space Propulsion Technology program to reduce the travel time, mass, and cost of SMD spacecraft. Advancements in chemical and electric propulsion systems related to sample return missions to Mars, small bodies (like asteroids, comets, and Near-Earth Objects), outer planet moons, and Venus are desired. Additional electric propulsion technology innovations are also sought to enable low cost systems for Discovery class missions, and eventually to enable radioisotope electric propulsion (REP) type missions. Roadmaps for propulsion technologies can be found from the National Research Council (http://www.nap.edu/openbook.php?record_id=13354&page=168)
The focus of this solicitation is for next generation propulsion systems and components, including chemical rocket technologies, low cost/low mass electric propulsion technologies, and micro-propulsion. Propulsion technologies related specifically to sample return vehicles will be sought under S5.04 Spacecraft Technology for Sample Return Missions. Propulsion technologies related specifically to Power Processing Units will be sought under S3.04 Power Electronics and Management, and Energy Storage.

Chemical Propulsion Systems

Technology needs include:

- Alternative manufacturing processes for low cost production of components of propulsion systems less than 200 lbf class.
- Catalytic and non-catalytic ignition technologies that provide reliable long-life ignition of high-performance (Isp > 240 sec), toxic and nontoxic monopropellants.

Electric Propulsion Systems

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

- 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.
- Any electric propulsion technology under 10 kW/thruster that would either significantly reduce system costs or increase system efficiency over a wide throttling range.

Micro-Propulsion Systems

This subtopic also seeks proposals that address the propulsion for spacecraft

- Low mass and low volume fractions.
- Wide range of ?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.
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.

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.

S3.04 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 that could potentially benefit from these technology developments include S4.01 – Planetary Entry, Descent and Landing Technology. Battery development could also be beneficial to H8.02 – Ultra High Specific Energy Batteries, which is investigating some similar technologies in the secondary battery area but with very different operational requirements. This subtopic is also directly tied to S3.03 – Propulsion Systems for the development of advanced Power Processing Units and associated components.

Power Electronics and Management

The 2009 Heliophysics roadmap (http://sec.gsfc.nasa.gov/2009_Roadmap.pdf [28]), the 2010 SMD Science Plan (http://science.nasa.gov/about-us/science-strategy/ [34]), the 2010 Planetary Decadal Survey White Papers & Roadmap Inputs (http://sites.nationalacademies.org/SSB/CurrentProjects/ssb_052412 [35]), the 2011 PSD Relevant Technologies document, the 2006 Solar System Exploration (SSE) Roadmap (http://nasascience.nasa.gov/about-us/science-strategy [25]), and the 2003 SSE Decadal Survey describe the need for lighter weight, lower power electronics along with radiation hardened, extreme environment electronics for planetary exploration. Radioisotope power systems (RPS) and Power Processing Units (PPUs) for Electric Propulsion (EP) are two programs of interest that would directly benefit from advancements in this technology area. Advances in electrical power technologies are required for the electrical components and systems for these future platforms to address program size, mass, efficiency, capacity, durability, and reliability requirements. In addition, the Outer Planet Assessment Group has called out high power density/high efficiency power electronics as needs for the Titan/Enceladus Flagship and planetary exploration missions. These types of missions, including Mars Sample Return using Hall thrusters and PPUs, require advancements in radiation hardened power electronics and systems beyond the state-of-the-art. Of importance are expected improvements in energy density, speed, efficiency, or wide-temperature operation (-125 °C to over 450 °C) with a number of thermal cycles. Novel approaches to minimizing the weight of advanced PPUs are also of interest. Advancements are sought for power electronic devices, components and packaging for programs with power ranges of a few watts for minimum
missions to up to 20 kilowatts for large missions. In addition to electrical component development, RPS has a need for intelligent, fault-tolerant Power Management And Distribution (PMAD) technologies to efficiently manage the system power for these deep space missions.

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

Overall technologies of interest include:

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

**Energy Storage**

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

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

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

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.

S3.05 Unmanned Aircraft and Sounding Rocket Technologies

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

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

Unmanned Aircraft Systems

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

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

Telemetry, Tracking and Control

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

Avionics and Flight Control
Precise/repeatable flight path control capabilities are needed to enable repeat path observations for Earth monitoring on seasonal and multi-year cycles. In addition, long endurance atmospheric sampling in extreme conditions (hurricanes, volcanic plumes) can provide needed observations that are otherwise not possible at this time:

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

Guided Dropsondes

NASA Earth Science Research activities can benefit from more capable dropsondes than are currently available. Specifically, dropsondes that can effectively be guided through atmospheric regions of interest such as volcanic plumes could enable unprecedented observations of important phenomena. Capabilities of interest include:

- Compatibility with existing dropsonde dispensing systems on NASA/NOAA P-3’s, the NASA Global Hawk, and other unmanned aircraft.
- Guidance schemes, autonomous or active control.
- Cross-range performance and flight path accuracy.
- Operational considerations including airspace utilization and de-confliction.

Novel Platforms and Systems

Innovative fixed wing, rotary wing, or lighter than air platforms and associated systems offering unique capabilities for Earth science research and environmental monitoring are desired. Commercially viable concepts that may have alternative short-term utility for other civil research agencies are in-scope. Systems that are tailored to support new miniaturized instruments for Earth science research, for example those developed under subtopic S1.08 (Airborne Measurement Systems), are encouraged.

Sounding Rockets

The NASA Sounding Rocket Program (NSRP) provides low-cost, sub-orbital access to space in support of space and Earth sciences research and technology development sponsored by NASA and other users by providing...
payload development, launch vehicles, and mission support services. NASA utilizes a variety of vehicle systems comprised of military surplus and commercially available rocket motors, capable of lofting scientific payloads, up to 1300lbs, to altitudes from 100km to 1500km.

NASA launches sounding rocket vehicles worldwide, from both land-based and water-based ranges, based on the science needs to study phenomenon in specific locations.

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

- Autonomous vehicle environmental diagnostics system capable of monitoring flight loading (thermal, acceleration, stress/strain) for solid rocket vehicle systems.
- Location determination systems to provide over-the-horizon position of buoyant payloads to facilitate expedient location and retrieval from the ocean.
- Flotation systems, ranging from tethered flotation devices to self-encapsulation systems, for augmenting buoyancy of sealed payload systems launched from water-based launch ranges.

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 [36]) for mission information. 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 topic should provide measurements of physical forces or properties that support some aspect of EDL operations. NASA also seeks to use measurements made during EDL to better characterize the Martian atmosphere, providing data for improving atmospheric modeling for future landers. Proposals are invited for innovative sensor technologies that improve the reliability of EDL operations.

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

- Providing critical measurements during the entry phase (e.g., pressure and/or temperature sensors embedded into the aeroshell).
- Improving the accuracy on measurements needed for guidance decisions (e.g., surface relative velocities, altitudes, orientation, localization).
- Extending the range over which such measurements are collected (e.g., providing a method of imaging through the aeroshell or terrain-relative navigation that does not require imaging through the aeroshell).
- Enhancing 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
New 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 pressure and temperature (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. Consideration should be given to:

- Innovative "cleaning to sterility" technologies that will be compatible with spacecraft materials and processes.
- Surface cleaning validation methods that can be used routinely to quantify trace amount (~ng/cm²) of organic contamination and submicron particle (~100nm size) contamination.

Priority will be given to the cleaning and sterilization methods that have potential for in-situ applications. Avoiding cross contamination between samples is also a priority. Innovative mechanical or system solutions-e.g., single-use sample "sleeves" or fully integrated sample acquisition and encapsulation systems are also needed to ensure sample integrity.

Innovative component technologies for low-mass, low-power, and modular 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:

- Steep terrain adherence for vertical and horizontal mobility.
- Tether play-out and retrieval systems including tension and length sensing.
- Low-mass tether cables with power and communication.
- Sampling system deployment mechanisms.
- Low mass/power vision systems and processing capabilities that enable faster surface traverse while maintaining safety over a wide range of surface environments.
- Robotics autonomy.
- Modular actuators with 1000:1 scale gear ratios.
- Coring tool for 1cm X 10cm rock and regolith cores.
- 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/cm²) 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:** GRC  
**Participating Center(s):** AFRC, ARC, GSFC, JPL, LaRC, MSFC

NASA plans to perform sample return missions from a variety of targets including Mars, outer planet moons, and small bodies such as asteroids and comets. In terms of spacecraft technology, these types of targets present a variety of challenges. Some targets, such as Mars and some moons, have relatively large gravity wells and will require ascent propulsion. Other targets are small bodies with very complex geography and very little gravity, factors that present difficult navigation 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 mission implementation (e.g., reduce size, mass, power, cost, increase reliability, or increase autonomy). Specific areas of interest are listed below. SMD's In-space Propulsion technology program is a direct customer of this subtopic, and the solicitation is coordinated with the ISPT program each year. The ISPT program views this subtopic as a fertile area for providing possible Phase III efforts. Many of the Planetary Decadal Survey white papers/studies evaluating technologies needed for various planetary, small body, and sample return missions refer to the need for sample return spacecraft technologies.
Small Body Missions:

- Autonomous operation.
- Terrain based navigation.
- Guidance and control technology for landing and touch-and-go.
- Anchoring concepts for asteroids.
- Propulsion technology for proximity or landed operations.
- Low-power, long-life cryogenic sample storage.
- Earth Entry Vehicles for Sample Return 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.

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, and the need to support hundreds of complex application codes - many of which are frequently updated by the user/developer. As a result, solutions that involve the following must clearly explain how they would work in the NASA environment: Grid computing, web services, client-server models, embarrassingly parallel computations, and technologies that require significant application re-engineering. Projects need not benefit all NASA HEC users or application codes, but demonstrating applicability to an important NASA discipline, or even a key NASA application code, could provide significant value.

Specific technology areas of interest:

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

- Novel computational accelerators and architectures.
- 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.

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**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](http://nasascience.nasa.gov/earth-science/applied-sciences) [37]) seeks innovative and unique approaches to increase the utilization and extend the benefit of Earth Science research data to better meet societal needs. One area of interest is new decision support tools and systems for a variety of ecological applications such as managing coastal environments, natural resources or responding to natural disasters.

This subtopic seeks proposals for utilities, plug-ins or enhancements to geobrowsers that improve their utility for Earth science research and decision support. Examples of geobrowsers include Google Earth, Microsoft Virtual Earth, NASA World Wind ([http://worldwindcentral.com/wiki/Main_page](http://worldwindcentral.com/wiki/Main_page) [38]) and COAST ([http://www.coastal.ssc.nasa.gov/coast/COAST.aspx](http://www.coastal.ssc.nasa.gov/coast/COAST.aspx) [39]). Examples include, but are not limited to, the following:

- Visualization of high-resolution imagery in a geobrowser.
- Enhanced geobrowser animation capabilities to provide better visual-analytic displays of time-series and change-detection products.
- Discovery and integration of content from web-enabled sensors.
- Discovery and integration of new datasets based on parameters identified by the user and/or the datasets currently in use.
- Innovative mechanisms for collaboration and data layer sharing.
- Applications that subset, filter, merge, and reformat spatial data.
- Statistical tools and interfaces needed to downscale coarser resolution climate datasets for regional applications
- Rapid delivery of satellite data products and alerts concepts and architectures in case of emergency situation

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

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

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

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

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, and

- 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.

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**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 & validation and operations processes. FM approaches, architectures, and tools are needed to improve early understanding of needed FM capabilities by project managers and FM engineers and to improve the efficiency of implementing and testing FM.

Specific objectives are to:

- Improve ability to predict FM system complexity and estimate development and operations costs.
- Enable cost-effective FM design architectures and operations.
- Determine completeness and appropriateness of FM designs and implementations.
- Decrease the labor and time required to develop and test FM models and algorithms.
- 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 emphasis on compactness, efficiency, reliability, lifetime, and high performance. Innovative lidar subsystem and component technologies systems that directly address the measurements of the atmosphere and surface topography of the Earth, Mars, the Moon, and other planetary bodies will be considered under this subtopic.
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: Laser Interferometer Space Antenna (LISA), Doppler Wind Lidar (3D-WINDS), Ozone Lidar, Lidar for Surface Topography (LIST), Mars atmospheric sensing, Mars and earth re-entry atmospheric entry and descent, Active Sensing of CO₂ Emissions over Nights, Days, and Seasons (ASCENDS), and Aerosols-Clouds-Ecosystems (ACE). In addition, innovative technologies relevant to the NASA sub-orbital programs, such as Unmanned Aircraft Systems (UAS) and Venture-class focusing on the studies of the Earth climate, carbon cycle, weather, and atmospheric composition, are being sought.

The proposals should target components and subsystems development 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 or an aircraft platform. For the PY12 SBIR Program, we are soliciting the component and subsystem technologies described below.

Solid state, single frequency, pulsed, laser transmitter operating in the 1.0 µm - 1.7 µm range with wall-plug efficiency of greater than 25% suitable for CO₂ measurement, interferometry, and free-space laser communication applications. The laser transmitter must be capable of generating frequency transform-limited pulses with a quality beam M² of less than 1.5. We are interested in two different regimes of repetition rate and output energy: in one case, repetition rate from 5 KHz to 20 kHz with pulse energy from 1 - 4 mJ, and in the second case, repetition rate 20 Hz to 2 kHz with pulse energy from 30 - 300 mJ. In addition, development of non-traditional optical amplifier architectures that yield optical efficiency of >70% are of interest. Attention to the compact and rugged designs for possible aircraft flight tests is highly desirable.

Single-frequency solid-state crystal, planar waveguide or fiber amplifiers/lasers operating at 1.5 and 2.0 micron wavelength regimes suitable for direct detection differential absorption lidar (DIAL) and coherent lidar applications. These lasers must meet one of the two general requirements:

- Pulse energy 0.5 mJ to 2 mJ, repetition rate 2 kHz to 10 kHz, and pulse duration of 10 nsec for direct detection lidars.
- 5 mJ to 50 mJ, 20 Hz to 2 kHz, 200 nsec for coherent detection lidars.

2-micron single frequency laser system generating at least 30 mW of power with a precision frequency locking mechanism suitable for measurements of atmospheric CO₂. The laser must be locked to a CO₂ absorption line peak via a fiber gas cell with accuracy better than 200 kHz. The frequency locked laser shall be modulated to generate two preset offset frequencies from the center frequency alternatively, one at 3-4 GHz, and the other at 15-20GHz range. The frequency stability at these off-center frequencies shall be better than 500 KHz.

Pulsed, single frequency, solid state laser operating in the 450-500 nm range serving as a transmitter for an oceanography lidar. The laser must be able to produce bandwidth-limited pulses with 10 nsec or shorter duration. The proposed design must be scalable to at least 10 W of average power, preferably generating100 mJ at 100-200 Hz, but will consider lower pulse energies with higher repletion rates. Pulse energies can be less than the above stated goals by a factor of 10 for the Phase II delivered unit.
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](http://www.nap.edu/catalog/11820.html) [6]). These sensors include low frequency (less than 10) 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:

- **Space qualifiable, High power and efficiency P-band power amplifiers:** Center Frequency: 420-450, Gain: > 40 dB, Efficiency: >80%, Duty Cycle: 10%, Mass
- **Space-qualifiable Single-Board Digital Radar Transceiver in PC-104e form factor.** Frequency bands: 400-500, 1200-1300, with arbitrary waveform generator (100 us pulselength, 30 BW), 2-channel ADC, FPGA, PCIe bus, Size: Approx 9cm x 9.6cm x 3.1cm
- **Cryogenic LNAs for 180 to 270 GHz with noise temperatures of less than 100K.** Earth Science Decadal Survey missions that apply: PATH, GACM and future Earth Venture Class low cost millimeter wave instruments.
- **Receiver technologies for the PATH mission including:** low noise (Local Oscillator technologies for 2nd generation instruments for SOFIA, next generation HIFI, and suborbital instruments (GUSSTO). This can include: GaN based frequency multipliers that can work in the 200-400 GHz range (output frequency) with input powers up to 1 W. Graphene-based (or other suitable technology) devices that can work as frequency multipliers in the frequency range of 1-3 THz.
- **Compact, light-weight array antennas with 50 - 60% bandwidth using electronic frequency hopping and tuning capabilities, dual-polarization, high cross-polarization isolation (> 25 dB) for airborne and spaceborne radar applications**
- **P-, L-, C-, X band MMIC pulsed radar transceivers with dynamic load matching, wideband (> 50) high power efficiency (> 30%), high T/R isolation (> 90 dB)**
- **Large (~5m) deployable parabolic cylindrical antennas, F=35, 94 GHz**
- **G-Band Microwave Components:** For measurement of microphysical properties of clouds and upper atmospheric constituents (particles of less than mm sizes):
  - G-band Noise Source (ENR> 10dB).
  - W-band LO (6 dBm, Freq. Stability 5-10 (-20 C- 40 C) DC Power
  - G-band isolator (Isolation > 15 dB, Insertion Loss
  - G-band switching circulator (Isolation > 15 dB Insertion Loss
  - Integration and packaging G-band receiver for cubesat and microsat platforms.
- **Multi-Frequency and/or multi-Beam Focal Plane Arrays (FPA) as a primary feed for reflector antennas.** In NASA's SCLP mission, it is required to collect Earth science data at high spatial and as well as temporal resolutions simultaneously. In addition to high spatial and temporal resolutions, the proposed antenna system must offer ways to suppress RFI and control antenna illumination. NASA is looking for a small (3 x 3) focal plane array system to be used as a feed for its main reflector. Wideband array element covering 19, and 37 GHz must be used as a basic element of the proposed FPA.

**Sub Topics:**

**Microwave Technologies for Remote Sensing Topic S1.02**

**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](http://www.nap.edu/catalog/11820.html) [6]), planetary science ([http://www.nap.edu/catalog/10432.html](http://www.nap.edu/catalog/10432.html) [7]), and astronomy and astrophysics ([http://www.nap.edu/books/0309070317/html](http://www.nap.edu/books/0309070317/html) [8]).
The following technologies are of interest for the Scanning Microwave Limb Sounder (http://mls.jpl.nasa.gov/index-cameo.php [9]) on the Global Atmospheric Composition Mission and the SOFIA (Stratospheric Observatory for Infrared Astronomy) airborne observatory:

- Radiation tolerant digital polyphase filterbank back ends for sideband separating microwave spectrometers. Requirements are >5GHz instantaneous bandwidth per sideband, 2 MHz resolution, low power.
- Improved submillimeter mixers for frequencies >2 THz are needed for heterodyne receivers to fly on SOFIA. Minimum noise temperatures for cryogenic operation and instantaneous bandwidths >5 GHz are key parameters.
- Efficient, flight qualifiable, spur free, local oscillators for SIS mixers operating in low earth orbit. Two bands:
  - Tunable from 200 to 250 GHz.
  - Tunable from 610 to 650 GHz, phase-locked to or derived from an ultra-stable 5 MHz reference.
- Quantum cascade laser-based local oscillators >2THz for astrophysics applications

Thermal imaging, LANDSAT Thermal InfraRed Sensor (TIRS), Climate Absolute Radiance and Refractivity Observatory (CLARREO), BOREal Ecosystem Atmosphere Study (BOREAS), other infrared earth observing missions, Trojan Tour, Europa Jupiter System Mission (EJSM) such as a descoped Jupiter Europa Orbiter (JEO), Io Observer, or Jupiter Io Callisto Europa (JuICE) missions (see the Jupiter Europa Orbiter Mission Study 2008: Final Report, (http://opfm.jpl.nasa.gov/library/ [10]) and future planetary missions:

- Development of un-cooled or cooled Infrared detectors (hybridized or designed to be hybridized to an appropriate read-out integrated circuit) with NETT30% and dark currents 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 strain layer super-lattices to meet these specifications.
- 2-D arrays of thermopile detectors (wavelength range 20-100 µm; Detectivity = 4x10^9; operating temp 100-200 K).

1kx1k MCT detector arrays with cutoff wavelength extended to =12 µm for use in missions to NEOs, comets and the outer planets.

New or improved technologies leading to measurement of trace atmospheric species (e.g., CO, CH₄, N₂O) from geostationary and low-Earth orbital platforms; see Methane Trace Gas Sounder. Of particular interest are new techniques in gas filter correlation spectroscopy, Fabry-Perot spectroscopy, or improved component technologies. Technologies are needed for active and passive wave front and amplitude control, and relevant missions include Extra solar Planetary Imaging Coronagraph (EPIC), and other coronagraphic missions such as Terrestrial Planet Finder (http://exep.jpl.nasa.gov/TPF-C/tpf-C_index.cfm [11]) and Stellar Imager (http://hires.gsfc.nasa.gov/si/ [12]):

- MEMS based segmented deformable mirrors consisting of arrays of up to 1200 hexagonal packed segments with strokes over the range of 0 to 1.0 microns, quantized with 16-bit electronics with segment level stabilities of 0.015 nm rms (1-bit) over 1 hour intervals. Segments should be flat to 2 nm rms or better and the substrate flat to 125 nm or better and high uniformity of coatings (1% rms).
- 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 0.2 -0.5 mm range, with contrast between neighboring spectra of ~10-4. and uniform focal lengths to
- Spatial Filter Array (SFA) consisting of a monolithic array of up to 1200 coherent, polarization preserving, single mode fibers, or custom waveguides, that operate with minimal coupling losses over a large fraction of the spectral range from 0.4 - 1.0 microns. The SFA should have input and output lenslet with each pair mapped to a single fiber or waveguide and such that the lenslets maintain path length uniformity to
Blazed, holographic optical gratings on convex surfaces: The Offner spectrometer design uses a symmetric optical layout to balance aberrations, producing good imaging performance and spectral images with little or no distortion. Both of these attributes improve the measurement capability of the spectrometer by eliminating the spatial-spectral information mixing that other spectrometer forms typically produce. The key element in an Offner spectrometer is the convex spherical grating that is used to disperse the light spectrally. While such gratings can be made holographically, these gratings suffer from low efficiency due to their lack of signal-enhancing blazed groove structure. Development is needed for production of holographically-generated convex gratings that have a continuously-varying blaze angle to provide high efficiency diffraction into a chosen wavelength range and diffraction order (415 nm to 695 nm in first order and 290 nm to 390 nm in the second order). Such gratings also should have less scattered light than similar mechanically-ruled gratings, improving spectrometer performance.

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](http://www.nasa.gov/missions) [13].

Specific technology areas are listed below:

- 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
- Large format UV and X-ray focal plane detector arrays: micro-channel plates, CCDs, and active pixel sensors (>50% QE, 100 Megapixels).
- Advanced Charged Couple Device (CCD) detectors, including improvements in UV quantum efficiency and read noise, to increase the limiting sensitivity in long exposures and improved radiation tolerance. Electron-bombarded CCD and CMOS detectors, including improvements in efficiency, resolution, and global and local count rate capability. In the X-ray, we seek to extend the response to lower energies in some CCDs, and to higher, perhaps up to 50 keV, in others. Possible missions are future GOES missions and International X-ray Observatory.
- Wide band gap semiconductor, radiation hard, visible and solar blind large format imagers for next generation hyperspectral Earth remote sensing experiments. Need larger formats (>1Kx1K), much higher resolution (}
- Solar blind, compact, low-noise, radiation hard, EUV and soft X-ray detectors are required. Both single pixels (up to 1cm x 1cm) and large format 1D and 2D arrays are required to span the 0.05nm to 150nm spectral wavelength range. Future missions include GOES post R and T.
- Visible-blind SiC Avalanche Photodiodes (APDs) for EUV photon counting are required. The APDs must show a linear mode gain >1E6 at a breakdown reverse voltage between 80 and 100V. The APD's must demonstrate detection capability of better than 6 photons/pixel/s down to 135nm wavelength. See needs of National Research Council's Earth Science Decadal Survey (NRC, 2007): Tropospheric ozone.
- Large format 1D (1 x 2k) and 2D (2k x 2k) SiC arrays (operating temp 170-300K; D* = 3x1015) including Schottky diodes, PINs and ADPs for instruments on future outer planets missions.
- 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 (~106), low noise, fast time response (2. Focal plane mass must be minimized (2g/cm² goal). Individual pixel readout is required. The entire focal plane detector can be formed from smaller, individual sub-arrays.
- Large area (3 m²) photon counting near-UV detectors with 3 mm pixels and able to count at 10 MHz. Array with high active area fraction (>85%), 0.5 Megapixels and readout less than 1 mW/channel. Future instruments are JEM-EUSO and OWL.
- Large area (m²) X-ray detectors with 85%). Future instrument is a Phased-Fresnel X-ray Imager.
- Improve beyond CdZnTe detectors using micro-calorimeter arrays at hard X-ray, low gamma-ray bands (above 10 keV and Below 80 keV),
- Technologies to improve spatial resolution for the hard X-ray band to 10 and ultimately to 5 arc-second resolution.
- High-density, low-temperature electrical interfaces: In microcalorimeter and cryogenic IR detector assemblies, the large number of electrical connections required on the low-temperature stage (below 4 Kelvin) requires high-density, miniaturized cryogenic connectors. NASA needs suitable nano-miniature connectors that can connect to superconducting wires (Nb or Al) deposited on a high density flex cable. The metal traces will likely be layered into a stripline configuration to minimize cross-talk, leading to pads onto which the connector is attached. This type of flex cable has extremely low thermal conductivity. A modular connector, easily integrated into or removed from the superconducting flex cable, is sought.

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 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.
• Cooled (-60 ºC) solid-state ion detector capable of operating at a floating potential of -15 kV relative to ground.
• Low-noise magnetic materials for advanced magnetometer sensors with performance equal to or better than those in the 6-81.3 Mo-Permalloy family.
• Radiation-hardened ASICs including 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).
• Low-power, charge-sensitive preamplifiers on a chip.
• High efficiency (5% or greater) conversion surfaces for low-energy neutral atom conversion to ions possibly based on nanotechnology.
• Miniature low-power, high-efficiency, thermonic cathodes, capable of 1-mA electron emission per 100-mW heater power with emission surface area of 1-mm² and expected lifetime of 20,000 hours.
• Long wire boom (? 50 m) deployment systems for the deployment of very lightweight tethers or antennae on spinning spacecraft.
• Systems to determine the orthogonality of a deployed electric/magnetic field boom system in flight (for use with three-axis rigid 10-m booms) accurate to 0.10° dynamic.
• Die-level optical interferometer, micro-sized, for measuring Fabry-Perot plate spacing with 0.1-nm accuracy.
• Diffractive optics (photon sieves) of 0.1-m aperture or larger with micron-sized outer Fresnel zones for high-resolution EUV imaging.
• Avalanche Photodiode Detectors (APDs), in single pixel and multi-pixel form, to make a breakthrough in particle detection by taking advantage of their inherent gain compared to the unity gain SSDs. 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.
• Developing near real-time data-assimilative models and tools, for both solar quiet and active times, which allow for precise specification and forecasts of the space environment, beginning with solar eruptions and propagation, and including ionospheric electron density specification.

Sub Topics:
Cryogenic Systems for Sensors and Detectors Topic S1.06
Cryogenic cooling systems often serve as enabling technologies for detectors and sensors flown on scientific instruments as well as advanced telescopes and observatories. As such, technological improvements to cryogenic systems (as well as components) further advance the mission goals of NASA through enabling performance (and ultimately science gathering) capabilities of flight detectors and sensors. Presently, there are six potential investment areas that NASA is seeking to expand state of the art capabilities in for possible use on future programs such as GEOID, SPICA, WFirst (http://wfirst.gsfc.nasa.gov/ [17]), Spirit, Specs (http://nmdb.gsfc.nasa.gov/geons [18]) and the Europa Science missions (http://www.nasa.gov/multimedia/podcasting/pl-europa20090218.html [19]). The topic areas are as follows:

• Extremely Low Vibration Cooling Systems - Examples of such systems include pulse tube coolers and turbo brayton cycles. Desired cooling capabilities sought are on the order of 20 mW at 4K or 1W at 50K. Present state of the art capabilities display
• Advanced Magnetic Cooler Components - An example of an advanced magnetic cooler might be Adiabatic Demagnetization Refrigeration systems. Specific components sought include:
  ○ Low current superconducting magnets.
  ○ Active/Passive magnetic shielding (3-4 Tesla magnets).
  ○ Superconducting leads (10K - 90K) capable of 10 amp operation with 1 mW conduction.
  ○ 10 mK scale thermometry.
• Continuous Flow Distributed Cooling Systems - Distributed cooling provides increased lifetime of cryogen fluids for applications on both the ground and spaceborne platforms. This has impacts on payload mass and volume for flight systems which translate into costs (either on the ground, during launch or in flight). Cooling systems that provide continuous distributed flow are a cost effective alternative to present
techniques/methodologies. Cooling systems that can be used with large loads and/or deployable structures are presently being sought after.

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

- **Highly Efficient Magnetic and Dilution Cooling Technologies** - The desired temperature range for proposed systems is

- **Low Temperature/Input Power Cooling Systems** - Cooling systems providing cooling capacities approximately 0.3W at 35K with heat rejection capability to temperature sinks upwards of 150K are of interest. Presently there are no cooling systems operating at this heat rejection temperature. Input powers should be limited to no greater than 20W. Study of passive cooler in tandem with low power, low mass cryocooler satisfying the above mentioned requirements is also of interest.

Sub Topics:

In Situ Sensors and Sensor Systems for Lunar and Planetary Science Topic S1.07

This subtopic solicits development of advanced instrument technologies and components suitable for deployment on planetary and lunar missions. These technologies must be capable of withstanding operation in space and planetary environments, including the expected pressures, radiation levels, launch and impact stresses, and range of survival and operational temperatures. Technologies that reduce mass, power, volume, and data rates for instruments and instrument components without loss of scientific capability are of particular importance. In addition, technologies that can increase instrument resolution and sensitivity or achieve new & innovative scientific measurements are solicited. For example missions, see [http://science.hq.nasa.gov/missions](http://science.hq.nasa.gov/missions) [20]. 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/](http://solarsystem.nasa.gov/2013decadal/) [21]. 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.

- **Saturn, Uranus and Neptune** - Technologies are sought for components, sample acquisition and instrument systems that can enhance mission science return and withstand the low-temperatures/high-pressures of the atmospheric probes during entry.

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

Proposers are strongly encouraged to relate their proposed development to:

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

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

Proposers should show an understanding of relevant space science needs, and present a feasible plan to fully develop a technology and infuse it into a NASA program.
Sub Topics:
Airborne Measurement Systems Topic S1.08
A focus is on miniaturization and increased sensitivity/performance needed to support for NASA's airborne science missions. Linkage to other subtopics such as S3.05 Unmanned Aircraft and Sounding Rocket Technologies is encouraged. Complete instrument systems are desired, including features such as remote/unattended operation and data acquisition, low power consumption, and minimum size and weight.

Relevance to future space missions such as Active Sensing of CO₂ 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), 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 (multiphase).
- Surface snow thickness (5 cm resolution is desired), and potentially, snow density.
- Aerosols and cloud particles.
- Volcanic ash and gases.
- Gases: Reactive and tracers of source emissions. Examples include (but are not limited to) carbon dioxide, carbon monoxide, methane, water vapor.
- High quality three-dimensional wind instruments suitable for gas flux measurements, as well as advanced temperature and pressure systems.

Sub Topics:
Surface & Sub-surface Measurement Systems Topic S1.09
For ground-based surface vehicles, and submerged systems. Systems that are ultimately intended for flight or mobile platforms that will provide near-term benefit in a ground-based application are in scope, as this step will aid in maturation of new concepts.

Relevance to future space missions such as Active Sensing of CO₂ 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), 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., stabilized disdrometer).
- Particles: mineral, biogenic, nutrients.
- Gases – carbon dioxide, methane, etc.
- Air and water quality.
- Water and ice flow rates.
- Seismic monitoring.
- Autonomous sample collection and/or analysis systems.
- Air-dropped sensors for 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.

Oceanic, coastal, and fresh water measurements including inherent and apparent optical properties for calibration and validation of satellite ocean color radiometric data, temperature, salinity, currents, in situ biogeochemical and chemical particle composition, sediments, and biological or ecological properties of aquatic environments including but not limited to nutrients, phytoplankton and their functional groups, harmful algal blooms, fish or aquatic plants and animals.

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 a Earth science role are also encouraged.

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

- Advanced aperture apodization and aperture shaping techniques.
- Advanced apodization mask or occulting spot fabrication technology controlling smooth density gradients to 10-4 with spatial resolutions ~1 µm, low dispersion, and low dependence of phase on optical density, in linear and circular patterns.
- Metrology for detailed evaluation of compact, deep density apodizing masks, Lyot stops, and other types of graded and binary mask elements. Development of a system to measure spatial optical density, phase inhomogeneity, scattering, spectral dispersion, thermal variations, and to otherwise estimate the accuracy of masks and stops is needed.
- Interferometric starlight cancellation instruments and techniques to include aperture synthesis and single input beam combination strategies.
• Pupil remapping technologies to achieve beam apodization.

• Techniques to characterize highly aspheric optics.

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

• Methods of polarization control and polarization apodization.

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

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

**Wavefront Control Technologies**

• Development of small stroke, high precision, deformable mirrors and associated driving electronics scalable to 104 or more actuators (both to further the state-of-the-art towards flight-like hardware and to explore novel concepts). Multiple deformable mirror technologies in various phases of development and processes are encouraged to ultimately improve the state-of-the-art in deformable mirror technology. Process improvements are needed to improve repeatability, yield, and performance precision of current devices.

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

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

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

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

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

• Development of techniques to improve the wavefront stability of the telescope beam, and/or to mitigate the residual instability. These include but are not limited to: the development of low order wavefront sensors, improved pointing techniques, as well as model-based software algorithms that predict and subtract the instabilities in post-processing.

**Optical Coating and Measurement Technologies**

• Instruments capable of measuring polarization cross-talk and birefringence to parts per million.

• Highly reflecting broadband coatings for large (> 1 m diameter) optics.

• Polarization-insensitive coatings for large optics.
Other

- Artificial star and planet, point sources, with $1 \times 10^{10}$ 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.

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

Sub Topics:

**Precision Deployable Optical Structures and Metrology Topic S2.02**

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 optomechanical control. Large deployable multi-layer structures in support of sunshades for passive thermal control and 20m to 50m class planet finding external occulters are also relevant technologies. Potential architecture implementations must package into an existing launch volume, deploy and be self-aligning to the micron level. The target space environment is expected to be the Earth-Sun L2.

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

- Precision deployable structures and metrology for optical telescopes (e.g., innovative active or passive deployable primary or secondary support structures).

- Architectures, packaging and deployment designs for large sunshields and external occulters.

In particular, important subsystem considerations may include:

- Innovative concepts for packaging fully integrated subsystems (e.g., power distribution, sensing, and control components).

- Mechanical, inflatable, or other precision deployable technologies.
- Thermally-stable materials (CTE)
- Innovative systems, which minimize complexity, mass, power and cost.
- Innovative testing and verification methodologies.

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

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

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

Sub Topics:
Advanced Optical Component Systems Topic S2.03
This 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.
- Large aperture diffusers (up to 1 meter) to calibrate GeoStationary Earth viewing sensors.

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
- 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, effecting 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

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

**Technical Challenges**

In all cases, the most important metric for an advanced optical system is affordability or areal cost (cost per square meter of collecting aperture). Currently both X-ray and normal incidence space mirrors cost $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/m².

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 to 5 m² collecting area.
- Multilayer high-reflectance coatings for hard X-ray mirrors (similar to NuSTAR).
- X-ray transmission and/or reflection gratings.
Multiple technologies are needed to enable

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

Successful proposals will demonstrate an ability to manufacture, test and control a prototype X-ray mirror assembly in the 0.25 to 0.5 meter class; or to coat a 0.25 to 0.5 meter class representative optical component. An ideal Phase I deliverable would deliver a sub-scale component such as a 0.25 meter X-ray precision mirror. 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. Both deliverables would be accompanied by all necessary documentation, including the optical performance assessment and all data on processing and properties of its substrate materials. The Phase II would also include a mechanical and thermal stability analysis.

Optical Components, Coatings and Systems for potential UV/Optical missions

Potential UV/Optical missions require:

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

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

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 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.

Large aperture diffusers (up to 1 meter) to calibrate GeoStationary Earth viewing sensors

The geosynchronous orbit for GEO-CAPE coastal ecosystem imager requires technology for alternative periodic solar calibration strategies including new materials to reduce weight, and new optical analysis to reduce the size of calibration systems. GEO-CAPE will need a light-weight large aperture (greater than 0.5 m) diffuse solar calibrator, employing multiple diffusers to track on-orbit degradation. Typical materials of interest are PTFE (such as Spectralon® surface diffuser) or development of new Mie scattering materials for use as volume diffusers in transmission or reflection. Material needs to be stable in BTDF/BSDF to 2%/year from 250 to 2500 nm and highly lambertian (no formal specification for deviation from lambertian).

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:


Optical systems currently being researched for these missions are large area aspheres, requiring accurate figuring and polishing across six orders of magnitude in period. Technologies are sought that will enhance the figure quality of optics in any range as long as the process does not introduce artifacts in other ranges. For example, mm-period polishing should not introduce waviness errors at the 20 mm or 0.05 mm periods in the power spectral density. Also, novel metrological solutions that can measure figure errors over a large fraction of the PSD range are sought, especially techniques and instrumentation that can perform measurements while the optic is mounted to the figuring/polishing machine. Large lightweight monolithic metallic aspheres manufactured using innovative mirror substrate materials that can be assembled and welded together from smaller segments are sought. Also, optical system design and tolerancing requires software analysis tools capable of accurately ray tracing a broader range of materials and effects than are currently treated with conventional optical software. Updated software algorithms code is a technology of interest.

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 ° in azimuth and 200 mm axial length and cone angles vary from 0.1 to 1 °.

- Low stress metrology mounts that can hold very thin optics without introducing mounting distortion.

- Low normal force figuring/polishing systems operating in the 1 mm to 50 mm period range with minimal impact at significantly smaller and larger period ranges.

- In-situ metrology systems that can measure optics and provide feedback to figuring/polishing instruments without removing the part from the spindle.

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

- Extreme aspheric and/or anamorphic optics for pupil intensity amplitude apodization.

- Metrology systems useful for measuring large optics with high precision.

- Innovative method of bonding extremely lightweight (less than 1 kg/m² 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.

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

Sub Topics:
Command, Data Handling, and Electronics Topic S3.01
NASA's space-based observatories, fly-by spacecraft, orbiters, landers, and robotic and sample return missions require robust command and control capabilities. Advances in technologies relevant to command and data handling and instrument electronics are sought to support NASA’s goals and several missions and projects under development.
The subtopic goals are to:

- Develop high-performance processors, memory architectures, and reliable electronic systems.
- Develop tools and technologies that would enable rapid deployment of high-reliability, high-performance onboard processing applications and would interface to external sensors on flight hardware.

The subtopic objective is to elicit novel architectural concepts and component technologies that are realistic and operate effectively and credibly in environments consistent with the future NASA science missions.

However, it is also expected that some commercial non-radiation hardened, higher performance capabilities should also be leveraged to meet performance, fault tolerance and recovery, power management, or other unique requirements.

Successful proposal concepts should significantly advance the state-of-the-art. Proposals should clearly:

- State what the product is.
- Identify the needs it addresses.
- Identify the improvements over the current state-of-the-art.
- Outline the feasibility of the technical and programmatic approach.
- Present how it could be infused into a NASA program.

Furthermore, proposals should indicate an understanding of the intended operating environment, including temperature and radiation. It should be noted that environmental requirements will vary significantly from mission to mission. For example, some low Earth orbit missions have a total ionizing dose (TID) radiation requirement of less than 10 krad(Si), while some planetary missions can have requirements well in excess of 1 Mrad(Si). For descriptions of radiation effects in electronics, the proposer may visit:

(http://radhome.gsfc.nasa.gov/radhome/overview.htm [30]).

If a Phase II proposal is awarded, the combined Phase I and Phase II developments should produce a prototype that can be characterized by NASA.

The technology priorities sought are listed below:

- Novel, ruggedized packaging/Interconnect for high-density packaging (enclosures, printed wiring boards) enabling miniaturization.
- Miniaturization of C&DH subsystem components that enable reduced power computing.
- Innovative approaches for single event effects mitigation technologies leveraging non-RHBD (Radiation
Hardened By Design) devices for performance (speed, power, mass) that is capable of exceeding traditional RHBD devices and/or capabilities that are not yet available with RHBD devices. Area of interest for this year is to focus on processors.

Power Conversion and Distribution relevant to Command, Data Handling, and Electronics, will be covered in sub-topic S3.04 Power Electronics and Management, and Energy Storage.

Sub Topics:
- Power Generation and Conversion Topic S3.02

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:

- High temperature, high efficiency conversion greater than 10%.
- Long life, minimal degradation.

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 >300 watts/kilogram, decreased stowed volume, reduced initial and recurring cost, long-term operation in high radiation environments, high power arrays, and a wide range of space environmental operating conditions) are solicited. Technologies specifically addressing the following mission needs are highly sought:

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

Note to Proposer: Topic H8 under the Human Exploration and Operations Mission Directorate also addresses power. Proposals more aligned with very high power or with exploration mission requirements should be proposed in H8.

Sub Topics:

Propulsion Systems Topic S3.03

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 [31]). Future spacecraft and constellations of spacecraft will have high-precision propulsion requirements, usually in volume- and power-limited envelopes.

This subtopic seeks innovations to meet SMD propulsion requirements, which are reflected in the goals of NASA's In-Space Propulsion Technology program to reduce the travel time, mass, and cost of SMD spacecraft. Advancements in chemical and electric propulsion systems related to sample return missions to Mars, small bodies (like asteroids, comets, and Near-Earth Objects), outer planet moons, and Venus are desired. Additional electric propulsion technology innovations are also sought to enable low cost systems for Discovery class missions, and eventually to enable radioisotope electric propulsion (REP) type missions. Roadmaps for propulsion technologies can be found from the National Research Council (http://www.nap.edu/openbook.php?record_id=13354&page=168 [32]) and NASA's Office of the Chief Technologist (http://www.nasa.gov/pdf/501329main_TA02-InSpaceProp-DRAFT-Nov2010-A.pdf [33]).

The focus of this solicitation is for next generation propulsion systems and components, including chemical rocket technologies, low cost/low mass electric propulsion technologies, and micro-propulsion. Propulsion technologies related specifically to sample return vehicles will be sought under S5.04 Spacecraft Technology for Sample Return Missions. Propulsion technologies related specifically to Power Processing Units will be sought under S3.04 Power Electronics and Management, and Energy Storage
Chemical Propulsion Systems

Technology needs include:

- Alternative manufacturing processes for low cost production of components of propulsion systems less than 200 lbf class.
- Catalytic and non-catalytic ignition technologies that provide reliable long-life ignition of high-performance (Isp > 240 sec), toxic and nontoxic monopropellants.

Electric Propulsion Systems

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

- 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.
- Any electric propulsion technology under 10 kW/thruster that would either significantly reduce system costs or increase system efficiency over a wide throttling range.

Micro-Propulsion Systems

This subtopic also seeks proposals that address the propulsion for spacecraft

- Low mass and low volume fractions.
- Wide range of ?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.

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.

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 S3.04

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 that could potentially benefit from these technology developments include S4.01 – Planetary Entry, Descent and Landing Technology. Battery development could also be beneficial to H8.02 – Ultra High Specific Energy Batteries, which is investigating some similar technologies in the secondary battery area but with very different operational requirements. This subtopic is also directly tied to S3.03 – Propulsion Systems for the development of advanced Power Processing Units and associated components.

Power Electronics and Management

The 2009 Heliophysics roadmap (http://sec.gsfc.nasa.gov/2009_Roadmap.pdf [28]), the 2010 SMD Science Plan (http://science.nasa.gov/about-us/science-strategy/ [34]), the 2010 Planetary Decadal Survey White Papers & Roadmap Inputs (http://sites.nationalacademies.org/SSB/CurrentProjects/ssb_052412 [35]), the 2011 PSD Relevant Technologies document, the 2006 Solar System Exploration (SSE) Roadmap (http://nasascience.nasa.gov/about-us/science-strategy [25]), and the 2003 SSE Decadal Survey describe the need for lighter weight, lower power electronics along with radiation hardened, extreme environment electronics for planetary exploration. Radioisotope power systems (RPS) and Power Processing Units (PPUs) for Electric Propulsion (EP) are two programs of interest that would directly benefit from advancements in this technology area. Advances in electrical power technologies are required for the electrical components and systems for these future platforms to address program size, mass, efficiency, capacity, durability, and reliability requirements. In addition, the Outer Planet Assessment Group has called out high power density/high efficiency power electronics as needs for the Titan/Enceladus Flagship and planetary exploration missions. These types of missions, including Mars Sample Return using Hall thrusters and PPUs, require advancements in radiation hardened power electronics and systems beyond the state-of-the-art. Of importance are expected improvements in energy density, speed, efficiency, or wide-temperature operation (-125 °C to over 450 °C) with a number of thermal cycles. Novel approaches to minimizing the weight of advanced PPUs are also of interest. Advancements are sought for power electronic devices, components and packaging for programs with power ranges of a few watts for minimum missions to up to 20 kilowatts for large missions. In addition to electrical component development, RPS has a need for intelligent, fault-tolerant Power Management And Distribution (PMAD) technologies to efficiently manage the system power for these deep space missions.

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

Overall technologies of interest include:
High voltage, radiation hardened, high temperature components.
High power density/high efficiency power electronics.
High temperature devices and components/power converters (up to 450 °C).
Intelligent, fault-tolerant electrical components and PMAD systems.
Advanced electronic packaging for thermal control and electromagnetic shielding.

Energy Storage

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

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

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

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:
Unmanned Aircraft and Sounding Rocket Technologies Topic S3.05
All proposals should show an understanding of one or more relevant science needs, and present a feasible plan to
fully develop a technology and infuse it into a NASA program.

**Unmanned Aircraft Systems**

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

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

**Telemetry, Tracking and Control**

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

**Avionics and Flight Control**

Precise/repeatable flight path control capabilities are needed to enable repeat path observations for Earth monitoring on seasonal and multi-year cycles. In addition, long endurance atmospheric sampling in extreme conditions (hurricanes, volcanic plumes) can provide needed observations that are otherwise not possible at this time:

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

**UA Integrated Vehicle Health Management**

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

NASA Earth Science Research activities can benefit from more capable dropsondes than are currently available. Specifically, dropsondes that can effectively be guided through atmospheric regions of interest such as volcanic plumes could enable unprecedented observations of important phenomena. Capabilities of interest include:

- Compatibility with existing dropsonde dispensing systems on NASA/NOAA P-3’s, the NASA Global Hawk, and other unmanned aircraft.
- Guidance schemes, autonomous or active control.
- Cross-range performance and flight path accuracy.
- Operational considerations including airspace utilization and de-confliction.

Novel Platforms and Systems

Innovative fixed wing, rotary wing, or lighter than air platforms and associated systems offering unique capabilities for Earth science research and environmental monitoring are desired. Commercially viable concepts that may have alternative short-term utility for other civil research agencies are in-scope. Systems that are tailored to support new miniaturized instruments for Earth science research, for example those developed under subtopic S1.08 (Airborne Measurement Systems), are encouraged.

Sounding Rockets

The NASA Sounding Rocket Program (NSRP) provides low-cost, sub-orbital access to space in support of space and Earth sciences research and technology development sponsored by NASA and other users by providing payload development, launch vehicles, and mission support services. NASA utilizes a variety of vehicle systems comprised of military surplus and commercially available rocket motors, capable of lofting scientific payloads, up to 1300lbs, to altitudes from 100km to 1500km.

NASA launches sounding rocket vehicles worldwide, from both land-based and water-based ranges, based on the science needs to study phenomenon in specific locations.

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

- Autonomous vehicle environmental diagnostics system capable of monitoring flight loading (thermal, acceleration, stress/strain) for solid rocket vehicle systems.
- Location determination systems to provide over-the-horizon position of buoyant payloads to facilitate expedient location and retrieval from the ocean.
- Flotation systems, ranging from tethered flotation devices to self-encapsulation systems, for augmenting
buoyancy of sealed payload systems launched from water-based launch ranges.

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 topic should provide measurements of physical forces or properties that support some aspect of EDL operations. NASA also seeks to use measurements made during EDL to better characterize the Martian atmosphere, providing data for improving atmospheric modeling for future landers. Proposals are invited for innovative sensor technologies that improve the reliability of EDL operations.

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

- Providing critical measurements during the entry phase (e.g., pressure and/or temperature sensors embedded into the aeroshell).
- Improving the accuracy on measurements needed for guidance decisions (e.g., surface relative velocities, altitudes, orientation, localization).
- Extending the range over which such measurements are collected (e.g., providing a method of imaging through the aeroshell or terrain-relative navigation that does not require imaging through the aeroshell).
- Enhancing 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.
Robotic Mobility, Manipulation and Sampling Topic S4.02

New 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 pressure and temperature (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. Consideration should be given to:

- Innovative "cleaning to sterility" technologies that will be compatible with spacecraft materials and processes.
- Surface cleaning validation methods that can be used routinely to quantify trace amount (~ng/cm²) of organic contamination and submicron particle (~100nm size) contamination.

Priority will be given to the cleaning and sterilization methods that have potential for in-situ applications. Avoiding cross contamination between samples is also a priority. Innovative mechanical or system solutions-e.g., single-use sample “sleeves” or fully integrated sample acquisition and encapsulation systems are also needed to ensure sample integrity.
Innovative component technologies for low-mass, low-power, and modular 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:

- Steep terrain adherence for vertical and horizontal mobility.
- Tether play-out and retrieval systems including tension and length sensing.
- Low-mass tether cables with power and communication.
- Sampling system deployment mechanisms.
- Low mass/power vision systems and processing capabilities that enable faster surface traverse while maintaining safety over a wide range of surface environments.
- Robotics autonomy.
- Modular actuators with 1000:1 scale gear ratios.
- Coring tool for 1cm X 10cm rock and regolith cores.
- 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/cm²) 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 targets including Mars, outer planet moons, and small bodies such as asteroids and comets. In terms of spacecraft technology, these types of targets present a variety challenges. Some targets, such as Mars and some moons, have relatively large gravity wells and will require ascent propulsion. Other targets are small bodies with very complex geography and very little gravity, factors that present difficult navigation 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 mission implementation (e.g., reduce size, mass, power, cost, increase reliability, or increase autonomy). Specific areas of interest are listed below. SMD's In-space Propulsion technology program is a direct customer of this subtopic, and the solicitation is coordinated with the ISPT program each year. The ISPT program views this subtopic as a fertile area for providing possible Phase III efforts. Many of the Planetary Decadal Survey white papers/studies evaluating technologies needed for various planetary, small body, and sample return missions refer to the need for sample return spacecraft technologies.

Small Body Missions:
- Autonomous operation.
- Terrain based navigation.
- Guidance and control technology for landing and touch-and-go.
- Anchoring concepts for asteroids.
- Propulsion technology for proximity or landed operations.
- Low-power, long-life cryogenic sample storage.
- Earth Entry Vehicles for Sample Return 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.

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, and the need to support hundreds of complex application codes - many of which are frequently updated by the user/developer. As a result, solutions that involve the following must clearly explain how they would work in the NASA environment: Grid computing, web services, client-server models, embarrassingly parallel computations, and technologies that require significant application re-engineering. Projects need not benefit all NASA HEC users or application codes, but demonstrating applicability to an important NASA discipline, or even a key NASA application code, could provide significant value.

Specific technology areas of interest:

- **Efficient Computing**: In spite of the rapidly increasing capability and efficiency of supercomputers, NASA’s HEC facilities cannot purchase, power, and cool sufficient HEC resources to satisfy all user demands. This subtopic element seeks dramatically more efficient and effective supercomputing approaches in terms of their ability to supply increased HEC capability or capacity per dollar and/or per Watt for real NASA applications. Examples include:
  - Novel computational accelerators and architectures.
  - 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](http://nasascience.nasa.gov/earth-science/applied-sciences) [37]) seeks innovative and unique approaches to increase the utilization and extend the benefit of Earth Science research data to better meet societal needs. One area of interest is new decision support tools and systems for a variety of ecological applications such as managing coastal environments, natural resources or responding to natural disasters.

This subtopic seeks proposals for utilities, plug-ins or enhancements to geobrowsers that improve their utility for Earth science research and decision support. Examples of geobrowsers include Google Earth, Microsoft Virtual Earth, NASA World Wind ([http://worldwindcentral.com/wiki/Main_page](http://worldwindcentral.com/wiki/Main_page) [38]) and COAST ([http://www.coastal.ssc.nasa.gov/coast/COAST.aspx](http://www.coastal.ssc.nasa.gov/coast/COAST.aspx) [39]). Examples include, but are not limited to, the following:

- Visualization of high-resolution imagery in a geobrowser.
- Enhanced geobrowser animation capabilities to provide better visual-analytic displays of time-series and change-detection products.
- Discovery and integration of content from web-enabled sensors.
- Discovery and integration of new datasets based on parameters identified by the user and/or the datasets currently in use.
- Innovative mechanisms for collaboration and data layer sharing.
- Applications that subset, filter, merge, and reformat spatial data.
- Statistical tools and interfaces needed to downscale coarser resolution climate datasets for regional applications
- Rapid delivery of satellite data products and alerts concepts and architectures in case of emergency situation

This subtopic also seeks proposals for advanced information systems and decision environments that take full advantage of multiple data sources and platforms. Special consideration will be given to proposals that provide enhancements to existing, broadly used decision support tools or platforms. Tailored and timely products delivered to a broad range of users are needed to address air quality, public health and agriculture mapping and food security issues. Additional areas of interest will be to protect vital ecosystems such as coastal marshes, barrier islands and seagrass beds; monitor and manage utilization of critical resources such as water and energy; provide quick and effective response to manmade and natural disasters such as oil spills, earthquakes, hurricanes, floods and wildfires; and promote sustainable, resilient communities and urban environments.
Proposals shall present a feasible plan to fully develop and apply the subject technology.

Sub Topics:
Algorithms and Tools for Science Data Processing, Discovery and Analysis, in State-of-the-Art Data Environments
Topic 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, and

• 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 it 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 well as 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 & validation and operations processes. FM approaches, architectures, and tools are needed to improve early understanding of needed FM capabilities by project managers and FM engineers and to improve the efficiency of implementing and testing FM.

Specific objectives are to:

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