NASA SBIR 2007 Phase I Solicitation

Science

Sensors, Detectors, and Instruments Topic S1

NASA’s Science Mission Directorate (SMD) encompasses research in the areas of Astrophysics, Earth Science, Heliophysics, and Planetary Science. 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, large format 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, 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 which can be deployed on surface landers, rovers, and airborne platforms. Consequently, the 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. The following subtopics are concomitant with this objective and are organized by technology.

Sub Topics:

S1.01 Lidar System Components

Lead Center: LaRC
Participating Center(s): GSFC

Accurate measurements of atmospheric parameters with high spatial resolution from ground, airborne, and space-based platforms require advances in the state-of-the-art lidar technology with emphasis on compactness, efficiency, reliability, lifetime, and high performance. Innovative lidar component technologies that directly address the measurements of the atmosphere and surface topography of the Earth, Mars, the Moon, and other planetary bodies will be considered under this subtopic. Innovative technologies that can expand current measurement capabilities to spaceborne or Unmanned Aerial Vehicle (UAV) platforms are particularly desirable. Development of components that can be used in planned missions such as Laser Interferometer Space Antenna (LISA) or Earth and planetary composition is highly encouraged. Research should be conducted to demonstrate technical feasibility during Phase 1 and show a path toward a Phase 2 prototype demonstration. For the PY07 SBIR, we are soliciting only the specific component technologies described below.
• Flight qualified, radiation hardened fiber optic components for high power fiber amplifier packages at 1064 nm. Pulse energies in the hundreds of microJoules, and even milliJoule-level, are needed.

• Fiber optic components specifically for use with Yb-doped photonic crystal fibers (PCF), to permit removal of any bulk optics or air gaps in fiber amplifier systems that use a PCF amplifier stage. The following specific components are needed: standard multimode or singlemode fiber to PCF connections, pump couplers for 915 nm or 980 nm, high power isolators at 1064 nm, 1064 nm filters, fiber combiners, and fiber splitters.

• Development of polarization maintaining Er and/or Yb doped optical fibers that are optimized for suppression of stimulated Brillouin scattering (SBS). Resulting fiber must be capable of single frequency.

• Gravitational wave detection in space uses laser interferometric techniques to measure picometer distance changes over megameter baselines. The application requires a space-qualifiable high reliability frequency-stabilized CW laser source with 1 W output power and a 5 year mission lifetime. A Master Oscillator Power Amplifier (MOPA) configuration is desirable because the source must be phase-modulated.

• Efficient and compact single frequency solid state or fiber lasers operating at 1.5 and 2.0 micron wavelength regimes suitable for coherent lidar applications. These lasers must meet the following general requirements: pulse energy 0.2 mJ to 100 mJ, repetition rate 10 Hz to 1 kHz, and pulse duration of approximately 200 nsec.

• Single frequency semiconductor or fiber laser generating 10s of mW of CW power in 1.5 or 2.0 micron wavelength regions with less than 100 kHz linewidth. Frequency modulation with about 5 GHz bandwidth and wavelength tuning over several nanometers are desirable.

• Interferometer technology to separately derive aerosol and molecular backscatter via High Spectral Resolution Lidar (HSRL) technique at 532 and 355 nm. Resolving power of the order of 1 GHz over an acceptance angle up to several milliradians is required. High quantum efficiency detectors, such as electron multiplying CCDs, suitable for spaceborne HSRL instruments are also needed. Detectors should be capable of rapid sampling rates greater than 1.5 MHz at 532 and 355 nm operating wavelengths.

---

**S1.02 Active Microwave Technologies**

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

NASA employs active sensors (Radars) for a wide range of remote sensing applications. These sensors include low frequency (less than 10 MHz) sounders to W-band radars for measuring precipitation and clouds. We are seeking proposals for the development of innovative technologies to support future radar missions. Technology innovations should either enhance measurement capabilities (e.g., improve spatial, temporal, or spectral resolution) or ease implementation in spaceborne missions (e.g., reduce size, weight, power, improve reliability, or lower cost). The areas of interest for this call are listed below.
For L- and P-band radar components for surface deformation, topography and soil moisture measurements:

- Lightweight deployable L-band antenna structures and deployment mechanisms suitable for large aperture (reflectors or phased array of 50m² and larger) systems.
- Compact (probably sub-optimal), P-band antennas (possibly folded-dipole arrays, etc.) for airborne and spaceborne systems.
- Rad-hard, high-efficiency, low-cost, lightweight L- and P-band Transmit/Receive (TR) modules (~250 W peak RF output power at ~100 us pulsewidth and 20% duty cycle) with respective energy storage unit to provide pulsed DC power to the power amplifier while minimizing ripple on the primary DC power source.
- 12-bit, 1 GSps, 500MHz analog bandwidth ADCs and digital filtering with an emphasis on rad-tolerance and space-qualification.
- Implementation of radar transmitters/receivers using digital signal synthesis.

For Ku- and Ka-band radars for snow cover measurement (Ku) and wetland, river, ocean surface monitoring (Ka) and precipitation radars (X to W-band):

- Lightweight deployable reflectors (Ku-band and Ka-band) and active feed electronics.
- High efficiency Ka-band (34-36GHz) TR modules with output power of 5-10W. The LNAs should have a NF less than 3dB and gain better than 30dB. Included in the TR module is a low loss phase shifter.
- Power amplifier and associated LNA for a Ka-band (34-36GHz) radar system with a peak output power of 2KW to 10KW (duty cycle of 10%) and system bandwidth of up to 1 GHz and LNA NF of less than 1.5dB. The LNA needs to have enough isolation and power handling capability to operate in this high power transmission environment.
- Wide-bandwidth (~500 MHz BW), high-efficiency, rad-tolerant linear FM (chirp) signal generators (sweep rates ~500 MHz in 10 us).
- High performance, low power, compact, rad-hard, real-time radar processors, FPGA based digital receivers, SAR data processing algorithms and data reduction techniques.

**S1.03 Passive Microwave Technologies**

**Lead Center:** GSFC

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

NASA employs passive microwave and millimeter-wave instruments for a wide range of remote sensing applications from measurements of the Earth's surface and atmosphere to cosmic background emission. Proposals are sought for the development of innovative technology to support future science and exploration missions employing 450 MHz to 5 THz sensors. Technology innovations should either enhance measurement capabilities (e.g., improve spatial, temporal, or spectral resolution or improve calibration accuracy) or ease implementation in
spaceborne missions (e.g., reduce size, weight, or power, improve reliability, or lower cost). While other concepts will be entertained, specific technology innovations of interest are listed below for missions to measure soil moisture, temperature sounding, cloud particles, and cosmic microwave background.

- Low power >200 Mb/s 1-bit A/D converters and cross-correlators for microwave interferometers;
- Automated assembly of 180 GHz direct conversion I-Q receiver modules;
- Low power, tunable, local oscillators from 400 to 600 GHz with 4-5 mW output power;
- Low noise (3), heterodyne mixers requiring low local oscillator drive power;
- Low DC power spectrometers covering 500 MHz with 125 kHz resolution;
- Highly stable variable correlated noise sources for calibrating correlation-type receivers;
- MMIC Low Noise Amplifiers (LNA). Room temperature LNAs for 165 to 193 GHz with low 1/f noise, and a noise figure of 6.0 dB or better; and cryogenic LNAs for 180 to 270 GHz with noise temperatures of less than 150K;
- High emissivity (near-black-body, >40 dB return loss) surfaces/structures for use as onboard calibration targets that will reduce the weight of aluminum core targets, while reliably improving the uniformity and knowledge of the calibration target temperature;
- New approaches, concepts, and techniques for microwave radiometer system calibration over or within the 1-700 GHz frequency band which provide end-to-end calibration to better than 0.1K, including corrections for temperature changes, standing waves, linearity, and other potential sources of instrumental measurement drift and error;
- RF (GHz to THz) MEMS switches with low insertion loss (18 dB), capable of switching with speeds of >100 Hz at cryogenic temperatures (below 10 K) for 108 or more cycles;
- Lightweight deployable L-band antenna structures and deployment mechanisms suitable for large aperture (reflectors or phased array of 50m² and larger) systems;
- Dual-polarization multi-frequency micropatch array antenna designs for combinations of frequencies in the C-, X-, or K-bands.

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

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

Advances in detectors, readout electronics, and other technologies enabling polarimetry and large format imaging arrays for the visible, near IR, IR and far IR/submm and spectroscopy with unprecedented sensitivity are sought. These advances may enable future mission concepts such as the Single Aperture Far Infrared (SAFIR) Observatory (http://safir.jpl.nasa.gov/technologies.shtml [1]), Space Infrared Telescope for Cosmology and
Research should be conducted to demonstrate technical feasibility during Phase 1 and show a path toward a Phase 2 prototype demonstration. Innovations are sought in detector capability for the following wavelength ranges:

- 0.1-1 µm: Increased sensitivity and larger array size. Improved silicon response in the UV and NIR, smart pixel arrays, solar blind response detector arrays, energy resolving calorimeter arrays.
- 1-4 µm: Increased sensitivity and larger array size. Large format cryogenic readout multiplexers, large format (>1000x1000) array hybridization techniques.
- 4-40 µm: Increased sensitivity and larger array size (megapixels). Low power cryogenic multiplexers, new sensor materials (e.g., novel dopants for extrinsic Si detectors).
- 40-200 µm: Increased sensitivity and larger array size (megapixels). Monolithic focal plane arrays (BIB technologies, new sensor materials).
- 200 µm - 1 mm: Noise equivalent power (NEP) of $10^{-20}$ W Hz$^{-1/2}$ in a 1,000 pixel spectroscopic array with low-power readout electronics, and NEP $10^{-18}$ W Hz$^{-1/2}$ in a 10,000 pixel photometric imaging array. Capabilities for photon counting, polarimetry, and energy resolving detection. Heterodyne receiver arrays operating near the quantum limit.

In addition to technologies specific to the astrophysics mission concepts above, NASA is seeking technologies and improvements to technologies leading to successful measurement of carbon monoxide, methane, nitrous oxide and other related trace species from geostationary and low-Earth orbital platforms. Of particular interest are new techniques in gas filter correlation spectroscopy, Fabry-Perot spectroscopy, or better component technologies for these. The following technologies are also of interest for the Scanning Microwave Limb Sounder Earth science instrument concept (http://mls.jpl.nasa.gov/index-cameo.php[4]):

- Efficient, flight qualifiable, spur free, local oscillators for SIS mixers operating in low Earth orbit. Two bands: (1) tunable from 200 to 250 GHz, and (2) tunable from 610 to 650 GHz. Phase-locked to or derived from ultra-stable 5 MHz reference.
- Technologies for calibrating millimeter wave spectrometers for spaceborne missions, including:
  - Low power, flight qualifiable comb generators for gain, linearity, and sideband calibration of microwave spectrometers covering the bands from 180 to 270 GHz and from 600 to 660 GHz;
  - Flight qualifiable low noise diodes for the bands from 180 to 270 and 600 to 660 GHz;
- Very low return loss (70 dB or better) calibration targets;
- Techniques for quantifying and calibrating out the impact of standing waves in broadband heterodyne submillimeter spectrometers.
- Low power, stable, linear, spectrometers covering the band from 6-18 GHz with 100 MHz resolution.

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

Lead Center: GSFC
Participating Center(s): MSFC

This subtopic covers detector requirements for a broad range of wavelengths from UV through to gamma ray. As would be expected requirements across the board are for greater numbers of readout pixels, lower power, faster readout rates, greater quantum efficiency, and enhanced energy resolution. Typical semiconductor devices in this energy range are based on silicon or germanium. However, proposals for other detector materials are welcomed if a compelling case is made.

Proposals are specifically solicited for improvements in microchannel plate technology for UV focal plane use; for CCD and active pixel sensor development, both for UV and x-ray use; for technologies leading to very-large-area x-ray detectors for survey instruments; and for electronic systems capable of meeting the needs of Mega-to-Giga-channel detectors. The latter can include not just device development but also, for example, novel interconnect schemes enabling efficient packaging to aid in thermal control and to reduce system noise.

The proposed efforts must be directly linked to a requirement for a NASA mission. These include Explorers, Discovery, Origins, Beyond Einstein and Vision Missions. Details of these can be found at the following URL: http://science.hq.nasa.gov/missions/index.html [5].

Specific technologies are listed below. Highly desirable are developments that satisfy multiple requested parameters:

- Large-format focal plane detectors for use in UV and X-ray imaging and spectrometry:
  - Microchannel-plate UV detectors: up to 109 readout channels; quantum efficiency up to 50%;
- UV-sensitive CCD and active pixel sensors with large formats: to 6k x 6k abuttable; extended UV response below 0.2 nm;

- X-ray-sensitive CCD and active pixel sensors: up to 4k x 4k formats, 4-side abuttable; power levels of 0.1 W / Megapixel; resolutions less than 120 eV; readout rates of at least 30 Hz; extended x-ray response above 6 keV.

- Very-large-area X-ray detectors for survey instruments: square-meter area capability; response from 3-30 keV; ultra-low power (10 microW/channel).

- Significant improvements in wide band gap materials, individual detectors, and detector arrays for UV and EUV applications. Specific examples include AlGaN and SiC based detector arrays and associated readout systems.

- Mega-to-Giga-Channel analogue electronic systems for very-large-area X- and gamma-ray detectors as follows: up to 108 channel capability; less than 10 microW/channel power requirement; less than 100 electron rms noise level with interconnects.

S1.06 Particles and Field Sensors and Instrument Enabling Technologies

Lead Center: GSFC

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 Sentinels, GEC, MAGCON, ITSP 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 / sqrtHz, Max, max sensor unit size: 6 x 6 x 12 cm, max sensor mass: 0.6 kg, max electronics unit size: 8 x 13 x 5 cm, max electronics mass: 1 kg, and max power: 5 W operation, 0.5 W standby, including, but not limited to “sensors on a chip”.

- High-magnetic-field sensor that measures magnetic field magnitudes to 16 Gauss with an accuracy of 1 part 105.

- Strong, lightweight, thin, compactly-stowed electric field booms possibly using composite materials that deploy sensors to distances of 10m or more.

- Cooled (-60°C) solid state ion detector capable of operating at a floating potential of -15 kV relative to
Low noise magnetic materials for advanced magnetometer sensors with performance equal to or better than those in the 6-81.3 Mo-Permalloy family.

Radiation hardened ASIC spectrum analyzer module that determines mass spectra using fast algorithm deconvolution to produce ion counts for specific ion species.

Low cost, low power, high voltage power supplies 5-15 kV.

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.

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 field boom system in flight (for use with three-axis rigid 10-m booms) accurate to 0.1 degrees dynamic.

---

**S1.07 Cryogenic Systems for Sensors and Detectors**

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

Cryogenic cooling systems are often enabling technologies for cutting edge science from infrared imaging and spectroscopy to x-ray calorimetry. Improvements in cryogenic technologies enable further scientific advancement at lower cost, lower risk, reduced volume, and/or reduced mass. Lifetime, reliability, and power requirements of the cryogenic systems are critical performance concerns. Of interest are cryogenic technologies for cooling detectors for scientific instruments and sensors on advanced telescopes and observatories as well as on instruments for lunar and planetary exploration. Active coolers should have long life, low vibration, low mass, low cost, and high efficiency. Specific areas of interest include:

- Essentially vibration-free cooling systems such as reverse Brayton cycle cooler technologies with cooling capability of 20 mW at 4K.

- Highly efficient magnetic and dilution cooling technologies under 1 Kelvin.

- Components for advanced magnetic coolers (adiabatic demagnetization refrigerators) including:
  - Small (few cm bore), lightweight, low current (under 10A, goal under 5A) superconducting magnets capable of producing at least 3 Tesla central field while operating at least 10 Kelvin. Higher temperature superconductor (HTS) magnets operating at significantly higher temperatures are of particular interest.
Lightweight (relative to standard ferromagnetic flux guides) active and/or passive magnetic shielding for 3 to 4 Tesla magnets that reduces the stray field to tens of microTesla at a distance of several cm from the outside of the shield.

Large (several cm) single crystals of magnetocaloric materials.

Superconducting current leads operating between 90 Kelvin down to 10 Kelvin, capable of carrying up to 10 amperes while allowing only approximately 1 mW of heat to be conducted.

Compact, accurate, easy to use thermometers that operate down to 10 milliKelvin.

S1.08 in situ Airborne, Surface, and Submersible Instruments for Earth Science

Lead Center: GSFC

Participating Center(s): ARC, JPL, MSFC

There are new platform systems that have the potential to benefit Earth science research activities. To capitalize on these emerging capabilities, proposals are sought for the development of in situ instruments for use on radiosondes, dropsondes, tethered balloons, kites, Unmanned Aerial Vehicles (UAVs), Unmanned Surface Vehicles (USVs), or Unmanned Underwater Vehicles (UUVs). Both miniaturization of current techniques, as well as innovative new methods that lead to compact and lightweight systems are important. Details of complete instrument systems are desired, including data acquisition, power, and platform integration. Instrument performance goals such as resolution, accuracy, and response time should be discussed. A plan for commercial production and marketing should be included as well. Technology innovation areas of interest include:

- Atmospheric measurements including temperature, humidity, solar radiation, clouds, liquid water, ice, precipitation, chemical composition (carbon dioxide, methane, reactive gases and radicals, dynamical tracer species), and aerosol properties;

- Three-dimensional wind measurements near the Earth’s surface, and within the troposphere and lower stratosphere;

- Oceanic measurements including inherent and apparent optical properties, temperature, salinity, chemical composition, nutrient distribution, and currents.

The calibration/validation of the Orbiting Carbon Observatory (OCO - 2008) is a target application. Science campaigns to be conducted within the Sub-Orbital Science Program are also a high priority – the Tropical Composition, Cloud and Climate Coupling (TC4) is such an example: [http://www.espo.nasa.gov/tc4/] [6], as is the Arctic Research of the Composition of the Troposphere from Aircraft and Satellites (ARCTAS): [http://www.espo.nasa.gov/arctas/] [7]. Systems to enable field studies aimed to research fundamental processes are also of interest.
S1.09 In Situ Sensors and Sensor Systems for Planetary Science

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

The adaptation of current standard laboratory techniques for deployment on planetary missions is a focus. Proposers are strongly encouraged to relate their proposed technology development to future planetary exploration goals. These goals include geochemical, geophysical and astrobiological objectives.

Instruments for in situ investigations are required for NASA’s planned and potential solar system exploration missions. Instruments are required for the characterization of the atmosphere, surface and subsurface regions of planets, satellites, and small bodies. These instruments may be deployed for in situ measurements on surface landers and rovers, and airborne platforms. These instruments must be capable of withstanding operation in space and planetary environmental extremes, which include temperature, pressure, radiation, and impact stresses.

This subtopic seeks advances in instruments and critical components in the following areas:

- X-Ray Diffraction and X-Ray Fluorescence (XRD/XRF) instruments, with capabilities beyond those currently planned for the CHEMIN instrument on the Mars Science Laboratory (MSL - 2009), with a focus on elemental and mineralogical analysis in the Venus surface environment (90 bars CO$_2$, 450ºC).
- Scanning electron microscopy with chemical analysis capability.
- Mass spectrometry/Gas chromatography with improved capabilities over the SAM instrument on MSL or applicability to in situ atmospheric measurements on Venus or Titan.
- Geochronology, with a focus on isotopic dating of planetary surfaces in the 100 Ma to 4.5 Ga timeframe with better than 10% accuracy.
- Gamma-Ray Spectroscopy, with a focus in short duration (X-Ray Photoelectron Spectroscopy (XPS) and Auger Electron Spectroscopy (AES))

Astrobiology includes the study of the origin, evolution, and distribution of life in the universe. New technologies are required to enable the search for extant or extinct life elsewhere in the solar system, to obtain an organic history of planetary bodies, to discover and explore water sources elsewhere in the solar system, and to detect microorganisms and biologically important molecular structures within complex chemical mixtures.
Astrobiology solicits new measurement concepts, advances in existing instrument concepts, and advances in critical components in the following areas:

- Instrumentation focused on assessments of the identification and characterization of biomarkers of extinct or extant life, such as prebiotic molecules, complex organic molecules, biomolecules, or biominerals. At this time we are not soliciting DNA and RNA analysis techniques.

- High sensitivity (femtomole or better) characterization of molecular structure, chirality, and isotopic composition of biogenic elements (H, C, N, O, S) embodied within individual compounds and structures.

In addition, enabling instrument component and support technologies for the above, such as miniaturized pumps, sample inlet systems, valves, integrated bulk sample handling and processing systems, and fluidic technologies for sample preparation, are also solicited. These must be presented in the context of a complete instrument system.

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 nano-technology, and wavefront sensing and control are needed to build telescope for Earth science that have the potential to cost between $50 to $150M.

Sub Topics:
S2.01 Precision Spacecraft Formations for Telescope Systems

Lead Center: JPL
Participating Center(s): GSFC

This subtopic seeks hardware and software technologies necessary to establish, maintain, and operate precision spacecraft formations to a level that enables cost effective large aperture and separated spacecraft optical telescopes and interferometers. Also sought are technologies (analysis, algorithms, and testbeds) to enable detailed analysis, synthesis, modeling, and visualization of such distributed systems.

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

Innovations are solicited for: (a) development of nanometer to sub-nanometer metrology for measuring inter-spacecraft range and/or bearing for space telescopes and interferometers (b) development of combined cm-to-nanometer-level precision formation flying control of numerous spacecraft and their optics to enable large baseline, sparse aperture UV/optical and X-ray telescopes and interferometers for ultra-high angular resolution imagery. Proposals addressing staged-control experiments which combine coarse formation control with fine-level wavefront sensing based control are encouraged.

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

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

S2.02 Proximity Glare Suppression for Astronomical Coronagraphy

Lead Center: JPL

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

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

Starlight Suppression Technologies

• Advanced starlight canceling coronagraphic instrument concepts;
• Advanced aperture apodization and aperture shaping techniques;
• Pupil plane masks for interferometry;
• Advanced apodization mask or occulting spot fabrication technology controlling smooth density gradients to 10-4 with spatial resolutions ~1 μm, low dispersion, and low dependence of phase on optical density;
• Metrology for detailed evaluation of compact, deep density apodizing masks, Lyot stops, and other types of graded and binary mask elements. Development of a system to measure spatial optical density, phase in homogeneity, scattering, spectral dispersion, thermal variations, and to otherwise estimate the accuracy of
masks and stops is needed;

- Interferometric starlight cancellation instruments and techniques to include aperture synthesis and single input beam combination strategies;
- Single mode fiber filtering from visible to 20 µm wavelength;
- Methods of polarization control and polarization apodization; and
- Components and methods to insure amplitude uniformity in both coronagraphs and interferometers, specifically materials, processes, and metrology to insure coating uniformity.

Wavefront Control Technologies

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

S2.03 Precision Deployable Optical Structures and Metrology

Lead Center: JPL
Participating Center(s): GSFC

Planned future NASA Missions in astrophysics, such as the Single Aperture Far-IR (SAFIR) telescope, Life Finder, and Submillimeter Probe of the Evolution of Cosmic Structure (SPECs), and the UV Optical Imager (UVOIR) require 10 - 30 m class cost effective telescopes that are diffraction limited at wavelengths from the visible to the far IR, and operate at temperatures from 4 - 300 K. The desired areal density is 1 - 10 kg/m². Static and dynamic wavefront error tolerances may be achieved through passive means (e.g., via a high stiffness system) or through active control. Potential architecture implementations must package into an existing launch volume, deploy and be self-aligning to the micron level. The target space environment is expected to be L2.
This topic solicits proposals to develop enabling, cost effective component and subsystem technology for these telescopes. Research areas of particular interest include precision deployable structures and metrology (i.e., innovative active or passive deployable primary or secondary support structures); innovative concepts for packaging fully integrated (i.e., including power distribution, sensing, and control components); distributed and localized actuation systems; deployment packaging and mechanisms; active control distributed on or within the structure (downstream corrective and adaptive optics are not included in this topic area); actuator systems for alignment of reflector panels (order of cm stroke actuators, lightweight, submicron dynamic range, nanometer stability); mechanical, inflatable, or other deployable technologies; new thermally-stable materials (CTE

Also of interest are innovative metrology systems for direct measurement of the optical elements or their supporting structure; requirements for micron level absolute and subnanometer relative metrology for tens of points on the primary mirror; measurement of the metering truss; and innovative systems which minimize complexity, mass, power and cost.

The goal for this effort is to mature technologies that can be used to fabricate 20 m class, lightweight, ambient or cryogenic flight-qualified telescope primary mirror systems. Proposals to fabricate demonstration components and subsystems with direct scalability to flight systems (concept described in the proposal) will be given preference. The target launch volume and expected disturbances, along with the estimate of system performance, should be included in the discussion. A successful proposal shows a path toward a Phase 2 delivery of demonstration hardware on the scale of 3 m for characterization.

S2.04 Optical Devices for Starlight Detection and Wavefront Analysis

Lead Center: MSFC

Participating Center(s): GSFC, JPL

This subtopic solicits technology for collecting and controlling star light with advanced optical telescopes and telescope arrays. This topic includes innovative optical subsystems, devices and components that directly collect and process optical signals and images for all regions of the electromagnetic spectrum from X-ray to UV to Visible to Far-IR/Sub-MM. Pre-detection technologies of interest include capabilities to preprocess or analyze an optical wave front or signal to extract time-dependent, spectral, polarization and spatial information from scenes or signals prior to detection. Specific technology area of interest include high reflectance UV coatings and uniform polarization coatings for all wavelengths; high angular resolution imaging enabled via large-baseline segmented-aperture telescopes and sparse aperture telescopes/interferometers; component-level technology needed to enable the characterization and combination of wavefronts from multiple apertures. Innovative technology to integrate, assemble, align and control test large aperture segmented mirrors for x-ray, ambient and cryogenic applications.

Proposed effort should be conducted to demonstrate technical feasibility during Phase 1 and show a path toward a Phase 2 breadboard or prototype demonstration.

Proposals in the following areas are specifically solicited:

- **Optical coatings**: broad-band polarization preserving and polarizing for UV to Far-IR/Sub-MM; high-reflectivity EUV; large area, high acceptance angle narrow-band optical filters; broad-band wide-acceptance angle UV anti-reflection on PMMA substrates; environmentally stable protected silver.

- **High throughput, radiation hard, large area, X-ray imaging devices** such as Fresnel Zone plates and masks.

- **Innovative mounting/support and metrology/control technologies** to integrate, assemble, align and control large aperture lightweight low-cost segmented mirrors for x-ray, ambient and cryogenic normal incidence applications - also, systems with extreme alignment tolerances such as PIAA.

- **Techniques to mitigate optical surface errors** includes phase retrieval and wavefront sensing and control techniques and instrumentation, optical systems with high-precision controls, active and/or adaptive mirrors, shape control of deformable telescope mirrors, and image stabilization systems; techniques to sense/control segmented primary mirrors.

- **Techniques to combine beams** for wavelength-resolved fringe measurements from a large number of independent apertures with flat response over a broad wavelength range.

---

S2.05 Optics Manufacturing and Metrology for Telescope Optical Surfaces
Lead Center: GSFC
Participating Center(s): JPL, MSFC
This year’s 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, but are not limited to, Constellation-X (http://constellation.gsfc.nasa.gov/ [8]), TPF (http://planetquest.jpl.nasa.gov/TPF/tpf_index.cfm [9]), and SAFIR (http://safir.jpl.nasa.gov/technologies.shtml [1]). Optical systems currently being researched for these missions are large area aspheres, requiring accurate figuring and polishing across six orders of magnitude in period (i.e., 1st and 2nd order errors through micro-roughness). 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 (i.e., 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.

By the end of a Phase 2 program, technologies must be developed to the point where the technique or instrument can dovetail into an existing optics manufacturing facility producing optics at the R&D stage. Metrology instruments must have 10 nm or better surface height resolution and span at least 3 orders of magnitude in lateral spatial frequency.

Examples of technologies and instruments of interest include:

- Interferometric nulling optics for very shallow conical optics used in x-ray telescopes (segmented systems commonly span 60 degrees in azimuth and 200 mm axial length and cone angles vary from 0.1 to 1 degree);
- Low stress metrology mounts that can hold very thin optics without introducing mounting distortion;
- Low normal force figuring/polishing systems operating in the 1 mm to 50 mm period range with minimal impact at significantly smaller and larger period ranges;
- In situ metrology systems that can measure optics and provide feedback to figuring/polishing instruments without removing the part from the spindle;
- Innovative mirror substrate materials or manufacturing methods that produce thin mirror substrates that are stiffer and/or lighter than existing materials or methods;
- Extreme aspheric and/or anamorphic optics for pupil intensity amplitude apodization (PIAA).
The Science Mission Directorate will carry out the scientific exploration of our Earth, the planets, moons, comets, and asteroids of our Solar System and beyond; chart the best route of discovery; and reap the benefits of Earth and space exploration for society. A major objective of the NASA science spacecraft systems development programs is to implement science measurement capabilities using small, affordable spacecraft enabling a single spacecraft to meet multiple mission requirements thus making the best use of our limited resources. To accomplish this objective, NASA is fostering innovations in propulsion, power, and guidance and navigation systems that significantly reduce the mass and cost while maximizing the scientific return for future NASA missions. Innovations are sought in the areas of power generation, energy storage, guidance, navigation, command/control, on-board propulsion (electric propulsion, advanced chemical and propellantless propulsion), on-board power management and distribution (power electronics and packaging), and thermal control technologies for spacecraft, piloted and unpiloted aircraft, balloons, drop sondes, and sounding rockets used for NASA Science Missions.

Sub Topics:

S3.01 Avionics and Electronics

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

NASA’s space based observatories, fly by spacecraft, orbiters, landers, and robotic and sample return missions, require robust Command and Control capabilities. Advances in technologies relevant to guidance, navigation, command and data handling are sought to support NASA’s goals and several missions and projects under development, including the New World Observer, GEO Quick Ride and Radiation Hardened Electronics for Space Environments (RHESE).

The subtopic goals are to: (1) develop high-performance processors and memory architectures and reliable electronic systems and (2) develop precision line-of-sight sensing for large telescopes and spacecraft formations. 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 vision of the Science Mission Directorate (SMD).

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

Command and Data Handling

- Processors - General purpose (processor chips and radiation-hardened by design synthesizable IP cores) and special purpose single-chip components (DSPs and FPGAs) with sustainable processing performance (>500 MIPS), power efficiency (>100 MIPS/W) and radiation tolerance, including the tools to support the software flow.
Radiation hardened: low power memories and Ethernet physical layer components.

Models for analysis of interplanetary radiation and radiation belts, and technologies enabling in-flight total dose and single event radiation measurements.

**Guidance Navigation and Control**

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

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

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

**S3.02 Thermal Control Systems**

*Lead Center: GSFC*

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

Future Spacecraft and instruments for NASA’s Science Mission Directorate will require increasingly sophisticated thermal control technology. Research should be conducted to demonstrate technical feasibility during Phase 1 and show a path toward a Phase 2 demonstration, and when possible, deliver a demonstration unit for functional and environmental testing at the completion of the Phase 2 contract. Innovative proposals for thermal control technologies are sought in the following areas:

- Optical systems, lasers, and detectors require tight temperature control, often to better than +/- 1°C. Some new missions such as CON-X and LISA require thermal gradients held to micro-degree levels. Methods of precise temperature measurement and control to this level are needed.

- Heat flux levels from lasers and other high power devices are increasing, with some projected to go as high as 100 W/cm², especially for proposed wind/Lidar missions. They will require thermal technologies such as spray and jet impingement cooling. Also, high conductivity, vacuum-compatible interface materials will be needed to minimize losses across make/break interfaces.

- Future missions such as TPF will use large structures, like mirrors and detector arrays, at both ambient and cryogenic temperatures. Some anticipated technology needs include: advanced thermoelectric coolers capable of providing cooling at ambient and cryogenic temperatures, high conductivity materials to minimize temperature gradients and provide high efficiency light-weight radiators, and advanced thermal control coatings such as variable emittance surfaces and coatings with a high emissivity at ambient and cryogenic
temperatures.

- Future advanced spacecraft present engineering challenges requiring systems which are more self-sufficient.

Some of the technology needs are:

- Single and two-phase mechanically pumped fluid loop systems which accommodate multiple heat sources and sinks, and long life, lightweight pumps for these systems;
- Efficient, lightweight vapor compression systems for cooling up to 2 KW;
- Advanced thermal modeling techniques that can be easily integrated into existing codes, emphasizing inclusion of two-phase system and mechanically pumped system models;
- Integration of standardized formats into existing codes for the representation and exchange of Thermal Network Models and Thermal Geometric Models and results.

### S3.03 Power Generation and Storage

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

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

### Advanced Photovoltaic Energy Conversion

- Photovoltaic cell and array technologies with significant improvements in efficiency (>30%), mass specific power (>600W/kg), stowed volume, cost, radiation resistance, and wide operating conditions are solicited;
- Photovoltaic cell technologies for low intensity, low-temperature operation (LILT) are solicited;
- Array technologies of interest are concentrators, deployable arrays, ultra-lightweight arrays for flexible, thin-film cells, and electrostatically-clean solar arrays.
Stirling Power Conversion

Novel methods or approaches for radiation-tolerant, sensorless, autonomous control of the Stirling converters with very low vibration and having low mass, size, and electromagnetic interference (EMI). Technologies of interest include:

- High-temperature, high-performance regenerators;
- High-temperature, lightweight, high-efficiency, low EMI, linear alternators;
- High-temperature heater heads (> 850°C) and joining techniques.

Energy Storage

Energy storage requirements for Science mission are: >10,000 charge/discharge cycles for LEO spacecraft, as low as 40K low-temperature storage/operation for planetary missions, and high mass specific power for small spacecraft. Energy storage technologies that enable one or more of the above requirements are of interest. Technologies of interest include:

- Fuel cells;
- Batteries including structural batteries;
- Integrated power systems (generation/storage/control integrated into one module).

Power Management and Distribution

Advanced electrical power technologies are required for the electrical components and systems on future platforms to address the size, mass, efficiency, capacity, durability, and reliability requirements. In addition to the above requirements, proposals must address the expected improvements in energy density, speed, efficiency, or wide-temperature operation (-125°C to 200°C) with a high number of thermal cycles. Advancements are sought in power electronic devices, components, and packaging. Technologies of interest include:

- Power electronic components and subsystems;
- Power distribution;
- Fault protection;
- Advanced electronic packaging for thermal control and electromagnetic shielding.
S3.04 Propulsion Systems

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

The Science Mission Directorate (SMD) needs spacecraft with ever-increasing propulsive performance and flexibility for ambitious missions requiring high duty cycles and years of operation. Planetary spacecraft need the ability to rendezvous with, orbit, and conduct in situ exploration of planets, satellites and other solar system bodies. Platforms, satellites, and satellite constellations have high-precision propulsion requirements, usually in volume- and power-limited envelopes. This subtopic seeks innovations to meet SMD propulsion requirements, reflecting the goals of NASA’s In-Space Propulsion Technology program to reduce the travel time, mass, and cost of SMD spacecraft. Propulsion areas include chemical and electric propulsion systems, propulsion technologies related to sample return missions to asteroids, comets, and other small bodies, propellantless options (such as aerocapture and solar sails), and less developed but emerging propulsion concepts such as advanced plasma thrusters and momentum exchange/electrodynamic reboost (MXER) tethers.

Specifically, innovations are sought in the following areas:

- Characterization of high strength fibers and compatible resins for composite overwrapped pressure vessels (COPVs) for use in higher-pressure, in-space propulsion systems. Of particular interest are fiber/resin systems exhibiting high uniformity of mechanical properties and high resistance to debonding.

- Improved capability and reduced cost of low- to medium-power electric propulsion systems, including power processing, long-life, high-efficiency cathodes and neutralizers, low-erosion materials for ion optics and Hall discharge chambers, plume mitigation, and next generation thrusters.

- Thin film materials, elastomeric materials, and/or high temperature fabrics for inflatable decelerator concepts used in aerocapture applications at planetary destinations. The decelerator will be stowed for many years (up to 10 years) in an uncontrolled space environment (-130°C). The inflatable decelerator will experience temperatures up to 500°C during the aerocapture maneuver. Materials of particular interest include polyimide thin films, polybenzobisoxazole (PBO) thin films, and ceramic fabrics.

S3.05 Terrestrial Balloon Technology

Lead Center: GSFC
Participating Center(s): JPL

The Balloon Program Office (BPO) is soliciting innovations in two specific areas:
Currently, the Balloon Program Office is developing an Ultra Long Duration Balloon (ULDB) vehicle targeting 100 day duration missions in mid-latitude. This added capability will greatly enable new science investigations. The design of the current pumpkin shape vehicle utilizes light weight polyethylene film and high strength tendons made of twisted Zylon® yarn. The in-flight performance and health of the vehicle relies on accurate information on a number of environmental and design parameters. Therefore, NASA is seeking innovations in the following specific areas:

Tendons are the load carrying member in the pumpkin design. During a typical mission, loading on individual tendons should not exceed a critical design limit to insure structural integrity and survival. A key technology challenge is the development of devices or methods to accurately and continuously measure individual axial loading on an array of up to 200 separate tendons during a ULDB mission. Tendons are typically captured at the fitting via individual pins. Loading levels on the tendons can range from ~20 N to ~8,000 N and temperature can vary from room temperature to the troposphere temperatures of -90ºC or colder. The devices of interest shall be easily integrated with the tendons or fittings during balloon fabrication and shall have minimal impact on the overall mass of the balloon system.

Ambient air, helium gas, and balloon film temperature measurements are needed to accurately model the balloon performance during a typical flight at altitudes of approximately 120,000 feet. The measurement must compensate for the effects of direct solar radiation through shielding or calculation. Minimal mass and volume are highly desired. For film measurement, a non-invasive and non-contact approach is highly desired for the thin polyethylene film, with film thickness ranging from 0.8 to 1.5 mils, used as the balloon envelope.

The Balloon Program Office is also seeking innovations to reduce the effects of parachute opening shock on gondolas and balloon subsystems. This shock is produced by the rapid opening of a flight system's parachute after the payload is released from the balloon at mission termination.

Innovations may address the problem either by reducing the termination shock via modifications to the recovery system or by attenuating the shock produced by current recovery systems. Proposed technologies will be evaluated for their mass efficiency, ease of integration, effectiveness at reducing shock levels, compatibility with balloon flight environments, and cost effectiveness, among other factors.

Research should be conducted to demonstrate technical feasibility during Phase 1 and show a path toward a Phase 2 hardware/software demonstration, and when possible, deliver a demonstration unit for functional and environmental testing at the completion of the Phase 2 contract.
The Low-Cost Small Spacecraft and Technologies Topic focuses on the technologies, subsystems, methodologies, and mission concepts for space missions which lower the over-all cost for scientific exploration. The "Small" of spacecraft and missions refer to small spacecraft that have "wet" masses below 500 Kg. (micro satellites 10-100kg, nano satellite 1-10kg, pico satellite

Sub Topics:

S4.01 NanoSat Launch Vehicle Technologies

Lead Center: ARC

The space transportation industry is in need of low-cost, reliable, on-demand, routine space access. Both government and private entities are pursuing various launch systems and architectures aimed at addressing this market need. Significant technical risk and cost exists in new system development and operations - reducing incentive for private capital investment in this still-nascent industry. Public and private sector goals are aligned in reducing these risks and enabling the development of launch systems capable of reliably delivering payloads to low Earth orbit. The NanoSat Launch Vehicle Technology subtopic will particularly focus on higher risk entrepreneurial projects for dedicated nano and small spacecraft launch vehicles.

This subtopic is seeking proposals in the following, but not limited, areas:

- Conceptual designs of system/architectures capable of reducing the mission costs associated with small payload delivery to LEO.
- Maturation of low-cost propulsions systems using low-cost materials, and/or low-cost manufacturing processes.
- Maturation of low-cost propulsion systems using storable and environmentally friendly non-toxic propellants.
- Innovative propulsions system solutions, including robust integrated micro-propulsion systems for both primary propulsion, as well as on-board satellite propulsion.
• Maturation of hypersonic and small launch vehicle design and analysis tools or tool-sets aimed at increasing the state-of-the-art while reducing the required design cycle time and human interaction.

• Maturation of key technologies/processes for hypersonic and small launch vehicles including, but not limited to:
  ◦ Thermal Protection Systems;
  ◦ Airframe and subsystem structures that increase system performance and propellant mass fraction;
  ◦ Vehicle Sensor Networks.

• Novel, low-cost modular adapters and release mechanisms.

• Lightweight interstage designs.

Applications of wireless networking technologies for small launch vehicles are also specifically of interest to this subtopic. This technology could be used for vehicle to ground communications (spread-spectrum and non-licensed technologies), as well as within the vehicle itself. We desire new architectures for intelligent on-board communications as well as satellite-to-satellite communication using machine-to-machine (M2M) solutions. The traditional wire harness architecture could be replaced by the wireless technology for command and control, which would reduce vehicle mass and improve reliability. Also stage-to-stage interfaces and vehicle-payload interfaces are of interest. These wireless technologies can include but are not limited to WIMAX™ and ZIGBEE™.

Non-propulsive approaches and architectures for new launch vehicles can also achieve increases in launch vehicle payload mass delivered to orbit for small spacecraft missions. Offerors should consider development, test, and operational factors to show improvements in development and operational costs, payload mass fraction, and mission assurance. Special attention should be given to improved integration between the launch vehicle and payloads to further reduce operational costs. Furthermore, non-propulsive launch vehicle technologies have a dramatic impact on launch vehicle performance and constitute a large percentage of development and operational costs. They include, but are not limited to:

• Robust On-Board Guidance, Navigation and Control (GN&C) avionics. GN&C should be modular (including modular software architectures) and make use of modern architectures, including high-performance low-weight avionics hardware, and modern software tools. Emphasis is on low-weight architecture to allow maximum payload capacity.

• Range safety solutions and operational concepts to lower costs. These may include alternative solutions to expensive explosive destruct packages, including, but not limited to propulsion-cutoff systems, autonomous flight-abort systems, etc.

Phase 1 - Research should demonstrate the technical feasibility and show a path towards a hardware/software demonstration. Plan a demonstration to validate the technologies/tools/processes. Bench or lab-level demonstrations showing concept viability is encouraged. Commercial applicability should be addressed.
Phase 2 - Emphasis should be placed on developing and demonstrating the technology under relevant test conditions. Additionally, a path should be outlined that shows how the technology could be commercialized or further developed into space-worthy systems. When applicable, researchers should deliver a demonstration unit for functional and environmental testing at the completion of the Phase 2 contract.

S4.02 Secondary and Tertiary Launch Technologies

Lead Center: ARC

There are a growing number of secondary and tertiary flight opportunities for small spacecraft. These include Dual Payload Attach Fitting (DPAF) for the Delta launch vehicle, the EELV Secondary Payload Adapter (ESPA), as well as tertiary opportunities for spacecraft that are bolted to the upper stage of a booster (as was the case with GeneSat on the Minotaur launch vehicle). The Secondary and Tertiary Launch Technologies subtopic will particularly focus on adaptor and deployment technologies.

We specifically desire low-cost modular DPAF and ESPA solutions, which can be adapted for various nano and small-satellites. Solutions should have minimal impact on cost and schedule, protect the primary payload, and have clear and achievable paths to certification. Topics include, but are not limited to:

- Gentle non-explosive separation mechanisms;
- Autonomous or on demand deployment with build in safety factors;
- Robust, low-weight, and low-cost innovative deployment architectures for large numbers of nano- and small-satellites into predefined orbits.

Phase 1 - Research should demonstrate the technical feasibility and show a path towards a hardware/software demonstration. Plan a demonstration to validate the technologies/tools/processes. Bench or lab-level demonstrations showing concept viability is encouraged. Commercial applicability should be addressed.

Phase 2 - Emphasis should be placed on developing and demonstrating the technology under relevant test conditions. Additionally, a path should be outlined that shows how the technology could be commercialized or further developed into space-worthy systems. When applicable, researchers should deliver a demonstration unit for functional and environmental testing at the completion of the Phase 2 contract.
S4.03 Low-Cost, Rapid Spacecraft Design and Multi-Subsystem Functionality

Lead Center: ARC

To achieve low-cost small spacecraft missions, the resources necessary for the conceptual and detailed design of the spacecraft should be proportional to other phases of the successful project. Novel approaches are encouraged to re-use development from other projects and design current projects with the foresight to be reused for future flight projects. The Low-Cost, Rapid Spacecraft Design and Multi-Subsystem Functionality subtopic encourages offerors to utilize open source software and hardware solutions to be utilized for other actors, including entrepreneurial and university teams, for reusability.

This subtopic is seeking proposals in the following, but not limited, areas:

- Methods and tools to enable a geographically distributed, concurrent design of system concepts and functions.

- Dynamic, open source, on-line database and collection system of COTS components and subsystems suitable for spacecraft - a database of components open to the public, can be used for conceptual design and to determine an accurate Master Equipment List (MEL), cost, and schedule based on the current market value and lead time for the components; a prospective model. Such a database should include an API where companies can:
  - Plug into a design tool, whether open source or proprietary, to utilize the database for a prospective model;
  - Link to their components already publicized on their own webpage to collect the data on one centralized location;
  - Utilize database to extend options from a proprietary database of components or designs.

- Modular and scalable subsystem design of spacecraft.

- Consolidation of spacecraft functions to reduce mass, power, volume and interfaces (i.e., multi-functionality) - integrating the functions of two or more onboard disciplines such as structure/mechanical, power, avionics, telecommunications, propulsion, thermal control and attitude control and determination. Also consider cross-functional spacecraft-to-payload capabilities in the areas of attitude determination, navigation, telecommunications and other mission level functions.

- Internal wireless data and command communications systems that alleviate need for wire harness.
Phase 1 - Research should demonstrate the technical feasibility and show a path towards a hardware/software demonstration. Plan a demonstration to validate the technologies/tools/processes. Bench or lab-level demonstrations showing concept viability is encouraged. Commercial applicability should be addressed.

Phase 2 - Emphasis should be placed on developing and demonstrating the technology under relevant test conditions. Additionally, a path should be outlined that shows how the technology could be commercialized or further developed into space-worthy systems. When applicable, researchers should deliver a demonstration unit for functional and environmental testing at the completion of the Phase 2 contract.

S4.04 Project Management, Systems Engineering and Mission Assurance Tools

Lead Center: ARC

For cost effective management of multiple complex low-cost small spacecraft projects using distributed teams, management tools are required that integrate the various elements of management, systems engineering, and risk and mission assurance data. This subtopic is seeking tools where members of a spacecraft team are able exchange technical information and capture the salient decisions, trades, dependencies, etc. For a tool to be effective, it must make the job for each team member easier. There should be customizable views for each member so they are able to see the data that affects their job. This subtopic is seeking tools that:

- Simplify data integration resulting in top level roll-up or "dashboard" views as well as provide manager-friendly deep-drilling capability when depth of technical insight is required.

- Directly reflect the management and reporting requirements for NASA projects as defined in NPR7120.5D, NPR 7123.1A, NPR 8000.4, and related standards and directives.

- Facilitate or automate data entry for the Project Manager, Systems Engineer, and Risk and Mission Assurance Manager through secure web-based interfaces.

- Perform data integrity checks at the time of entry and upon request. Include automated e-mail notification of data integrity problems to responsible parties.

- Provide common-interface input portals and data library structures for data uploading from each project WBS element.

- Provide manager-controlled cross-linking of access to data resources from WBS to WBS.

- Provide the ability to specify and automatically generate and update metric and trend reporting on key
performance measures, quantities and changes in requirements, documents, configuration items, risk databases, and cost tracking including Earned Value Management metrics and schedule critical path and resource loading metrics.

- Make it possible for reasonably experienced managers to train themselves on tool use.
- Provide data entry and presentation interfaces that are reliable, accepting and presenting data without lengthy uploads or downloads.
- Provide simple, user-modifiable linking to related, keyword searchable archives.
- Provide data translation and capture tools for integration of any data that can be provided in spreadsheet formats or common text documents.
- Aid in building re-usable reporting formats linked to data resources including metric analysis data, snapshots of discipline-specific report sheets, standard subsystem progress reports, and other manager specified data.
- Provide integrated management and team support tools such as Action Item tracking including automatic e-mail alerts to individual and groups, and customizable tracking status schemes.

Data resources to be linked include cost tracking spreadsheets, task plans, risk management databases, requirements databases, technical performance metrics and margins sheets, top level and WBS element schedules, and standard monthly status reports from WBS elements. The tool should be easily scalable for large or small projects and the number of WBS elements and features included or excluded for a given project should be user-selectable. User and group permission and access controls are required.

Phase 1 - Research should provide examples of proven cost benefits and project successes based on the use of integrated management tools for management of multiple simultaneous distributed projects. Architectures should be proposed for implementation of an integrated multi-project management tool.

Phase 2 - A management tool set will be implemented and demonstrated as part of an actual small satellite management project. The tool will be evaluated for ease of use, effectiveness as a NASA project set-up tool, management information tool, and reporting tool. Feasibility for a single manager to effectively manage and report on multiple simultaneous projects will be assessed. Project users from the WBS elements of the satellite project will evaluate ease of use of uploading data.
The cost of flight software, including algorithms and data management, is continuing to increase and multiply in complexity. Novel on-board data analysis can greatly decrease the bandwidth needed back to Earth, and can alert scientists for time sensitive information and follow-up investigations.

This subtopic is seeking proposals in the following, but not limited, areas:

- Innovative flight software development techniques
  - Planning and scheduling software
  - Modular routines for repeatability on future missions.
- Autonomous fault tolerant software development that acts in a repeatable, predictable manner.
- Automated system level testing.
- On board automated approaches for data compression and payload data analysis to enable low bandwidth communications to the ground station.
- Participatory, distributed analysis techniques utilizing public interest and resources (e.g., Stardust @ Home and HiRise data analysis).

Phase 1 - Research should demonstrate the technical feasibility and show a path towards a software demonstration. Bench or lab-level demonstrations showing concept viability is encouraged. Commercial applicability and modularity should be addressed.

Phase 2 - Emphasis should be placed on developing and demonstrating the software technology under relevant test conditions. Additionally, a path should be outlined that shows how the technology could be commercialized or further developed into space-worthy systems. Researchers should deliver a demonstration package for functional evaluation by NASA at the completion of the Phase 2 contract.
This subtopic is seeking proposals to reduce the cost, mass, size, power and complexity of current spacecraft avionics systems, including processors, switch boxes, payload control units, mass storage devices, star trackers, IMUs, and power converters to support smaller (micro and nano) class space vehicles.

NASA has been studying methods to assemble space missions quicker and in a more straightforward manner using "plug and play" (PnP) approaches. Modern plug-and-play includes both the traditional boot-time assignment of I/O addresses and interrupts to prevent conflicts and identify drivers, as well as hot plug systems such as USB and Firewire. This SBIR will explore the hallmarks of next-generation avionics. A major challenge to achieving a usable and useful low cost small mission is the ability to rapidly compose the system to perform both the needed mission functionality using the available spacecraft components. Physical assembly of the PnP spacecraft components is a necessary, but insufficient condition for achieving a system. The assembled system needs to provide the functional capabilities to support the intended mission and also needs to provide the functional capabilities to ensure the operational health and safety of the resulting space mission. A preliminary architectural model to provide a reusable infrastructure is requested as part of effort this supports hard real time, soft real time and non-real time processes.

The objective of this SBIR effort is to prove the viability of modular, plug and play (PnP) spacecraft avionics architecture. This revolutionary architecture provides a near-term solution to modular, plug and play avionics while distributing power and data management functions. It enables full PnP modularity reducing spacecraft integration and test to a few days.

Areas of interest include:

- Low cost open architecture avionics systems;
- Plug and Play adapters that facilitate transition from traditional point to point proprietary control to an open architecture industry standard interface both hardware and software;
- Validate components by producing low cost standard plug and play components including processors, switch boxes, payload control units, mass storage devices, star trackers, IMUs, and power converters.

Phase 1 - Research should identifying and evaluating candidate telecommunications technology applications to demonstrate the technical feasibility and show a path towards a hardware/software demonstration. Plan a demonstration to validate the technologies/tools/processes. Bench or lab-level demonstrations showing concept viability is encouraged. Commercial applicability should be addressed.

Phase 2 - Emphasis should be placed on developing and demonstrating the technology under simulated flight
conditions. Additionally, a path should be outlined that shows how the technology could be commercialized or further developed into space-worthy systems defining interfaces (both on the spacecraft and to candidate ground segments). When applicable, researchers should deliver a demonstration unit for functional and environmental testing at the completion of the Phase 2 contract.

S4.07 Mini-Micro Thrusters, LOX / Hydrocarbon Propulsion, and Attitude Control Systems

Lead Center: ARC

This subtopic is seeking proposals that explore uses of technologies that will provide superior performance in attitude control and overall orbit control.

Propellants play a vital role. The use of liquid oxygen / liquid hydrocarbon fuel (e.g., liquid propylene (LP) in small spacecraft for implementing attitude control and for orbital maneuvers is of interest. This subtopic is looking for candidate fuels that have superior performance to kerosene for on-orbit applications including storage stability and propulsion.

This subtopic is also seeking proposals in the following, but not limited, areas:

- Low-cost reaction wheels;
- Low-mass micro-propulsion systems;
- Propulsion systems that allow transfers from LEO or GTO to lunar orbit or other destinations;
- Propellantless means to achieve delta-V (e.g., momentum exchange, electrodynamic interaction with the Earth's magnetosphere) as a viable Cis-Lunar transport system;
- Flexible and modular (i.e., non-customized) tankage that is scalable to accommodate multiple mission delta-V requirements without safety and design re-qualification for each mission.

Phase 1 - Research should demonstrate the technical feasibility and show a path towards a hardware/software demonstration. Plan a demonstration to validate the technologies/tools/processes. Bench or lab-level demonstrations showing concept viability is encouraged. Commercial applicability should be addressed.
Phase 2 - Emphasis should be placed on developing and demonstrating the technology under relevant test conditions. Additionally, a path should be outlined that shows how the technology could be commercialized or further developed into space-worthy systems. When applicable, researchers should deliver a demonstration unit for functional and environmental testing at the completion of the Phase 2 contract.

S4.08 Low-cost Assembly, Integration, and Testing

Lead Center: ARC

Current programs take a step-wise approach to various phases of space missions that may lead to inconsistencies between conceptual development, design, assembly, integration, testing, and operations. This subtopic seeks to integrate these phases by providing a consistent software/hardware environment for spacecraft development to operations. Extensible/modular, standards-based, and COTS solutions for software and hardware to improve transition through the various phases, especially transition to operations, is highly encouraged.

One of the potential benefits of small spacecraft missions is transformation of the payload integration process. Traditionally payloads and experiments were delivered to payload integration facilities that were geographically close to the launch site.

This subtopic is looking for ways to streamline this process by reducing the need for this activity to be carried out to close proximity to the launch site. This will result in integration occurring at home facilities and reduced lead times due to a decrease in associated planning activities.

Similarly, to facilitate integration of spacecraft subsystems when using COTS products from multiple vendors, integration of the spacecraft subsystems themselves could benefit from the early use of flexible-standard smart interfacing hardware that can accommodate an array of interface standards including Ethernet, Spacewire™, USB 2.0, RS-422, and I2C.

This subtopic is seeking proposals in the following, but not limited, areas:
Automated test equipment / automated Breakout boxes;

Testing of subsystems in geographically distributed locations;

Standardized interfaces with launch vehicles with frequent launch opportunities.

Phase 1 - Research should demonstrate the technical feasibility of systems-level approach to streamlining processes while simultaneously improving program consistency, repeatability, improved testing, and lower cost. Additionally, the scope of Phase 1 includes identification and evaluation of these alternative subsystem integration, test, and payload processing architectures, as well as the associated payload accommodations hardware and technologies that might be required. Commercial applicability should be addressed.

Phase 2 - Emphasis should be placed on developing and demonstrating the technology under test conditions based on emerging nanosat and small launch vehicles now in development or integration with secondary and tertiary payload launch opportunities. Additionally, a path should be outlined that shows how the technology could be commercialized or further developed into space-worthy systems. When applicable, researchers should deliver a demonstration unit for testing at the completion of the Phase 2 contract.

S4.09 Autonomous Multi-Mission Virtual Ground and Spacecraft Operations

Lead Center: ARC

Future ground and spacecraft operations for low-cost spacecraft missions must decrease the complexity, cost, and human intervention required for successful operations of missions.

This subtopic is seeking proposals in the following, but not limited, areas:

- Virtual ground stations;
• Internet-based protocol modules and architectures that will provide seamless network command and control continuity between terrestrial and space-based platforms and environments;

• Autonomous lights-out ground control software (e.g., the ground station operates autonomously without human intervention, and can have remote access);

• Alternate Ground station approaches (e.g., Antenna Arrays or Amateur Radio bands);

• Networked operations of distributed ground stations (e.g., University consortium);

• Software/methods enhancing multiple-mission consolidated operations.

Phase 1 - Research should demonstrate the technical feasibility and show a path towards a hardware/software demonstration. Plan a demonstration to validate the technologies/tools/processes. Bench or lab-level demonstrations showing concept viability is encouraged. Commercial applicability should be addressed.

Phase 2 - Emphasis should be placed on developing and demonstrating the technology under relevant test conditions. Additionally, a path should be outlined that shows how the technology could be commercialized or further developed into space-worthy systems. When applicable, researchers should deliver a demonstration package for functional and environmental testing at the completion of the Phase 2 contract.

Robotic Exploration Technologies Topic S5

NASA is pursuing technologies to enable robotic exploration of the Solar System including its planets, their moons, and small bodies. NASA has a development program that includes technologies for the atmospheric entry, descent, and landing, mobility systems, extreme environments technology, sample acquisition and preparation for in situ experiments, and in situ planetary science instruments. Robotic exploration missions that are planned include a Europa lander, a rover or balloon-borne experiment on Titan, a surface mission to Venus, and continued Mars exploration missions launching every 26 months including a network lander mission, an Astrobiology Field Laboratory, 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 [10] for mission information. See URL: http://marstech.jpl.nasa.gov/ [11] for additional information on Mars Exploration technologies.
In 2007 the emphasis for SBIR in robotic exploration will be in the following areas: (1) Surface and subsurface robotic exploration; (2) Sample collection, processing and handling devices; (3) Planetary entry, descent and landing technology; (4) Extreme environments technology; and (5) Planetary balloons and aerobots.

Sub Topics:

**S5.01 Extreme Environments Technology**

**Lead Center:** JPL

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

**High temperature, high pressure, and chemically corrosive environments:**

Proposals are sought for technologies that enable the in situ exploration of the surface and deep atmosphere of Venus and the deep atmospheres of Jupiter or Saturn for future NASA missions. Venus features a dense, CO\(_2\) atmosphere completely covered by sulfuric acid clouds at about 55 km above the surface, a surface temperature of about 486°C and a surface pressure of about 90 atmospheres. Although already explored by various orbiters and short-lived atmospheric probes and landers, Venus retains many secrets pertaining to its formation and evolution. NASA is interested in expanding its ability to explore the deep atmosphere and surface of Venus through the use of long-lived (days or weeks) balloons and landers. Survivability in extreme high temperatures and high pressures is also required for deep atmospheric probes to giant planets. Technology advancements to permit operation and survivability in high-temperature/high-pressure planetary environments are sought in the following areas:

**Thermal Control Systems:** Survivability of electronic components in high temperature environments relies on three basic areas of thermal control: isolation, thermal capacitance and/or refrigeration. Specific improvements in are sought in the development of:

- Thermal energy storage systems with 300 - 1000 kJ/kg energy density through either phase changes or chemical heat absorption;

- High performance, low mass refrigeration cooling systems capable of pumping on the order of 100 Watts of heat from a 100°C source to the Venus sink temperature of 486°C. In this area, particular attention must be paid to the power source for such a system. A total systems approach must be considered as opposed to development of a particular component.

**Pressure Vessel Components:**

- Optical Window systems that are transparent in IR, Visible and UV wavelengths at Venus surface temperatures that remain sealed under expected mission temperature variations from -50°C to 486°C and from external pressure variation from 0 to 90 atmospheres.

- Pressure vessel flange seal technology compatible with materials such as stainless steels, titanium and beryllium. Seals shall exhibit leakage rates lower than 10-5 cc He/sec over the expected mission temperature variations from -50°C to 486°C and from external pressure variation from 0 to 90 atmospheres. Clamping loads for the seals shall be less than 1500 pounds per linear inch.
Low temperature environments:

Moon equatorial regions experience wide temperature swings from -180°C to +130°C during the lunar day/night cycle, and the sustained temperature at the shadowed regions of lunar poles can be as low as -230°C. Mars diurnal temperature changes from about -120°C to +20°C. Low temperature survivability is also required for missions to Titan, surface of Europa and comets. Proposals are sought in the following specific areas:

- Wide temperature (-180°C to +130°C) and low-temperature (-230°C), radiation-tolerant and SEL immune, low power, mixed-signal circuits including analog-to-digital converters, digital-to-analog converters, low-noise pre-amplifiers, voltage and current references, multiplexers, power switches, microcontrollers, and integrated command/control/drive electronics for sensors, actuators, and communications transponders.

- Computer Aided Design (CAD) tools for predicting the electrical performance, reliability, and life cycle for low-temperature electronic systems and components.

- Physics-based transistor device models valid at temperature ranging from -230°C to +130°C to enable design, verification and fabrication of custom low power mixed-signal and analog circuits.

- Low-temperature (-230°C) circuit design methodologies facilitating novel layout designs for integrated mixed-signal and analog circuits.

- Selected hardware and support technologies for motors, drive systems and related mechanisms that will operate in low temperature environments. Specific areas of interest include gear boxes, suspension systems, material components (i.e., wiring, harnesses, insulating materials, and jackets/covers) that can operate in cryogenic environments; advanced lubricants and lubrication technology.

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

S5.02 Planetary Entry, Descent and Landing Technology

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

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

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

- Providing critical measurements during the entry phase (e.g., pressure and/or temperature sensors embedded into the aeroshell);
- Improving the accuracy on measurements needed for guidance decisions (e.g., surface relative velocities, altitudes, orientation, localization);
- Extending the range over which such measurements are collected (e.g., providing a method of imaging through the aeroshell, or terrain-relative navigation that does not require imaging through the aeroshell);
- Enhancing the situational awareness during landing by identifying hazards (rocks, craters, slopes), or providing indications of approach velocities and touchdown;
- Substantially reducing the amount of external processing needed to calculate the measurements; and
- Significantly reducing the impact of incorporating such sensors on the spacecraft in terms of volume, mass, placement, or cost.

S5.03 Sample Collection, Processing, and Handling Devices

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

Robust systems for sample acquisition from the subsurface of planetary bodies are critical to the next generation of robotic explorers. Limited spacecraft resources (power, volume, mass, computational capabilities, and telemetry bandwidth) demand innovative, integrated sampling systems that can survive and operate in challenging environments (extremes in temperature, pressure, gravity, vibration and thermal cycling).

Research should be conducted to develop compact, low-power, lightweight subsurface sampling systems with access to depths of 1 - 3 m below the surface. A relevant mission scenario for this type of drill would include drilling
multiple holes from a mobile platform, such as a rover. For reference, current Mars-relevant rovers range in mass from 200 - 800 kg. Also of interest are integrated systems for 1-10 cm subsurface sampling. Consideration should be given to potential failure scenarios for integrated systems. For example, recovery and mitigation techniques for platform slip and borehole misalignment should be addressed. Significant attention should be given to the sensing and automation required for real-time control, fault diagnosis and recovery. Additional areas of interest include understanding the limitations of dry drilling into mixed media such as icy mixtures of rock and regolith and hot subsurface materials at high pressure (up to 740 K in a 90 bar CO$_2$ environment).

Sample manipulation technologies are needed to enable handling and transfer of unstructured samples from a sampling device to instruments and sample processing systems. Shallow rock core and regolith samples may be variable in size and composition so a sample manipulation system needs to be flexible enough to handle the sample variability. Core samples will be on the order of 1 cm diameter and up to 10 cm long. Soil and rock fragment samples will be of similar volumes. Actual samples to be analyzed in instruments will likely be small subsamples so the means for subsampling and manipulation of the original sample and subsamples needs to be developed. Minimal size and mass components and systems have the greatest benefit.

Also of particular need are means of acquiring subsurface rock and regolith samples with minimum contamination. This contamination may include contaminants brought to the sample by the drill itself, material from one stratigraphic layer contaminating samples collected at another depth (sample cross-contamination), or Earth-source microorganisms brought to the Martian surface prior to drilling ('clean' sampling from a 'dirty' surface).

**S5.04 Surface and Subsurface Robotic Exploration**

**Lead Center:** JPL

**Participating Center(s):** ARC, GSFC

Technologies are needed to enable access to surface and subsurface sampling sites of scientific interest on Mars. Mobility technology is needed to enable access to difficult-to-reach sites such as access through steep terrain. Many scientifically valuable sites are accessible only via terrain that is too steep for state-of-the-art planetary rovers to traverse. Sites include crater walls, canyons, and gullies. Tethered systems, non-wheeled systems, and marsupial systems are examples of mobility technologies that are of interest. Tether technology could enable new approaches for deployment, retrieval and mobility. Innovative marsupial systems could allow a pair of vehicles with different mobility characteristics to collaborate to enable access to challenging terrain. It is envisioned that a 500-800 kg primary vehicle could provide long traverse to the vicinity of a challenging site and then deploy a smaller 20-50 kg vehicle with steep mobility access capability for access to the site.
Technologies to enable subsurface access and sampling in multiple holes at least 1 - 3 meters deep through rock, regolith or ice compositions are also sought. Subsurface access solutions to be integrated onto 500-800 kg stationary landers and mobile platforms are of interest. Consideration should be given for potential failure scenarios, such as platform slip and borehole misalignment for integrated systems, and the challenges of dry drilling into mixed media including icy mixtures of rock and regolith. Systems should ensure minimal contamination of samples from Earth-source contaminants and cross-contamination from samples at different depths.

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

- Tether play-out and retrieval systems including tension and length sensing;
- Low-mass tether cables with power and communication;
- Steep terrain adherence for vertical and horizontal mobility;
- Modular actuators with 1000:1 scale gear ratios;
- Electro-mechanical couplers to enable change out of instruments on an arm end-effector;
- Drill, core, and boring systems for subsurface sampling at 1 to 3 meters.

**S5.05 Planetary Balloons and Aerobots**

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

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

**Aerial Deployment Modeling Tool**
Many aerobot concepts for Mars, Titan, and Venus involve the aerial deployment and inflation of the balloon during parachute descent after arrival at the destination. Proposals are sought that would provide computer modeling tools that can simulate this complex process. Of particular importance is the ability to model the balloon shape and material stresses as a function of time, taking into account the aerodynamic forces generated by the parachute and by the uninflated or partially inflated balloon, as well as transient loads during balloon deployment from its storage container. The balloons can be either polymer film or polymer film plus reinforcing fabric laminates.

**Metal Bellows for High Temperature Venus Balloons**

Cylindrically-shaped metal bellows are a potential solution to the problem of making balloons that can tolerate the 460°C temperatures near the surface of Venus. Commercial off-the-shelf metal bellows are limited in diameter to approximately 0.4 m. NASA seeks proposals for metal bellows technology that can produce prototypes in the range of 1 - 2 m in diameter and 5 - 10 m long; tolerant of sulfuric acid; good fatigue properties at 460°C; and areal densities of up to 1 kg/m².

**High Strength Envelope Materials for Titan Aerobots**

NASA currently has viable cryogenic balloon materials based on polyester film plus fabric laminates. It is desired to have new, advanced materials that possess at least a 50% improvement in the strength to weight ratio while retaining comparable flexibility to the current polyester materials. The desired areal densities are in the range of 40-80 g/m² so as to support both superpressure and zero pressure balloon concepts. Of particular interest is the use of existing high strength fiber materials like Vectran, Spectra, Dyneema, PBO and Twaron/Kevlar to achieve the desired performance. Preference will be given to proposals that include significant material sample fabrication and cryogenic testing.

**Ground-launched Mars Balloons**

NASA is interested in small balloons with very light payloads.
Modeling and simulation are being used more pervasively and more effectively throughout NASA, for both engineering and science pursuits, than ever before. These are tools that allow high fidelity simulations of systems in environments that are difficult or impossible to create on Earth, allow removal of humans from experiments in dangerous situations, and provide visualizations of datasets that are extremely large and complicated. Examples of past simulation successes include simulations of entry conditions for man-rated space flight vehicles, visualizations of distant planet topography via simulated fly-over and three-dimensional visualizations of coupled ocean and weather systems. In many of these situations, assimilation of real data into a highly sophisticated physics model is needed. Also use NASA missions and other activities to inspire and motivate the nation's students and teachers, to engage and educate the public, and to advance the scientific and technological capabilities of the nation.

Sub Topics:

S6.01 Modeling, Simulation and Analysis Technologies

Lead Center: ARC

This subtopic solicits proposals for technologies and systems that allow spacecraft and ground systems to robustly perform complex tasks in dynamic environments with minimal human direction. Areas of interest include support of decision support systems, distributed sensor webs and component systems, and the creation of automation loops connecting scientific modeling and analysis to mission planning, data collection, processing and operations. NASA is moving from a stove-pipe observational architecture to one that permits data interoperability and dynamic coordination of observational assets to generate desired data products. Technology innovations include:

- Automation and autonomous systems that support high-level command abstraction;
- Efficient and effective techniques assessing gaps in data collection to assure complete coverage;
- Intelligent searches of distributed data archives, and data discovery through searches of heterogeneous data sets and architectures; and
- Automation of routine, labor intensive tasks to that either increase reliability or throughput of current process.

Specific areas of interest include the following:

- Search agents that support applications involving the use of NASA data using emerging interoperability such as Sensor Model Language;
- Methods that support the planning and scheduling of sensor webs in support of data product processing when given a set of high-level goals and constraints;
- Autonomous data collection including the coordination of space or airborne platforms while adhering to a set of data collection goals and resource constraints;
• System and subsystem health and maintenance, both space- and ground-based;
• Distributed decision making, using multiple agents, and/or mixed autonomous systems;
• Automatic software generation and processing algorithms; and
• Control of Field Programmable Gate-Arrays (FPGA) to provide real-time products.

S6.02 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 Earth and astrophysical systems, as well as to conduct high-fidelity engineering analyses. The goal of this subtopic is to make NASA's supercomputing systems and associated resources easier to use, thereby broadening NASA's supercomputing user base and increasing user productivity. Specific objectives are to:

• Reduce the learning curve for using supercomputing resources;
• Minimize total time-to-solution (i.e., time to discovery, understanding, or prediction);
• Increase the scale and complexity of computational analysis and data assimilation;
• Accelerate advancement of system models and designs.

The approach of this subtopic is to develop intuitive, high-level tools, interfaces, and environments for users, and to infuse them into NASA supercomputing operations. Successful technology development efforts under this subtopic would be considered for follow-on funding by, and infusion into either of the NASA high-end computing projects, including the High End Computing Columbia (HECC) project at Ames and the NASA Center for Computational Sciences (NCCS) at Goddard. Research should be conducted to demonstrate technical feasibility during Phase 1 and show a path toward a Phase 2 prototype demonstration. Open Source software and open standards are strongly preferred.

Specific areas of interest include:
Application Development

With the increasing scale and complexity of supercomputers, users must often expend a tremendous effort to translate their physical system model or algorithm into a correct and efficient supercomputer application code. This subtopic element seeks intuitive, high-level application development environments, ideally leveraging high-level programming languages (e.g., parallel Matlab or IDL) to enable rapid supercomputer application development, even for novice users. This environment should dramatically simplify application development activities such as porting, parallelization, debugging, scaling, performance analysis, and optimization.

Results V&V

A primary barrier to effective use of supercomputing by novices is understanding the accuracy of their computational results. Errors in the input data, domain definition, grids, algorithms, and application code can individually or in combination produce non-physical results that a user may not detect. This subtopic element seeks tools and environments to help users with verification and validation (V&V) of simulation results. This could be accomplished by enabling comparison of results from similar applications or with known accurate results, access to results analysis tools and domain experts, or access to error estimation tools and training.

Data Analysis and Visualization

Supercomputing computations almost invariably result in tremendous amounts of data, measuring in the gigabytes or terabytes, and with many dimensions and other complexity aspects. This subtopic element seeks user-friendly tools and environments for analysis and visualization of large-scale, complex data sets typically resulting from supercomputing computations.

Ensemble Management

Conducting and fusing the results from an ensemble of related computations is an increasingly common use of supercomputers. However, ensemble computing and analysis introduces a new set of challenges for deriving full value from using supercomputing. This subtopic element seeks tools and environments for managing and automating ensemble supercomputing-based simulation, analysis, and discovery. Functions could include managing and automating the computations, model or design optimization, interactive computational steering, input and output data handling, data analysis, visualization, progress monitoring, and completion assurance.

Integrated Environments

The user interface to a supercomputer is typically a command line or text window, where users may struggle to locate or develop applications, understand the job queue structure, develop scripts to submit jobs to the queue,
manage input and output files, archive data, monitor resource allocations, and many other essential supercomputing tasks. This subtopic element seeks more intuitive, intelligent, and integrated interfaces to supercomputing resources. This integrated environment could include access to user training (e.g., tutorials, case studies, and experts), application development tools, standard (e.g., production, commercial, and Open Source) supercomputing applications, results V&V tools, computing and storage resources, ensemble management tools, workflow management, data analysis and visualization tools, and remote collaboration.

S6.03 On-Board Data Processing and Control

Lead Center: ARC

Participating Center(s): GSFC

Technology advances allow scientists to build devices that often collect more data than can be cost effectively transmitted or summarized within mission time constraints. NASA is developing sensor web capabilities which can require these data be analyzed for rapid decision making, either autonomously or with human in the loop controller. This subtopic enables sensor web capabilities and increases mission data return by developing on-board methods that can operate with very limited resources to increase the efficiency and scientific return of existing and future sensors. Approaches range form losses less data compression prior to transmission to some degree of "data understanding" that enables data management and prioritization based on potential science content. These software capabilities will enable sensor webs that operate semi-autonomously and are capable of reacting to what is being sensed and triggering notifications or additional actions. Algorithms can be embedded into an instrument or device or algorithms can target on-board computer resources for data management and/or transmission as part of the post collection data flow.

The selection of on-board methods to increase scientific return is highly dependent on mission objectives. Successful candidate technologies will need to demonstrate suitability to the general requirements of the proposed use scenario as they pertain to different instrument (or device) types. Generally, scientists do not want to throw away data given that significant discoveries have been made reinterpretation archived data. Methods that reduce information content such as lossy compression are often not desirable unless significant, new capabilities are enabled by this tradeoff. Examples exist where instruments are turned off and on and instances when sensor or camera data is saved and transmitted only when features are detected by on-board software. These instances occur when transmission costs, relative to available resources, are high. E.g., a Mars Exploration Rover was reprogrammed to detect and transmit camera images containing dust devils.

Algorithms can be designed to run on general purpose computing resources or specialized i.e., field programmable gate arrays (FPGA). Novel approaches that can leverage specialized, space qualified computing resources such as FPGAs that return order of magnitude reduction in data volume or screening capabilities are desirable. There is a trade-off between sensor volume and complexity against distance and degree of on-board autonomy needed for mission success so performance metrics are relative to the science mission scenario. Example sensor types include data intensive instruments such as hyperspectral, RADAR, and LIDAR but can include any sensor technology that is shown relevant to the board scope of science within the NASA science mission directorate.

For instance, aggressive metrics for compression and data volume are in Earth science the Decadal survey has the following requirements on data compression:

<table>
<thead>
<tr>
<th>RADAR Missions</th>
<th>SMAP (RADAR)</th>
<th>DESDynI (RADAR)</th>
<th>SWOT (RADAR)</th>
</tr>
</thead>
</table>

Page 45 of 92
<table>
<thead>
<tr>
<th>OBP Input data rate (MHz)</th>
<th>32</th>
<th>400</th>
<th>500</th>
</tr>
</thead>
<tbody>
<tr>
<td>Processor Throughput (GFLOPS)</td>
<td>7</td>
<td>20</td>
<td>90</td>
</tr>
<tr>
<td>Data Compression Ratio</td>
<td>80:1</td>
<td>10:1</td>
<td>90:1</td>
</tr>
</tbody>
</table>

Where raw data sample spacing is 0.75 m x 1.5 m (16 bits per sample), and the output data sample spacing is 10 m x 10 m (16 bits per sample).

For Hyperspectral imaging instruments, here is an exemplar requirement on data compression on board feature detection.

<table>
<thead>
<tr>
<th>Data Rate:</th>
<th>660 gigabits per orbit, 220 megabits per second</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data Compression Ratio:</td>
<td>&gt; 3.0</td>
</tr>
<tr>
<td>On-board detection capability:</td>
<td>A quick look at the data for presence of cloud cover.</td>
</tr>
</tbody>
</table>

**S6.04 Data Analyzing and Processing Algorithms**

**Lead Center: GSFC**

This subtopic seeks technical innovation and unique approaches for the processing and analysis of data from NASA's space and Earth science missions. Analysis of NASA science data is used to understand dynamic systems such as the sun, oceans, and Earth's climate as well as to look back in time to explore the origins of the universe. Algorithms are used to consider data over time, at various energy ranges, and at different points in space. Complex algorithms and intensive data processing are needed to understand and make use of this data. What novel discoveries can be made with existing NASA data? What applications would benefit from the combination of NASA data with additional information and processing?

NASA seeks to exploit spatial tools in order to increase the utility of scientific research data, models, simulations, and visualizations. Of particular interest are innovative computational methods to dramatically increase algorithm efficiency and thus performance. Interpolation, clustering, and registration algorithms are examples of the type of algorithms of interest in this area, as well as real-time visualization and simulation algorithms. Tools to improve predictive capabilities, to optimize data collection by identifying gaps in real-time, and to derive information through synthesis of data from multiple sources are needed. The ultimate goal is to increase the value of data collected in terms of scientific discovery and application. Data analysis and processing must relate to advancement of NASA's scientific objectives.
We are soliciting proposals for software tools which access, fuse, process, and analyze image and vector data for the purpose of analyzing NASA's space and Earth science mission data. Tools can be plug-ins or enhancements to existing software or on-line services. Tools and products might be used for broad public dissemination or for communicating within a narrower scientific community. Tools can be new stand-alone applications or web services, provided that they are compatible with most widely-used computer platforms and exchange information effectively (via standard protocols and file formats) with existing, popular applications. The Phase 1 contract should demonstrate the feasibility of the approach. The Phase 2 contract should provide prototype software that can be demonstrated at the company and a prime contractor or NASA. It is desirable to have the development lead to software that is commercialized or infused into NASA program use.

To promote interoperability, tools shall use industry standard protocols, formats, and APIs, including compliance with the ISO, FDGC, and OGC standards as appropriate. For example a tool may manipulate XML of various types, such as GML, SensorML, KML; or use standard services, such as WSDL and UDDI. Applications may subset, filter, merge, and reformat existing spatial data; provide links to attribute data; or visualize results. Combining NASA research data with popular geospatial services is encouraged.

S6.05 Data Management - Storage, Mining and Visualization

Lead Center: GSFC

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

3D Virtual Reality Environments

- 3D virtual reality environments for scientific data visualization that make use of novel 3D presentation techniques that minimize or eliminate the need for special user devices like goggles or helmets;
- Software tools that will enable users to 'fly' through the data space to locate specific areas of interest.

Distributed Scientific Collaboration

- Tools that enable high bandwidth scientific collaboration in a wide area distributed environment;
• Novel tools for data viewing, real-time data browse, and general purpose rendering of multivariate geospatial scientific data sets that use geo-rectification, data overlays, data reduction, and data encoding across widely differing data types and formats.

Distributed Data Management and Access

• Metadata catalog environments to locate very large and diverse science data sets that are distributed over large geographic areas;

• Dynamically configurable high speed access to data distributed and shared over wide area high speed network environments;

• Object based storage systems, file systems, and data management systems that promote the long term preservation of data in a distributed online (i.e., disk based) storage environment, and provide for recovery from system and user errors.

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

S6.06 Spatial and Visual Methods for Search, Analysis and Display of Science Data

Lead Center: SSC

This subtopic seeks technical innovation and unique approaches to exploit spatial tools in order to increase the use of NASA research data, models, simulations, and visualizations. The goal is to facilitate NASA’s Science and Exploration Missions, and outreach to the interested public. These tools will be used by the NASA Applied Sciences Program managed by the Applied Research and Technology Project Office at Stennis Space Center. The tools should be easy to use by non-specialists, from scientists and policy makers to the general public. Tools and services will be prototyped for accessing and fusing (or mashing) image and vector data with popular Web-based or stand-alone applications. Tools can be plug-ins or enhancements to existing software or on-line services. Tools and the products might be used for broad public dissemination or for communicating within a narrower scientific community.

For example, an authoring tool may help a non-GIS expert to map a National Weather Service modeled hurricane path over a background of NASA MODIS sea surface temperatures, in turn draped on a visualization of the globe served by GoogleEarth.
To promote interoperability, tools shall use industry standard protocols, formats, and APIs. For example a tool may manipulate XML of various types, such as GML, SensorML, KML; or use standard services, such as WSDL and UDDI. Applications may subset, filter, merge, and reformat existing spatial data; provide links to attribute data; or visualize results. Combining NASA research data with popular geospatial services is encouraged. Examples of popular applications and services currently include:

- Imagery servers: e.g., NASA DAACs, OGA servers (USGS, NOAA, DOI), Microsoft Terraserver, Google Maps;
- Mapping platforms: e.g., Google Earth, NASA WorldWind;
- Map servers: e.g., Census Bureau, EPA Maps, Google Maps, MapQuest, Yahoo Maps.

Lidar System Components Topic S1.01
Accurate measurements of atmospheric parameters with high spatial resolution from ground, airborne, and space-based platforms require advances in the state-of-the-art lidar technology with emphasis on compactness, efficiency, reliability, lifetime, and high performance. Innovative lidar component technologies that directly address the measurements of the atmosphere and surface topography of the Earth, Mars, the Moon, and other planetary bodies will be considered under this subtopic. Innovative technologies that can expand current measurement capabilities to spaceborne or Unmanned Aerial Vehicle (UAV) platforms are particularly desirable. Development of components that can be used in planned missions such as Laser Interferometer Space Antenna (LISA) or Earth and planetary composition is highly encouraged. Research should be conducted to demonstrate technical feasibility during Phase 1 and show a path toward a Phase 2 prototype demonstration. For the PY07 SBIR, we are soliciting only the specific component technologies described below.

- Flight qualified, radiation hardened fiber optic components for high power fiber amplifier packages at 1064 nm. Pulse energies in the hundreds of microJoules, and even milliJoule-level, are needed.
- Fiber optic components specifically for use with Yb-doped photonic crystal fibers (PCF), to permit removal of any bulk optics or air gaps in fiber amplifier systems that use a PCF amplifier stage. The following specific components are needed: standard multimode or singlemode fiber to PCF connections, pump couplers for 915 nm or 980 nm, high power isolators at 1064 nm, 1064 nm filters, fiber combiners, and fiber splitters.
- Development of polarization maintaining Er and/or Yb doped optical fibers that are optimized for suppression of stimulated Brillouin scattering (SBS). Resulting fiber must be capable of single frequency (Gravitational wave detection in space uses laser interferometric techniques to measure picometer distance changes over megameter baselines. The application requires a space-qualifiable high reliability frequency-stabilized CW laser source with 1 W output power and a 5 year mission lifetime. A Master Oscillator Power
Amplifier (MOPA) configuration is desirable because the source must be phase-modulated.

- Efficient and compact single frequency solid state or fiber lasers operating at 1.5 and 2.0 micron wavelength regimes suitable for coherent lidar applications. These lasers must meet the following general requirements: pulse energy 0.2 mJ to 100 mJ, repetition rate 10 Hz to 1 kHz, and pulse duration of approximately 200 nsec.

- Single frequency semiconductor or fiber laser generating 10s of mW of CW power in 1.5 or 2.0 micron wavelength regions with less than 100 kHz linewidth. Frequency modulation with about 5 GHz bandwidth and wavelength tuning over several nanometers are desirable.

- Interferometer technology to separately derive aerosol and molecular backscatter via High Spectral Resolution Lidar (HSRL) technique at 532 and 355 nm. Resolving power of the order of 1 GHz over an acceptance angle up to several milliradians is required. High quantum efficiency detectors, such as electron multiplying CCDs, suitable for spaceborne HSRL instruments are also needed. Detectors should be capable of rapid sampling rates greater than 1.5 MHz at 532 and 355 nm operating wavelengths.

Sub Topics:

Active Microwave Technologies Topic S1.02
NASA employs active sensors (Radars) for a wide range of remote sensing applications. These sensors include low frequency (less than 10 MHz) sounders to W-band radars for measuring precipitation and clouds. We are seeking proposals for the development of innovative technologies to support future radar missions. Technology innovations should either enhance measurement capabilities (e.g., improve spatial, temporal, or spectral resolution) or ease implementation in spaceborne missions (e.g., reduce size, weight, power, improve reliability, or lower cost). The areas of interest for this call are listed below.

For L- and P-band radar components for surface deformation, topography and soil moisture measurements:

- Lightweight deployable L-band antenna structures and deployment mechanisms suitable for large aperture (reflectors or phased array of 50m² and larger) systems.

- Compact (probably sub-optimal), P-band antennas (possibly folded-dipole arrays, etc.) for airborne and spaceborne systems.

- Rad-hard, high-efficiency, low-cost, lightweight L- and P-band Transmit/Receive (TR) modules (~250 W peak RF output power at ~100 us pulsewidth and 20% duty cycle) with respective energy storage unit to provide pulsed DC power to the power amplifier while minimizing ripple on the primary DC power source.

- 12-bit, 1 GSps, 500MHz analog bandwidth ADCs and digital filtering with an emphasis on rad-tolerance and space-qualification.

- Implementation of radar transmitters/receivers using digital signal synthesis.

For Ku- and Ka-band radars for snow cover measurement (Ku) and wetland, river, ocean surface monitoring (Ka) and precipitation radars (X to W-band):
• Lightweight deployable reflectors (Ku-band and Ka-band) and active feed electronics.

• High efficiency Ka-band (34-36GHz) TR modules with output power of 5-10W. The LNAs should have a NF less than 3dB and gain better than 30dB. Included in the TR module is a low loss phase shifter.

• Power amplifier and associated LNA for a Ka-band (34-36GHz) radar system with a peak output power of 2KW to 10KW (duty cycle of 10%) and system bandwidth of up to 1 GHz and LNA NF of less than 1.5dB. The LNA needs to have enough isolation and power handling capability to operate in this high power transmission environment.

• Wide-bandwidth (~500 MHz BW), high-efficiency, rad-tolerant linear FM (chirp) signal generators (sweep rates ~500 MHz in 10 us).

• High performance, low power, compact, rad-hard, real-time radar processors, FPGA based digital receivers, SAR data processing algorithms and data reduction techniques.

Sub Topics:
Passive Microwave Technologies Topic S1.03
NASA employs passive microwave and millimeter-wave instruments for a wide range of remote sensing applications from measurements of the Earth’s surface and atmosphere to cosmic background emission. Proposals are sought for the development of innovative technology to support future science and exploration missions employing 450 MHz to 5 THz sensors. Technology innovations should either enhance measurement capabilities (e.g., improve spatial, temporal, or spectral resolution or improve calibration accuracy) or ease implementation in spaceborne missions (e.g., reduce size, weight, or power, improve reliability, or lower cost). While other concepts will be entertained, specific technology innovations of interest are listed below for missions to measure soil moisture, temperature sounding, cloud particles, and cosmic microwave background.

• Low power >200 Mb/s 1-bit A/D converters and cross-correlators for microwave interferometers;

• Automated assembly of 180 GHz direct conversion I-Q receiver modules;

• Low power, tunable, local oscillators from 400 to 600 GHz with 4-5 mW output power;

• Low noise (3), heterodyne mixers requiring low local oscillator drive power (Low DC power spectrometers covering 500 MHz with 125 kHz resolution;

• Highly stable variable correlated noise sources for calibrating correlation-type receivers;

• MMIC Low Noise Amplifiers (LNA). Room temperature LNAs for 165 to 193 GHz with low 1/f noise, and a noise figure of 6.0 dB or better; and cryogenic LNAs for 180 to 270 GHz with noise temperatures of less than 150K;

• High emissivity (near-black-body, >40 dB return loss) surfaces/structures for use as onboard calibration targets that will reduce the weight of aluminum core targets, while reliably improving the uniformity and knowledge of the calibration target temperature;

• New approaches, concepts, and techniques for microwave radiometer system calibration over or within the 1-700 GHz frequency band which provide end-to-end calibration to better than 0.1K, including corrections for temperature changes, standing waves, linearity, and other potential sources of instrumental
measurement drift and error;

- RF (GHz to THz) MEMS switches with low insertion loss (18 dB), capable of switching with speeds of >100 Hz at cryogenic temperatures (below 10 K) for 108 or more cycles;
- Lightweight deployable L-band antenna structures and deployment mechanisms suitable for large aperture (reflectors or phased array of 50m² and larger) systems;
- Dual-polarization multi-frequency micropatch array antenna designs for combinations of frequencies in the C-, X-, or K-bands.

Sub Topics:

Under the category of Sensor and Detector Technology for Visible, IR, Far IR and Submillimeter Topic S1.04, NASA is seeking advances in detectors, readout electronics, and other technologies enabling polarimetry and large format imaging arrays for the visible, near IR, and far IR/submm and spectroscopy with unprecedented sensitivity. These advances may enable future mission concepts such as the Single Aperture Far Infrared (SAFIR) Observatory (http://safir.jpl.nasa.gov/technologies.shtml [1]), Space Infrared Telescope for Cosmology and Astrophysics (SPICA) (http://www.ir.isas.ac.jp/SPICA/ [2]), Cosmic Microwave Background Polarization (CMBPol), and Supernova Acceleration Probe (SNAP) (http://snap.lbl.gov [3]).

Research should be conducted to demonstrate technical feasibility during Phase 1 and show a path toward a Phase 2 prototype demonstration. Innovations are sought in detector capability for the following wavelength ranges:

- 0.1-1 µm: Increased sensitivity and larger array size. Improved silicon response in the UV and NIR, smart pixel arrays, solar blind response detector arrays, energy resolving calorimeter arrays.
- 1-4 µm: Increased sensitivity and larger array size. Large format cryogenic readout multiplexers, large format (>1000x1000) array hybridization techniques.
- 4-40 µm: Increased sensitivity and larger array size (megapixels). Low power cryogenic multiplexers, new sensor materials (e.g., novel dopants for extrinsic Si detectors).
- 40-200 µm: Increased sensitivity and larger array size (megapixels). Monolithic focal plane arrays (BIB technologies, new sensor materials).
- 200 µm - 1 mm: Noise equivalent power (NEP) of $10^{-20}$ W Hz$^{-1/2}$ in a 1,000 pixel spectroscopic array with low-power readout electronics, and NEP $10^{-18}$ W Hz$^{-1/2}$ in a 10,000 pixel photometric imaging array. Capabilities for photon counting, polarimetry, and energy resolving detection. Heterodyne receiver arrays operating near the quantum limit.

In addition to technologies specific to the astrophysics mission concepts above, NASA is seeking technologies and improvements to technologies leading to successful measurement of carbon monoxide, methane, nitrous oxide and other related trace species from geostationary and low-Earth orbital platforms. Of particular interest are new
techniques in gas filter correlation spectroscopy, Fabry-Perot spectroscopy, or better component technologies for these. The following technologies are also of interest for the Scanning Microwave Limb Sounder Earth science instrument concept (http://mls.jpl.nasa.gov/index-cameo.php [4]):

- Efficient, flight qualifiable, spur free, local oscillators for SIS mixers operating in low Earth orbit. Two bands: (1) tunable from 200 to 250 GHz, and (2) tunable from 610 to 650 GHz. Phase-locked to or derived from ultra-stable 5 MHz reference.

- Technologies for calibrating millimeter wave spectrometers for spaceborne missions, including:
  
  - Low power, flight qualifiable comb generators for gain, linearity, and sideband calibration of microwave spectrometers covering the bands from 180 to 270 GHz and from 600 to 660 GHz;
  
  - Flight qualifiable low noise diodes for the bands from 180 to 270 and 600 to 660 GHz;
  
  - Very low return loss (70 dB or better) calibration targets;
  
  - Techniques for quantifying and calibrating out the impact of standing waves in broadband heterodyne submillimeter spectrometers.

  - Low power, stable, linear, spectrometers covering the band from 6-18 GHz with 100 MHz resolution.

Sub Topics:
Detector Technologies for UV, X-Ray, Gamma-Ray and Cosmic-Ray Instruments Topic S1.05
This subtopic covers detector requirements for a broad range of wavelengths from UV through to gamma ray. As would be expected requirements across the board are for greater numbers of readout pixels, lower power, faster readout rates, greater quantum efficiency, and enhanced energy resolution. Typical semiconductor devices in this energy range are based on silicon or germanium. However, proposals for other detector materials are welcomed if a compelling case is made.

Proposals are specifically solicited for improvements in microchannel plate technology for UV focal plane use; for CCD and active pixel sensor development, both for UV and x-ray use; for technologies leading to very-large-area x-ray detectors for survey instruments; and for electronic systems capable of meeting the needs of Mega-to-Giga-channel detectors. The latter can include not just device development but also, for example, novel interconnect schemes enabling efficient packaging to aid in thermal control and to reduce system noise.

The proposed efforts must be directly linked to a requirement for a NASA mission. These include Explorers, Discovery, Origins, Beyond Einstein and Vision Missions. Details of these can be found at the following URL: http://science.hq.nasa.gov/missions/index.html [5].
Specific technologies are listed below. Highly desirable are developments that satisfy multiple requested parameters:

- Large-format focal plane detectors for use in UV and X-ray imaging and spectrometry:
  - Microchannel-plate UV detectors: up to 109 readout channels; quantum efficiency up to 50%;
  - UV-sensitive CCD and active pixel sensors with large formats: to 6k x 6k abuttable; extended UV response below 0.2 nm;
  - X-ray-sensitive CCD and active pixel sensors: up to 4k x 4k formats, 4-side abuttable; power levels of 0.1 W / Megapixel; resolutions less than 120 eV; readout rates of at least 30 Hz; extended x-ray response above 6 keV.

- Very-large-area X-ray detectors for survey instruments: square-meter area capability; response from 3-30 keV; ultra-low power (10 microW/channel).

- Significant improvements in wide band gap materials, individual detectors, and detector arrays for UV and EUV applications. Specific examples include AlGaN and SiC based detector arrays and associated readout systems.

- Mega-to-Giga-Channel analogue electronic systems for very-large-area X- and gamma-ray detectors as follows: up to 108 channel capability; less than 10 microW/channel power requirement; less than 100 electron rms noise level with interconnects.

Sub Topics:

Particles and Field Sensors and Instrument Enabling Technologies Topic S1.06
Advanced sensors for the detection of elementary particles (atoms, molecules and their ions) and electric and magnetic fields in space and associated instrument technologies are often critical for enabling transformational science from the study of the sun’s outer corona, to the solar wind, to the trapped radiation in Earth’s and other planetary magnetic fields, and to the atmospheric composition of the planets and their moons. Improvements in particles and fields sensors and associated instrument technologies enable further scientific advancement for upcoming NASA missions such as Solar Sentinels, GEC, MAGCON, ITSP 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 / sqrtHz,Max.
max sensor unit size: 6 x 6 x 12 cm, max sensor mass: 0.6 kg, max electronics unit size: 8 x 13 x 5 cm, max electronics mass: 1 kg, and max power: 5 W operation, 0.5 W standby, including, but not limited to “sensors on a chip”.

- High-magnetic-field sensor that measures magnetic field magnitudes to 16 Gauss with an accuracy of 1 part 105.
- Strong, lightweight, thin, compactly-stowed electric field booms possibly using composite materials that deploy sensors to distances of 10m or more.
- Cooled (-60°C) solid state ion detector capable of operating at a floating potential of -15 kV relative to ground.
- Low noise magnetic materials for advanced magnetometer sensors with performance equal to or better than those in the 6-81.3 Mo-Permalloy family.
- Radiation hardened ASIC spectrum analyzer module that determines mass spectra using fast algorithm deconvolution to produce ion counts for specific ion species.
- Low cost, low power, high voltage power supplies 5-15 kV.
- 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.
- 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 field boom system in flight (for use with three-axis rigid 10-m booms) accurate to 0.1 degrees dynamic.

Sub Topics:
Cryogenic Systems for Sensors and Detectors Topic S1.07
Cryogenic cooling systems are often enabling technologies for cutting edge science from infrared imaging and spectroscopy to x-ray calorimetry. Improvements in cryogenic technologies enable further scientific advancement at lower cost, lower risk, reduced volume, and/or reduced mass. Lifetime, reliability, and power requirements of the cryogenic systems are critical performance concerns. Of interest are cryogenic technologies for cooling detectors for scientific instruments and sensors on advanced telescopes and observatories as well as on instruments for lunar and planetary exploration. Active coolers should have long life, low vibration, low mass, low cost, and high efficiency. Specific areas of interest include:

- Essentially vibration-free cooling systems such as reverse Brayton cycle cooler technologies with cooling capability of 20 mW at 4K.
- Highly efficient magnetic and dilution cooling technologies under 1 Kelvin.
- Components for advanced magnetic coolers (adiabatic demagnetization refrigerators) including:
Small (few cm bore), lightweight, low current (under 10A, goal under 5A) superconducting magnets capable of producing at least 3 Tesla central field while operating at least 10 Kelvin. Higher temperature superconductor (HTS) magnets operating at significantly higher temperatures are of particular interest.

Lightweight (relative to standard ferromagnetic flux guides) active and/or passive magnetic shielding for 3 to 4 Tesla magnets that reduces the stray field to tens of microTesla at a distance of several cm from the outside of the shield.

Large (several cm) single crystals of magnetocaloric materials.

Superconducting current leads operating between 90 Kelvin down to 10 Kelvin, capable of carrying up to 10 amperes while allowing only approximately 1 mW of heat to be conducted.

Compact, accurate, easy to use thermometers that operate down to 10 milliKelvin.

Sub Topics:

in situ Airborne, Surface, and Submersible Instruments for Earth Science Topic S1.08

There are new platform systems that have the potential to benefit Earth science research activities. To capitalize on these emerging capabilities, proposals are sought for the development of in situ instruments for use on radiosondes, dropsondes, tethered balloons, kites, Unmanned Aerial Vehicles (UAVs), Unmanned Surface Vehicles (USVs), or Unmanned Underwater Vehicles (UUVs). Both miniaturization of current techniques, as well as innovative new methods that lead to compact and lightweight systems are important. Details of complete instrument systems are desired, including data acquisition, power, and platform integration. Instrument performance goals such as resolution, accuracy, and response time should be discussed. A plan for commercial production and marketing should be included as well. Technology innovation areas of interest include:

- Atmospheric measurements including temperature, humidity, solar radiation, clouds, liquid water, ice, precipitation, chemical composition (carbon dioxide, methane, reactive gases and radicals, dynamical tracer species), and aerosol properties;
- Three-dimensional wind measurements near the Earth’s surface, and within the troposphere and lower stratosphere;
- Oceanic measurements including inherent and apparent optical properties, temperature, salinity, chemical composition, nutrient distribution, and currents.

The calibration/validation of the Orbiting Carbon Observatory (OCO - 2008) is a target application. Science campaigns to be conducted within the Sub-Orbital Science Program are also a high priority – the Tropical Composition, Cloud and Climate Coupling (TC4) is such an example: [http://www.espo.nasa.gov/tc4/](http://www.espo.nasa.gov/tc4/) [6], as is the Arctic Research of the Composition of the Troposphere from Aircraft and Satellites (ARCTAS): [http://www.espo.nasa.gov/arctas/](http://www.espo.nasa.gov/arctas/) [7]. Systems to enable field studies aimed to research fundamental processes are also of interest.
Sub Topics:

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

The adaptation of current standard laboratory techniques for deployment on planetary missions is a focus. Proposers are strongly encouraged to relate their proposed technology development to future planetary exploration goals. These goals include geochemical, geophysical and astrobiological objectives.

Instruments for in situ investigations are required for NASA’s planned and potential solar system exploration missions. Instruments are required for the characterization of the atmosphere, surface and subsurface regions of planets, satellites, and small bodies. These instruments may be deployed for in situ measurements on surface landers and rovers, and airborne platforms. These instruments must be capable of withstanding operation in space and planetary environmental extremes, which include temperature, pressure, radiation, and impact stresses.

This subtopic seeks advances in instruments and critical components in the following areas:

- X-Ray Diffraction and X-Ray Fluorescence (XRD/XRF) instruments, with capabilities beyond those currently planned for the CHEMIN instrument on the Mars Science Laboratory (MSL - 2009), with a focus on elemental and mineralogical analysis in the Venus surface environment (90 bars CO$_2$, 450°C).
- Scanning electron microscopy with chemical analysis capability.
- Mass spectrometry/Gas chromatography with improved capabilities over the SAM instrument on MSL or applicability to in situ atmospheric measurements on Venus or Titan.
- Geochronology, with a focus on isotopic dating of planetary surfaces in the 100 Ma to 4.5 Ga timeframe with better than 10% accuracy.
- Gamma-Ray Spectroscopy, with a focus in short duration (X-Ray Photoelectron Spectroscopy (XPS) and Auger Electron Spectroscopy (AES))

Astrobiology includes the study of the origin, evolution, and distribution of life in the universe. New technologies are required to enable the search for extant or extinct life elsewhere in the solar system, to obtain an organic history of planetary bodies, to discover and explore water sources elsewhere in the solar system, and to detect microorganisms and biologically important molecular structures within complex chemical mixtures.

Astrobiology solicits new measurement concepts, advances in existing instrument concepts, and advances in critical components in the following areas:
- Instrumentation focused on assessments of the identification and characterization of biomarkers of extinct or extant life, such as prebiotic molecules, complex organic molecules, biomolecules, or biominerals. At this time we are not soliciting DNA and RNA analysis techniques.

- High sensitivity (femtomole or better) characterization of molecular structure, chirality, and isotopic composition of biogenic elements (H, C, N, O, S) embodied within individual compounds and structures.

In addition, enabling instrument component and support technologies for the above, such as miniaturized pumps, sample inlet systems, valves, integrated bulk sample handling and processing systems, and fluidic technologies for sample preparation, are also solicited. These must be presented in the context of a complete instrument system.

Sub Topics:

Precision Spacecraft Formations for Telescope Systems Topic S2.01

This subtopic seeks hardware and software technologies necessary to establish, maintain, and operate precision spacecraft formations to a level that enables cost effective large aperture and separated spacecraft optical telescopes and interferometers. Also sought are technologies (analysis, algorithms, and testbeds) to enable detailed analysis, synthesis, modeling, and visualization of such distributed systems.

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

Innovations are solicited for: (a) development of nanometer to sub-nanometer metrology for measuring inter-spacecraft range and/or bearing for space telescopes and interferometers (b) development of combined cm-to-nanometer-level precision formation flying control of numerous spacecraft and their optics to enable large baseline, sparse aperture UV/optical and X-ray telescopes and interferometers for ultra-high angular resolution imagery. Proposals addressing staged-control experiments which combine coarse formation control with fine-level wavefront sensing based control are encouraged.
Innovations are also solicited for distributed spacecraft systems in the following areas:

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

Sub Topics:

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

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

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

**Starlight Suppression Technologies**

- Advanced starlight canceling coronagraphic instrument concepts;
- Advanced aperture apodization and aperture shaping techniques;
- Pupil plane masks for interferometry;
- Advanced apodization mask or occulting spot fabrication technology controlling smooth density gradients to 10^-4 with spatial resolutions ~1 µm, low dispersion, and low dependence of phase on optical density;
- Metrology for detailed evaluation of compact, deep density apodizing masks, Lyot stops, and other types of graded and binary mask elements. Development of a system to measure spatial optical density, phase in homogeneity, scattering, spectral dispersion, thermal variations, and to otherwise estimate the accuracy of masks and stops is needed;
- Interferometric starlight cancellation instruments and techniques to include aperture synthesis and single input beam combination strategies;
- Single mode fiber filtering from visible to 20 µm wavelength;
- Methods of polarization control and polarization apodization; and
- Components and methods to insure amplitude uniformity in both coronographs and interferometers, specifically materials, processes, and metrology to insure coating uniformity.

**Wavefront Control Technologies**

- Development of small stroke, high precision, deformable mirrors (DM) 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 DM technologies in various phases of development and processes are encouraged to ultimately improve the state-of-the-art in deformable mirror technology. Process improvements are needed to improve repeatability, yield, and performance precision of current devices;
- Development of instruments to perform broad-band sensing of wavefronts and distinguish amplitude and phase in the wavefront;
- Adaptive optics actuators, integrated mirror/actuator programmable deformable mirror;
- Reliability and qualification of actuators and structures in deformable mirrors to eliminate or mitigate single actuator failures;
- Multiplexer development for electrical connection to deformable mirrors that has ultra-low power dissipation;
- High precision wavefront error sensing and control techniques to improve and advance coronagraphic
imaging performance; and

- Highly reflecting broadband coatings.

Sub Topics:

- Precision Deployable Optical Structures and Metrology Topic S2.03

Planned future NASA Missions in astrophysics, such as the Single Aperture Far-IR (SAFIR) telescope, Life Finder, and Submillimeter Probe of the Evolution of Cosmic Structure (SPECS), and the UV Optical Imager (UVOIR) require 10 - 30 m class cost effective telescopes that are diffraction limited at wavelengths from the visible to the far IR, and operate at temperatures from 4 - 300 K. The desired areal density is 1 - 10 kg/m². Static and dynamic wavefront error tolerances may be achieved through passive means (e.g., via a high stiffness system) or through active control. Potential architecture implementations must package into an existing launch volume, deploy and be self-aligning to the micron level. The target space environment is expected to be L2.

This topic solicits proposals to develop enabling, cost effective component and subsystem technology for these telescopes. Research areas of particular interest include precision deployable structures and metrology (i.e., innovative active or passive deployable primary or secondary support structures); innovative concepts for packaging fully integrated (i.e., including power distribution, sensing, and control components); distributed and localized actuation systems; deployment packaging and mechanisms; active control distributed on or within the structure (downstream corrective and adaptive optics are not included in this topic area); actuator systems for alignment of reflector panels (order of cm stroke actuators, lightweight, submicron dynamic range, nanometer stability); mechanical, inflatable, or other deployable technologies; new thermally-stable materials (CTE

Also of interest are innovative metrology systems for direct measurement of the optical elements or their supporting structure; requirements for micron level absolute and subnanometer relative metrology for tens of points on the primary mirror; measurement of the metering truss; and innovative systems which minimize complexity, mass, power and cost.

The goal for this effort is to mature technologies that can be used to fabricate 20 m class, lightweight, ambient or cryogenic flight-qualified telescope primary mirror systems. Proposals to fabricate demonstration components and subsystems with direct scalability to flight systems (concept described in the proposal) will be given preference. The target launch volume and expected disturbances, along with the estimate of system performance, should be included in the discussion. A successful proposal shows a path toward a Phase 2 delivery of demonstration hardware on the scale of 3 m for characterization.
This subtopic solicits technology for collecting and controlling star light with advanced optical telescopes and telescope arrays. This topic includes innovative optical subsystems, devices and components that directly collect and process optical signals and images for all regions of the electromagnetic spectrum from X-ray to UV to Visible to Far-IR/Sub-MM. Pre-detection technologies of interest include capabilities to preprocess or analyze an optical wave front or signal to extract time-dependent, spectral, polarization and spatial information from scenes or signals prior to detection. Specific technology area of interest include high reflectance UV coatings and uniform polarization coatings for all wavelengths; high angular resolution imaging enabled via large-baseline segmented-aperture telescopes and sparse aperture telescopes/interferometers; component-level technology needed to enable the characterization and combination of wavefronts from multiple apertures. Innovative technology to integrate, assemble, align and control test large aperture segmented mirrors for x-ray, ambient and cryogenic applications.

Proposed effort must address technical need of a recognized future NASA space science mission, science measurement objective or science sensor for a Discovery, Explorer, Beyond Einstein, Origins, GOESS, New Millennium, Landmark-Discovery, or Vision mission. Specific missions of interest include the following: Constellation-X (http://constellation.gsfc.nasa.gov/ [8]); Terrestrial Planet Finder (http://planetquest.jpl.nasa.gov/TPF/tpf_index.cfm [9]); Single Aperture Far-Infrared (http://safir.jpl.nasa.gov/technologies.shtml [1]).

Proposed effort should be conducted to demonstrate technical feasibility during Phase 1 and show a path toward a Phase 2 breadboard or prototype demonstration.

Proposals in the following areas are specifically solicited:

- Optical coatings: broad-band polarization preserving and polarizing for UV to Far-IR/Sub-MM; high-reflectivity EUV; large area, high acceptance angle narrow-band optical filters; broad-band wide-acceptance angle UV anti-reflection on PMMA substrates; environmentally stable protected silver.

- High throughput, radiation hard, large area, X-ray imaging devices such as Fresnel Zone plates and masks.

- Innovative mounting/support and metrology/control technologies to integrate, assemble, align and control large aperture lightweight low-cost segmented mirrors for x-ray, ambient and cryogenic normal incidence applications - also, systems with extreme alignment tolerances such as PIAA.

- Techniques to mitigate optical surface errors includes phase retrieval and wavefront sensing and control techniques and instrumentation, optical systems with high-precision controls, active and/or adaptive mirrors, shape control of deformable telescope mirrors, and image stabilization systems; techniques to sense/control segmented primary mirrors.

- Techniques to combine beams for wavelength-resolved fringe measurements from a large number of independent apertures with flat response over a broad wavelength range.
Sub Topics:
Optics Manufacturing and Metrology for Telescope Optical Surfaces Topic S2.05
This year's 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, but are not limited to, Constellation-X (http://constellation.gsfc.nasa.gov/ [8]), TPF (http://planetquest.jpl.nasa.gov/TPF/tpf_index.cfm [9]), and SAFIR (http://safir.jpl.nasa.gov/technologies.shtml [1]). Optical systems currently being researched for these missions are large area aspheres, requiring accurate figuring and polishing across six orders of magnitude in period (i.e., 1st and 2nd order errors through micro-roughness). 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 (i.e., 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.

By the end of a Phase 2 program, technologies must be developed to the point where the technique or instrument can dovetail into an existing optics manufacturing facility producing optics at the R&D stage. Metrology instruments must have 10 nm or better surface height resolution and span at least 3 orders of magnitude in lateral spatial frequency.

Examples of technologies and instruments of interest include:

- Interferometric nulling optics for very shallow conical optics used in x-ray telescopes (segmented systems commonly span 60 degrees in azimuth and 200 mm axial length and cone angles vary from 0.1 to 1 degree);
- Low stress metrology mounts that can hold very thin optics without introducing mounting distortion;
- Low normal force figuring/polishing systems operating in the 1 mm to 50 mm period range with minimal impact at significantly smaller and larger period ranges;
- In situ metrology systems that can measure optics and provide feedback to figuring/polishing instruments without removing the part from the spindle;
- Innovative mirror substrate materials or manufacturing methods that produce thin mirror substrates that are stiffer and/or lighter than existing materials or methods;
- Extreme aspheric and/or anamorphic optics for pupil intensity amplitude apodization (PIAA).
Sub Topics:
Avionics and Electronics Topic S3.01

NASA's space based observatories, fly by spacecraft, orbiters, landers, and robotic and sample return missions, require robust Command and Control capabilities. Advances in technologies relevant to guidance, navigation, command and data handling are sought to support NASA's goals and several missions and projects under development, including the New World Observer, GEO Quick Ride and Radiation Hardened Electronics for Space Environments (RHESE).

The subtopic goals are to: (1) develop high-performance processors and memory architectures and reliable electronic systems and (2) develop precision line-of-sight sensing for large telescopes and spacecraft formations. 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 vision of the Science Mission Directorate (SMD).

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

Command and Data Handling

- Processors - General purpose (processor chips and radiation-hardened by design synthesizable IP cores) and special purpose single-chip components (DSPs and FPGAs) with sustainable processing performance (>500 MIPS), power efficiency (>100 MIPS/W) and radiation tolerance, including the tools to support the software flow.
- Radiation hardened: low power memories and Ethernet physical layer components.
- Models for analysis of interplanetary radiation and radiation belts, and technologies enabling in-flight total dose and single event radiation measurements.

Guidance Navigation and Control

- Navigation systems (including multiple sensors and algorithms/estimators, possibly based on existing component technologies) that work collectively on multiple vehicles to enable inertial alignment of the formation of vehicles (i.e., pointing of the line-of-sight defined by fixed points on the vehicles) on the level of milli-arcseconds relative to the background star field.
- Light-weight sensors (gyroscopic or other approach) to enable milli-arcsecond class pointing measurement
for individual large telescopes.

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

Sub Topics:

Thermal Control Systems Topic S3.02

Future Spacecraft and instruments for NASA's Science Mission Directorate will require increasingly sophisticated thermal control technology. Research should be conducted to demonstrate technical feasibility during Phase 1 and show a path toward a Phase 2 demonstration, and when possible, deliver a demonstration unit for functional and environmental testing at the completion of the Phase 2 contract. Innovative proposals for thermal control technologies are sought in the following areas:

- Optical systems, lasers, and detectors require tight temperature control, often to better than +/- 1°C. Some new missions such as CON-X and LISA require thermal gradients held to micro-degree levels. Methods of precise temperature measurement and control to this level are needed.

- Heat flux levels from lasers and other high power devices are increasing, with some projected to go as high as 100 W/cm², especially for proposed wind/Lidar missions. They will require thermal technologies such as spray and jet impingement cooling. Also, high conductivity, vacuum-compatible interface materials will be needed to minimize losses across make/break interfaces.

- Future missions such as TPF will use large structures, like mirrors and detector arrays, at both ambient and cryogenic temperatures. Some anticipated technology needs include: advanced thermoelectric coolers capable of providing cooling at ambient and cryogenic temperatures, high conductivity materials to minimize temperature gradients and provide high efficiency light-weight radiators, and advanced thermal control coatings such as variable emittance surfaces and coatings with a high emissivity at ambient and cryogenic temperatures.

- Future advanced spacecraft present engineering challenges requiring systems which are more self-sufficient.

Some of the technology needs are:

- Single and two-phase mechanically pumped fluid loop systems which accommodate multiple heat sources and sinks, and long life, lightweight pumps for these systems;

- Efficient, lightweight vapor compression systems for cooling up to 2 KW;

- Advanced thermal modeling techniques that can be easily integrated into existing codes, emphasizing inclusion of two-phase system and mechanically pumped system models;

- Integration of standardized formats into existing codes for the representation and exchange of Thermal Network Models and Thermal Geometric Models and results.
Sub Topics:

Power Generation and Storage Topic S3.03

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

Advanced Photovoltaic Energy Conversion

- Photovoltaic cell and array technologies with significant improvements in efficiency (>30%), mass specific power (>600W/kg), stowed volume, cost, radiation resistance, and wide operating conditions are solicited;
- Photovoltaic cell technologies for low intensity, low-temperature operation (LILT) are solicited;
- Array technologies of interest are concentrators, deployable arrays, ultra-lightweight arrays for flexible, thin-film cells, and electrostatically-clean solar arrays.

Stirling Power Conversion

Novel methods or approaches for radiation-tolerant, sensorless, autonomous control of the Stirling converters with very low vibration and having low mass, size, and electromagnetic interference (EMI). Technologies of interest include:

- High-temperature, high-performance regenerators;
- High-temperature, lightweight, high-efficiency, low EMI, linear alternators;
- High-temperature heater heads (> 850°C) and joining techniques.

Energy Storage

Energy storage requirements for Science mission are: >10,000 charge/discharge cycles for LEO spacecraft, as low as 40K low-temperature storage/operation for planetary missions, and high mass specific power for small spacecraft. Energy storage technologies that enable one or more of the above requirements are of interest. Technologies of interest include:

- Fuel cells;
• Batteries including structural batteries;
• Integrated power systems (generation/storage/control integrated into one module).

Power Management and Distribution

Advanced electrical power technologies are required for the electrical components and systems on future platforms to address the size, mass, efficiency, capacity, durability, and reliability requirements. In addition to the above requirements, proposals must address the expected improvements in energy density, speed, efficiency, or wide-temperature operation (-125°C to 200°C) with a high number of thermal cycles. Advancements are sought in power electronic devices, components, and packaging. Technologies of interest include:

• Power electronic components and subsystems;
• Power distribution;
• Fault protection;
• Advanced electronic packaging for thermal control and electromagnetic shielding.

Sub Topics:
   Propulsion Systems Topic S3.04
The Science Mission Directorate (SMD) needs spacecraft with ever-increasing propulsive performance and flexibility for ambitious missions requiring high duty cycles and years of operation. Planetary spacecraft need the ability to rendezvous with, orbit, and conduct in situ exploration of planets, satellites and other solar system bodies. Platforms, satellites, and satellite constellations have high-precision propulsion requirements, usually in volume- and power-limited envelopes. This subtopic seeks innovations to meet SMD propulsion requirements, reflecting the goals of NASA’s In-Space Propulsion Technology program to reduce the travel time, mass, and cost of SMD spacecraft. Propulsion areas include chemical and electric propulsion systems, propulsion technologies related to sample return missions to asteroids, comets, and other small bodies, propellantless options (such as aerocapture and solar sails), and less developed but emerging propulsion concepts such as advanced plasma thrusters and momentum exchange/electrodynamic reboost (MXER) tethers.

Specifically, innovations are sought in the following areas:

• Characterization of high strength fibers and compatible resins for composite overwrapped pressure vessels (COPVs) for use in higher-pressure, in-space propulsion systems. Of particular interest are fiber/resin systems exhibiting high uniformity of mechanical properties and high resistance to debonding.
• Improved capability and reduced cost of low- to medium-power electric propulsion systems, including power processing, long-life, high-efficiency cathodes and neutralizers, low-erosion materials for ion optics
and Hall discharge chambers, plume mitigation, and next generation thrusters.

- Thin film materials, elastomeric materials, and/or high temperature fabrics for inflatable decelerator concepts used in aerocapture applications at planetary destinations. The decelerator will be stowed for many years (up to 10 years) in an uncontrolled space environment (-130°C). The inflatable decelerator will experience temperatures up to 500°C during the aerocapture maneuver. Materials of particular interest include polyimide thin films, polybenzobisoxazole (PBO) thin films, and ceramic fabrics.

Sub Topics:
Terrestrial Balloon Technology Topic S3.05

The Balloon Program Office (BPO) is soliciting innovations in two specific areas:

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

Tendons are the load carrying member in the pumpkin design. During a typical mission, loading on individual tendons should not exceed a critical design limit to insure structural integrity and survival. A key technology challenge is the development of devices or methods to accurately and continuously measure individual axial loading on an array of up to 200 separate tendons during a ULDB mission. Tendons are typically captured at the fitting via individual pins. Loading levels on the tendons can range from ~20 N to ~8,000 N and temperature can vary from room temperature to the troposphere temperatures of -90ºC or colder. The devices of interest shall be easily integrated with the tendons or fittings during balloon fabrication and shall have minimal impact on the overall mass of the balloon system.

Ambient air, helium gas, and balloon film temperature measurements are needed to accurately model the balloon performance during a typical flight at altitudes of approximately 120,000 feet. The measurement must compensate for the effects of direct solar radiation through shielding or calculation. Minimal mass and volume are highly desired. For film measurement, a non-invasive and non-contact approach is highly desired for the thin polyethylene film, with film thickness ranging from 0.8 to 1.5 mils, used as the balloon envelope.

(2) The Balloon Program Office is also seeking innovations to reduce the effects of parachute opening shock on gondolas and balloon subsystems. This shock is produced by the rapid opening of a flight system's parachute after the payload is released from the balloon at mission termination.
Innovations may address the problem either by reducing the termination shock via modifications to the recovery system or by attenuating the shock produced by current recovery systems. Proposed technologies will be evaluated for their mass efficiency, ease of integration, effectiveness at reducing shock levels, compatibility with balloon flight environments, and cost effectiveness, among other factors.

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

Sub Topics:

NanoSat Launch Vehicle Technologies Topic S4.01
The space transportation industry is in need of low-cost, reliable, on-demand, routine space access. Both government and private entities are pursuing various launch systems and architectures aimed at addressing this market need. Significant technical risk and cost exists in new system development and operations - reducing incentive for private capital investment in this still-nascent industry. Public and private sector goals are aligned in reducing these risks and enabling the development of launch systems capable of reliably delivering payloads to low Earth orbit. The NanoSat Launch Vehicle Technology subtopic will particularly focus on higher risk entrepreneurial projects for dedicated nano and small spacecraft launch vehicles.

This subtopic is seeking proposals in the following, but not limited, areas:

- Conceptual designs of system/architectures capable of reducing the mission costs associated with small payload delivery to LEO.
- Maturation of low-cost propulsion systems using low-cost materials, and/or low-cost manufacturing processes.
- Maturation of low-cost propulsion systems using storable and environmentally friendly non-toxic propellants.
• Innovative propulsions system solutions, including robust integrated micro-propulsion systems for both primary propulsion, as well as on-board satellite propulsion.

• Maturation of hypersonic and small launch vehicle design and analysis tools or tool-sets aimed at increasing the state-of-the-art while reducing the required design cycle time and human interaction.

• Maturation of key technologies/processes for hypersonic and small launch vehicles including, but not limited to:
  o Thermal Protection Systems;
  o Airframe and subsystem structures that increase system performance and propellant mass fraction;
  o Vehicle Sensor Networks.

• Novel, low-cost modular adapters and release mechanisms.

• Lightweight interstage designs.

Applications of wireless networking technologies for small launch vehicles are also specifically of interest to this subtopic. This technology could be used for vehicle to ground communications (spread-spectrum and non-licensed technologies), as well as within the vehicle itself. We desire new architectures for intelligent on-board communications as well as satellite-to-satellite communication using machine-to-machine (M2M) solutions. The traditional wire harness architecture could be replaced by the wireless technology for command and control, which would reduce vehicle mass and improve reliability. Also stage-to-stage interfaces and vehicle-payload interfaces are of interest. These wireless technologies can include but are not limited to WIMAX™ and ZIGBEE™.

Non-propulsive approaches and architectures for new launch vehicles can also achieve increases in launch vehicle payload mass delivered to orbit for small spacecraft missions. Offerors should consider development, test, and operational factors to show improvements in development and operational costs, payload mass fraction, and mission assurance. Special attention should be given to improved integration between the launch vehicle and payloads to further reduce operational costs. Furthermore, non-propulsive launch vehicle technologies have a dramatic impact on launch vehicle performance and constitute a large percentage of development and operational costs. They include, but are not limited to:

• Robust On-Board Guidance, Navigation and Control (GN&C) avionics. GN&C should be modular (including modular software architectures) and make use of modern architectures, including high-performance low-weight avionics hardware, and modern software tools. Emphasis is on low-weight architecture to allow maximum payload capacity.

• Range safety solutions and operational concepts to lower costs. These may include alternative solutions to expensive explosive destruct packages, including, but not limited to propulsion-cutoff systems, autonomous flight-abort systems, etc.

Phase 1 - Research should demonstrate the technical feasibility and show a path towards a hardware/software demonstration. Plan a demonstration to validate the technologies/tools/processes. Bench or lab-level demonstrations showing concept viability is encouraged. Commercial applicability should be addressed.
Phase 2 - Emphasis should be placed on developing and demonstrating the technology under relevant test conditions. Additionally, a path should be outlined that shows how the technology could be commercialized or further developed into space-worthy systems. When applicable, researchers should deliver a demonstration unit for functional and environmental testing at the completion of the Phase 2 contract.

Sub Topics:
Secondary and Tertiary Launch Technologies Topic S4.02

There are a growing number of secondary and tertiary flight opportunities for small spacecraft. These include Dual Payload Attach Fitting (DPAF) for the Delta launch vehicle, the EELV Secondary Payload Adapter (ESPA), as well as tertiary opportunities for spacecraft that are bolted to the upper stage of a booster (as was the case with GeneSat on the Minotaur launch vehicle). The Secondary and Tertiary Launch Technologies subtopic will particularly focus on adaptor and deployment technologies.

We specifically desire low-cost modular DPAF and ESPA solutions, which can be adapted for various nano and small-satellites. Solutions should have minimal impact on cost and schedule, protect the primary payload, and have clear and achievable paths to certification. Topics include, but are not limited to:

- Gentle non-explosive separation mechanisms;
- Autonomous or on demand deployment with built-in safety factors;
- Robust, low-weight, and low-cost innovative deployment architectures for large numbers of nano- and small-satellites into predefined orbits.

Phase 1 - Research should demonstrate the technical feasibility and show a path towards a hardware/software demonstration. Plan a demonstration to validate the technologies/tools/processes. Bench or lab-level demonstrations showing concept viability is encouraged. Commercial applicability should be addressed.

Phase 2 - Emphasis should be placed on developing and demonstrating the technology under relevant test conditions. Additionally, a path should be outlined that shows how the technology could be commercialized or further developed into space-worthy systems. When applicable, researchers should deliver a demonstration unit for functional and environmental testing at the completion of the Phase 2 contract.
Sub Topics:
Low-Cost, Rapid Spacecraft Design and Multi-Subsystem Functionality Topic S4.03
To achieve low-cost small spacecraft missions, the resources necessary for the conceptual and detailed design of the spacecraft should be proportional to other phases of the successful project. Novel approaches are encouraged to re-use development from other projects and design current projects with the foresight to be reused for future flight projects. The Low-Cost, Rapid Spacecraft Design and Multi-Subsystem Functionality subtopic encourages offerors to utilize open source software and hardware solutions to be utilized for other actors, including entrepreneurial and university teams, for reusability.

This subtopic is seeking proposals in the following, but not limited, areas:

- Methods and tools to enable a geographically distributed, concurrent design of system concepts and functions.

- Dynamic, open source, on-line database and collection system of COTS components and subsystems suitable for spacecraft - a database of components open to the public, can be used for conceptual design and to determine an accurate Master Equipment List (MEL), cost, and schedule based on the current market value and lead time for the components; a prospective model. Such a database should include an API where companies can:
  - Plug into a design tool, whether open source or proprietary, to utilize the database for a prospective model;
  - Link to their components already publicized on their own webpage to collect the data on one centralized location;
  - Utilize database to extend options from a proprietary database of components or designs.

- Modular and scalable subsystem design of spacecraft.

- Consolidation of spacecraft functions to reduce mass, power, volume and interfaces (i.e., multi-functionality) - integrating the functions of two or more onboard disciplines such as structure/mechanical, power, avionics, telecommunications, propulsion, thermal control and attitude control and determination. Also consider cross-functional spacecraft-to-payload capabilities in the areas of attitude determination, navigation, telecommunications and other mission level functions.

- Internal wireless data and command communications systems that alleviate need for wire harness.

Phase 1 - Research should demonstrate the technical feasibility and show a path towards a hardware/software demonstration. Plan a demonstration to validate the technologies/tools/processes. Bench or lab-level demonstrations showing concept viability is encouraged. Commercial applicability should be addressed.
Phase 2 - Emphasis should be placed on developing and demonstrating the technology under relevant test conditions. Additionally, a path should be outlined that shows how the technology could be commercialized or further developed into space-worthy systems. When applicable, researchers should deliver a demonstration unit for functional and environmental testing at the completion of the Phase 2 contract.

Sub Topics:

Project Management, Systems Engineering and Mission Assurance Tools Topic S4.04

For cost effective management of multiple complex low-cost small spacecraft projects using distributed teams, management tools are required that integrate the various elements of management, systems engineering, and risk and mission assurance data. This subtopic is seeking tools where members of a spacecraft team are able to exchange technical information and capture the salient decisions, trades, dependencies, etc. For a tool to be effective, it must make the job for each team member easier. There should be customizable views for each member so they are able to see the data that affects their job. This subtopic is seeking tools that:

- Simplify data integration resulting in top level roll-up or "dashboard" views as well as provide manager-friendly deep-drilling capability when depth of technical insight is required.

- Directly reflect the management and reporting requirements for NASA projects as defined in NPR7120.5D, NPR 7123.1A, NPR 8000.4, and related standards and directives.

- Facilitate or automate data entry for the Project Manager, Systems Engineer, and Risk and Mission Assurance Manager through secure web-based interfaces.

- Perform data integrity checks at the time of entry and upon request. Include automated e-mail notification of data integrity problems to responsible parties.

- Provide common-interface input portals and data library structures for data uploading from each project WBS element.

- Provide manager-controlled cross-linking of access to data resources from WBS to WBS.

- Provide the ability to specify and automatically generate and update metric and trend reporting on key performance measures, quantities and changes in requirements, documents, configuration items, risk databases, and cost tracking including Earned Value Management metrics and schedule critical path and resource loading metrics.

- Make it possible for reasonably experienced managers to train themselves on tool use.

- Provide data entry and presentation interfaces that are reliable, accepting and presenting data without lengthy uploads or downloads.

- Provide simple, user-modifiable linking to related, keyword searchable archives.
- Provide data translation and capture tools for integration of any data that can be provided in spreadsheet formats or common text documents.

- Aid in building re-usable reporting formats linked to data resources including metric analysis data, snapshots of discipline-specific report sheets, standard subsystem progress reports, and other manager specified data.

- Provide integrated management and team support tools such as Action Item tracking including automatic e-mail alerts to individual and groups, and customizable tracking status schemes.

Data resources to be linked include cost tracking spreadsheets, task plans, risk management databases, requirements databases, technical performance metrics and margins sheets, top level and WBS element schedules, and standard monthly status reports from WBS elements. The tool should be easily scalable for large or small projects and the number of WBS elements and features included or excluded for a given project should be user-selectable. User and group permission and access controls are required.

Phase 1 - Research should provide examples of proven cost benefits and project successes based on the use of integrated management tools for management of multiple simultaneous distributed projects. Architectures should be proposed for implementation of an integrated multi-project management tool.

Phase 2 - A management tool set will be implemented and demonstrated as part of an actual small satellite management project. The tool will be evaluated for ease of use, effectiveness as a NASA project set-up tool, management information tool, and reporting tool. Feasibility for a single manager to effectively manage and report on multiple simultaneous projects will be assessed. Project users from the WBS elements of the satellite project will evaluate ease of use of uploading data.

Sub Topics:

Smart, Autonomous Command and Data Handling System, Algorithms and Data Management Topic S4.05

The cost of flight software, including algorithms and data management, is continuing to increase and multiply in complexity. Novel on-board data analysis can greatly decrease the bandwidth needed back to Earth, and can alert scientists for time sensitive information and follow-up investigations.

This subtopic is seeking proposals in the following, but not limited, areas:
• Innovative flight software development techniques
  ○ Planning and scheduling software
  ○ Modular routines for repeatability on future missions.
• Autonomous fault tolerant software development that acts in a repeatable, predictable manner.
• Automated system level testing.
• On board automated approaches for data compression and payload data analysis to enable low bandwidth communications to the ground station.
• Participatory, distributed analysis techniques utilizing public interest and resources (e.g., Stardust @ Home and HiRise data analysis).

Phase 1 - Research should demonstrate the technical feasibility and show a path towards a software demonstration. Bench or lab-level demonstrations showing concept viability is encouraged. Commercial applicability and modularity should be addressed.

Phase 2 - Emphasis should be placed on developing and demonstrating the software technology under relevant test conditions. Additionally, a path should be outlined that shows how the technology could be commercialized or further developed into space-worthy systems. Researchers should deliver a demonstration package for functional evaluation by NASA at the completion of the Phase 2 contract.

Sub Topics:
  Advanced Avionics Topic S4.06
This subtopic is seeking proposals to reduce the cost, mass, size, power and complexity of current spacecraft avionics systems, including processors, switch boxes, payload control units, mass storage devices, star trackers, IMUs, and power converters to support smaller (micro and nano) class space vehicles.

NASA has been studying methods to assemble space missions quicker and in a more straightforward manner using “plug and play” (PnP) approaches. Modern plug-and-play includes both the traditional boot-time assignment of I/O addresses and interrupts to prevent conflicts and identify drivers, as well as hot plug systems such as USB and Firewire. This SBIR will explore the hallmarks of next-generation avionics. A major challenge to achieving a usable and useful low cost small mission is the ability to rapidly compose the system to perform both the needed mission functionality using the available spacecraft components. Physical assembly of the PnP spacecraft components is a necessary, but insufficient condition for achieving a system. The assembled system needs to provide the functional capabilities to support the intended mission and also needs to provide the functional capabilities to ensure the operational health and safety of the resulting space mission. A preliminary architectural model to provide a reusable infrastructure is requested as part of effort this supports hard real time, soft real time and non-real time processes.
The objective of this SBIR effort is to prove the viability of modular, plug and play (PnP) spacecraft avionics architecture. This revolutionary architecture provides a near-term solution to modular, plug and play avionics while distributing power and data management functions. It enables full PnP modularity reducing spacecraft integration and test to a few days.

Areas of interest include:

- Low cost open architecture avionics systems;
- Plug and Play adapters that facilitate transition from traditional point to point proprietary control to an open architecture industry standard interface both hardware and software;
- Validate components by producing low cost standard plug and play components including processors, switch boxes, payload control units, mass storage devices, star trackers, IMUs, and power converters.

Phase 1 - Research should identifying and evaluating candidate telecommunications technology applications to demonstrate the technical feasibility and show a path towards a hardware/software demonstration. Plan a demonstration to validate the technologies/tools/processes. Bench or lab-level demonstrations showing concept viability is encouraged. Commercial applicability should be addressed.

Phase 2 - Emphasis should be placed on developing and demonstrating the technology under simulated flight conditions. Additionally, a path should be outlined that shows how the technology could be commercialized or further developed into space-worthy systems defining interfaces (both on the spacecraft and to candidate ground segments). When applicable, researchers should deliver a demonstration unit for functional and environmental testing at the completion of the Phase 2 contract.

Sub Topics:
  Mini-Micro Thrusters, LOX / Hydrocarbon Propulsion, and Attitude Control Systems Topic S4.07
This subtopic is seeking proposals that explore uses of technologies that will provide superior performance in attitude control and overall orbit control.
Propellants play a vital role. The use of liquid oxygen / liquid hydrocarbon fuel (e.g., liquid propylene (LP) in small spacecraft for implementing attitude control and for orbital maneuvers is of interest. This subtopic is looking for candidate fuels that have superior performance to kerosene for on-orbit applications including storage stability and propulsion.

This subtopic is also seeking proposals in the following, but not limited, areas:

- Low-cost reaction wheels;
- Low-mass micro-propulsion systems;
- Propulsion systems that allow transfers from LEO or GTO to lunar orbit or other destinations;
- Propellantless means to achieve delta-V (e.g., momentum exchange, electrodynamic interaction with the Earth’s magnetosphere) as a viable Cis-Lunar transport system;
- Flexible and modular (i.e., non-customized) tankage that is scalable to accommodate multiple mission delta-V requirements without safety and design re-qualification for each mission.

Phase 1 - Research should demonstrate the technical feasibility and show a path towards a hardware/software demonstration. Plan a demonstration to validate the technologies/tools/processes. Bench or lab-level demonstrations showing concept viability is encouraged. Commercial applicability should be addressed.

Phase 2 - Emphasis should be placed on developing and demonstrating the technology under relevant test conditions. Additionally, a path should be outlined that shows how the technology could be commercialized or further developed into space-worthy systems. When applicable, researchers should deliver a demonstration unit for functional and environmental testing at the completion of the Phase 2 contract.

Sub Topics:
Low-cost Assembly, Integration, and Testing Topic S4.08
Current programs take a step-wise approach to various phases of space missions that may lead to inconsistencies between conceptual development, design, assembly, integration, testing, and operations. This subtopic seeks to integrate these phases by providing a consistent software/hardware environment for spacecraft development to operations. Extensible/modular, standards-based, and COTS solutions for software and hardware to improve transition through the various phases, especially transition to operations, is highly encouraged.
One of the potential benefits of small spacecraft missions is transformation of the payload integration process. Traditionally payloads and experiments were delivered to payload integration facilities that were geographically close to the launch site.

This subtopic is looking for ways to streamline this process by reducing the need for this activity to be carried out to close proximity to the launch site. This will result in integration occurring at home facilities and reduced lead times due to a decrease in associated planning activities.

Similarly, to facilitate integration of spacecraft subsystems when using COTS products from multiple vendors, integration of the spacecraft subsystems themselves could benefit from the early use of flexible-standard smart interfacing hardware that can accommodate an array of interface standards including Ethernet, Spacewire™, USB 2.0, RS-422, and I2C.

This subtopic is seeking proposals in the following, but not limited, areas:

- Automated test equipment / automated Breakout boxes;
- Testing of subsystems in geographically distributed locations;
- Standardized interfaces with launch vehicles with frequent launch opportunities.

Phase 1 - Research should demonstrate the technical feasibility of systems-level approach to streamlining processes while simultaneously improving program consistency, repeatability, improved testing, and lower cost. Additionally, the scope of Phase 1 includes identification and evaluation of these alternative subsystem integration, test, and payload processing architectures, as well as the associated payload accommodations hardware and technologies that might be required. Commercial applicability should be addressed.

Phase 2 - Emphasis should be placed on developing and demonstrating the technology under test conditions based on emerging nanosat and small launch vehicles now in development or integration with secondary and tertiary payload launch opportunities. Additionally, a path should be outlined that shows how the technology could be commercialized or further developed into space-worthy systems. When applicable, researchers should deliver a demonstration unit for testing at the completion of the Phase 2 contract.
Sub Topics:

Autonomous Multi-Mission Virtual Ground and Spacecraft Operations Topic S4.09

Future ground and spacecraft operations for low-cost spacecraft missions must decrease the complexity, cost, and human intervention required for successful operations of missions.

This subtopic is seeking proposals in the following, but not limited, areas:

- Virtual ground stations;
- Internet-based protocol modules and architectures that will provide seamless network command and control continuity between terrestrial and space-based platforms and environments;
- Autonomous lights-out ground control software (e.g., the ground station operates autonomously without human intervention, and can have remote access);
- Alternate Ground station approaches (e.g., Antenna Arrays or Amateur Radio bands);
- Networked operations of distributed ground stations (e.g., University consortium);
- Software/methods enhancing multiple-mission consolidated operations.

Phase 1 - Research should demonstrate the technical feasibility and show a path towards a hardware/software demonstration. Plan a demonstration to validate the technologies/tools/processes. Bench or lab-level demonstrations showing concept viability is encouraged. Commercial applicability should be addressed.

Phase 2 - Emphasis should be placed on developing and demonstrating the technology under relevant test conditions. Additionally, a path should be outlined that shows how the technology could be commercialized or further developed into space-worthy systems. When applicable, researchers should deliver a demonstration package for functional and environmental testing at the completion of the Phase 2 contract.
Sub Topics:
Extreme Environments Technology Topic S5.01

High temperature, high pressure, and chemically corrosive environments:

Proposals are sought for technologies that enable the in situ exploration of the surface and deep atmosphere of Venus and the deep atmospheres of Jupiter or Saturn for future NASA missions. Venus features a dense, CO$_2$ atmosphere completely covered by sulfuric acid clouds at about 55 km above the surface, a surface temperature of about 486ºC and a surface pressure of about 90 atmospheres. Although already explored by various orbiters and short-lived atmospheric probes and landers, Venus retains many secrets pertaining to its formation and evolution. NASA is interested in expanding its ability to explore the deep atmosphere and surface of Venus through the use of long-lived (days or weeks) balloons and landers. Survivability in extreme high temperatures and high pressures is also required for deep atmospheric probes to giant planets. Technology advancements to permit operation and survivability in high-temperature/high-pressure planetary environments are sought in the following areas:

Thermal Control Systems: Survivability of electronic components in high temperature environments relies on three basic areas of thermal control: isolation, thermal capacitance and/or refrigeration. Specific improvements in are sought in the development of:

- Thermal energy storage systems with 300 - 1000 kJ/kg energy density through either phase changes or chemical heat absorption;
- High performance, low mass refrigeration cooling systems capable of pumping on the order of 100 Watts of heat from a 100ºC source to the Venus sink temperature of 486ºC. In this area, particular attention must be paid to the power source for such a system. A total systems approach must be considered as opposed to development of a particular component.

Pressure Vessel Components:

- Optical Window systems that are transparent in IR, Visible and UV wavelengths at Venus surface temperatures that remain sealed under expected mission temperature variations from -50ºC to 486ºC and from external pressure variation from 0 to 90 atmospheres.
- Pressure vessel flange seal technology compatible with materials such as stainless steels, titanium and beryllium. Seals shall exhibit leakage rates lower than 10-5 cc He/sec over the expected mission temperature variations from -50ºC to 486ºC and from external pressure variation from 0 to 90 atmospheres. Clamping loads for the seals shall be less than 1500 pounds per linear inch.

Low temperature environments:
Moon equatorial regions experience wide temperature swings from -180°C to +130°C during the lunar day/night cycle, and the sustained temperature at the shadowed regions of lunar poles can be as low as -230°C. Mars diurnal temperature changes from about -120°C to +20°C. Low temperature survivability is also required for missions to Titan, surface of Europa and comets. Proposals are sought in the following specific areas:

- Wide temperature (-180°C to +130°C) and low-temperature (-230°C), radiation-tolerant and SEL immune, low power, mixed-signal circuits including analog-to-digital converters, digital-to-analog converters, low-noise pre-amplifiers, voltage and current references, multiplexers, power switches, microcontrollers, and integrated command/control/drive electronics for sensors, actuators, and communications transponders.

- Computer Aided Design (CAD) tools for predicting the electrical performance, reliability, and life cycle for low-temperature electronic systems and components.

- Physics-based transistor device models valid at temperature ranging from -230°C to +130°C to enable design, verification and fabrication of custom low power mixed-signal and analog circuits.

- Low-temperature (-230°C) circuit design methodologies facilitating novel layout designs for integrated mixed-signal and analog circuits.

- Selected hardware and support technologies for motors, drive systems and related mechanisms that will operate in low temperature environments. Specific areas of interest include gear boxes, suspension systems, material components (i.e., wiring, harnesses, insulating materials, and jackets/covers) that can operate in cryogenic environments; advanced lubricants and lubrication technology.

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

Sub Topics:

Planetary Entry, Descent and Landing Technology Topic S5.02

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

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

- Providing critical measurements during the entry phase (e.g., pressure and/or temperature sensors embedded into the aeroshell);
- Improving the accuracy on measurements needed for guidance decisions (e.g., surface relative velocities, altitudes, orientation, localization);
- Extending the range over which such measurements are collected (e.g., providing a method of imaging through the aeroshell, or terrain-relative navigation that does not require imaging through the aeroshell);
- Enhancing the situational awareness during landing by identifying hazards (rocks, craters, slopes), or providing indications of approach velocities and touchdown;
- Substantially reducing the amount of external processing needed to calculate the measurements; and
- Significantly reducing the impact of incorporating such sensors on the spacecraft in terms of volume, mass, placement, or cost.

Sub Topics:
Sample Collection, Processing, and Handling Devices Topic S5.03
Robust systems for sample acquisition from the subsurface of planetary bodies are critical to the next generation of robotic explorers. Limited spacecraft resources (power, volume, mass, computational capabilities, and telemetry bandwidth) demand innovative, integrated sampling systems that can survive and operate in challenging environments (extremes in temperature, pressure, gravity, vibration and thermal cycling).

Research should be conducted to develop compact, low-power, lightweight subsurface sampling systems with access to depths of 1 - 3 m below the surface. A relevant mission scenario for this type of drill would include drilling multiple holes from a mobile platform, such as a rover. For reference, current Mars-relevant rovers range in mass from 200 - 800 kg. Also of interest are integrated systems for 1-10 cm subsurface sampling.

Consideration should be given to potential failure scenarios for integrated systems. For example, recovery and mitigation techniques for platform slip and borehole misalignment should be addressed. Significant attention should be given to the sensing and automation required for real-time control, fault diagnosis and recovery. Additional areas of interest include understanding the limitations of dry drilling into mixed media such as icy mixtures of rock and regolith and hot subsurface materials at high pressure (up to 740 K in a 90 bar CO₂ environment).
Sample manipulation technologies are needed to enable handling and transfer of unstructured samples from a sampling device to instruments and sample processing systems. Shallow rock core and regolith samples may be variable in size and composition so a sample manipulation system needs to be flexible enough to handle the sample variability. Core samples will be on the order of 1 cm diameter and up to 10 cm long. Soil and rock fragment samples will be of similar volumes. Actual samples to be analyzed in instruments will likely be small subsamples so the means for subsampling and manipulation of the original sample and subsamples needs to be developed. Minimal size and mass components and systems have the greatest benefit.

Also of particular need are means of acquiring subsurface rock and regolith samples with minimum contamination. This contamination may include contaminants brought to the sample by the drill itself, material from one stratigraphic layer contaminating samples collected at another depth (sample cross-contamination), or Earth-source microorganisms brought to the Martian surface prior to drilling ('clean' sampling from a 'dirty' surface).

Sub Topics:
Surface and Subsurface Robotic Exploration Topic S5.04
Technologies are needed to enable access to surface and subsurface sampling sites of scientific interest on Mars. Mobility technology is needed to enable access to difficult-to-reach sites such as access through steep terrain. Many scientifically valuable sites are accessible only via terrain that is too steep for state-of-the-art planetary rovers to traverse. Sites include crater walls, canyons, and gullies. Tethered systems, non-wheeled systems, and marsupial systems are examples of mobility technologies that are of interest. Tether technology could enable new approaches for deployment, retrieval and mobility. Innovative marsupial systems could allow a pair of vehicles with different mobility characteristics to collaborate to enable access to challenging terrain. It is envisioned that a 500-800 kg primary vehicle could provide long traverse to the vicinity of a challenging site and then deploy a smaller 20-50 kg vehicle with steep mobility access capability for access to the site.

Technologies to enable subsurface access and sampling in multiple holes at least 1 - 3 meters deep through rock, regolith or ice compositions are also sought. Subsurface access solutions to be integrated onto 500-800 kg stationary landers and mobile platforms are of interest. Consideration should be given for potential failure scenarios, such as platform slip and borehole misalignment for integrated systems, and the challenges of dry drilling into mixed media including icy mixtures of rock and regolith. Systems should ensure minimal contamination of samples from Earth-source contaminants and cross-contamination from samples at different depths.

Innovative low-mass, low-power, and modular systems and subsystems are of particular interest. Technical feasibility should be demonstrated during Phase 1 and a full capability unit of at least TRL level 4-6 should be delivered in Phase 2. Specific areas of interest include the following:
• Tether play-out and retrieval systems including tension and length sensing;
• Low-mass tether cables with power and communication;
• Steep terrain adherence for vertical and horizontal mobility;
• Modular actuators with 1000:1 scale gear ratios;
• Electro-mechanical couplers to enable change out of instruments on an arm end-effector;
• Drill, core, and boring systems for subsurface sampling at 1 to 3 meters.

Sub Topics:
Planetary Balloons and Aerobots Topic S5.05
Innovations in materials, structures, and systems concepts have enabled buoyant vehicles to play an expanding role in NASA's Solar System Exploration Program. Balloons and airships will carry scientific payloads on Mars, Venus, Titan, and the outer planets in order to investigate their atmospheres in situ and their surfaces from close proximity. Their envelopes will be subject to extreme environments and must support missions with a range of durations. Proposals are sought in the following areas:

Aerial Deployment Modeling Tool

Many aerobot concepts for Mars, Titan, and Venus involve the aerial deployment and inflation of the balloon during parachute descent after arrival at the destination. Proposals are sought that would provide computer modeling tools that can simulate this complex process. Of particular importance is the ability to model the balloon shape and material stresses as a function of time, taking into account the aerodynamic forces generated by the parachute and by the uninflated or partially inflated balloon, as well as transient loads during balloon deployment from its storage container. The balloons can be either polymer film or polymer film plus reinforcing fabric laminates.

Metal Bellows for High Temperature Venus Balloons

Cylindrically-shaped metal bellows are a potential solution to the problem of making balloons that can tolerate the 460°C temperatures near the surface of Venus. Commercial off-the-shelf metal bellows are limited in diameter to approximately 0.4 m. NASA seeks proposals for metal bellows technology that can produce prototypes in the range of 1 - 2 m in diameter and 5 - 10 m long; tolerant of sulfuric acid; good fatigue properties at 460°C; and areal densities of up to 1 kg/m².

High Strength Envelope Materials for Titan Aerobots

NASA currently has viable cryogenic balloon materials based on polyester film plus fabric laminates. It is desired to
have new, advanced materials that possess at least a 50% improvement in the strength to weight ratio while retaining comparable flexibility to the current polyester materials. The desired areal densities are in the range of 40-80 g/m² so as to support both superpressure and zero pressure balloon concepts. Of particular interest is the use of existing high strength fiber materials like Vectran, Spectra, Dyneema, PBO and Twaron/Kevlar to achieve the desired performance. Preference will be given to proposals that include significant material sample fabrication and cryogenic testing.

**Ground-launched Mars Balloons**

NASA is interested in small balloons with very light payloads.

---

**Sub Topics:**

Modeling, Simulation and Analysis Technologies Topic S6.01

This subtopic solicits proposals for technologies and systems that allow spacecraft and ground systems to robustly perform complex tasks in dynamic environments with minimal human direction. Areas of interest include support of decision support systems, distributed sensor webs and component systems, and the creation of automation loops connecting scientific modeling and analysis to mission planning, data collection, processing and operations. NASA is moving from a stove-pipe observational architecture to one that permits data interoperability and dynamic coordination of observational assets to generate desired data products. Technology innovations include:

- Automation and autonomous systems that support high-level command abstraction;
- Efficient and effective techniques assessing gaps in data collection to assure complete coverage;
- Intelligent searches of distributed data archives, and data discovery through searches of heterogeneous data sets and architectures; and
- Automation of routine, labor intensive tasks to that either increase reliability or throughput of current process.

Specific areas of interest include the following:
• Search agents that support applications involving the use of NASA data using emerging interoperability such as Sensor Model Language;

• Methods that support the planning and scheduling of sensor webs in support of data product processing when given a set of high-level goals and constraints;

• Autonomous data collection including the coordination of space or airborne platforms while adhering to a set of data collection goals and resource constraints;

• System and subsystem health and maintenance, both space- and ground-based;

• Distributed decision making, using multiple agents, and/or mixed autonomous systems;

• Automatic software generation and processing algorithms; and

• Control of Field Programmable Gate-Arrays (FPGA) to provide real-time products.

Sub Topics:
Technologies for Large-Scale Numerical Simulation Topic S6.02
NASA scientists and engineers are increasingly turning to large-scale numerical simulation on supercomputers to advance understanding of Earth and astrophysical systems, as well as to conduct high-fidelity engineering analyses. The goal of this subtopic is to make NASA’s supercomputing systems and associated resources easier to use, thereby broadening NASA’s supercomputing user base and increasing user productivity. Specific objectives are to:

• Reduce the learning curve for using supercomputing resources;

• Minimize total time-to-solution (i.e., time to discovery, understanding, or prediction);

• Increase the scale and complexity of computational analysis and data assimilation;

• Accelerate advancement of system models and designs.

The approach of this subtopic is to develop intuitive, high-level tools, interfaces, and environments for users, and to infuse them into NASA supercomputing operations. Successful technology development efforts under this subtopic would be considered for follow-on funding by, and infusion into either of the NASA high-end computing projects, including the High End Computing Columbia (HECC) project at Ames and the NASA Center for Computational Sciences (NCCS) at Goddard. Research should be conducted to demonstrate technical feasibility during Phase 1 and show a path toward a Phase 2 prototype demonstration. Open Source software and open standards are strongly preferred.

Specific areas of interest include:
Application Development

With the increasing scale and complexity of supercomputers, users must often expend a tremendous effort to translate their physical system model or algorithm into a correct and efficient supercomputer application code. This subtopic element seeks intuitive, high-level application development environments, ideally leveraging high-level programming languages (e.g., parallel Matlab or IDL) to enable rapid supercomputer application development, even for novice users. This environment should dramatically simplify application development activities such as porting, parallelization, debugging, scaling, performance analysis, and optimization.

Results V&V

A primary barrier to effective use of supercomputing by novices is understanding the accuracy of their computational results. Errors in the input data, domain definition, grids, algorithms, and application code can individually or in combination produce non-physical results that a user may not detect. This subtopic element seeks tools and environments to help users with verification and validation (V&V) of simulation results. This could be accomplished by enabling comparison of results from similar applications or with known accurate results, access to results analysis tools and domain experts, or access to error estimation tools and training.

Data Analysis and Visualization

Supercomputing computations almost invariably result in tremendous amounts of data, measuring in the gigabytes or terabytes, and with many dimensions and other complexity aspects. This subtopic element seeks user-friendly tools and environments for analysis and visualization of large-scale, complex data sets typically resulting from supercomputing computations.

Ensemble Management

Conducting and fusing the results from an ensemble of related computations is an increasingly common use of supercomputers. However, ensemble computing and analysis introduces a new set of challenges for deriving full value from using supercomputing. This subtopic element seeks tools and environments for managing and automating ensemble supercomputing-based simulation, analysis, and discovery. Functions could include managing and automating the computations, model or design optimization, interactive computational steering, input and output data handling, data analysis, visualization, progress monitoring, and completion assurance.

Integrated Environments
The user interface to a supercomputer is typically a command line or text window, where users may struggle to locate or develop applications, understand the job queue structure, develop scripts to submit jobs to the queue, manage input and output files, archive data, monitor resource allocations, and many other essential supercomputing tasks. This subtopic element seeks more intuitive, intelligent, and integrated interfaces to supercomputing resources. This integrated environment could include access to user training (e.g., tutorials, case studies, and experts), application development tools, standard (e.g., production, commercial, and Open Source) supercomputing applications, results V&V tools, computing and storage resources, ensemble management tools, workflow management, data analysis and visualization tools, and remote collaboration.

Sub Topics:

On-Board Data Processing and Control Topic S6.03

Technology advances allow scientists to build devices that often collect more data than can be cost effectively transmitted or summarized within mission time constraints. NASA is developing sensor web capabilities which can require these data be analyzed for rapid decision making, either autonomously or with human in the loop controller. This subtopic enables sensor web capabilities and increases mission data return by developing on-board methods that can operate with very limited resources to increase the efficiency and scientific return of existing and future sensors. Approaches range form losses less data compression prior to transmission to some degree of "data understanding" that enables data management and prioritization based on potential science content. These software capabilities will enable sensor webs that operate semi-autonomously and are capable of reacting to what is being sensed and triggering notifications or additional actions. Algorithms can be embedded into an instrument or device or algorithms can target on-board computer resources for data management and/or transmission as part of the post collection data flow.

The selection of on-board methods to increase scientific return is highly dependent on mission objectives. Successful candidate technologies will need to demonstrate suitability to the general requirements of the proposed use scenario as they pertain to different instrument (or device) types. Generally, scientists do not want to throw away data given that significant discoveries have been made reinterpretation archived data. Methods that reduce information content such as lossy compression are often not desirable unless significant, new capabilities are enabled by this tradeoff. Examples exist where instruments are turned off and on and instances when sensor or camera data is saved and transmitted only when features are detected by on-board software. These instances occur when transmission costs, relative to available resources, are high. E.g., a Mars Exploration Rover was reprogrammed to detect and transmit camera images containing dust devils.

Algorithms can be designed to run on general purpose computing resources or specialized i.e., field programmable gate arrays (FPGA). Novel approaches that can leverage specialized, space qualified computing resources such as FPGAs that return order of magnitude reduction in data volume or screening capabilities are desirable. There is a trade-off between sensor volume and complexity against distance and degree of on-board autonomy needed for mission success so performance metrics are relative to the science mission scenario. Example sensor types include data intensive instruments such as hyperspectral, RADAR, and LIDAR but can include any sensor technology that is shown relevant to the board scope of science within the NASA science mission directorate.

For instance, aggressive metrics for compression and data volume are in Earth science the Decadal survey has the following requirements on data compression:

<table>
<thead>
<tr>
<th>RADAR Missions</th>
<th>SMAP (RADAR)</th>
<th>DESDynI (RADAR)</th>
<th>SWOT (RADAR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>OBP Input data rate (MHz)</td>
<td>32</td>
<td>400</td>
<td>500</td>
</tr>
<tr>
<td>Processor Throughput (GFLOPS)</td>
<td>7</td>
<td>20</td>
<td>90</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>---</td>
<td>----</td>
<td>----</td>
</tr>
<tr>
<td>Data Compression Ratio</td>
<td>80:1</td>
<td>10:1</td>
<td>90:1</td>
</tr>
</tbody>
</table>

Where raw data sample spacing is 0.75 m x 1.5 m (16 bits per sample), and the output data sample spacing is 10 m x 10 m (16 bits per sample).

For Hyperspectral imaging instruments, here is an exemplar requirement on data compression on board feature detection.

<table>
<thead>
<tr>
<th>Data Rate:</th>
<th>660 gigabits per orbit, 220 megabits per second</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data Compression Ratio:</td>
<td>&gt; 3.0</td>
</tr>
<tr>
<td>On-board detection capability:</td>
<td>A quick look at the data for presence of cloud cover.</td>
</tr>
</tbody>
</table>

Sub Topics:
Data Analyzing and Processing Algorithms Topic S6.04
This subtopic seeks technical innovation and unique approaches for the processing and analysis of data from NASA's space and Earth science missions. Analysis of NASA science data is used to understand dynamic systems such as the sun, oceans, and Earth's climate as well as to look back in time to explore the origins of the universe. Algorithms are used to consider data over time, at various energy ranges, and at different points in space. Complex algorithms and intensive data processing are needed to understand and make use of this data. What novel discoveries can be made with existing NASA data? What applications would benefit from the combination of NASA data with additional information and processing?

NASA seeks to exploit spatial tools in order to increase the utility of scientific research data, models, simulations, and visualizations. Of particular interest are innovative computational methods to dramatically increase algorithm efficiency and thus performance. Interpolation, clustering, and registration algorithms are examples of the type of algorithms of interest in this area, as well as real-time visualization and simulation algorithms. Tools to improve predictive capabilities, to optimize data collection by identifying gaps in real-time, and to derive information through synthesis of data from multiple sources are needed. The ultimate goal is to increase the value of data collected in terms of scientific discovery and application. Data analysis and processing must relate to advancement of NASA's scientific objectives.

We are soliciting proposals for software tools which access, fuse, process, and analyze image and vector data for the purpose of analyzing NASA's space and Earth science mission data. Tools can be plug-ins or enhancements to existing software or on-line services. Tools and products might be used for broad public dissemination or for communicating within a narrower scientific community. Tools can be new stand-alone applications or web services,
provided that they are compatible with most widely-used computer platforms and exchange information effectively (via standard protocols and file formats) with existing, popular applications. The Phase 1 contract should demonstrate the feasibility of the approach. The Phase 2 contract should provide prototype software that can be demonstrated at the company and a prime contractor or NASA. It is desirable to have the development lead to software that is commercialized or infused into NASA program use.

To promote interoperability, tools shall use industry standard protocols, formats, and APIs, including compliance with the ISO, FDGC, and OGC standards as appropriate. For example a tool may manipulate XML of various types, such as GML, SensorML, KML; or use standard services, such as WSDL and UDDI. Applications may subset, filter, merge, and reformat existing spatial data; provide links to attribute data; or visualize results. Combining NASA research data with popular geospatial services is encouraged.

Sub Topics:

Data Management - Storage, Mining and Visualization Topic S6.05
This subtopic focuses on supporting science analysis through innovative approaches to managing and visualizing collections of science data which are extremely large, complicated, and are highly distributed in a networked environment that encompasses large geographic areas. There are specific areas for which proposals are being sought:

3D Virtual Reality Environments

- 3D virtual reality environments for scientific data visualization that make use of novel 3D presentation techniques that minimize or eliminate the need for special user devices like goggles or helmets;
- Software tools that will enable users to ‘fly’ through the data space to locate specific areas of interest.

Distributed Scientific Collaboration

- Tools that enable high bandwidth scientific collaboration in a wide area distributed environment;
- Novel tools for data viewing, real-time data browse, and general purpose rendering of multivariate geospatial scientific data sets that use geo-rectification, data overlays, data reduction, and data encoding across widely differing data types and formats.

Distributed Data Management and Access
• Metadata catalog environments to locate very large and diverse science data sets that are distributed over large geographic areas;

• Dynamically configurable high speed access to data distributed and shared over wide area high speed network environments;

• Object based storage systems, file systems, and data management systems that promote the long term preservation of data in a distributed online (i.e., disk based) storage environment, and provide for recovery from system and user errors.

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

Sub Topics:

Spatial and Visual Methods for Search, Analysis and Display of Science Data Topic S6.06
This subtopic seeks technical innovation and unique approaches to exploit spatial tools in order to increase the use of NASA research data, models, simulations, and visualizations. The goal is to facilitate NASA's Science and Exploration Missions, and outreach to the interested public. These tools will be used by the NASA Applied Sciences Program managed by the Applied Research and Technology Project Office at Stennis Space Center. The tools should be easy to use by non-specialists, from scientists and policy makers to the general public. Tools and services will be prototyped for accessing and fusing (or mashing) image and vector data with popular Web-based or stand-alone applications. Tools can be plug-ins or enhancements to existing software or on-line services. Tools and the products might be used for broad public dissemination or for communicating within a narrower scientific community.

For example, an authoring tool may help a non-GIS expert to map a National Weather Service modeled hurricane path over a background of NASA MODIS sea surface temperatures, in turn draped on a visualization of the globe served by GoogleEarth.

To promote interoperability, tools shall use industry standard protocols, formats, and APIs. For example a tool may manipulate XML of various types, such as GML, SensorML, KML; or use standard services, such as WSDL and UDDI. Applications may subset, filter, merge, and reformat existing spatial data; provide links to attribute data; or visualize results. Combining NASA research data with popular geospatial services is encouraged. Examples of popular applications and services currently include:

• Imagery servers: e.g., NASA DAACs, OGA servers (USGS, NOAA, DOI), Microsoft Terraserver, Google Maps;

• Mapping platforms: e.g., Google Earth, NASA WorldWind;
• Map servers: e.g., Census Bureau, EPA Maps, Google Maps, MapQuest, Yahoo Maps.

Sub Topics: