NASA is aggressively pursuing the search for resources on the Moon necessary to sustain prolonged human habitation and the search for water and life on Mars using robotic explorers. NASA is investing in key capabilities to enable advanced robotic missions to the Moon and Mars. This suite of technologies will enable NASA to rapidly respond to discoveries this decade and pursue the search for water and life at Mars wherever it may lead. The technologies developed and tested in each mission will help enable even greater achievements in the missions that follow. See URL: [http://marstech.jpl.nasa.gov/](http://marstech.jpl.nasa.gov/) for additional information on Mars Exploration technologies. Key goals are to (1) conduct robotic expeditions to further science and to test new exploration approaches, technologies, and systems that will enable future human exploration of the Moon and Mars; and (2) conduct sustained, long-term robotic exploration of Mars to understand its history and evolution, to search for evidence of life, and to expand the frontiers of human experience and knowledge.

Sub Topics:

**S1.01 Surface Robotic Exploration**

Lead Center: JPL

Participating Center(s): ARC

Sample acquisition and handling will be important elements of future landed missions. Sample manipulation technologies are needed to enable handling and transfer of unstructured samples from a sampling device to instruments and sample processing systems. Shallow core, rock, 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 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.

Mobility technology is needed to enable access to difficult-to-reach sites such as distant locations or 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 and marsupial systems are two 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, e.g., a primary vehicle could provide long traverse to the vicinity of a challenging site and then deploy a smaller vehicle with steep mobility access capability for access to the site. Innovative low-mass, low-power, and highly modular systems and subsystems are of particular interest.

The program is also interested in new sensors such as small, low-power lidar for more robust navigation.
Examples of planetary robotics system are shown at http://robotics.jpl.nasa.gov [2].

S1.02 Subsurface Robotic Exploration

Lead Center: JPL

Participating Center(s): ARC

Robust systems for accessing the subsurface of the Moon and Mars 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.

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, including icy mixtures of rock and regolith.

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 microbes brought to the Martian surface prior to drilling (‘clean’ sampling from a ‘dirty’ surface).

S1.03 Martian Entry, Descent and Landing Sensors

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.

Robotic Exploration Throughout the Solar System Topic S2

NASA's program for Solar System Exploration seeks to answer fundamental questions about the Solar System and life: How do planets form? Why are planets different from one another? Where did the makings of life come from? Did life arise elsewhere in the solar system? What is the future habitability of Earth and other planets? The search for answers to these questions requires that we augment the current remote sensing approach to solar system exploration with a robust program that includes in situ measurements at key places in the solar system, and the return of materials from them for later study on the Earth. We envision a rich suite of missions to achieve this including a comet nucleus sample return, a Europa lander, and a rover or balloon-borne experiment on Saturn's moon, Titan, to name a few. These robotic explorers will pursue compelling scientific questions, demonstrate breakthrough technologies, identify space resources, and extend an advanced telepresence that will send stunning imagery back to Earth. Numerous new technologies will be required to enable such ambitious missions. This topic includes investments in technology to enable the delivery and access of scientific instruments to planetary surfaces and atmospheres. This includes landing, flying, roving, and digging, as well as sample acquisition for delivery to instruments. This topic will also address Earth entry vehicles for sample return missions, planetary protection, and contamination control for in situ missions. The planetary bodies of interest are the Moon, Mars, Venus, Titan, and the icy satellites of the outer planets.
Sub Topics:

**S2.01 Astrobiology and Atmospheric Instruments for Planetary Exploration**

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

This subtopic supports the development of advanced instruments and instrument technologies to enable or enhance scientific investigations on future planetary missions. New measurement concepts, advances in existing instrument concepts, and advances in critical components are all of interest. Proposers are strongly encouraged to relate their proposed technology development to future planetary exploration goals. These goals include geochemical, geophysical and astrobiological objectives.

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. Biomarkers produced by microbial communities are profoundly affected by internal biogeochemical cycling. The small spatial scales at which these biogeochemical processes operate necessitate measurements made using microsensors. The search for life on other planetary bodies will also require systems capable of moving and deploying instruments across, and through, varied terrain to access biologically important environments.

Instruments for both remote sensing and 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 remote sensing, on orbital or flyby spacecraft, or for in situ measurements, on surface landers and rovers, subsurface penetrators, and airborne platforms. In situ instruments cover spatial scales from surface reconnaissance to microscopic investigations. These instruments must be capable of withstanding operation in space and planetary environmental extremes, which include temperature, pressure, radiation, and impact stresses.

Examples of instruments that will meet the goals include, but are not limited to, the following:

- Instrumentation for definitive chemical, mineralogy, and isotopic analysis of surface materials: soils, dusts, rocks, liquids, and ices at all spatial scales, from planetary mapping to microscopic investigation. Examples include advanced techniques in reflectance spectroscopy, wet chemistry, laser-induced breakdown spectrometers, water and ice detectors, novel gas chromatograph and mass spectrometry, and age-dating systems;

- Instrumentation for the assessment of surface terrain and features. Examples include lidar systems and advanced imaging systems;

- Geophysical sensing systems to determine the near-surface and subsurface structure, textures, bulk components, and composition, such as seismic sensors, porosity measurement devices, permeameters, and surface penetrating radars;

- Instrumentation focused on the identification and characterization of biomarkers of extinct or extant life, such as prebiotic molecules, complex organic molecules, biomolecules, or biominerals;

- Instrumentation for the chemical and isotopic analysis of planetary atmospheres;
• Advanced detectors for solar absorption spectrometry. One example is a detector that is fast and linear, i.e., does not saturate under high photon fluxes;

• Environmental sensing systems, such as meteorological sensors, humidity sensors, wind and particle size distribution sensors, and sounders for atmospheric profiling;

• Particles and fields measurements, such as magnetometers, and electric field monitors; and

• Enabling instrument component and support technologies, such as laser sources, miniaturized pumps, sample inlet systems, valves, integrated bulk sample handling and processing systems, and fluidic technologies for sample preparation.

Instruments specific to astrobiology include:

• For Mars or Venus exploration, technologies that (using X-ray, neutron, ultrasonic, and other types of tomography) would enable a noninvasive, nondestructive analysis of biomarkers inside rocks and ice to depths 10 - 20 cm with spatial resolutions of 2 - 10 microns;

• Technologies that would enable the aseptic acquisition of samples under conditions of extreme environments;

• For Europa and Enceladus exploration, technologies to enable the penetration of ice and/or access to subsurface vents are required;

• High sensitivity (femtomole or better), high-resolution methods applicable to all biologically relevant classes of compounds for separation of complex mixtures into individual components;

• 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;

• Biotechnology-determining mutation rates and genetic stability in a variety of organisms as well as accurately determining protein regulation changes in microgravity and radiation environments;

• Automated chemical analytical instrumentation for determining gross metabolic characteristics of individual organisms and ecologies as well as chemical composition of environments;

• High-resolution, high-sensitivity (femtomole or better) methods for the isolation and characterization of nucleic acids (DNA and RNA) from a variety of organic and inorganic matrices; and

• Microscopic techniques and technologies to study soil cores, microbial communities, pollen samples, etc., in a laboratory environment for the detailed spectroscopic analysis relevant to evolution as a function of climate changes.

S2.02 In Situ Planetary Atmospheric Measurement Technologies

Lead Center: JPL

Participating Center(s): ARC, GRC, GSFC, MSFC
Proposals are sought for technologies that enable the in situ exploration of the surface and deep atmosphere of Venus and the deep atmospheres of Jupiter or Saturn for future NASA missions. Venus features a dense, CO₂ atmosphere completely covered by clouds with sulfuric acid aerosols, a surface temperature of 486°C, and a surface pressure of 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 (~480°C) and high pressures (~100 atmospheres) 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:

**Pressure Vessels and Structural Shells**

Historically, titanium and aluminum have been used as structural shells or pressure vessels for extreme environment planetary probes and landers. Improvements in the state-of-the-art of pressure vessel materials are sought to reduce the mass of such components by 20 to 50% over titanium shells. New structural shell materials shall exhibit high strength and stiffness at elevated temperatures and shall be resistant to creep and buckling under high external pressures.

**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:

- Lightweight and stable insulation materials with a conductivity less than 0.1 W/m-K at 486°C and 90 atm pressure;
- 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.

**High Temperature Electronics**

- Science and engineering sensors able to operate at 486°C and 100 bar, including for example, high temperature imagers, hybrid imaging system that utilizes high temperature fiber optics, seismometers, and pressure sensors;
- High-temperature, low-power, and ultra low-power electronics and electronic packaging technology for sensor and actuator interfaces at 486°C, including low-noise (10 nV/sqHz) preamplifiers, power amplifiers and transmitters (S-band), temperature stable oscillators, drivers (with 0-100 V digital output for driving piezoelectric, electrostatic, or electromagnetic actuators), and high value (on the order of one to hundreds of micro Farad) capacitors;
- Computer aided simulation tools for predicting the performance, reliability, and life cycle for high-temperature electronic systems and components.
High Temperature Motors and Actuators

- Actuators for sample handling and acquisition systems including high-temperature drills, motors, and actuators able to operate in the 486°C, 90 atmosphere surface environment of Venus.

S2.03 Energy Conversion and Power Electronics for Deep Space Missions

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

Proposals are solicited to develop advanced energy conversion and power electronics to enable or enhance the capabilities of next decadal deep space missions, with potential missions to Europa, Venus, Titan, and primitive bodies. These missions require power systems with long life capability and high reliability and offering significant mass and volume savings and improved efficiency compared to the state of practice (SOP) devices. Other desired capabilities are high radiation tolerance, and ability to operate in extreme environments (high and low temperatures and over wide temperature ranges).

Extreme Photovoltaics Energy Conversion

NASA has an increasing interest in solar array technology for deep space missions. The science community is currently pushing for solar missions that go as far as Saturn. PV proposals are sought to develop advanced photovoltaic devices and systems that can operate in extreme environments and offer significant mass and volume savings over the SOP systems. Photovoltaic cell and array technologies should also have significant improvements in efficiency, specific power, cost, and ability to operate in high-radiation, extreme-temperature environments such as near sun (high-intensity, high-temperature - HIHT) environment or deep space (low-intensity, low-temperature - LILT) environments. Extreme Photovoltaic technologies of interest are:

- Solar cells that can function effectively under LILT conditions and high radiation environments for deep space missions beyond 4 AU;
- Solar cells that can operate high temperatures (up to 450°C) for near sun missions ( 
- Solar arrays with high specific power (> 250 W/kg) and low stowage volume for solar electric propulsion missions.

RPS Energy Conversion

Radioisotope power systems (RPS) are presently used in some planetary surface missions and deep space science missions that go beyond 4 AU. Proposals are sought to develop advanced RPS technologies that would contribute to a system with long life capability (> 14 years), high conversion efficiency (> 20%), and high specific power (> 8 - 10 W/kg). The radioisotope power conversion systems of interest are, Stirling, Thermoelectrics (TE), and Thermophotovoltaics (TPV). All proposed energy conversion technologies must be able to operate in deep space environments with high radiation and wide-temperature operations (-200°C to >300°C). A high priority for NASA is the development of advanced static power conversion technologies (TPV or TE) that offer greater than 20% thermal-to-electric conversion efficiency for an RPS system, as well as power conversion approaches that can
operate in the extreme environments of Venus and Europa.

Thermophotovoltaic technologies should focus on demonstrating converter component technologies that offer improved performance parameters:

- Photovoltaic devices capable of operating at high temperature (> 50°C) and high current density for extended durations (> 14 yr) while maintaining high performance;
- Optical filters that offer high spectral efficiency and high temperature survivability (> 150°C);
- Emitter materials that offer high efficiency as well as low evaporative losses suitable for extended (14 yr) operation;
- Solar concentrator based TPV systems with concepts for thermal energy storage and their integration with the emitter systems.

Thermoelectric technologies should focus on:

- High temperature and performance thermoelectric materials. NASA is interested in nanostructured thermoelectric materials with potential for ZT > 2 and ability to operate at temperatures and lifetimes compatible with RPS systems;
- Innovative packaging of thermoelectric elements in closed or compact arrays;
- Sublimation coatings or methods.

Stirling power conversion technologies should focus on:

- 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);
- Advanced regenerators with improved durability and high temperature capability while maintaining high performance;
- Lightweight, high-efficiency linear alternators with low EMI and capable of high-temperature operation;
- High temperature heater heads (> 850°C) and joining techniques.

Advanced Photovoltaics Energy Conversion

Photovoltaic cell and array technologies with significant improvements in efficiency, mass specific power, stowed volume, cost, radiation resistance, and wide operating conditions are solicited. Photovoltaic cell technologies for
wide temperature operation and radiation environments are solicited. Potential array technologies of interest include:

- Rigid and deployable arrays;
- Concentrators (rigid or inflatable, primary or secondary);
- Ultra-lightweight arrays for lightweight, flexible;
- Thin-film photovoltaic cells;
- Electrostatically clean spacecraft solar arrays.

**Energy Conversion Thermal Management**

Thermal technology areas include heat rejection, composite materials, heat pipes, pumped loop systems, packaging and deployment, including integration with the power conversion technology. Highly integrated systems are sought that combine elements of the above subsystems to show system level benefits.

**S2.04 Flexible Antennas and Electronics for L-Band Remote Sensing**

Lead Center: JPL

Electronically steerable L-band, phased array antennas are needed for missions to the Moon, Mars, Titan, Europa and Venus for remote sensing applications and support of communications. Flexible, lightweight active arrays enable better packaging efficiency for the antenna and are critical for these missions. These antennas will be deployed on orbiting spacecraft and on rovers or aerial platforms such as lighter than atmospheres (LTA) vehicles or airplanes.

When used for active remote sensing, L-band also provides the capability to detect surface and subsurface topology including density contrasts within the ice or dust and subsurface water or warm ice. In addition, the use of L band frequencies enables proximity communications between the in situ vehicle and a spacecraft in orbit or on a flyby trajectory.

Currently, manufacturing reliable passive arrays with required tolerances is challenging and the only method for integration of the electronics is to attach and interconnect the electronic components on the surface. This method is expensive, unreliable, and impractical for large arrays. Technologies enabling large area flexible antennas, including flexible electronics, are needed. State-of-the-art, flexible, printable electronics have low switching frequencies. Innovative new materials or processes will be needed to enable devices that can handle the gigahertz frequencies needed for radar. In addition, large area manufacturing methods are needed to manufacture these passive and active antennas.
S2.05 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:

Hot Air (Montgolfiere) Balloons for Titan

NASA is considering the use of hot air (Montgolfiere) balloons for Titan using waste heat from the radioisotope power source (RPS). Proposals are sought for concepts and prototypes for this balloon that have the following nominal characteristics: 2000 Watts of available RPS waste heat, a 100 gm/m² balloon envelope material, 160 kg of payload mass (including the RPS but excluding the balloon), and a controllable altitude over the range of 0 to 10 km with the ability to maintain a +/- 20 m tolerance near the surface (93K, 1.46 bar). It is important that the balloon be storable in a typical entry vehicle for transport to Titan and be deployed and inflated upon arrival. Preference will be given to proposals that include cryogenic testing to validate the thermal performance models upon which the design is based.

Apex Valve for Montgolfiere Balloons

Solar-heated Montgolfiere balloons are an attractive platform for the exploration of Mars, particularly the polar regions which experience long periods of solar illumination during summer solstice. These balloons can be altitude controlled through selective venting of the heated gas through a valve located at the apex of the balloon. Proposals are sought for concepts and prototypes for this valve to be used on a solar-heated balloon on Mars. Typical specifications include large flow area (10 m²), low mass (few kilograms), packaged into a small volume for transport to Mars (3) and consume minimal electrical energy.

Aerial Deployment Modeling Tool

Planetary aerobots at Mars, Titan, and Venus will likely be aerially deployed and inflated 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.
Advanced Telescope Systems Topic S3

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

S3.01 Precision Spacecraft Formations for Advanced Telescope Systems

Lead Center: JPL
Participating Center(s): GSFC

This subtopic seeks hardware and software technologies necessary to establish, maintain, and operate hyper-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, testbeds) to enable detailed analysis, synthesis, modeling, and visualization of such constellations.

In a formation for large effective telescope apertures, multiple, collaborative spacecraft in a precision formation collectively form a variable-baseline interferometer. 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. It is important that, in order to enable precision spacecraft formation keeping from coarse requirements (relative position control of any two spacecraft to less than 1 cm, and relative bearing of 1 arcmin over target range of separations from a few meters to tens of kilometers) to fine requirements (micron relative position control and relative bearing control of 0.1 arcsec), the interferometer payload would still need to provide at least 1 - 3 orders of magnitude improvement on top of the S/C control requirements. The spacecraft also require onboard capability for optimal path planning and time optimal maneuver design and execution.

Development of combined nanometer-level precision formation flying control of numerous spacecraft and their optics is required to enable large baseline (1 to 10's of km), sparse aperture UV/optical (and perhaps X-ray)
telescopes and interferometers needed for ultra-high angular resolution imagery.

Proposals addressing staged-control experiments that combine coarse formation control with fine-level wavefront sensing based control are particularly encouraged. Innovations that address the above precision requirements are solicited for formation systems in the following areas:

- Integrated optical/formation/control simulation tools;
- 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; and
- Six degrees of freedom precision formation test beds.

S3.02 Proximity Glare Suppression for Characterization of Faint Astrophysical Objects

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 are not limited to, the following areas:

**Starlight Suppression Technologies**

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

**Wavefront Control Technologies**

- Development of small stroke, high precision, deformable mirrors (DM) and associated driving electronics scalable to 104 or more actuators (both to further the state-of-the-art towards flight-like hardware and to explore novel concepts). Multiple 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;
- 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. The most promising DM technology may be sensitive to temperature, so developing a MUX that has very low thermal hot spots, and very uniform temperature performance will improve the control of the mirror surface;

- High precision wavefront error sensing and control techniques to improve and advance coronagraphic imaging performance; and

- Highly reflecting broadband coatings.

**S3.03 Precision Deployable Structures and Metrology for Advanced Telescope Systems**

**Lead Center: JPL**

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. Also measurement of the metering truss. Innovative systems which minimize complexity, mass, power and cost are sought.

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.
S3.04 Optical Devices for Starlight Detection and Wavefront Analysis
Lead Center: MSFC
Participating Center(s): GSFC, JPL

This subtopic addresses the unique problems associated with collecting and pre-detection processing of star light for 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. These devices can be placed anywhere within an optical system, between the entrance aperture and the focal plane. A specific technology area of interest is high reflectance UV coatings and uniform polarization coatings for all wavelengths. Collection technologies of interest include capabilities which enable large-baseline segmented-aperture telescopes and sparse aperture telescopes and interferometers that will be needed to obtain high angular resolution observations to support future science goals. This subtopic addresses problems associated with formation flying including development of high-precision, high-stability laser and phase sensors, as well as of techniques to enable the monitoring of the separations of the individual spacecraft and overall orientation of the constellation. Specifically of interest is component-level technology needed to enable the characterization and combination of wavefronts from multiple apertures. Innovative technology to fabricate and test large aperture optical substrates continues to be an interest of this subtopic. Additionally, this interest is specifically extended to include technology to fabricate and test large aperture very lightweight x-ray mirrors. The primary objective of this subtopic is to reduce the mass and volume of advanced telescopes and observatories - either the primary mirror or the relay and science instrument optics. The proposed effort must address the 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.

Proposals in the following areas are specifically solicited:

- Design and construction of UV, optical, infrared or far-infrared beam combiners suitable for wavelength-resolved fringe measurements from a large number of independent apertures with flat response over a broad wavelength range;

- Development of a metrology system suitable for monitoring path lengths in the meter to kilometer range with incremental resolutions of picometers and milliseconds, and sub-micron absolute distance resolution;

- Development and test of low cost laser metrology gauges and optical pathlength control devices for alignment and control in multi-stage, multi-vehicle formations;

- Single frequency, long lifetime (>10 years), visible, IR stable semiconductor lasers in the power range 1 to 10 watt for metrology of optical systems, wavefront sensing and control and interferometry;

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

- Wavelength division demultiplexers, integrated optics waveguide, fiber optic and light pipe devices for spectral analysis of scene information from UV to IR;

- Innovative mirror substrate material/fabrication/test technologies and mounting/support technologies for
large aperture lightweight low-cost x-ray, ambient and cryogenic applications in space telescopes;

- 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.

- Components or devices for spectroscopy and imaging applications using hyperspectral, polarometric, Stokes photo-polarimeters, etc. technology for visible to infrared.

Exploration of the Universe Beyond our Solar System Topic S4
The Universe division of the NASA/GSFC is charged with exploring the universe beyond the solar system - out to its very edges. To do this requires ever more sophisticated instruments (surpassing Chandra, Spitzer, and Hubble) with larger and better optics and more sensitive detector systems. Future mission may include spacecraft in formation-flyin; optics that fold and deploy and can be assembled on orbit; as well as larger arrays of detectors: bolometers, microcalorimeters, and room temperature semiconductors. Some of these arrays may contain billions of pixels. Our missions cover the full range of the electromagnetic spectrum (from sub-mm to gamma-rays) and gravitational waves. Some of our major science goals are to identify dark matter, to understand dark energy, to produce a census of black holes, to image material in the accretion disks around black holes and to measure gravitational waves from a wide range of sources. In addition, we are exploring new technologies for terrestrial sub-orbital platforms including long duration balloons, tethered balloons, and airships. We are soliciting ideas and concepts in six areas covering optical systems, UV, visible, IR and sub-mm detectors, x-ray and gamma-ray detectors, lasers for gravitational wave measurements, and sub-orbital platforms. The subtopics in this area are described in detail in each subtopic section.

Sub Topics:

S4.01 Sensor and Detector Technology for Visible, IR, Far IR and Submillimeter

Lead Center: JPL
Participating Center(s): GSFC

NASA astrophysics missions currently under development, such as the Herschel and Planck, (http://science.hq.nasa.gov/missions/phase.html) have been enabled by improvements in detectors. Beyond 2007, advances are expected in detectors, readout electronics, and other technologies, particularly those enabling polarimetry and large format imaging arrays for the visible, near IR, 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/index.shtml), SPICA (http://www.ir.isas.ac.jp/SPICA/), CMBPOL, and SNAP (http://snap.lbl.gov). Space science sensor and detector technology innovations are sought in the following areas:

Future space-based observatories in the 10 - 40 micron spectral regime will be passively cooled to about 30 K. They will make use of large, sensitive detector arrays with low-power dissipation array readout electronics. Improvements in sensitivity, stability, array size, and power consumption are sought. In particular, novel doping approaches to extend wavelength response, lower dark current and readout noise, novel energy discrimination approaches, and low noise superconducting electronics are applicable areas. Future space observatories in the 40 micron to 1 mm spectral regime will be cooled to even lower temperatures, frequently < 10 K, greatly reducing background noise from the telescope. In order to take advantage of this potentially huge gain in sensitivity, improved far infrared/submillimeter detector arrays are required. The goal is to provide noise equivalent power as low as $10^{-20}$ W Hz$^{-1/2}$ over most of the spectral range in a 10,000 pixel detector array with low-power dissipation array readout electronics. The ideal detector element would count individual photons and provide some energy discrimination. For detailed line mapping (e.g., C+ at 158 micron), heterodyne receiver arrays are desirable,
operating in the same frequency range near the quantum limit.

In addition to technologies specific to the astrophysics missions previously mentioned, the following cross-cutting technologies are also of interest:

- Large (4 meter), lightweight, deployable antennas for frequencies between 180 to 660 GHz. Reflectors for such antennas with surface densities of 10 kg/m² or less.
- Broadband (> 2 GHz, 4 GHz preferred), modest resolution (10 MHz), low power (< 5 watt) digital spectrometers for submillimeter spectroscopy. This may include enabling technologies such as:
  - Efficient FPGA firmware for spectral analysis including polyphase filterbanks;
  - High speed, low power, space qualifiable digitizers with analog bandwidths of > 5 GHz and preferably up to 18 GHz, sample rates > 5 Gs/s, 4 to 6 bit resolution, and simple interface to present FPGAs;
  - Hardware (ex. ASICs) for low power implementation of digital signal processing.
- Broad band, low power, flight qualifiable spectrometers. Band of interest is 6 to 18 GHz or higher with ~200 MHz resolution.
- Reliable, tunable, spurious free, and flight qualifiable local oscillators for SIS mixers covering 190 to 270 GHz and 600 to 660 GHz.
- Broadband cryogenic isolators covering 6 to 18 GHz.

While focused technology and instrument developments are progressing for missions in the development phases such as the Space Interferometry Mission (SIM) and the James Webb Space Telescope (JWST), ambitious mission concepts are being pursued for future opportunities to address cosmology questions, galactic/stellar astrophysics and extrasolar planet finding quests. Innovative concepts that will significantly advance the state of the art in sensitivity, spectral coverage, array format, power dissipation, and other instrument critical parameters are sought. Also solicited are proposals that address key improvements in current techniques and devices in terms of performance, reliability and technology maturity. In such efforts, the proposer must demonstrate expertise and capability with respect to the existing technique/device/process/system. Optical/electronic devices that enhance or complement the detector function in an instrument are also of interest. Examples are micro shutter arrays to select objects across a focal plane for spectroscopy, timing and analog to digital converters for large focal plane instruments. The optical and near-IR requirements include giga pixel arrays, exceptionally stable sensitivity and precision calibration.

<table>
<thead>
<tr>
<th>Spectral Coverage</th>
<th>Detector Functionality</th>
<th>Parameters to Push</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1 um - 1.0 um</td>
<td>Improving silicon response in UV and NIR, smart pixel arrays, solar blind response detector arrays, energy resolving calorimeter arrays</td>
<td>Sensitivity, array format size, high purity silicon processes</td>
</tr>
<tr>
<td>1.0 um - 4.0 um</td>
<td>New sensor materials, Large format cryogenic readout multiplexers, Large format (&gt;1kx1k) array hybridization techniques</td>
<td>Sensitivity, array format size</td>
</tr>
<tr>
<td>4.0 um - 40 um</td>
<td>Low power cryo operated multiplexers, new sensor materials (e.g., novel dopants for extrinsic Si detectors)</td>
<td>Sensitivity, array format size (~megapixels)</td>
</tr>
<tr>
<td>40 um - 200 um</td>
<td>Monolithic focal plane arrays (BIB technologies, new sensor materials)</td>
<td>Sensitivity, array format size (~megapixels)</td>
</tr>
</tbody>
</table>
Supporting Device Categories

<table>
<thead>
<tr>
<th>Spectral Coverage / Function</th>
<th>Technology</th>
<th>Parameters to Push</th>
</tr>
</thead>
<tbody>
<tr>
<td>mm wave</td>
<td>MMIC packaging</td>
<td>Cost, cryo operation</td>
</tr>
<tr>
<td>Digital spectrometer (back-end for coherent receivers)</td>
<td>Autocorrelation spectrometers, high resolution FFT spectrometers</td>
<td>15 GHz or greater bandwidth (autocorrelation), 2 GHz or greater bandwidth (FFT &gt;32K points); low power, compact configurations</td>
</tr>
<tr>
<td>Shutter arrays for multi-object spectrographs</td>
<td>Micro-electromechanical shutter arrays or new technologies to do the same thing better</td>
<td>Reliability, low off state scatter or leakage, cryo operability</td>
</tr>
<tr>
<td>Infrared optical filters</td>
<td>Thin film or other technologies to realize ~1&quot; aperture filters</td>
<td>High out of band rejection, well defined passbands (especially in 4-40um), cryo operation</td>
</tr>
<tr>
<td>Array hybridizing techniques</td>
<td>New, high yield bump bonding techniques</td>
<td>Yield, format size</td>
</tr>
</tbody>
</table>

S4.02 Detector Technologies for UV, X-Ray, Gamma-Ray and Cosmic-Ray Instruments

Lead Center: GSFC
Participating Center(s): MSFC

The next generation of astrophysics observatories for the infrared, ultraviolet (UV), X-ray, and Gamma-ray bands require order-of-magnitude performance advances in detectors, detector arrays, readout electronics, and other supporting and enabling technologies. Although the relative value of the improvements may differ among the four energy regions, many of the parameters where improvements are needed are present in all four bands. In particular, all bands need improvements in spatial and spectral resolutions in the ability to cover large areas and in the ability to support the readout of the thousands to millions of resultant spatial resolution elements. Innovative technologies are sought to enhance the scope, efficiency, and resolution of instrument systems at all energies and wavelengths:

- The next generation of gravitational missions will require greatly improved inertial sensors. Such an inertial sensor must provide a carefully fabricated test mass, which has interactions with external forces (i.e., low magnetic susceptibility, high degree of symmetry, low variation in electrostatic surface potential, etc.) below $10^{-16}$ of the Earth's gravity, over time scales from several seconds to several hours. The inertial sensor must also provide housing for containing the proof mass in a suitable environment (i.e., high vacuum, low magnetic and electrostatic potentials, etc.);
- Advanced Charged Couple Device (CCD) detectors, including improvements in UV quantum efficiency and...
read noise, to increase the limiting sensitivity in long exposures and improved radiation tolerance. Electron-bombarded CCD detectors, including improvements in efficiency, resolution, and global and local count rate capability. In the X-ray, we seek to extend the response to lower energies in some CCDs, and to higher, perhaps up to 50 keV, in others:

- Significant improvements in wide band gap (such as GaN and AlGaN) materials, individual detectors, and arrays for UV applications;
- Improved microchannel plate detectors, including improvements to the plates themselves (smaller pores, greater lifetimes, alternative fabrication technologies, e.g., silicon), as well as improvements to the associated electronic readout systems (spatial resolution, signal-to-noise capability, and dynamic range), and in sealed tube fabrication yield;
- Imaging from low-Earth orbit of air fluorescence, UV light generated by giant airshower by ultra-high energy (E >1019 eV) cosmic rays require the development of high sensitivity and efficiency detection of 300 - 400 nm UV photons to measure signals at the few photon (single photo-electron) level. A secondary goal minimizes the sensitivity to photons with a wavelength greater than 400 nm. High electronic gain (~106), low noise, fast time response (2 to 10 x 10 mm². Focal plane mass must be minimized (2 g/cm² goal). Individual pixel readout. The entire focal plane detector can be formed from smaller, individual sub-arrays.

For advanced X-ray calorimetry improvements in several areas are needed, including:

- Superconducting electronics for cryogenic X-ray detectors such as SQUID-based amplifiers and their multiplexers for low impedance cryogenic sensors and superconducting single-electron transistors and their multiplexers for high impedance cryogenic sensors;
- Micromachining techniques that enhance the fabrication, energy resolution, or count rate capability of closely-packed arrays of X-ray calorimeters operating in the energy range from 0.1 - 10 keV; and
- Surface micromachining techniques for improving integration of X-ray calorimeters with read-out electronics in large-scale arrays.

Improvements in readout electronics, including:

- Low-power ASICs and the associated high-density interconnects and component arrays to interface them to detector arrays;
- Superconducting tunnel junction devices and transition edge sensors for the UV and X-ray regions. For the UV, these offer a promising path to having “three-dimensional” arrays (spatial plus energy).

Improvements in energy resolution, pixel count, count rate capability, and long wavelength rejection are of particular interest:

- Techniques for fabrication of close-packed arrays, with any requisite thermal isolation, and sensitive (SQUID or single electron transistor), fast, readout schemes and/or multiplexers;
- Arrays of CZT detectors of thickness 5 - 10 mm to cover the 10 - 500 keV range, and hybrid detector systems with a Si CCD over a CZT pixelated detector operating in the 2 - 150 keV range.

For improvements to detector systems for solar and night-time UV and EUV (approx. 20-300nm) observing, the following areas are of interest:

- Large format (4 K x 4 K and larger); high quantum efficiency;
- Small pixel size;
- Large well depth;
- Low read noise;
- Fast readout;
- Low power consumption (including readout);
- Intrinsic energy and/or polarization discrimination (3D or 4D detector);
- Active pixel sensors (back-illumination, UV sensitivity); and
- High-resolution image intensifiers, UV and EUV sensitive, insensitive to moisture.
Space spectroscopic observations in the UV, visible, and IR requiring long observation times would be much more sensitive with high quantum efficiency (QE) and zero read noise. Techniques are sought which improve the QE of photon counters, or eliminate the read noise of solid-state detectors; and X-ray and Gamma-ray imaging with higher sensitivity, dynamic range and angular resolution requires innovations in modulation collimators and detection devices. The energy range of interest is from a few kilo-electron Volts to hundreds of milli-electron Volts for observations of solar flares and cosmic sources. Collimators with size scales down to a few microns and thicknesses commensurate with photon absorption over a significant fraction of this energy range are required. Low-background detectors capable of

S4.03 Cryogenic Systems for Sensors and Detectors

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

Stored cryogenic systems have long been used to perform cutting edge space science, but at high cost and with a limited lifetime. Improvements in cryogenic system technology 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 coolers for cooling detectors for scientific instruments and sensors on advanced telescopes and observatories as well as lunar and planetary exploration. The coolers should have long life, low vibration, low mass, low cost, and high efficiency. Specific areas of interest include:

- Highly efficient coolers in the range of 4 - 10 Kelvin as well as at 50 milli-Kelvin and below, and cryogen-free systems, which integrate these coolers together;
- Highly reliable, efficient, low-cost Stirling and pulse tube cooler technologies in the 15 Kelvin and 35 Kelvin regions;
- Essentially vibration-free cooling systems such as reverse Brayton cycle cooler technologies;
- Highly efficient magnetic and dilution cooling technologies, particularly at very low temperatures;
- Hybrid cooling systems that make optimal use of radiative coolers; and
- Miniature, MEMS, and solid-state cooler systems.

S4.04 Optics Manufacturing and Metrology for Telescopes

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

This subtopic focuses on optics manufacturing, metrology of optical surfaces, and mitigation of optical surface errors through direct manipulation of the optical surface and/or wavefront sensing and control techniques and technologies.

Optics manufacturing includes all areas associated with generation and maintenance of the optical surface, including both mirror and grating surfaces (and volumes). Improvements in substrate materials, hybrid structures, replication from masters, lightweighting techniques, and figuring and polishing (especially near-edge for segmented optics) are all sought.

Metrology of optical surfaces includes test methods and hardware to measure the surface to fractional wave tolerance, especially for large, aspheric optics and/or while the part is still mounted on the figuring/polishing apparatus or spindle. Metrology systems with artificial intelligence that can deterministically feed back to the
polishing instrument, e.g., with a map of dwell times for subaperture polishing.

Mitigation of 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.

**S4.05 Data Analysis Technologies for Potential Gravity Wave Signals**

*Lead Center: GSFC*

NASA is developing the Laser Interferometer Space Antenna (LISA) mission to search for gravitational waves from astrophysical phenomena such as the Big Bang, mergers of super massive black holes, and galactic binary inspirals. Detection of gravitational waves would open a new astrophysical window on the universe, with great potential for unexpected discoveries. A number of gravitational wave follow on missions to LISA are also under study.

The disturbance caused by the passage of a gravitational wave is expected to be very small and will be measured with laser interferometry. Technologies are sought to deal with the data analysis of the gravitational wave signals in these measurements. Background information on LISA along with preliminary data analysis discussions can be found in the Proceedings of the 5th International LISA Symposium, Estec, Noordwijk, The Netherlands, 12-15, July 2004, published in the Classical and Quantum Gravity Journal, Vol 22, Number 10, 21 May 2005.

Software development for application of the Hilbert-Huang Transform to gravitational wave data analysis: *The Hilbert-Huang Transform (HHT) is a new method of time-series analysis which is specifically target to the analysis of non-linear, transient signals (N. Huang, et al., "The empirical mode decomposition and the Hilbert spectrum for non-linear and non-stationary time series analysis", Proceedings of the Royal Society of London, A (1998) v. 454, 903-995). It will have a direct application to data analysis for LISA, Big Bang Observer (BBO), and other space-based gravitational wave missions in particular, and more generally to any mission with non-linear, transient data. For this task the vendor will be asked to build a software package that will provide a full HHT analysis of the data, using as an example a NASA-provided simulated LISA data stream, and incorporating a user-friendly interface. The vendor will need to familiarize himself with the HHT algorithm, and show relevant experience in the development of related software packages.*

**S4.06 Terrestrial Balloon Technology**

*Lead Center: GSFC*

Innovations in materials, structures, and systems concepts have enabled buoyant vehicles to play an expanding role in NASA's Science Mission Directorate and Exploration Systems Mission Directorate. A new generation of large, stratospheric balloons, based on advanced balloon envelope technologies, will be able to deliver payloads of several thousand kilograms to above 99.9% of the Earth's absorbing atmosphere and maintain them there for months of continuous observation. NASA is seeking innovative and cost-effective solutions in support of terrestrial balloons in the following areas:

- Innovative concepts for trajectory control and/or station keeping for effectively maneuvering large terrestrial balloons in either the horizontal latitude or vertical altitude plane or both;
- Innovative floatation systems for water recovery of NASA's scientific payloads;
- Innovative guided or gliding parachutes systems for use in thin atmospheres.
We live in the extended atmosphere of an active star. While sunlight enables and sustains life, the Sun's variability produces streams of high energy particles and radiation that can harm life or alter its evolution. Under the protective shield of a magnetic field and atmosphere, the Earth is an island in the Universe where life has developed and flourished. The origins and fate of life on Earth are intimately connected to the way the Earth responds to the Sun's variations. Understanding the Sun, Heliosphere, and Planetary Environments as a single connected system is the goal of the Science Mission Directorate's Heliophysics Research Program. In addition to solar processes, our domain of study includes the interaction of solar plasma and radiation with Earth, the other planets, and the Galaxy. By analyzing the connections between the Sun, solar wind, planetary space environments, and our place in the Galaxy, we are uncovering the fundamental physical processes that occur throughout the Universe. Understanding the connections between the Sun and its planets will allow us to predict the impacts of solar variability on humans, technological systems, and even the presence of life itself. There are three primary objectives that define the multi-decadal studies needed:

- To understand the changing flow of energy and matter throughout the Sun, Heliosphere, and Planetary Environments;
- To explore the fundamental physical processes of space plasma systems; and
- To define the origins and societal impacts of variability in the Earth-Sun System.

A combination of interrelated elements is used to achieve these objectives. They include complementary missions of various sizes; timely development of enabling and enhancing technologies; and acquisition of knowledge through research, analysis, theory, and modeling.

Sub Topics:

**S5.01 Voltage Supplies and Charge Amplifiers for Solar Science Missions**

**Lead Center: GSFC**

For success of future solar science missions, it is critical to develop future enabling technologies which are modular, compact and efficient. This subtopic focuses on innovations for two technology areas: (1) The first area is compact, sealed and efficient high voltage supplies for space use; (2) The second technology area is high gain, wide dynamic range charge amplifiers. Specific module details are provided as below.

High voltage power supplies can be divided into 3 kilovolt categories: low (
The proposer shall describe the innovation and specific improvement over the current state of the art.

S5.02 Sensors for Measurement of Particles and Fields

Lead Center: GSFC

Understanding the connections between the Sun and its planets will allow us to predict the impacts of solar variability on humans, technological systems, and even the presence of life itself. This requires remote and in situ sensing of upper atmospheres and ionospheres, magnetospheres and interfaces with the solar wind, the heliosphere, and the Sun. Improving our knowledge and understanding of these requires accurate in situ measurements of the composition, flow, and thermodynamic state of space plasmas and their interactions with atmospheres, as well as the physics and chemistry of the upper atmosphere and ionosphere systems. Remote sensing of neutral atoms is required for the physics and chemistry of the Sun, the heliosphere, magnetospheres, and planetary atmospheres and ionospheres. Because instrumentation is severely constrained by spacecraft resources, miniaturization, low power consumption, and autonomy are common technological challenges across this entire category of sensors. Specific technologies are sought in the following categories:

Plasma Remote Sensing (e.g., neutral atom cameras)

This may involve techniques for high-efficiency and robust imaging of energetic neutral atoms covering any part of the energy spectrum from 1 eV to 100 keV, within resource envelopes less than 5 kg and 5W.

- Miniaturized, radiation-tolerant, autonomous electronic systems for the above, within resource envelopes of 1 - 2 kg and 1 - 2 W.

In Situ Plasma Sensors

- Improved techniques for imaging of charged particle (electrons and ions) velocity distributions as well as improvements in mass spectrometers in terms of smaller size or higher mass resolution;
- Improved techniques for the regulation of spacecraft floating potential near the local plasma potential with minimal effects on the ambient plasma and field environment;
- Low power, digital, time-of-flight analyzer chips with sub-nanosecond resolution and multiple channels of parallel processing; and
- Miniaturized, radiation-tolerant, autonomous electronic systems for the above, within resource envelopes of 1 - 2 kg and 1 - 2 W.

Fields Sensors
• Improved techniques for measurement of plasma floating potential and DC electric field (and by extension, the plasma drift velocity), especially in the direction parallel to the spin axis of a spinning spacecraft;

• Measurement of the gradient of the electric field in space around a single spacecraft or cluster of spacecraft;

• Improved techniques for the measurement of the gradients (curl) of the magnetic field in space local to a single spacecraft or group of spacecraft;

• Direct measurement of the local electric current density at spatial and time resolutions typical of space plasma structures such as shocks, magnetopauses, and auroral arcs; and

• Miniaturized, radiation-tolerant, and autonomous electronic systems for the above within resource envelopes of 1 - 2 kg and 1 - 2 W.

**Electromagnetic Radiation Sensors**

• Radar sounding and echo imaging of plasma density and field structures from orbiting spacecraft; and

• Miniaturized, radiation-tolerant, and autonomous electronic systems for the above within resource envelopes of 1 - 2 kg and 1 - 2 W.

**Earth Science Instrument and Sensor Technology Topic S6**

NASA's Earth Science (ES) Division is committed to studying how our global environment is changing. Using the unique perspective available from spaceborne and airborne platforms, NASA is observing, documenting, and assessing large-scale environmental processes with emphasis on atmospheric composition, climate, carbon cycle and ecosystems, the Earth's surface and interior, the water and energy cycles, and weather. A major objective of ES instrument development programs is to implement science measurement capabilities with small 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. 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 Earth observing instruments and to enable new Earth observations measurements. The following subtopics are concomitant with this objective and are organized by measurement technique. For more on science and technology needs, visit [http://estips.nasa.gov](http://estips.nasa.gov) [7].

**Sub Topics:**

**S6.01 Passive Optics and Stepping Motors for Spaceborne and Airborne Platforms**

**Lead Center:** LaRC

**Participating Center(s):** GSFC
Passive optical remote sensing generally requires that deployed devices have large apertures and large throughput. NASA is interested primarily in instrument technologies suitable for aircraft or space flight platforms, and these inherently also prefer low mass, low power, fast measurement times, and a high degree of robustness to survive vibrations in flight or at launch. Wavelengths of interest range from ultraviolet through the far infrared. Development of techniques, components and instrument concepts that can be developed for use in actual deployed devices and systems within the next few years is highly encouraged.

Technologies and components that are not clearly suitable for use in high throughput remote sensing instruments are not applicable to this subtopic. The technology areas of primary interest are described below:

- Technology leading to significant improvements in capability, availability, or cost of large format (> 2.5 cm diameter), very narrow band (-1 full-width at half-maximum), polarization insensitive, high throughput infrared (6 - 15 µm) optical filters. These filters must be able to operate in vacuum at cryogenic temperatures.

- High performance four-band two-dimensional (2D) arrays (128x128 elements or more) in the 0.4 - 2.5 µm wavelength range with high quantum efficiencies (60%-80% or higher) in all spectral bands, low noise, and ambient temperature operation.

- Detector arrays with unusual 3-dimensional geometries. Of particular interest is the development of a photon counting system with multiple cylindrical detecting elements (detecting surface on the outside edge) formed into a stack connected through one end to the cable leading to the readout electronics. The stack should be 2 to 5 cm in length with at least 12, and up to 48, individual elements. The diameter of the stack/elements should be minimized and on the order of 0.5 cm or less. Each detector element should have a clear field of view for most of the 360 degrees perpendicular to the stack. Exact details for the sensitivity are negotiable at this early stage, but applications are for fluorescence type measurements.

- High performance 2-color array detectors (128x128 or higher) covering the 3 - 15 micron spectral range with high efficiencies, low noise and operating at relatively high temperatures (>150K desired, 80K minimum).

- Improved cryogenic stepping motors with high running torques at 80K. The motors must operate in vacuum and at temperatures at or below 80K. It is desired that these motors have minimal size and power requirements, and especially important that they use minimal current. Typical torque values desired are in the range of 10 - 20 oz-inches. Proposed motors should have at least 200 steps per revolution of the axis.

S6.02 Lidar System Components for Sapceborne and Airborne Platforms

Lead Center: LaRC
Participating Center(s): GSFC

High spatial resolution, high accuracy measurements of atmospheric parameters from ground-based, airborne, and spaceborne platforms require advances in the state-of-the-art lidar technology with emphasis on compactness, reliability, efficiency, low weight, lifetime, and high performance. Innovative technologies that can expand current measurement capabilities to airborne, Unmanned Aerial Vehicle (UAV), or spaceborne platforms are particularly desirable. Development of components that can be used in actual deployed systems within the next few years is highly encouraged. Technologies and components that are not clearly suitable for effective lidar remote sensing or
field deployment are not applicable to this subtopic. This subtopic considers components that enable Earth-sun system measurements such as:

- Cloud and aerosols with emphasis on aerosol optical properties;
- Wind profiles using direct-detection (noncoherent) lidar, or coherent-detection (heterodyne) lidar, or both;
- Land topography (vegetation, ice, land use); and
- Molecular species (carbon dioxide, ozone, and water vapor).

Innovative component technologies that directly address the measurement needs above will be considered. Dual-use technologies addressing Planetary Exploration are highly desirable. This subtopic is soliciting only the specific component technologies described below.

1. Pulsed, single frequency, diode laser or fiber laser based seeded MOPA systems are desired due to inherent robustness, efficiency, thermal and alignment stability. If the cost per unit is reasonable, and the size is small, then many of these can be installed on a spacecraft for either parallel operation or as backup units to lengthen the life of the mission. Systems with the following specifications are solicited:

- Stable single frequency operation at 1047nm, 1064 nm, or 1570 nm;
- Small, integrated assemblies that can generate CW powers in the 100's of mW to several Watts range and higher peak power pulsed operation yielding at least 10 to 500 nJ pulse energies;
- Fiber laser and amplifier designs with high SBS suppression;
- Gaussian pulsewidths between 100 ps and 50 ns;
- MOPA design configuration is desired where the pulse production cavity is short and more readily impedance matched for the fast rise times, gain switching, etc.;
- A semiconductor amplifier, or possibly a small cm-scale rare Earth doped fiber amplifier, can be coupled to the oscillator chip's output, itself contained in a hermetic butterfly or similar package;
- Repetition rates as low as 100 Hz and as high as 10 kHz are needed, with pulsed lifetimes in the trillion shot regime ($10^{12}$);
- Single mode, polarization maintaining (PM) fiber output is needed;
- Short term drift less than 1 MHz;
- Second and third harmonic generation techniques that can be packaged with the CW and pulsed diode or fiber laser sources to produce additional wavelengths in the visible or ultraviolet.
2. High speed fiber multiplexers for single and multimode fiber. A 1-to-10, or greater, multiplexer that is capable of switching on the order of 10 to 100 kHz with low insertion losses is required. Unit must be small, lightweight, and use little power. Single mode fiber version must be capable of handling high power (>100 microJoules at 10 kHz at 1064 nm). Multimode version will be used in low power applications and must be compatible with 0.22 NA fiber with 100 to 600 micron core size. Switching speeds faster than 10 microseconds are required.

3. 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 2 mJ to 100 mJ, repetition rate 10 Hz to 200 Hz, and pulse duration of approximately 200 nsec.

4. Single element, low noise, high quantum efficiency, HgCdTe avalanche photodiode detector (APD) capable of photon counting at rates >10 MHz for use in the 1570 nm range. Should be suitable for operation with a thermal electric cooler.

5. Lightweight compact lidar telescopes operating at one or more of the primary laser wavelengths in 1.0 to 2.0 micron wavelength region. The general requirements are: optical quality better than 1/6 wave at 632 nm, mass density less than 12 kg/m², and aperture diameter from 10 cm to 30 cm. Proof of scalability to 50 to 75 cm diameter for deployment in space is required.

6. Interferometric lidar aft-optics receiver subsystems/components to separately derive aerosol and molecular backscatter via High Spectral Resolution Lidar (HSRL) technique. The subsystem/component is to be implemented into a HSRL system with the goal of independently derive aerosol backscatter and extinction. Subsystems/components are needed at 355 and 532 nm wavelengths. Architectures could be based on Fabry Perot, Mach Zehnder, or other interferometric implementations. Resolving power of the order of 1 GHz and high frequency stability of pass/stop bands are required. Concepts must address issues associated with etendue of large-aperture (1 - 1.5 m) lidar receivers with field of view of the order of 200 micro-radians.

7. CCD detectors with high quantum efficiency at 355 and 532 nm for spaceborne lidar instruments measuring cloud and aerosol backscatter and extinction. CCD detectors are needed to replace single element PMT detectors for imaging fringes from interferometric elements of a HSRL instrument. Clocking schemes to move charge on the CCD to achieve on-chip profile averaging and reduce dark current and readout noise should be considered.
Proposals are sought for the development of in situ measurement systems. These systems are sought for use on radiosondes, dropsondes, tethered balloons, kites, mini-Unmanned Airborne Vehicles (UAVs), Unmanned Undersea Vehicles (UUVs), or Unmanned Surface Vehicles (USVs). Data acquisition methods should be included. Technology innovation areas of interest include:

- Measurements of atmospheric properties including temperature, humidity, solar radiation, clouds, liquid water, ice, precipitation, carbon dioxide, methane, and sulfur dioxide;
- Measurements of three-dimensional atmospheric winds near the Earth's surface, and within the troposphere and lower stratosphere, with high spatial resolution and accuracy. Of particular interest are systems intended for measurements of atmospheric fluxes as well as those for convection;
- Measurements of oceanic properties including inherent and apparent optical properties, ocean temperature and salinity, and sea surface height.

S6.04 Passive Microwave

Lead Center: GSFC

Proposals are sought for the development of innovative passive microwave technology in support of Earth System Science measurements of the Earth's atmosphere and surface. These microwave radiometry technology innovations are intended for use in the frequency band from about 1 GHz to 1 THz. The key science goal is to increase our understanding of the interacting physical, chemical, and biological processes that form the complex Earth system. Atmospheric measurements of interest include climate and meteorological parameters-including temperature, water vapor, clouds, precipitation, and aerosols; air pollution; and chemical constituents such as ozone, NOX, and carbon monoxide. Earth surface measurements of interest include water, land, and ice surface temperatures, land surface moisture, snow coverage and water content, sea surface salinity and winds, and multi-spectral imaging.

Technology innovations are sought that will provide the needed concepts, components, subsystems, or complete systems that will improve these needed Earth System Science measurements. Technology innovations should address enhanced measurement capabilities such as improved spatial or temporal resolution, improved spectral resolution, or improved calibration accuracies. Technology innovations should provide reduced size, weight, power, improved reliability, and lower cost. The innovations should expand the capabilities of airborne systems (manned and unmanned) as well as next generation spaceborne systems. Highly innovative approaches that open new pathways are also an important element of competitive proposals under this solicitation.

Specific technology innovation areas include:

**Electronics Technologies**
- Imaging radiometers, receivers, or receiver arrays on a chip;
- Microwave and millimeter-wave frequency sources as an alternative to Gunn diode oscillators. Compact (3) self-contained oscillators with output frequency between 40 GHz and 120 GHz, low phase noise 100 mW), and low power consumption (3);
- Wideband and ultra-wideband sensors with >15dB cross-pole isolation across the bandwidth;
- Low noise (3), heterodyne mixers requiring low local oscillator drive power (3);
- Undersampling, multibit, analog-to-digital converters with Multigigahertz RF input bandwidth, low power consumption, and associated digital signal processing logic circuit;
- Low power, lightweight microwave with DC power consumption of less than 2 W;
- Electronic design approaches and subsystems that can be incorporated into microwave radiometers to detect and suppress RFI within or near the reception band of the radiometer, thus insuring higher data quality;
- Innovative new designs for highly stable noise-diode or other electronic devices as additional reference sources for onboard calibration. Of particular interest are variable correlated noise sources for calibrating correlation-type receivers used in interferometric and polarimetric radiometers;
- Monolithic microwave integrated circuit (MMIC), low-noise amplifiers (LNA). Of particular interest are LNAs covering the frequency range of 165 to 193 GHz with low 1/f noise, and having a noise figure of 6.0 dB or better; and
- GPS receiver systems for application as bi-static altimeters and scatterometers.

**Antenna Technologies**

- Sensor elements with low mutual coupling allowing close spacing within large arrays;
- Large format, millimeter wave, focal plane array modules for large-aperture passive imaging applications; and
- Large aperture, deployable antenna concepts. Such large apertures can be real or synthetic. Of particular interest are highly compact launch configurations.

**Calibration Technologies**

- New technology calibration reference sources for microwave radiometers that provide greatly improved reference measurement accuracy. Of particular interest are high emissivity (near-black-body) surfaces for use as onboard calibration targets for microwave radiometers—which will significantly reduce the weight of aluminum core target designs, while reliably improving the uniformity and knowledge of the calibration target temperature; and
- New approaches, concepts, and techniques for microwave radiometer system calibration over or within the 1-300 GHz frequency band—which provide end-to-end calibration to better than 0.1K, including corrections for temperature changes and other potential sources of instrumental measurement drift and error.
Active microwave sensors have proven to be ideal instruments for many Earth science applications. For global coverage and the long-term study of Earth’s eco-systems, space-based radar is of particular interest to Earth scientists. Radar instruments for Earth science measurements include Synthetic Aperture Radar (SAR), scatterometer, sounder, altimeter and atmospheric radar. The life-cycle cost of such radar missions has always been driven by the resources - power, mass, size, and data rate - required by the radar instrument, often making radar not cost competitive with other remote sensing instruments. Order-of-magnitude advancement in key sensor components will make the radar instrument more power efficient, much lighter weight and smaller in stow volume, leading to substantial savings in overall mission life-cycle cost by requiring smaller and less expensive spacecraft buses and launch vehicles. On-board processing techniques will reduce data rates sufficiently to enable global coverage. Technologies that may lead to advances in instrument design, architectures, hardware, and algorithms are the focused areas of this subtopic. In order to increase the radar remote sensing user community, this subtopic will also consider radar data applications and post processing techniques. Specific areas in which advances are needed include:

- L-band SAR for surface deformation, topography, soil moisture measurements:
  - Lightweight, electronically steerable, dual-polarized, L-band phased-array antennas;
  - Lightweight deployable antenna structures and deployment mechanisms suitable for very large aperture systems (e.g., 2x100m antennas);
  - Rad-hard, high-efficiency, low-cost, lightweight L-band T/R modules;
  - L-band MMIC single-chip T/R modules;
  - High-power L-band transmitters (2KW to 10KW);
  - Integrated (e.g., ASIC) arbitrary waveform generators;
  - High performance, low power, rad-hard, real-time SAR processors and SAR data processing algorithms and data reduction techniques;
  - Thin-film membrane compatible electronics. This includes: Reliable integration of electronics with the membrane, high performance (>1.2GHz) transistor fabrication on flex material including identifying new materials, process development and techniques that have potential to produce large area passive and active flexible antenna arrays.

- Ku-band and Ka-band interferometers for snow cover measurement over land (Ku-band) and wetland and river monitoring (Ka-band):
  - Large, stable, lightweight, deployable structures (10-50 meter interferometric baseline);
  - Phase-stable Ku-band and Ka-band electronically steered phased arrays and multi-beam antennas;
  - Lightweight deployable reflectors (Ku-band and Ka-band);
Phase stable Ku-band and Ka-band receive electronics and T/R modules;
High-power Ka-band transmitters (2KW to 10KW);
High performance, low power, rad-hard, real-time radar processors and SAR data processing algorithms and data reduction techniques.

- X-band to W-band doppler radars for precipitation and cloud measurements:
  - High efficiency RF power amplifier (Ku-, Ka-, and W-band);
  - Compact, low loss phase shifters (Ka- and W-band);
  - High power and low insertion loss transmit-receive switches (Ka-, W-band);
  - Wide dynamic range low noise amplifiers (Ka- and W-band);
  - Low sidelobe (-90 dB) pulse compression technology (W-band);
  - Compact frequency synthesizer (Ku- and Ka-band);
  - High power, low sidelobe, compact antennas for high altitudes (X-Ka-band).

- Low Frequency (HF, VHF and UHF) airborne sounders:
  - Technology for creating large Ground Penetrating Radar (GPR) baselines with wireless phase lock loops;
  - High Power (800W), linear amplifiers;
  - Innovations in system design or hardware improvements to minimize the effect of the transmit signal leakage into receiver.

Science Spacecraft Systems Technology Topic S7

The Science Mission Directorate will carry out the scientific exploration of our Earth, and 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 with small or more affordable spacecraft so development programs can meet multiple mission needs and therefore, make the best use of limited resources. NASA is fostering innovations in cross-cutting technologies that can be leveraged by spacecraft and other platforms to enable new investigations of Earth space, the solar system, and the universe. These missions all require propulsion, power, and guidance and navigation systems that must be implemented at minimal mass and
cost to maximize the scientific return for a given budget. To this end, innovations are sought in the areas of Guidance, Navigation and Control, Command and Data Handling, Electric Propulsion, Advanced Chemical and Propellantless Propulsion, Platform Power Management and Distribution (including power electronics and packaging), and Thermal Control Technologies for Science Spacecraft. These technologies need not be limited to spacecraft, but can also be applicable to other platforms such as piloted and unpiloted aircraft, balloons, drop sondes, and sounding rockets. These application examples are given to illustrate the wide diversity of possibilities for acquiring Earth and Space Science data consistent with the future vision of the Science Mission Directorate for which technology development is required. For this solicitation, related science spacecraft system technologies like energy conversion, energy storage, and extreme environment electronics can be found under S2 Robotic Exploration Throughout the Solar System and X8 Energy Generation and Storage.

Sub Topics:

**S7.01 Guidance, Navigation and Control Beyond Low Earth Orbit (LEO)**

*Lead Center: GSFC*

*Participating Center(s): JPL*

Envisioned NASA science missions will increasingly use large, and/or distributed, observatories in orbits beyond LEO. Advanced Guidance Navigation and Control (GN&C) technology is required for these platforms to address high performance and reliability requirements while simultaneously satisfying low power, mass, volume and affordability constraints. In particular, there are many technology gaps in challenging orbital environments, including highly elliptical Earth orbits, libration point orbits, and lunar and planetary orbits. A vigorous effort is needed to develop guidance, navigation and control methodologies, algorithms, and sensor-actuator technologies to enable revolutionary science missions. Of particular interest are highly innovative GN&C technology proposals directed towards enabling scientific investigators to exploit new vantage points, develop new sensing strategies, and implement new system-level observational concepts that promote agility, adaptability, evolvability, scalability, and affordability. Specific areas of research include:

**Precision Pointing**

Innovative GN&C solutions for scientific instrument and laser communication system pointing, tracking, and stabilization are sought. Proposals that exploit and combine recent advances in attitude determination and control, lasers, advanced electro-mechanical packaging are encouraged. Proposed NASA science missions provide applications with pointing accuracies of 3 microradians or less with jitter of 30 nanoradians or less.

**Formation Flying**

Novel approaches to autonomous sensing and navigation of multiple distributed space platforms are sought. Of particular interest are sensing systems for formation, relative navigation and attitude. Proposed NASA science missions provide applications with relative range accuracies of 1 cm or less over formation scales of several km.

**Low Impact Sensors and Actuators**

GN&C sensors and actuators such as Sun sensors, Earth sensors, star/celestial object trackers, fine guidance sensors, gyroscopes, accelerometers, magnetometers, reaction/momentum wheels, control-moment gyros, magnetic torquers, tethers, attitude control thrusters, etc are sought. Of particular interest are technologies that will provide a sensing or actuation function, having performance (e.g., dynamic range, stability, accuracy, noise, sensitivity, bandwidth, control authority, etc.) consistent with the state-of-the-art, but with significantly reduced impact (mass, power, volume, and cost) to the host spacecraft. These resource reduction improvement factors should be quantified in the proposal and show a minimum factor of 2 with a goal of 10 or greater.
S7.02 Long Duration Command and Data Handling for Harsh Environments

Lead Center: GSFC

NASA's space based observatories, fly by spacecraft, orbiters, landers, and robotic and sample return missions, require robust command and data handling system capabilities. Advances in command and data handling technologies are sought to support the NASA's goals for improved investigations of Earth space, the solar system, and the universe.

The subtopic goal is to develop high-performance processors and architectures and reliable electronic systems that can operate effectively for long periods of time in harsh environments. The subtopic objective is to elicit novel architectural concepts and component technologies that are realistic and have credible applications to NASA missions.

A proposal's ideas should reflect (1) that the final end product(s) lead to usable hardware that can be integrated into NASA programs within 5 to 7 years, (2) effective and sustainable hardware and software development environments, (3) sustainability (affordable, reliable and effective), and (4) applicability to deep space missions (i.e., resource efficient and reliable over extreme environments of temperature and radiation), and will significantly advance solutions to the challenges of high performance processing, reconfiguration, and fault tolerant operations.

Technology priorities:

**High Performance Processing**

- Distributed or multi-core processing, with math co-processor or floating point capability that significantly exceeds the present state of the art;
- FPGA-based processing, targeting performance and fault tolerance, based on voting processors implemented as part of a rad-tolerant FPGA fabric

**Onboard Networks**

- Rad-hard Ethernet physical layer components, fully compatible with the current ground based 10/100 Ethernet. The board side interface would have the Ethernet MII and RMII interface standards;
- Rad-hard multi gigabit fiber optic transceiver to support high data rate network protocols.

**Data System Support Electronics**

- Radiation hard oscillators (greater than 150 MHz with equal duty cycles);
• Models for analysis of interplanetary radiation and radiation belts, and technologies that enable in-flight radiation measurements such as total dose and single event effects in computing systems.

S7.03 Electric Propulsion

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

Innovations in propulsion technologies are needed to support the Science Mission Directorate (SMD) goals of better understanding the Earth-Sun system, exploring our solar system, and investigating the nature of the universe beyond our solar system. Planetary spacecraft need ever-increasing propulsive performance and flexibility for ambitious missions requiring high duty cycles and years of operation. Satellites and satellite constellations have high-precision propulsion requirements, usually in volume- and power-limited envelopes. Electric propulsion systems also present challenging plasma plume and contamination environments to the host spacecraft and payloads. This subtopic seeks innovations in propulsion technologies to increase the capabilities of SMD spacecraft.

Specifically, technology innovations are sought to improve the capability of low- to medium-power electric propulsion systems, including ion, Hall, and advanced plasma thrusters. Areas where innovations are sought include power processing, long-life, high-efficiency cathodes and neutralizers, electrode-less plasma production, low-erosion materials for ion optics and Hall discharge chambers, high-temperature magnetic circuits, plume mitigation, and next generation thrusters. Innovations sought include, but are not limited to those that improve performance, increase lifetime, reduce mass, decrease cost, and facilitate electric propulsion integration. Improvements are also sought for propellant management system components including storage, distribution, and flow control to support solar electric propulsion applications. Innovations in miniature electrostatic and electromagnetic propulsion devices are sought for miniature (less than 10 kg) spacecraft and for high-precision (impulse bit

S7.04 Chemical and Propellantless Propulsion for Deep Space

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

Spacecraft propulsion technology innovations are sought for future deep space science missions. Propulsion system functions for these missions include primary propulsion, maneuvering, planetary injection, and planetary descent and ascent. Innovations are needed to reduce spacecraft propulsion system mass, volume, and/or cost. Applicable propulsion technologies include advanced chemical, emerging technologies, and aerocapture.

Advanced Chemical Propulsion

Innovations in low-thrust chemical propulsion system technologies are sought for robotic, deep-space, scientific, mission applications. Delta Vs for the missions of interest range from 1000 m/sec to 3000 m/sec. Advanced chemical propulsion technologies of interest are:
• Advanced material and component technology to enable development of bipropellant engines with Isp greater than 360 seconds, both pressure-fed and pump-fed, with chamber pressures ranging from 100 to 500 psia systems;

• Non-catalytic ignition technology and critical component materials (e.g., tank bladders, valve seats, and filters) for power-limited spacecraft using high-performance (Isp >275 s), high-density (>1 g/cc) monopropellant formulations.

**Tether Technologies**

Focus on technologies that support the development of tethers that can survive in the space environment. The near-Earth environment contains a significant amount of atomic oxygen (AO) formed by photo-dissociation of atmospheric oxygen. This AO attacks the chemical bonds of polymeric materials, which are desirable for their high specific tensile strength. Furthermore, ultraviolet radiation also attacks tether materials. A coating for a polymeric tether must be able to protect the tether against both effects. Coatings that can be uniformly applied after the fabrication of a multi-strand tether structure are especially desirable, because of the requirement that a space tether have a multitude of separate load paths in the event of a cut by an orbital debris particle. Certain materials (such as titanium oxide/zinc oxide) offer both ultraviolet radiation protection as well as atomic oxygen resistance. Tether technologies of interest are:

• Techniques and processes to coat and protect polymeric tether materials from offer both ultraviolet radiation protection as well as atomic oxygen resistance effects. Such coatings must be as thin as possible because of the importance in maintaining a high specific tensile strength in tether materials, although they must be able to adhere uniformly and reliably to tether materials, even in the face of winding and ground handling. Degradation to the strength characteristics of the tether generated by the coating process must be absolutely minimized.

**Aeroassist (Aerocapture)**

Aerocapture relies on the exchange of momentum with an atmosphere to achieve a decelerating thrust leading to orbit capture. This technique permits spacecraft to be launched from Earth at higher velocities, thus providing a shorter overall trip time. At the destination, the velocity is reduced by aerodynamic drag within the atmosphere. The aerocapture maneuver can be accomplished by utilizing either rigid or inflatable deceleration systems.

Preliminary analysis has shown that the inflatable decelerator concepts may provide mass reduction and improved packaging efficiency over a rigid aeroshell system. However, the TRL for these inflatable decelerators must be increased before an adequate comparison to traditional rigid aeroshells can be made. Current inflatable decelerator concepts are expected to be manufactured from thin film materials, elastomeric materials, and/or high temperature fabrics, stowed during transport and inflated prior to atmospheric entry for aerocapture applications at planetary destinations. Materials of particular interest include: polyimide thin films, polybenzobisoxazole (PBO) thin films, and ceramic fabrics. Prior to the aerocapture maneuver, the inflatable decelerator will be tightly stowed for many years (up to 10 years) in an uncontrolled space environment (-130°C) during transport to outer solar system destination. Before final atmospheric entry, the inflatable decelerator will be unstowed and inflated (cold GN₂). During the aerocapture maneuver, up to 24 hours after the inflation process is initiated, the inflatable decelerator will experience temperatures to 500°C (or higher).
Low Temperature/High Temperature Structural Materials/Adhesives

Development for Inflatable Deceleration Systems: This task focuses on the development and testing of structural materials/adhesives that can be utilized for aerocapture inflatable decelerator systems. This task should include:

- A thorough survey of the thin film polymer, elastomeric;
- A high temperature fabric trade space for materials that will maintain structural properties during the temperature extremes and long term space exposure experienced by inflatable decelerators;
- Investigation of the effects of various coatings, surface treatments, or impregnation processes to enhance material properties, which may include optical, mechanical, thermal or physical properties;
- A thorough survey of the adhesives trade space for materials that will maintain bond strength during the temperature extremes of long term space exposure and atmospheric entry experienced by inflatable decelerator systems must also be included.

Final deliverables should include selection criteria for final materials/adhesives, an evaluation of technology readiness levels (TRL) of candidates, technology development and testing of candidates that require further TRL advancement.

S7.05 Power Electronic Devices, Components and Packaging

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

NASA science missions employ Earth orbit and planetary spacecraft, along with terrestrial balloons, surface assets, aircraft, and marine craft as observation platforms. Advanced electrical power technologies are required for the electrical components and systems on these platforms to address the issues of size, mass, efficiency, capacity, durability, and reliability. Advancements are sought in power electronic devices, components, and packaging.

Power Electronic Components

Advanced inductors, transformers, capacitors, micro batteries, semiconductor switches, diodes, and current sensors are of interest. Proposals must address improvements in energy density, speed, efficiency, or wide temperature operation (-125°C to 200°C) with a high number of thermal cycles.

Power Conversion, Motor Drive, Protection, and Distribution

Technologies that provide significant improvements in mass, size, power quality, reliability, or efficiency in electrical power conversion, motor drives, and protective switchgear components are of interest. Candidate
applications include solar array regulators, battery charge and discharge regulators, battery by-pass switches, power conversion, power distribution, fault protection, high-speed motors/generators, magnetic bearing drivers, and integrated flywheel energy storage and attitude control electronics.

**Electrical Packaging**

Thermal control technologies are sought that are integral to electrical devices with high heat flux capability and advanced electronic packaging technologies which reduce volume and mass or combine electromagnetic shielding with thermal control.

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**S7.06 Thermal Control Technologies for Science Spacecraft**

**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. Innovative proposals for thermal control technologies are sought in the following areas:

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

2. Heat flux levels from lasers and other high power devices are increasing, with some projected to go as high as 100 W/cm². 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.

3. Future missions 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.

4. The push for miniaturization also drives the need for new thermal technologies approaching the MEMS level. Miniaturized heat transport devices, especially those suitable for cooling small sensors, devices and electronics are of interest.

5. Future robotic missions and reconfigurable 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.

Advanced Modeling, Simulation, and Analysis for Science Topic S8

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:

S8.01 Automation and Planning for Complex Tasks

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, but are not limited to:

- 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.

**S8.02 Distributed Information Systems and Numerical Simulation**

**Lead Center: ARC**

This subtopic seeks advances in tools, techniques, and technologies for distributed information systems and large-scale numerical simulation. The goal of this work is to create an efficient and effective information and computing environment that enables NASA scientists to work naturally with distributed teams and resources to dramatically reduce total time-to-solution (i.e., time to discovery, understanding, or prediction), vastly increase the feasible scale and complexity of analysis and data assimilation, and greatly accelerate model advancement cycles. Areas of interest are described below.

**Distributed Information Systems**

- Supercomputing environment simulation, to identify or anticipate bottlenecks in the environment and to effectively engage all supercomputing program resources. The simulation could include models of application behavior, the full computing and data workload, computing and data systems, local and wide area networks, data analysis and visualization systems, the interface to various facility and user services personnel, and the interface to the remote user at their desktop.

- Services (autonomous software systems) for automated, scalable, and reliable management of distributed, dynamic, and heterogeneous computing, data, and instrument resources. Services of interest include those for authentication and security, resource and service discovery, resource scheduling, event monitoring, uniform access to compute and data resources, and efficient and reliable data transfer.
• Science portals for cross-disciplinary discovery, understanding, and prediction, encapsulating services for single sign-on access, semantic resource and service discovery, workflow composition and management, remote collaboration, and results analysis and visualization.

Large-Scale Numerical Simulation

• Tools for automating large-scale modeling, simulation, and analysis, including those for managing computational ensembles, performing model-optimization studies, interactive computational steering, and maintaining progress in long-running computations in spite of unreliable computing, data, and network resources.

• Tools for computer system performance modeling, prediction, and optimization for real applications.

• Techniques and tools for supercomputing application porting, parallelization, debugging, scaling, performance analysis, and optimization.

• Tools for effective load balancing, and high reliability, availability, and serviceability (RAS) in commodity clusters and other large-scale computing systems.

• Novel supercomputing approaches using FPGAs, graphics processors, and other novel architectures and technologies.

S8.03 On-Board Science for Decisions and Actions

Lead Center: ARC

The focus of this subtopic is enhanced capabilities for NASA observatories in the sensor or platform, or early in the data stream, that can prioritize data for transmission and analysis, or summarize the data for future use. NASA's vision of a sensor-web capability will demand more onboard autonomy and content based data management to support rapid decision making and re-tasking. This subtopic is interested in methods to autonomously understand data as part of a sensor web system capable of rapid redirection and configuration.

Onboard Satellite Data Processing and Intelligent Sensor Control

Software technologies that support the configuration of sensors, satellites, and sensor webs of space-based resources. Examples include capabilities that allow the reconfiguration or re-targeting of sensors in response to user demand or in significant events seen in other sensors. Included are software that supports the reasoning and modeling of such capabilities for demonstration and mission simulation. Also included in this category is onboard analysis of sensor data that could run on reconfigurable computing environments as well as technologies that support or enable the generation of data products for direct distribution to users.

Onboard Satellite Data Organization, Analysis, and Storage

Software technologies that support the storage, handling, analysis, and interpretation of data. Examples include innovations in the enhancement, classification, or feature extraction processes. Also included are data mining, intelligent agent applications for tracking data, distributed heterogeneous frameworks (including open system
interfaces and protocols), and data and/or metadata structures to support autonomous data handling, as well as compaction (lossless) or compression of data for storage and transmission.

**Simulation and Analysis of Sensor Webs for Improving Science Models or Mission Operations**

Software that allows for the simulation of a sensor web of varying platform types producing a variety of data streams. These platforms could be in various orbits (L1, L2, NEO, LEO, etc.) and suborbital (UAV) that are automatically assigned different temporal and spatial coverages. Data streams would be assigned to these platforms and the system computes how the sensor web would cover of events (e.g., volcanic eruption, fires, and crop monitoring) at user designated, particular, geospatial locations (or areas).

**S8.04 Spatial and Visual Methods for Search, Analysis and Display of Science Data**

**Lead Center:** SSC  
**Participating Center(s):** ARC

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. 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.
S8.05 Data Management 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.
Surface Robotic Exploration Topic S1.01
Sample acquisition and handling will be important elements of future landed missions. Sample manipulation technologies are needed to enable handling and transfer of unstructured samples from a sampling device to instruments and sample processing systems. Shallow core, rock, 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 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.

Mobility technology is needed to enable access to difficult-to-reach sites such as distant locations or 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 and marsupial systems are two 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, e.g., a primary vehicle could provide long traverse to the vicinity of a challenging site and then deploy a smaller vehicle with steep mobility access capability for access to the site. Innovative low-mass, low-power, and highly modular systems and subsystems are of particular interest.

The program is also interested in new sensors such as small, low-power lidar for more robust navigation.

Examples of planetary robotics system are shown at [http://robotics.jpl.nasa.gov](http://robotics.jpl.nasa.gov) [2].

Sub Topics:

Subsurface Robotic Exploration Topic S1.02
Robust systems for accessing the subsurface of the Moon and Mars 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.

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, including icy mixtures of rock and regolith.
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 microbes brought to the Martian surface prior to drilling (‘clean’ sampling from a ‘dirty’ surface).

Sub Topics:

Martian Entry, Descent and Landing Sensors Topic S1.03

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:
Astrobiology and Atmospheric Instruments for Planetary Exploration Topic S2.01
This subtopic supports the development of advanced instruments and instrument technologies to enable or enhance scientific investigations on future planetary missions. New measurement concepts, advances in existing instrument concepts, and advances in critical components are all of interest. Proposers are strongly encouraged to relate their proposed technology development to future planetary exploration goals. These goals include geochemical, geophysical and astrobiological objectives.

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. Biomarkers produced by microbial communities are profoundly affected by internal biogeochemical cycling. The small spatial scales at which these biogeochemical processes operate necessitate measurements made using microsensors. The search for life on other planetary bodies will also require systems capable of moving and deploying instruments across, and through, varied terrain to access biologically important environments.

Instruments for both remote sensing and 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 remote sensing, on orbital or flyby spacecraft, or for in situ measurements, on surface landers and rovers, subsurface penetrators, and airborne platforms. In situ instruments cover spatial scales from surface reconnaissance to microscopic investigations. These instruments must be capable of withstanding operation in space and planetary environmental extremes, which include temperature, pressure, radiation, and impact stresses.

Examples of instruments that will meet the goals include, but are not limited to, the following:

- Instrumentation for definitive chemical, mineralogy, and isotopic analysis of surface materials: soils, dusts, rocks, liquids, and ices at all spatial scales, from planetary mapping to microscopic investigation. Examples include advanced techniques in reflectance spectroscopy, wet chemistry, laser-induced breakdown spectrometers, water and ice detectors, novel gas chromatograph and mass spectrometry, and age-dating systems;

- Instrumentation for the assessment of surface terrain and features. Examples include lidar systems and advanced imaging systems;

- Geophysical sensing systems to determine the near-surface and subsurface structure, textures, bulk components, and composition, such as seismic sensors, porosity measurement devices, permeameters, and surface penetrating radars;

- Instrumentation focused on the identification and characterization of biomarkers of extinct or extant life, such as prebiotic molecules, complex organic molecules, biomolecules, or biominerals;

- Instrumentation for the chemical and isotopic analysis of planetary atmospheres;

- Advanced detectors for solar absorption spectrometry. One example is a detector that is fast and linear, i.e., does not saturate under high photon fluxes;

- Environmental sensing systems, such as meteorological sensors, humidity sensors, wind and particle size...
distribution sensors, and sounders for atmospheric profiling;

- Particles and fields measurements, such as magnetometers, and electric field monitors; and

- Enabling instrument component and support technologies, such as laser sources, miniaturized pumps, sample inlet systems, valves, integrated bulk sample handling and processing systems, and fluidic technologies for sample preparation.

Instruments specific to astrobiology include:

- For Mars or Venus exploration, technologies that (using X-ray, neutron, ultrasonic, and other types of tomography) would enable a noninvasive, nondestructive analysis of biomarkers inside rocks and ice to depths 10 - 20 cm with spatial resolutions of 2 - 10 microns;

- Technologies that would enable the aseptic acquisition of samples under conditions of extreme environments;

- For Europa and Enceladus exploration, technologies to enable the penetration of ice and/or access to subsurface vents are required;

- High sensitivity (femtomole or better), high-resolution methods applicable to all biologically relevant classes of compounds for separation of complex mixtures into individual components;

- 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;

- Biotechnology-determining mutation rates and genetic stability in a variety of organisms as well as accurately determining protein regulation changes in microgravity and radiation environments;

- Automated chemical analytical instrumentation for determining gross metabolic characteristics of individual organisms and ecologies as well as chemical composition of environments;

- High-resolution, high-sensitivity (femtomole or better) methods for the isolation and characterization of nucleic acids (DNA and RNA) from a variety of organic and inorganic matrices; and

- Microscopic techniques and technologies to study soil cores, microbial communities, pollen samples, etc., in a laboratory environment for the detailed spectroscopic analysis relevant to evolution as a function of climate changes.

Sub Topics:

In Situ Planetary Atmospheric Measurement Technologies Topic S2.02

Proposals are sought for technologies that enable the in situ exploration of the surface and deep atmosphere of Venus and the deep atmospheres of Jupiter or Saturn for future NASA missions. Venus features a dense, CO₂ atmosphere completely covered by clouds with sulfuric acid aerosols, a surface temperature of 486°C, and a surface pressure of 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 (~480°C) and high pressures (~100 atmospheres) 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:

**Pressure Vessels and Structural Shells**

Historically, titanium and aluminum have been used as structural shells or pressure vessels for extreme environment planetary probes and landers. Improvements in the state-of-the-art of pressure vessel materials are sought to reduce the mass of such components by 20 to 50% over titanium shells. New structural shell materials shall exhibit high strength and stiffness at elevated temperatures and shall be resistant to creep and buckling under high external pressures.

**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:

- Lightweight and stable insulation materials with a conductivity less than 0.1 W/m-K at 486°C and 90 atm pressure;
- 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.

**High Temperature Electronics**

- Science and engineering sensors able to operate at 486°C and 100 bar, including for example, high temperature imagers, hybrid imaging system that utilizes high temperature fiber optics, seismometers, and pressure sensors;
- High-temperature, low-power, and ultra low-power electronics and electronic packaging technology for sensor and actuator interfaces at 486°C, including low-noise (10 nV/sqHz) preamplifiers, power amplifiers and transmitters (S-band), temperature stable oscillators, drivers (with 0-100 V digital output for driving piezoelectric, electrostatic, or electromagnetic actuators), and high value (on the order of one to hundreds of micro Farad) capacitors;
- Computer aided simulation tools for predicting the performance, reliability, and life cycle for high-temperature electronic systems and components.

**High Temperature Motors and Actuators**

- Actuators for sample handling and acquisition systems including high-temperature drills, motors, and actuators able to operate in the 486°C, 90 atmosphere surface environment of Venus.
Sub Topics:

Energy Conversion and Power Electronics for Deep Space Missions Topic S2.03

Proposals are solicited to develop advanced energy conversion and power electronics to enable or enhance the capabilities of next decadal deep space missions, with potential missions to Europa, Venus, Titan, and primitive bodies. These missions require power systems with long life capability and high reliability and offering significant mass and volume savings and improved efficiency compared to the state of practice (SOP) devices. Other desired capabilities are high radiation tolerance, and ability to operate in extreme environments (high and low temperatures and over wide temperature ranges).

Extreme Photovoltaics Energy Conversion

NASA has an increasing interest in solar array technology for deep space missions. The science community is currently pushing for solar missions that go as far as Saturn. PV proposals are sought to develop advanced photovoltaic devices and systems that can operate in extreme environments and offer significant mass and volume savings over the SOP systems. Photovoltaic cell and array technologies should also have significant improvements in efficiency, specific power, cost, and ability to operate in high-radiation, extreme-temperature environments such as near sun (high-intensity, high-temperature - HIHT) environment or deep space (low-intensity, low-temperature - LILT) environments. Extreme Photovoltaic technologies of interest are:

- Solar cells that can function effectively under LILT conditions and high radiation environments for deep space missions beyond 4 AU;
- Solar cells that can operate high temperatures (up to 450°C) for near sun missions;
- Solar arrays with high specific power (> 250 W/kg) and low stowage volume for solar electric propulsion missions.

RPS Energy Conversion

Radioisotope power systems (RPS) are presently used in some planetary surface missions and deep space science missions that go beyond 4 AU. Proposals are sought to develop advanced RPS technologies that would contribute to a system with long life capability (> 14 years), high conversion efficiency (> 20%), and high specific power (> 8 - 10 W/kg). The radioisotope power conversion systems of interest are, Stirling, Thermoelectrics (TE), and Thermophotovoltaics (TPV). All proposed energy conversion technologies must be able to operate in deep space environments with high radiation and wide-temperature operations (-200°C to >300°C). A high priority for NASA is the development of advanced static power conversion technologies (TPV or TE) that offer greater than 20% thermal-to-electric conversion efficiency for an RPS system, as well as power conversion approaches that can operate in the extreme environments of Venus and Europa.

Thermophotovoltaic technologies should focus on demonstrating converter component technologies that offer improved performance parameters:

- Photovoltaic devices capable of operating at high temperature (> 50°C) and high current density for extended durations (> 14 yr) while maintaining high performance;
Optical filters that offer high spectral efficiency and high temperature survivability (> 150°C);

Emitter materials that offer high efficiency as well as low evaporative losses suitable for extended (14 yr) operation;

Solar concentrator based TPV systems with concepts for thermal energy storage and their integration with the emitter systems.

Thermoelectric technologies should focus on:

- High temperature and performance thermoelectric materials. NASA is interested in nanostructured thermoelectric materials with potential for ZT > 2 and ability to operate at temperatures and lifetimes compatible with RPS systems;
- Innovative packaging of thermoelectric elements in closed or compact arrays;
- Sublimation coatings or methods.

Stirling power conversion technologies should focus on:

- 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);
- Advanced regenerators with improved durability and high temperature capability while maintaining high performance;
- Lightweight, high-efficiency linear alternators with low EMI and capable of high-temperature operation;
- High temperature heater heads (> 850°C) and joining techniques.

**Advanced Photovoltaics Energy Conversion**

Photovoltaic cell and array technologies with significant improvements in efficiency, mass specific power, stowed volume, cost, radiation resistance, and wide operating conditions are solicited. Photovoltaic cell technologies for wide temperature operation and radiation environments are solicited. Potential array technologies of interest include:

- Rigid and deployable arrays;
- Concentrators (rigid or inflatable, primary or secondary);
- Ultra-lightweight arrays for lightweight, flexible;
- Thin-film photovoltaic cells;
• Electrostatically clean spacecraft solar arrays.

Energy Conversion Thermal Management

Thermal technology areas include heat rejection, composite materials, heat pipes, pumped loop systems, packaging and deployment, including integration with the power conversion technology. Highly integrated systems are sought that combine elements of the above subsystems to show system level benefits.

Sub Topics:
Flexible Antennas and Electronics for L-Band Remote Sensing Topic S2.04
Electronically steerable L-band, phased array antennas are needed for missions to the Moon, Mars, Titan, Europa and Venus for remote sensing applications and support of communications. Flexible, lightweight active arrays enable better packaging efficiency for the antenna and are critical for these missions. These antennas will be deployed on orbiting spacecraft and on rovers or aerial platforms such as lighter than atmospheres (LTA) vehicles or airplanes.

When used for active remote sensing, L-band also provides the capability to detect surface and subsurface topology including density contrasts within the ice or dust and subsurface water or warm ice. In addition, the use of L-band frequencies enables proximity communications between the in situ vehicle and a spacecraft in orbit or on a flyby trajectory.

Currently, manufacturing reliable passive arrays with required tolerances is challenging and the only method for integration of the electronics is to attach and interconnect the electronic components on the surface. This method is expensive, unreliable, and impractical for large arrays. Technologies enabling large area flexible antennas, including flexible electronics, are needed. State-of-the-art, flexible, printable electronics have low switching frequencies. Innovative new materials or processes will be needed to enable devices that can handle the gigahertz frequencies needed for radar. In addition, large area manufacturing methods are needed to manufacture these passive and active antennas.

Sub Topics:
Planetary Balloons and Aerobots Topic S2.05
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:

Hot Air (Montgolfiere) Balloons for Titan

NASA is considering the use of hot air (Montgolfiere) balloons for Titan using waste heat from the radioisotope power source (RPS). Proposals are sought for concepts and prototypes for this balloon that have the following
nominal characteristics: 2000 Watts of available RPS waste heat, a 100 gm/m² balloon envelope material, 160 kg of payload mass (including the RPS but excluding the balloon), and a controllable altitude over the range of 0 to 10 km with the ability to maintain a +/- 20 m tolerance near the surface (93K, 1.46 bar). It is important that the balloon be storable in a typical entry vehicle for transport to Titan and be deployed and inflated upon arrival. Preference will be given to proposals that include cryogenic testing to validate the thermal performance models upon which the design is based.

Apex Valve for Montgolfiere Balloons

Solar-heated Montgolfiere balloons are an attractive platform for the exploration of Mars, particularly the polar regions which experience long periods of solar illumination during summer solstice. These balloons can be altitude controlled through selective venting of the heated gas through a valve located at the apex of the balloon. Proposals are sought for concepts and prototypes for this valve to be used on a solar-heated balloon on Mars. Typical specifications include large flow area (10 m²), low mass (few kilograms), packaged into a small volume for transport to Mars (3) and consume minimal electrical energy (1).

Aerial Deployment Modeling Tool

Planetary aerobots at Mars, Titan, and Venus will likely be aerially deployed and inflated 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.

Sub Topics:

Sub Topic S3.01

Precision Spacecraft Formations for Advanced Telescope Systems

This subtopic seeks hardware and software technologies necessary to establish, maintain, and operate hyper-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, testbeds) to enable detailed analysis, synthesis, modeling, and visualization of such constellations.

In a formation for large effective telescope apertures, multiple, collaborative spacecraft in a precision formation
collectively form a variable-baseline interferometer. 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. It is important that, in order to enable precision spacecraft formation keeping from coarse requirements (relative position control of any two spacecraft to less than 1 cm, and relative bearing of 1 arcmin over target range of separations from a few meters to tens of kilometers) to fine requirements (micron relative position control and relative bearing control of 0.1 arcsec), the interferometer payload would still need to provide at least 1 - 3 orders of magnitude improvement on top of the S/C control requirements. The spacecraft also require onboard capability for optimal path planning and time optimal maneuver design and execution.

Development of combined nanometer-level precision formation flying control of numerous spacecraft and their optics is required to enable large baseline (1 to 10's of km), sparse aperture UV/optical (and perhaps X-ray) telescopes and interferometers needed for ultra-high angular resolution imagery.

Proposals addressing staged-control experiments that combine coarse formation control with fine-level wavefront sensing based control are particularly encouraged. Innovations that address the above precision requirements are solicited for formation systems in the following areas:

- Integrated optical/formation/control simulation tools;
- 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; and
- Six degrees of freedom precision formation test beds.
Sub Topics:
Proximity Glare Suppression for Characterization of Faint Astrophysical Objects Topic S3.02

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 are 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;
- Metrology for detailed evaluation of compact, deep density apodizing masks, Lyot stops, and other types of graded and binary mask elements. Development of a system to measure spatial optical density, phase inhomogeneity, scattering, spectral dispersion, thermal variations, and to otherwise estimate the accuracy of masks and stops is needed;
- Interferometric starlight cancellation instruments and techniques to include aperture synthesis and single input beam combination strategies;
- Fiber optic spatial filter development for visible coronagraph wavelengths;
- 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 104 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;

• 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. The most promising DM technology may be sensitive to temperature, so developing a MUX that has very low thermal hot spots, and very uniform temperature performance will improve the control of the mirror surface;

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

• Highly reflecting broadband coatings.

Sub Topics:
Precision Deployable Structures and Metrology for Advanced Telescope Systems Topic S3.03
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. Also measurement of the metering truss. Innovative systems which minimize complexity, mass, power and cost are sought.

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.

Sub Topics:

Optical Devices for Starlight Detection and Wavefront Analysis Topic S3.04

This subtopic addresses the unique problems associated with collecting and pre-detection processing of star light for 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. These devices can be placed anywhere within an optical system, between the entrance aperture and the focal plane. A specific technology area of interest is high reflectance UV coatings and uniform polarization coatings for all wavelengths. Collection technologies of interest include capabilities which enable large-baseline segmented-aperture telescopes and sparse aperture telescopes and interferometers that will be needed to obtain high angular resolution observations to support future science goals. This subtopic addresses problems associated with formation flying including development of high-precision, high-stability laser and phase sensors, as well as of techniques to enable the monitoring of the separations of the individual spacecraft and overall orientation of the constellation. Specifically of interest is component-level technology needed to enable the characterization and combination of wavefronts from multiple apertures. Innovative technology to fabricate and test large aperture optical substrates continues to be an interest of this subtopic. Additionally, this interest is specifically extended to include technology to fabricate and test large aperture very lightweight x-ray mirrors. The primary objective of this subtopic is to reduce the mass and volume of advanced telescopes and observatories - either the primary mirror or the relay and science instrument optics. The proposed effort must address the 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.

Proposals in the following areas are specifically solicited:

- Design and construction of UV, optical, infrared or far-infrared beam combiners suitable for wavelength-resolved fringe measurements from a large number of independent apertures with flat response over a broad wavelength range;
- Development of a metrology system suitable for monitoring path lengths in the meter to kilometer range with incremental resolutions of picometers and milliseconds, and sub-micron absolute distance resolution;
- Development and test of low cost laser metrology gauges and optical pathlength control devices for alignment and control in multi-stage, multi-vehicle formations;
- Single frequency, long lifetime (>10 years), visible, IR stable semiconductor lasers in the power range 1 to 10 watt for metrology of optical systems, wavefront sensing and control and interferometry;
- High throughput, radiation hard, large area, X-ray imaging devices such as Fresnel Zone plates and masks;
- Wavelength division demultiplexers, integrated optics waveguide, fiber optic and light pipe devices for spectral analysis of scene information from UV to IR;
Innovative mirror substrate material/fabrication/test technologies and mounting/support technologies for large aperture lightweight low-cost x-ray, ambient and cryogenic applications in space telescopes;

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.

Components or devices for spectroscopy and imaging applications using hyperspectral, polarometric, Stokes photo-polarimeters, etc. technology for visible to infrared.

Sub Topics:

Sensor and Detector Technology for Visible, IR, Far IR and Submillimeter Topic S4.01 NASA astrophysics missions currently under development, such as the Herschel and Planck, (http://science.hq.nasa.gov/missions/phase.html [3]) have been enabled by improvements in detectors. Beyond 2007, advances are expected in detectors, readout electronics, and other technologies, particularly those enabling polarimetry and large format imaging arrays for the visible, near IR, 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/index.shtml [4]), SPICA (http://www.ir.isas.ac.jp/SPICA/ [5]), CMBPOL, and SNAP (http://snap.lbl.gov [6]). Space science sensor and detector technology innovations are sought in the following areas:

Future space-based observatories in the 10 - 40 micron spectral regime will be passively cooled to about 30 K. They will make use of large, sensitive detector arrays with low-power dissipation array readout electronics. Improvements in sensitivity, stability, array size, and power consumption are sought. In particular, novel doping approaches to extend wavelength response, lower dark current and readout noise, novel energy discrimination approaches, and low noise superconducting electronics are applicable areas. Future space observatories in the 40 micron to 1 mm spectral regime will be cooled to even lower temperatures, frequently < 10 K, greatly reducing background noise from the telescope. In order to take advantage of this potentially huge gain in sensitivity, improved far infrared/submillimeter detector arrays are required. The goal is to provide noise equivalent power as low as 10^{-20} W Hz^{-1/2} over most of the spectral range in a 10,000 pixel detector array with low-power dissipation readout electronics. The ideal detector element would count individual photons and provide some energy discrimination. For detailed line mapping (e.g., C+ at 158 micron), heterodyne receiver arrays are desirable, operating in the same frequency range near the quantum limit.

In addition to technologies specific to the astrophysics missions previously mentioned, the following cross-cutting technologies are also of interest:

- Large (4 meter), lightweight, deployable antennas for frequencies between 180 to 660 GHz. Reflectors for such antennas with surface densities of 10 kg/m^2 or less.
- Broadband (> 2 GHz, 4 GHz preferred), modest resolution (10 MHz), low power (< 5 watt) digital spectrometers for submillimeter spectroscopy. This may include enabling technologies such as:
  - Efficient FPGA firmware for spectral analysis including polyphase filterbanks;
  - High speed, low power, space qualified digitizers with analog bandwidths of > 5 GHz and preferably up to 18 GHz, sample rates > 5 Gs/s, 4 to 6 bit resolution, and simple interface to present FPGAs;
  - Hardware (ex. ASICs) for low power implementation of digital signal processing.
- Broad bandwidth, low power, flight qualifiable spectrometers. Band of interest is 6 to 18 GHz or higher with ~200 MHz resolution.
- Reliable, tunable, spurious free, and flight qualifiable local oscillators for SIS mixers covering 190 to 270...
GHz and 600 to 660 GHz.
- Broadband cryogenic isolators covering 6 to 18 GHz.

While focused technology and instrument developments are progressing for missions in the development phases such as the Space Interferometry Mission (SIM) and the James Webb Space Telescope (JWST), ambitious mission concepts are being pursued for future opportunities to address cosmology questions, galactic/stellar astrophysics and extrasolar planet finding quests. Innovative concepts that will significantly advance the state of the art in sensitivity, spectral coverage, array format, power dissipation, and other instrument critical parameters are sought. Also solicited are proposals that address key improvements in current techniques and devices in terms of performance, reliability and technology maturity. In such efforts, the proposer must demonstrate expertise and capability with respect to the existing technique/device/process/system. Optical/electronic devices that enhance or complement the detector function in an instrument are also of interest. Examples are micro shutter arrays to select objects across a focal plane for spectroscopy, timing and analog to digital converters for large focal plane instruments. The optical and near-IR requirements include giga pixel arrays, exceptionally stable sensitivity and precision calibration.

<table>
<thead>
<tr>
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<th>Detector Functionality</th>
<th>Parameters to Push</th>
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<tr>
<td>0.1 um - 1.0 um</td>
<td>Improving silicon response in UV and NIR, smart pixel arrays, solar blind response detector arrays, energy resolving calorimeter arrays</td>
<td>Sensitivity, array format size, high purity silicon processes</td>
</tr>
<tr>
<td>1.0 um - 4.0 um</td>
<td>New sensor materials, Large format cryogenic readout multiplexers, Large format (&gt;1x1k) array hybridization techniques</td>
<td>Sensitivity, array format size</td>
</tr>
<tr>
<td>4.0 um - 40 um</td>
<td>Low power cryo operated multiplexers, new sensor materials (e.g., novel dopants for extrinsic Si detectors)</td>
<td>Sensitivity, array format size (~megapixels)</td>
</tr>
<tr>
<td>40 um - 200 um</td>
<td>Monolithic focal plane arrays (BIB technologies, new sensor materials)</td>
<td>Sensitivity, array format size (~megapixels)</td>
</tr>
<tr>
<td>200 um - 1000 um</td>
<td>Photometric imaging arrays, spectroscopy arrays, THz coherent receiver arrays (mixers, sources, precision packaging)</td>
<td>Photometric imaging arrays (NEP<del>1e-18 W/Hz^{0.5}, 10,000 pixels); Spectroscopic arrays (NEP</del>1e-20 W/Hz^{0.5}, 1,000 pixels)</td>
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</table>

**Supporting Device Categories**

<table>
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<th>Parameters to Push</th>
</tr>
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<td>mm wave</td>
<td>MMIC packaging</td>
<td>Cost, cryo operation</td>
</tr>
<tr>
<td>Digital spectrometer (back-end for)</td>
<td>Autocorrelation spectrometers, high</td>
<td>15 GHz or greater bandwidth</td>
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### Detector Technologies for UV, X-Ray, Gamma-Ray and Cosmic-Ray Instruments Topic S4.02

The next generation of astrophysics observatories for the infrared, ultraviolet (UV), X-ray, and Gamma-ray bands require order-of-magnitude performance advances in detectors, detector arrays, readout electronics, and other supporting and enabling technologies. Although the relative value of the improvements may differ among the four energy regions, many of the parameters where improvements are needed are present in all four bands. In particular, all bands need improvements in spatial and spectral resolutions in the ability to cover large areas and in the ability to support the readout of the thousands to millions of resultant spatial resolution elements. Innovative technologies are sought to enhance the scope, efficiency, and resolution of instrument systems at all energies and wavelengths:

- The next generation of gravitational missions will require greatly improved inertial sensors. Such an inertial sensor must provide a carefully fabricated test mass, which has interactions with external forces (i.e., low magnetic susceptibility, high degree of symmetry, low variation in electrostatic surface potential, etc.) below $10^{-16}$ of the Earth's gravity, over time scales from several seconds to several hours. The inertial sensor must also provide housing for containing the proof mass in a suitable environment (i.e., high vacuum, low magnetic and electrostatic potentials, etc.);
- Advanced Charged Couple Device (CCD) detectors, including improvements in UV quantum efficiency and read noise, to increase the limiting sensitivity in long exposures and improved radiation tolerance. Electron-bombarded CCD detectors, including improvements in efficiency, resolution, and global and local count rate capability. In the X-ray, we seek to extend the response to lower energies in some CCDs, and to higher, perhaps up to 50 keV, in others;
- Significant improvements in wide band gap (such as GaN and AlGaN) materials, individual detectors, and arrays for UV applications;
- Improved microchannel plate detectors, including improvements to the plates themselves (smaller pores, greater lifetimes, alternative fabrication technologies, e.g., silicon), as well as improvements to the associated electronic readout systems (spatial resolution, signal-to-noise capability, and dynamic range), and in sealed tube fabrication yield;
- Imaging from low-Earth orbit of air fluorescence, UV light generated by giant airshowers by ultra-high energy ($E > 10^{19}$ eV) cosmic rays require the development of high sensitivity and efficiency detection of 300 - 400 nm UV photons to measure signals at the few photon (single photo-electron) level. A secondary goal minimizes the sensitivity to photons with a wavelength greater than 400 nm. High electronic gain (~106), low noise, fast time response ($2 \times 10^{-7}$ mm$^2$). Focal plane mass must be minimized (2 g/cm$^2$ goal).

For advanced X-ray calorimetry improvements in several areas are needed, including:

- Superconducting electronics for cryogenic X-ray detectors such as SQUID-based amplifiers and their multiplexers for low impedance cryogenic sensors and superconducting single-electron transistors and their

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<th>(Autocorrelation), 2 GHz or Greater Bandwidth (FFT &gt; 32K Points); Low Power, Compact Configurations</th>
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<td>Reliability, Low Off State Scatter or Leakage, Cryo Operability</td>
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<td>Infrared Optical Filters</td>
<td>Thin Film or Other Technologies to Realize ~1&quot; Aperture Filters</td>
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<td>New, High Yield Bump Bonding Techniques</td>
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multiplexers for high impedance cryogenic sensors;
- Micromachining techniques that enhance the fabrication, energy resolution, or count rate capability of closely-packed arrays of X-ray calorimeters operating in the energy range from 0.1 - 10 keV; and
- Surface micromachining techniques for improving integration of X-ray calorimeters with read-out electronics in large-scale arrays.

Improvements in readout electronics, including:

- Low-power ASICs and the associated high-density interconnects and component arrays to interface them to detector arrays;
- Superconducting tunnel junction devices and transition edge sensors for the UV and X-ray regions. For the UV, these offer a promising path to having "three-dimensional" arrays (spatial plus energy).

Improvements in energy resolution, pixel count, count rate capability, and long wavelength rejection are of particular interest:

- Techniques for fabrication of close-packed arrays, with any requisite thermal isolation, and sensitive (SQUID or single electron transistor), fast, readout schemes and/or multiplexers;
- Arrays of CZT detectors of thickness 5 - 10 mm to cover the 10 - 500 keV range, and hybrid detector systems with a Si CCD over a CZT pixelated detector operating in the 2 - 150 keV range.

For improvements to detector systems for solar and night-time UV and EUV (approx. 20-300nm) observing, the following areas are of interest:

- Large format (4 K x 4 K and larger); high quantum efficiency;
- Small pixel size;
- Large well depth;
- Low read noise;
- Fast readout;
- Low power consumption (including readout);
- Intrinsic energy and/or polarization discrimination (3D or 4D detector);
- Active pixel sensors (back-illumination, UV sensitivity); and
- High-resolution image intensifiers, UV and EUV sensitive, insensitive to moisture.

Space spectroscopic observations in the UV, visible, and IR requiring long observation times would be much more sensitive with high quantum efficiency (QE) and zero read noise. Techniques are sought which improve the QE of photon counters, or eliminate the read noise of solid-state detectors; and X-ray and Gamma-ray imaging with higher sensitivity, dynamic range and angular resolution requires innovations in modulation collimators and detection devices. The energy range of interest is from a few kilo-electron Volts to hundreds of milli-electron Volts for observations of solar flares and cosmic sources. Collimators with size scales down to a few microns and thicknesses commensurate with photon absorption over a significant fraction of this energy range are required. Low-background detectors capable of

Sub Topics:
- Cryogenic Systems for Sensors and Detectors Topic S4.03

stored cryogenic systems have long been used to perform cutting edge space science, but at high cost and with a limited lifetime. Improvements in cryogenic system technology 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 coolers for cooling detectors for scientific instruments and sensors on advanced telescopes and observatories as well as lunar and planetary exploration. The coolers should have long life, low vibration, low mass, low cost, and high efficiency. Specific areas of interest include:
- Highly efficient coolers in the range of 4 - 10 Kelvin as well as at 50 milli-Kelvin and below, and cryogen-free systems, which integrate these coolers together;
- Highly reliable, efficient, low-cost Stirling and pulse tube cooler technologies in the 15 Kelvin and 35 Kelvin regions;
- Essentially vibration-free cooling systems such as reverse Brayton cycle cooler technologies;
- Highly efficient magnetic and dilution cooling technologies, particularly at very low temperatures;
- Hybrid cooling systems that make optimal use of radiative coolers; and
- Miniature, MEMS, and solid-state cooler systems.

Sub Topics:

**Optics Manufacturing and Metrology for Telescopes Topic S4.04**

This subtopic focuses on optics manufacturing, metrology of optical surfaces, and mitigation of optical surface errors through direct manipulation of the optical surface and/or wavefront sensing and control techniques and technologies.

Optics manufacturing includes all areas associated with generation and maintenance of the optical surface, including both mirror and grating surfaces (and volumes). Improvements in substrate materials, hybrid structures, replication from masters, lightweighting techniques, and figuring and polishing (especially near-edge for segmented optics) are all sought.

Metrology of optical surfaces includes test methods and hardware to measure the surface to fractional wave tolerance, especially for large, aspheric optics and/or while the part is still mounted on the figuring/polishing apparatus or spindle. Metrology systems with artificial intelligence that can deterministically feed back to the polishing instrument, e.g., with a map of dwell times for subaperture polishing.

Mitigation of 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.

Sub Topics:

**Data Analysis Technologies for Potential Gravity Wave Signals Topic S4.05**

NASA is developing the Laser Interferometer Space Antenna (LISA) mission to search for gravitational waves from astrophysical phenomena such as the Big Bang, mergers of super massive black holes, and galactic binary inspirals. Detection of gravitational waves would open a new astrophysical window on the universe, with great potential for unexpected discoveries. A number of gravitational wave follow on missions to LISA are also under study.

The disturbance caused by the passage of a gravitational wave is expected to be very small and will be measured with laser interferometry. Technologies are sought to deal with the data analysis of the gravitational wave signals in these measurements. Background information on LISA along with preliminary data analysis discussions can be found in the Proceedings of the 5th International LISA Symposium, Estec, Noordwijk, The Netherlands, 12-15, July 2004, published in the Classical and Quantum Gravity Journal, Vol 22, Number 10, 21 May 2005.

Software development for application of the Hilbert-Huang Transform to gravitational wave data analysis: The Hilbert-Huang Transform (HHT) is a new method of time-series analysis which is specifically target to the analysis of non-linear, transient signals (N. Huang, et al., "The empirical mode decomposition and the Hilbert spectrum for non-linear and non-stationary time series analysis", Proceedings of the Royal Society of London, A (1998) v. 454, 903-995). It will have a direct application to data analysis for LISA, Big Bang Observer (BBO), and other space-based gravitational wave missions in particular, and more generally to any mission with non-linear, transient data. For this task the vendor will be asked to build a software package that will provide a full HHT analysis of the data, using as an example a NASA-provided
simulated LISA data stream, and incorporating a user-friendly interface. The vendor will need to familiarize himself with the HHT algorithm, and show relevant experience in the development of related software packages.

Sub Topics:
Terrestrial Balloon Technology Topic S4.06

Innovations in materials, structures, and systems concepts have enabled buoyant vehicles to play an expanding role in NASA’s Science Mission Directorate and Exploration Systems Mission Directorate. A new generation of large, stratospheric balloons, based on advanced balloon envelope technologies, will be able to deliver payloads of several thousand kilograms to above 99.9% of the Earth's absorbing atmosphere and maintain them there for months of continuous observation. NASA is seeking innovative and cost-effective solutions in support of terrestrial balloons in the following areas:

- Innovative concepts for trajectory control and/or station keeping for effectively maneuvering large terrestrial balloons in either the horizontal latitude or vertical altitude plane or both;
- Innovative floatation systems for water recovery of NASA’s scientific payloads;
- Innovative guided or gliding parachutes systems for use in thin atmospheres.

Sub Topics:
Voltage Supplies and Charge Amplifiers for Solar Science Missions Topic S5.01

For success of future solar science missions, it is critical to develop future enabling technologies which are modular, compact and efficient. This subtopic focuses on innovations for two technology areas: (1) The first area is compact, sealed and efficient high voltage supplies for space use; (2) The second technology area is high gain, wide dynamic range charge amplifiers. Specific module details are provided as below.

High voltage power supplies can be divided into 3 kilovolt categories: low (The charge amplifier ASIC shall be of low power, high gain and low noise. The ASIC shall be developed for at least 16 channels, with capability to daisy chain the amplifiers. Individual channels shall contain offset correction, gain correction and input capacitance tuning. The ASIC shall be designed for optimum operating temperature, radiation tolerance and ESD safe inputs.

The proposer shall describe the innovation and specific improvement over the current state of the art.

Sub Topics:
Sensors for Measurement of Particles and Fields Topic S5.02
Understanding the connections between the Sun and its planets will allow us to predict the impacts of solar variability on humans, technological systems, and even the presence of life itself. This requires remote and in situ
sensing of upper atmospheres and ionospheres, magnetospheres and interfaces with the solar wind, the heliosphere, and the Sun. Improving our knowledge and understanding of these requires accurate in situ measurements of the composition, flow, and thermodynamic state of space plasmas and their interactions with atmospheres, as well as the physics and chemistry of the upper atmosphere and ionosphere systems. Remote sensing of neutral atoms is required for the physics and chemistry of the Sun, the heliosphere, magnetospheres, and planetary atmospheres and ionospheres. Because instrumentation is severely constrained by spacecraft resources, miniaturization, low power consumption, and autonomy are common technological challenges across this entire category of sensors. Specific technologies are sought in the following categories:

**Plasma Remote Sensing** (e. g., neutral atom cameras)

This may involve techniques for high-efficiency and robust imaging of energetic neutral atoms covering any part of the energy spectrum from 1 eV to 100 keV, within resource envelopes less than 5 kg and 5W.

- Miniaturized, radiation-tolerant, autonomous electronic systems for the above, within resource envelopes of 1 - 2 kg and 1 - 2 W.

**In Situ Plasma Sensors**

- Improved techniques for imaging of charged particle (electrons and ions) velocity distributions as well as improvements in mass spectrometers in terms of smaller size or higher mass resolution;
- Improved techniques for the regulation of spacecraft floating potential near the local plasma potential with minimal effects on the ambient plasma and field environment;
- Low power, digital, time-of-flight analyzer chips with sub-nanosecond resolution and multiple channels of parallel processing; and
- Miniaturized, radiation-tolerant, autonomous electronic systems for the above, within resource envelopes of 1 - 2 kg and 1 - 2 W.

**Fields Sensors**

- Improved techniques for measurement of plasma floating potential and DC electric field (and by extension, the plasma drift velocity), especially in the direction parallel to the spin axis of a spinning spacecraft;
- Measurement of the gradient of the electric field in space around a single spacecraft or cluster of spacecraft;
- Improved techniques for the measurement of the gradients (curl) of the magnetic field in space local to a single spacecraft or group of spacecraft;
- Direct measurement of the local electric current density at spatial and time resolutions typical of space plasma structures such as shocks, magnetopause, and auroral arcs; and
- Miniaturized, radiation-tolerant, and autonomous electronic systems for the above within resource envelopes of 1 - 2 kg and 1 - 2 W.
Electromagnetic Radiation Sensors

- Radar sounding and echo imaging of plasma density and field structures from orbiting spacecraft; and
- Miniaturized, radiation-tolerant, and autonomous electronic systems for the above within resource envelopes of 1 - 2 kg and 1 - 2 W.

Sub Topics:

Passive Optics and Stepping Motors for Spaceborne and Airborne Platforms Topic S6.01
Passive optical remote sensing generally requires that deployed devices have large apertures and large throughput. NASA is interested primarily in instrument technologies suitable for aircraft or space flight platforms, and these inherently also prefer low mass, low power, fast measurement times, and a high degree of robustness to survive vibrations in flight or at launch. Wavelengths of interest range from ultraviolet through the far infrared. Development of techniques, components and instrument concepts that can be developed for use in actual deployed devices and systems within the next few years is highly encouraged.

Technologies and components that are not clearly suitable for use in high throughput remote sensing instruments are not applicable to this subtopic. The technology areas of primary interest are described below:

- Technology leading to significant improvements in capability, availability, or cost of large format (> 2.5 cm diameter), very narrow band (~ full-width at half-maximum), polarization insensitive, high throughput infrared (6 - 15 µm) optical filters. These filters must be able to operate in vacuum at cryogenic temperatures.

- High performance four-band two-dimensional (2D) arrays (128x128 elements or more) in the 0.4 - 2.5 µm wavelength range with high quantum efficiencies (60%-80% or higher) in all spectral bands, low noise, and ambient temperature operation.

- Detector arrays with unusual 3-dimensional geometries. Of particular interest is the development of a photon counting system with multiple cylindrical detecting elements (detecting surface on the outside edge) formed into a stack connected through one end to the cable leading to the readout electronics. The stack should be 2 to 5 cm in length with at least 12, and up to 48, individual elements. The diameter of the stack/elements should be minimized and on the order of 0.5 cm or less. Each detector element should have a clear field of view for most of the 360 degrees perpendicular to the stack. Exact details for the sensitivity are negotiable at this early stage, but applications are for fluorescence type measurements.

- High performance 2-color array detectors (128x128 or higher) covering the 3 - 15 micron spectral range with high efficiencies, low noise and operating at relatively high temperatures (>150K desired, 80K minimum).

- Improved cryogenic stepping motors with high running torques at 80K. The motors must operate in vacuum and at temperatures at or below 80K. It is desired that these motors have minimal size and power requirements, and especially important that they use minimal current. Typical torque values desired are in
the range of 10 - 20 oz-inches. Proposed motors should have at least 200 steps per revolution of the axis.

Sub Topics:
Lidar System Components for Spaceborne and Airborne Platforms Topic S6.02
High spatial resolution, high accuracy measurements of atmospheric parameters from ground-based, airborne, and spaceborne platforms require advances in the state-of-the-art lidar technology with emphasis on compactness, reliability, efficiency, low weight, lifetime, and high performance. Innovative technologies that can expand current measurement capabilities to airborne, Unmanned Aerial Vehicle (UAV), or spaceborne platforms are particularly desirable. Development of components that can be used in actual deployed systems within the next few years is highly encouraged. Technologies and components that are not clearly suitable for effective lidar remote sensing or field deployment are not applicable to this subtopic. This subtopic considers components that enable Earth-sun system measurements such as:

- Cloud and aerosols with emphasis on aerosol optical properties;
- Wind profiles using direct-detection (noncoherent) lidar, or coherent-detection (heterodyne) lidar, or both;
- Land topography (vegetation, ice, land use); and
- Molecular species (carbon dioxide, ozone, and water vapor).

Innovative component technologies that directly address the measurement needs above will be considered. Dual-use technologies addressing Planetary Exploration are highly desirable. This subtopic is soliciting only the specific component technologies described below.

1. Pulsed, single frequency, diode laser or fiber laser based seeded MOPA systems are desired due to inherent robustness, efficiency, thermal and alignment stability. If the cost per unit is reasonable, and the size is small, then many of these can be installed on a spacecraft for either parallel operation or as backup units to lengthen the life of the mission. Systems with the following specifications are solicited:

   - Stable single frequency operation at 1047nm, 1064 nm, or 1570 nm;
   - Small, integrated assemblies that can generate CW powers in the 100's of mW to several Watts range and higher peak power pulsed operation yielding at least 10 to 500 nJ pulse energies;
   - Fiber laser and amplifier designs with high SBS suppression;
   - Gaussian pulsewidths between 100 ps and 50 ns;
   - MOPA design configuration is desired where the pulse production cavity is short and more readily impedance matched for the fast rise times, gain switching, etc.;
   - A semiconductor amplifier, or possibly a small cm-scale rare Earth doped fiber amplifier, can be coupled to the oscillator chip's output, itself contained in a hermetic butterfly or similar package;
Repetition rates as low as 100 Hz and as high as 10 kHz are needed, with pulsed lifetimes in the trillion shot regime ($10^{12}$);

- Single mode, polarization maintaining (PM) fiber output is needed;
- Short term drift less than 1 MHz;
- Second and third harmonic generation techniques that can be packaged with the CW and pulsed diode or fiber laser sources to produce additional wavelengths in the visible or ultraviolet.

2. High speed fiber multiplexers for single and multimode fiber. A 1-to-10, or greater, multiplexer that is capable of switching on the order of 10 to 100 kHz with low insertion losses is required. Unit must be small, lightweight, and use little power. Single mode fiber version must be capable of handling high power (>100 microJoules at 10 kHz at 1064 nm). Multimode version will be used in low power applications and must be compatible with 0.22 NA fiber with 100 to 600 micron core size. Switching speeds faster than 10 microseconds are required.

3. 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 2 mJ to 100 mJ, repetition rate 10 Hz to 200 Hz, and pulse duration of approximately 200 nsec.

4. Single element, low noise, high quantum efficiency, HgCdTe avalanche photodiode detector (APD) capable of photon counting at rates >10 MHz for use in the 1570 nm range. Should be suitable for operation with a thermal electric cooler.

5. Lightweight compact lidar telescopes operating at one or more of the primary laser wavelengths in 1.0 to 2.0 micron wavelength region. The general requirements are: optical quality better than 1/6 wave at 632 nm, mass density less than 12 kg/m$^2$, and aperture diameter from 10 cm to 30 cm. Proof of scalability to 50 to 75 cm diameter for deployment in space is required.

6. Interferometric lidar aft-optics receiver subsystems/components to separately derive aerosol and molecular backscatter via High Spectral Resolution Lidar (HSRL) technique. The subsystem/component is to be implemented into a HSRL system with the goal of independently derive aerosol backscatter and extinction. Subsystems/components are needed at 355 and 532 nm wavelengths. Architectures could be based on Fabry Perot, Mach Zehnder, or other interferometric implementations. Resolving power of the order of 1 GHz and high frequency stability of pass/stop bands are required. Concepts must address issues associated with etendue of large-aperture (1 - 1.5 m) lidar receivers with field of view of the order of 200 micro-radians.

7. CCD detectors with high quantum efficiency at 355 and 532 nm for spaceborne lidar instruments measuring cloud and aerosol backscatter and extinction. CCD detectors are needed to replace single
element PMT detectors for imaging fringes from interferometric elements of a HSRL instrument. Clocking schemes to move charge on the CCD to achieve on-chip profile averaging and reduce dark current and readout noise should be considered.

Sub Topics:
Earth In Situ Sensors Topic S6.03
Proposals are sought for the development of in situ measurement systems. These systems are sought for use on radiosondes, dropsondes, tethered balloons, kites, mini-Unmanned Airborne Vehicles (UAVs), Unmanned Undersea Vehicles (UUVs), or Unmanned Surface Vehicles (USVs). Data acquisition methods should be included. Technology innovation areas of interest include:

- Measurements of atmospheric properties including temperature, humidity, solar radiation, clouds, liquid water, ice, precipitation, carbon dioxide, methane, and sulfur dioxide;
- Measurements of three-dimensional atmospheric winds near the Earth’s surface, and within the troposphere and lower stratosphere, with high spatial resolution and accuracy. Of particular interest are systems intended for measurements of atmospheric fluxes as well as those for convection;
- Measurements of oceanic properties including inherent and apparent optical properties, ocean temperature and salinity, and sea surface height.

Sub Topics:
Passive Microwave Topic S6.04
Proposals are sought for the development of innovative passive microwave technology in support of Earth System Science measurements of the Earth’s atmosphere and surface. These microwave radiometry technology innovations are intended for use in the frequency band from about 1 GHz to 1 THz. The key science goal is to increase our understanding of the interacting physical, chemical, and biological processes that form the complex Earth system. Atmospheric measurements of interest include climate and meteorological parameters—including temperature, water vapor, clouds, precipitation, and aerosols; air pollution; and chemical constituents such as ozone, NOX, and carbon monoxide. Earth surface measurements of interest include water, land, and ice surface temperatures, land surface moisture, snow coverage and water content, sea surface salinity and winds, and multi-spectral imaging.

Technology innovations are sought that will provide the needed concepts, components, subsystems, or complete systems that will improve these needed Earth System Science measurements. Technology innovations should address enhanced measurement capabilities such as improved spatial or temporal resolution, improved spectral resolution, or improved calibration accuracies. Technology innovations should provide reduced size, weight, power, improved reliability, and lower cost. The innovations should expand the capabilities of airborne systems (manned and unmanned) as well as next generation spaceborne systems. Highly innovative approaches that open new pathways are also an important element of competitive proposals under this solicitation.

Specific technology innovation areas include:
Electronics Technologies

- Imaging radiometers, receivers, or receiver arrays on a chip;
- Microwave and millimeter-wave frequency sources as an alternative to Gunn diode oscillators. Compact (3) self-contained oscillators with output frequency between 40 GHz and 120 GHz, low phase noise 100 mW, and low power consumption (3);
- Wideband and ultra-wideband sensors with >15dB cross-pole isolation across the bandwidth;
- Low noise (3), heterodyne mixers requiring low local oscillator drive power (3);
- Undersampling, multibit, analog-to-digital converters with Multigigahertz RF input bandwidth, low power consumption, and associated digital signal processing logic circuit;
- Low power, lightweight microwave with DC power consumption of less than 2 W;
- Electronic design approaches and subsystems that can be incorporated into microwave radiometers to detect and suppress RFI within or near the reception band of the radiometer, thus insuring higher data quality;
- Innovative new designs for highly stable noise-diode or other electronic devices as additional reference sources for onboard calibration. Of particular interest are variable correlated noise sources for calibrating correlation-type receivers used in interferometric and polarimetric radiometers;
- Monolithic microwave integrated circuit (MMIC), low-noise amplifiers (LNA). Of particular interest are LNAs covering the frequency range of 165 to 193 GHz with low 1/f noise, and having a noise figure of 6.0 dB or better; and
- GPS receiver systems for application as bi-static altimeters and scatterometers.

Antenna Technologies

- Sensor elements with low mutual coupling allowing close spacing within large arrays;
- Large format, millimeter wave, focal plane array modules for large-aperture passive imaging applications; and
- Large aperture, deployable antenna concepts. Such large apertures can be real or synthetic. Of particular interest are highly compact launch configurations.

Calibration Technologies

- New technology calibration reference sources for microwave radiometers that provide greatly improved reference measurement accuracy. Of particular interest are high emissivity (near-black-body) surfaces for use as onboard calibration targets for microwave radiometers which will significantly reduce the weight of aluminum core target designs, while reliably improving the uniformity and knowledge of the calibration target temperature; and
- New approaches, concepts, and techniques for microwave radiometer system calibration over or within the 1-300 GHz frequency band which provide end-to-end calibration to better than 0.1K, including corrections.
Sub Topics:

Active Microwave Topic S6.05

Active microwave sensors have proven to be ideal instruments for many Earth science applications. For global coverage and the long-term study of Earth's eco-systems, space-based radar is of particular interest to Earth scientists. Radar instruments for Earth science measurements include Synthetic Aperture Radar (SAR), scatterometer, sounder, altimeter and atmospheric radar. The life-cycle cost of such radar missions has always been driven by the resources - power, mass, size, and data rate - required by the radar instrument, often making radar not cost competitive with other remote sensing instruments. Order-of-magnitude advancement in key sensor components will make the radar instrument more power efficient, much lighter weight and smaller in stow volume, leading to substantial savings in overall mission life-cycle cost by requiring smaller and less expensive spacecraft buses and launch vehicles. On-board processing techniques will reduce data rates sufficiently to enable global coverage. Technologies that may lead to advances in instrument design, architectures, hardware, and algorithms are the focused areas of this subtopic. In order to increase the radar remote sensing user community, this subtopic will also consider radar data applications and post processing techniques. Specific areas in which advances are needed include:

- L-band SAR for surface deformation, topography, soil moisture measurements:
  - Lightweight, electronically steerable, dual-polarized, L-band phased-array antennas;
  - Lightweight deployable antenna structures and deployment mechanisms suitable for very large aperture systems (e.g., 2x100m antennas);
  - Rad-hard, high-efficiency, low-cost, lightweight L-band T/R modules;
  - L-band MMIC single-chip T/R modules;
  - High-power L-band transmitters (2KW to 10KW);
  - Integrated (e.g., ASIC) arbitrary waveform generators;
  - High performance, low power, rad-hard, real-time SAR processors and SAR data processing algorithms and data reduction techniques;
  - Thin-film membrane compatible electronics. This includes: Reliable integration of electronics with the membrane, high performance (>1.2GHz) transistor fabrication on flex material including identifying new materials, process development and techniques that have potential to produce large area passive and active flexible antenna arrays.

- Ku-band and Ka-band interferometers for snow cover measurement over land (Ku-band) and wetland and river monitoring (Ka-band):
  - Large, stable, lightweight, deployable structures (10-50 meter interferometric baseline);
  - Phase-stable Ku-band and Ka-band electronically steered phased arrays and multi-beam antennas;
- Lightweight deployable reflectors (Ku-band and Ka-band);
- Phase stable Ku-band and Ka-band receive electronics and T/R modules;
- High-power Ka-band transmitters (2KW to 10KW);
- High performance, low power, rad-hard, real-time radar processors and SAR data processing algorithms and data reduction techniques.

- X-band to W-band doppler radars for precipitation and cloud measurements:
  - High efficiency RF power amplifier (Ku-, Ka-, and W-band);
  - Compact, low loss phase shifters (Ka- and W-band);
  - High power and low insertion loss transmit-receive switches (Ka-, W-band);
  - Wide dynamic range low noise amplifiers (Ka- and W-band);
  - Low sidelobe (-90 dB) pulse compression technology (W-band);
  - Compact frequency synthesizer (Ku- and Ka-band);
  - High power, low sidelobe, compact antennas for high altitudes (X-Ka-band).

- Low Frequency (HF, VHF and UHF) airborne sounders:
  - Technology for creating large Ground Penetrating Radar (GPR) baselines with wireless phase lock loops;
  - High Power (800W), linear amplifiers;
  - Innovations in system design or hardware improvements to minimize the effect of the transmit signal leakage into receiver.

Sub Topics:
- Guidance, Navigation and Control Beyond Low Earth Orbit (LEO) Topic S7.01
  Envisioned NASA science missions will increasingly use large, and/or distributed, observatories in orbits beyond LEO. Advanced Guidance Navigation and Control (GN&C) technology is required for these platforms to address high performance and reliability requirements while simultaneously satisfying low power, mass, volume and affordability constraints. In particular, there are many technology gaps in challenging orbital environments, including highly elliptical Earth orbits, libration point orbits, and lunar and planetary orbits. A vigorous effort is needed to develop guidance, navigation and control methodologies, algorithms, and sensor-actuator technologies to enable revolutionary science missions. Of particular interest are highly innovative GN&C technology proposals directed towards enabling scientific investigators to exploit new vantage points, develop new sensing strategies, and implement new system-level observational concepts that promote agility, adaptability, evolvability, scalability, and affordability. Specific areas of research include:
Precision Pointing

Innovative GN&C solutions for scientific instrument and laser communication system pointing, tracking, and stabilization are sought. Proposals that exploit and combine recent advances in attitude determination and control, lasers, advanced electro-mechanical packaging are encouraged. Proposed NASA science missions provide applications with pointing accuracies of 3 microradians or less with jitter of 30 nanoradians or less.

Formation Flying

Novel approaches to autonomous sensing and navigation of multiple distributed space platforms are sought. Of particular interest are sensing systems for formation, relative navigation and attitude. Proposed NASA science missions provide applications with relative range accuracies of 1 cm or less over formation scales of several km.

Low Impact Sensors and Actuators

GN&C sensors and actuators such as Sun sensors, Earth sensors, star/celestial object trackers, fine guidance sensors, gyroscopes, accelerometers, magnetometers, reaction/momentum wheels, control-moment gyros, magnetic torquers, tethers, attitude control thrusters, etc are sought. Of particular interest are technologies that will provide a sensing or actuation function, having performance (e.g., dynamic range, stability, accuracy, noise, sensitivity, bandwidth, control authority, etc.) consistent with the state-of-the-art, but with significantly reduced impact (mass, power, volume, and cost) to the host spacecraft. These resource reduction improvement factors should be quantified in the proposal and show a minimum factor of 2 with a goal of 10 or greater.

Sub Topics:

Long Duration Command and Data Handling for Harsh Environments Topic S7.02

NASA's space based observatories, fly by spacecraft, orbiters, landers, and robotic and sample return missions, require robust command and data handling system capabilities. Advances in command and data handling technologies are sought to support the NASA's goals for improved investigations of Earth space, the solar system, and the universe.

The subtopic goal is to develop high-performance processors and architectures and reliable electronic systems that can operate effectively for long periods of time in harsh environments. The subtopic objective is to elicit novel architectural concepts and component technologies that are realistic and have credible applications to NASA missions.

A proposal's ideas should reflect (1) that the final end product(s) lead to usable hardware that can be integrated into NASA programs within 5 to 7 years, (2) effective and sustainable hardware and software development environments, (3) sustainability (affordable, reliable and effective), and (4) applicability to deep space missions (i.e., resource efficient and reliable over extreme environments of temperature and radiation), and will significantly advance solutions to the challenges of high performance processing, reconfiguration, and fault tolerant operations.

Technology priorities:
High Performance Processing

- Distributed or multi-core processing, with math co-processor or floating point capability that significantly exceeds the present state of the art;
- FPGA-based processing, targeting performance and fault tolerance, based on voting processors implemented as part of a rad-tolerant FPGA fabric

Onboard Networks

- Rad-hard Ethernet physical layer components, fully compatible with the current ground based 10/100 Ethernet. The board side interface would have the Ethernet MII and RMII interface standards;
- Rad-hard multi gigabit fiber optic transceiver to support high data rate network protocols.

Data System Support Electronics

- Radiation hard oscillators (greater than 150 MHz with equal duty cycles);
- Models for analysis of interplanetary radiation and radiation belts, and technologies that enable in-flight radiation measurements such as total dose and single event effects in computing systems.

Sub Topics:

Electric Propulsion Topic S7.03
Innovations in propulsion technologies are needed to support the Science Mission Directorate (SMD) goals of better understanding the Earth-Sun system, exploring our solar system, and investigating the nature of the universe beyond our solar system. Planetary spacecraft need ever-increasing propulsive performance and flexibility for ambitious missions requiring high duty cycles and years of operation. Satellites and satellite constellations have high-precision propulsion requirements, usually in volume- and power-limited envelopes. Electric propulsion systems also present challenging plasma plume and contamination environments to the host spacecraft and payloads. This subtopic seeks innovations in propulsion technologies to increase the capabilities of SMD spacecraft.

Specifically, technology innovations are sought to improve the capability of low- to medium-power electric propulsion systems, including ion, Hall, and advanced plasma thrusters. Areas where innovations are sought include power processing, long-life, high-efficiency cathodes and neutralizers, electrode-less plasma production, low-erosion materials for ion optics and Hall discharge chambers, high-temperature magnetic circuits, plume mitigation, and next generation thrusters. Innovations sought include, but are not limited to those that improve performance, increase lifetime, reduce mass, decrease cost, and facilitate electric propulsion integration. Improvements are also sought for propellant management system components including storage, distribution, and flow control to support solar electric propulsion applications. Innovations in miniature electrostatic and electromagnetic propulsion devices are sought for miniature (less than 10 kg) spacecraft and for high-precision (impulse bit
Sub Topics:
Chemical and Propellantless Propulsion for Deep Space Topic S7.04

Spacecraft propulsion technology innovations are sought for future deep space science missions. Propulsion system functions for these missions include primary propulsion, maneuvering, planetary injection, and planetary descent and ascent. Innovations are needed to reduce spacecraft propulsion system mass, volume, and/or cost. Applicable propulsion technologies include advanced chemical, emerging technologies, and aerocapture.

Advanced Chemical Propulsion

Innovations in low-thrust chemical propulsion system technologies are sought for robotic, deep-space, scientific, mission applications. Delta Vs for the missions of interest range from 1000 m/sec to 3000 m/sec. Advanced chemical propulsion technologies of interest are:

- Advanced material and component technology to enable development of bipropellant engines with Isp greater than 360 seconds, both pressure-fed and pump-fed, with chamber pressures ranging from 100 to 500 psia systems;
- Non-catalytic ignition technology and critical component materials (e.g., tank bladders, valve seats, and filters) for power-limited spacecraft using high-performance (Isp >275 s), high-density (>1 g/cc) monopropellant formulations.

Tether Technologies

Focus on technologies that support the development of tethers that can survive in the space environment. The near-Earth environment contains a significant amount of atomic oxygen (AO) formed by photo-dissociation of atmospheric oxygen. This AO attacks the chemical bonds of polymeric materials, which are desirable for their high specific tensile strength. Furthermore, ultraviolet radiation also attacks tether materials. A coating for a polymeric tether must be able to protect the tether against both effects. Coatings that can be uniformly applied after the fabrication of a multi-strand tether structure are especially desirable, because of the requirement that a space tether have a multitude of separate load paths in the event of a cut by an orbital debris particle. Certain materials (such as titanium oxide/zinc oxide) offer both ultraviolet radiation protection as well as atomic oxygen resistance. Tether technologies of interest are:

- Techniques and processes to coat and protect polymeric tether materials from offer both ultraviolet radiation protection as well as atomic oxygen resistance effects. Such coatings must be as thin as possible because of the importance in maintaining a high specific tensile strength in tether materials, although they must be able to adhere uniformly and reliably to tether materials, even in the face of winding and ground handling. Degradation to the strength characteristics of the tether generated by the coating process must be absolutely minimized.

Aeroassist (Aerocapture)
Aerocapture relies on the exchange of momentum with an atmosphere to achieve a decelerating thrust leading to orbit capture. This technique permits spacecraft to be launched from Earth at higher velocities, thus providing a shorter overall trip time. At the destination, the velocity is reduced by aerodynamic drag within the atmosphere. The aerocapture maneuver can be accomplished by utilizing either rigid or inflatable deceleration systems.

Preliminary analysis has shown that the inflatable decelerator concepts may provide mass reduction and improved packaging efficiency over a rigid aeroshell system. However, the TRL for these inflatable decelerators must be increased before an adequate comparison to traditional rigid aeroshells can be made. Current inflatable decelerator concepts are expected to be manufactured from thin film materials, elastomeric materials, and/or high temperature fabrics, stowed during transport and inflated prior to atmospheric entry for aerocapture applications at planetary destinations. Materials of particular interest include: polyimide thin films, polybenzobisoxazole (PBO) thin films, and ceramic fabrics. Prior to the aerocapture maneuver, the inflatable decelerator will be tightly stowed for many years (up to 10 years) in an uncontrolled space environment (-130°C) during transport to outer solar system destination. Before final atmospheric entry, the inflatable decelerator will be unstowed and inflated (cold GN\textsubscript{2}). During the aerocapture maneuver, up to 24 hours after the inflation process is initiated, the inflatable decelerator will experience temperatures to 500°C (or higher).

**Low Temperature/High Temperature Structural Materials/Adhesives**

Development for Inflatable Deceleration Systems: This task focuses on the development and testing of structural materials/adhesives that can be utilized for aerocapture inflatable decelerator systems. This task should include:

- A thorough survey of the thin film polymer, elastomeric;
- A high temperature fabric trade space for materials that will maintain structural properties during the temperature extremes and long term space exposure experienced by inflatable decelerators;
- Investigation of the effects of various coatings, surface treatments, or impregnation processes to enhance material properties, which may include optical, mechanical, thermal or physical properties;
- A thorough survey of the adhesives trade space for materials that will maintain bond strength during the temperature extremes of long term space exposure and atmospheric entry experienced by inflatable decelerator systems must also be included.

Final deliverables should include selection criteria for final materials/adhesives, an evaluation of technology readiness levels (TRL) of candidates, technology development and testing of candidates that require further TRL advancement.

Sub Topics:

- **Power Electronic Devices, Components and Packaging Topic S7.05**

  NASA science missions employ Earth orbit and planetary spacecraft, along with terrestrial balloons, surface assets, aircraft, and marine craft as observation platforms. Advanced electrical power technologies are required for the electrical components and systems on these platforms to address the issues of size, mass, efficiency, capacity, durability, and reliability. Advancements are sought in power electronic devices, components, and packaging.
Power Electronic Components

Advanced inductors, transformers, capacitors, micro batteries, semiconductor switches, diodes, and current sensors are of interest. Proposals must address improvements in energy density, speed, efficiency, or wide temperature operation (-125°C to 200°C) with a high number of thermal cycles.

Power Conversion, Motor Drive, Protection, and Distribution

Technologies that provide significant improvements in mass, size, power quality, reliability, or efficiency in electrical power conversion, motor drives, and protective switchgear components are of interest. Candidate applications include solar array regulators, battery charge and discharge regulators, battery by-pass switches, power conversion, power distribution, fault protection, high-speed motors/generators, magnetic bearing drivers, and integrated flywheel energy storage and attitude control electronics.

Electrical Packaging

Thermal control technologies are sought that are integral to electrical devices with high heat flux capability and advanced electronic packaging technologies which reduce volume and mass or combine electromagnetic shielding with thermal control.

Sub Topics:

Thermal Control Technologies for Science Spacecraft Topic S7.06

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

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

2. Heat flux levels from lasers and other high power devices are increasing, with some projected to go as high as 100 W/cm². 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.

3. Future missions 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.

4. The push for miniaturization also drives the need for new thermal technologies approaching the MEMS level. Miniaturized heat transport devices, especially those suitable for cooling small sensors, devices and electronics are of interest.

5. Future robotic missions and reconfigurable 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:
Automation and Planning for Complex Tasks Topic S8.01
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, but are not limited to:

- 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:

Distributed Information Systems and Numerical Simulation Topic S8.02
This subtopic seeks advances in tools, techniques, and technologies for distributed information systems and large-scale numerical simulation. The goal of this work is to create an efficient and effective information and computing environment that enables NASA scientists to work naturally with distributed teams and resources to dramatically reduce total time-to-solution (i.e., time to discovery, understanding, or prediction), vastly increase the feasible scale and complexity of analysis and data assimilation, and greatly accelerate model advancement cycles. Areas of interest are described below.

Distributed Information Systems

• Supercomputing environment simulation, to identify or anticipate bottlenecks in the environment and to effectively engage all supercomputing program resources. The simulation could include models of application behavior, the full computing and data workload, computing and data systems, local and wide area networks, data analysis and visualization systems, the interface to various facility and user services personnel, and the interface to the remote user at their desktop.

• Services (autonomous software systems) for automated, scalable, and reliable management of distributed, dynamic, and heterogeneous computing, data, and instrument resources. Services of interest include those for authentication and security, resource and service discovery, resource scheduling, event monitoring, uniform access to compute and data resources, and efficient and reliable data transfer.

• Science portals for cross-disciplinary discovery, understanding, and prediction, encapsulating services for single sign-on access, semantic resource and service discovery, workflow composition and management, remote collaboration, and results analysis and visualization.

Large-Scale Numerical Simulation

• Tools for automating large-scale modeling, simulation, and analysis, including those for managing computational ensembles, performing model-optimization studies, interactive computational steering, and maintaining progress in long-running computations in spite of unreliable computing, data, and network
resources.

- Tools for computer system performance modeling, prediction, and optimization for real applications.
- Techniques and tools for supercomputing application porting, parallelization, debugging, scaling, performance analysis, and optimization.
- Tools for effective load balancing, and high reliability, availability, and serviceability (RAS) in commodity clusters and other large-scale computing systems.
- Novel supercomputing approaches using FPGAs, graphics processors, and other novel architectures and technologies.

Sub Topics:

**On-Board Science for Decisions and Actions Topic S8.03**
The focus of this subtopic is enhanced capabilities for NASA observatories in the sensor or platform, or early in the data stream, that can prioritize data for transmission and analysis, or summarize the data for future use. NASA's vision of a sensor-web capability will demand more onboard autonomy and content based data management to support rapid decision making and re-tasking. This subtopic is interested in methods to autonomously understand data as part of a sensor web system capable of rapid redirection and configuration.

**Onboard Satellite Data Processing and Intelligent Sensor Control**

Software technologies that support the configuration of sensors, satellites, and sensor webs of space-based resources. Examples include capabilities that allow the reconfiguration or re-targeting of sensors in response to user demand or in significant events seen in other sensors. Included are software that supports the reasoning and modeling of such capabilities for demonstration and mission simulation. Also included in this category is onboard analysis of sensor data that could run on reconfigurable computing environments as well as technologies that support or enable the generation of data products for direct distribution to users.

**Onboard Satellite Data Organization, Analysis, and Storage**

Software technologies that support the storage, handling, analysis, and interpretation of data. Examples include innovations in the enhancement, classification, or feature extraction processes. Also included are data mining, intelligent agent applications for tracking data, distributed heterogeneous frameworks (including open system interfaces and protocols), and data and/or metadata structures to support autonomous data handling, as well as compaction (lossless) or compression of data for storage and transmission.

**Simulation and Analysis of Sensor Webs for Improving Science Models or Mission Operations**

Software that allows for the simulation of a sensor web of varying platform types producing a variety of data streams. These platforms could be in various orbits (L1, L2, NEO, LEO, etc.) and suborbital (UAV) that are automatically assigned different temporal and spatial coverages. Data streams would be assigned to these platforms and the system computes how the sensor web would cover of events (e.g., volcanic eruption, fires, and crop monitoring) at user designated, particular, geospatial locations (or areas).
Sub Topics:  
Spatial and Visual Methods for Search, Analysis and Display of Science Data Topic S8.04  
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. 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:  
Data Management and Visualization Topic S8.05  
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.

Sub Topics: