NASA is aggressively pursuing the search for resources on the Moon necessary to sustain prolonged human habitation and water and life on Mars using robotic explorers. NASA will augment this program and prepare for the next decade of research missions by 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://mars.jpl.nasa.gov/technology/](http://mars.jpl.nasa.gov/technology/) 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 Detection and Reduction of Biological Contamination on Flight Hardware

**Lead Center:** JPL

**Participating Center(s):** ARC

As solar system exploration continues, NASA remains committed to the implementation of its planetary protection policy and regulations. A Mars sample return mission is being planned for the next decade. Other missions will seek evidence of life through *in situ* investigations far from Earth. One of the great challenges, therefore, is to develop or find the technologies or system approaches that will make compliance with planetary protection policy routine and affordable. Planetary protection is directed to 1) the control of terrestrial microbial contamination associated with robotic space vehicles intended to land, orbit, flyby, or otherwise be in the vicinity of extraterrestrial solar system bodies, and 2) the control of contamination of the Earth by extraterrestrial solar system material collected and returned by such missions. The implementation of these requirements will ensure that biological safeguards, to maintain extraterrestrial bodies as biological preserves for scientific investigations, are being followed in NASA's space program. Methods for the detection and reduction of biological contamination are also frequently applicable to non-biological particulate and molecular contamination. To fulfill its commitment, NASA seeks technologies and systems approaches that will support mission compliance with planetary protection requirements. Examples of such technologies include:

- Techniques for cleaning of organics to the level of nanograms per square centimeter on complex surfaces (nondestructively and without residues) and for validation of cleanliness at this level or better;
- Nonabrasive cleaning techniques for narrow aperture occluded areas on spacecraft;
- Techniques for *in situ* (i.e., at the exploration site) cleaning and sterilization to prevent cross-contamination between planetary surface samples;
Nondestructive and highly efficient sampling methods for detection of the remnants of microbial, particles, and molecular contamination on cleaned spacecraft surfaces;

Methodology for the quantitative detection of viable microbial cells in the interior of non-metallic space-craft materials;

Rapid cleaning validation methods with ultra high sensitivity for the major classes of biomolecules: proteins, amino acids, DNA/RNA, lipids, polysaccharides, etc.;

A device or methodology for controlled measurement of microbial reduction at temperatures from 200-300°C to enable generation of microbial lethality curves. Rapid ramp-up and cool-down rates are critical to minimize the microbial killing that occurs during the ramp periods;

Device or methodology for direct observation and evaluation of particles and biological contamination on spacecraft parts;

Device or methodology for quantitative and homogeneous deposition of particles, microbial cells, and biomolecules on material surfaces for cleaning, sampling, and contamination transport studies;

System design concepts to enable facile and rapid use of cleaning and sterilization technologies during flight hardware assembly;

System design concepts to maintain the integrity of cleaned and sterilized complex flight systems and/or subsystems; and

System concepts that would facilitate spacecraft sterilization at the system level just before launch or in flight.

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

S1.02 Mars In Situ Robotics Technology

Lead Center: JPL
Participating Center(s): LaRC

During future exploration of planets, moons, and small solar system bodies (such as comets and asteroids), developments are needed in new innovative robotic technologies for surface operations, subsurface access, and autonomous software for each. Because of limited spacecraft resources, elements must be robust and have low power, volume, mass, computation, telemetry bandwidth, and operational overhead requirements. Successful technologies will have to operate in environments characterized by extremes of temperatures, pressures, gravity, high-gravity landing impacts, vibration, and thermal cycling. In particular, this subtopic seeks technology innovations in the following areas:

Subsurface Access

Research should be conducted to develop complete, lightweight, dry drilling systems with a penetration depth of
10-50 m and have the capability of penetrating both regolith and rocks. The development should focus on significant reduction in mass from the currently available state-of-the-art interplanetary drilling systems as well as the automation required for real-time control and fault diagnosis and recovery. In addition, because of the lack of water in most of the environments of interest, the drilling should be performed without a lubricant between the bit and rock. Of interest also is the development of ice penetrators, designed with explicit consideration of limited computation and power, which use heat to melt their way through the surface.

Rover Technology

Long-range autonomous navigation systems that focus on long distance (greater than 5 km) traverses through natural terrain, using no a priori knowledge of the subject terrain. Inflatable rover technology with a focus on the development of low-mass, highly capable platforms for exploration of extreme terrain through innovations in novel mechanisms and the automation required for real-time control. Concepts for new mobility systems or components, such as innovative wheel or suspension designs. Instrument placement with a focus on improved tools for the design of manipulation systems, to perform contact and noncontact operations such as drilling, grasping, sample acquisition, sample transfer, and contact and noncontact science instrument placement and pointing. Modular robotic joints that are small (0.5 kg), low power, low mass and can be used to build prototype manipulators and/or legs. Quick changeout mechanisms for planetary manipulators that can enable changing of tools or instruments on the end of a manipulator.

Of particular interest is infrastructure for research, including low-cost, mass producible, research-quality rovers and supporting elements. The development of a low-cost, Rocker-Bogie style, six-wheel steerable, robotic research platform that can drive around in rough terrain is desired.

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

S1.03 Long Range Optical Telecommunications

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

This subtopic seeks innovative technologies for long range optical telecommunications supporting the needs of space missions. Proposals are sought in the following areas:

- Space-qualifiable, efficient (greater than 20% wall plug), lightweight, variable repetition-rate (1-60 MHz), tunable (± 0.1 nm) pulsed 1064-nm transmitter sources (diode-pumped fiber amplifier or bulk crystal laser/amplifier) with greater than 1 kW of peak power per pulse (over the entire pulse-repetition rate), and greater than 10 W of average power, and narrow (
1000 nm single-mode-fiber pigtailed laser diode transmitters (includes necessary modulator; internal or external driver) with narrow spectral width (25%);

- Space-qualifiable, reliable (> 3 years at 100 Mega photons per second continuous photon flux), photon counting 1064 nm and/or 1550 nm detectors with the gain greater than 1000, detection efficiency greater than 50%, very low (50Mcounts/s. and non-gated (continuous operation);

- Lightweight, compact, high precision (less than 0.1 micro-radian), high bandwidth (0-2kHz), inertial reference sensors (angle sensors, gyros) for use onboard spacecraft;

- Novel schemes for stray-light control and sunlight mitigation, especially for large (> 5 m) ground-based optical telescopes that must operate when pointed to within a few (about 3) degrees of the Sun;

- Low-cost, lightweight, efficient, r pigtailed laser diode transmitters including compact, high precision (one micro-radian accuracy) star-trackers for spaceflight application that can be integrated with an optical communications terminal;

- Novel techniques and technologies that will enable very low cost, large aperture (>5m equivalent aperture diameter) telescopes for ground or space-borne use;

- High power ground-based, relatively low-cost diode-pumped laser technology capable of reaching 100 kW average power levels in a TEMoo mode, for uplink to spacecraft;

- Artificial laser guide-star and beam compensation techniques capable of removing all significant atmospheric turbulence distortions (tilt and higher-order components) on an uplink laser beam;

- Novel techniques to reduce the development cost and risk of future space-borne optical communications transceivers (e.g. automatic focusing or alignment techniques);

- High BW Intersatellite Links (ISL) in Earth orbit and deep space ISL or possibly satellite to ground communications; and

- Systems and technologies relating to sub-microradian pointing, acquisition, and spacecraft vibration.

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

S1.04 Entry, Descent and Landing

Lead Center: JPL

Participating Center(s): ARC, JSC, LaRC

Entry, Descent, and Landing (EDL) systems are an enabling component of future planetary surface and airborne explorations. EDL systems are naturally comprised of a wide variety of tightly integrated subsystems. These subsystems can include, but are not limited to: entry body, thermal protection, avionics for guidance during entry and/or powered descent (including terrain sensors), aerodynamic decelerators including supersonic or subsonic parachutes, and touch-down systems. In addition to these hardware specific subsystems, algorithms for guidance and hazard detection are an integral element of future EDL systems. Innovations are sought that provide benefits in the following general areas: increased payload delivery mass, improved delivery accuracy, and improved hazard.
detection and avoidance. The intended outcome of these improvements is to develop the capability to land safely within 100m or less of a preselected landing site and to deliver larger payloads for future Mars missions. In particular, this subtopic seeks technology innovations in the following areas:

- Entry body systems and subsystems including lightweight aeroshells and thermal protection;
- Entry guidance algorithms/methods/techniques capable of reducing uncertainty in parachute deployment altitude, for missions employing bank-only control (i.e., no control of angle of attack) during hypersonic entry;
- Aerodynamic decelerator systems including supersonic and subsonic parachutes. Particular areas of interest include approaches that hold promise for delivering increased mass to the surface (e.g., increasing the Mach-Q deployment envelope beyond Viking-heritage capability) and techniques of reducing the cost of testing/validating the performance of new aerodynamic decelerator systems for use at Mars. Also of interest are para-guidance techniques for pinpoint landing;
- Terrain hazard detection approaches that provide real-time three-dimensional terrain mapping capability during parachute descent and powered terminal descent. In addition, compact, low-mass, high accuracy, and high bandwidth GNC sensors such as attitude and velocity sensors are highly desirable; and
- Lightweight, low-cost, hazard-tolerant touchdown system approaches including (but not limited to) airbag, shock struts, and structural crush zones; allowing landings in moderately cratered terrains with surface rock distribution encountered over a wide variety of Martian landing sites.

S1.05 Sample Return Technologies

Lead Center: JPL
Participating Center(s): JSC

The NASA Mars Exploration Program has recently adopted a plan that includes a Mars Sample Return mission. Such a mission would require breaking the chain of contact with Mars: the exterior of the sample container must not be contaminated with unsterilized Mars material. One mission concept involves placing a grapefruit sized sample container in Mars orbit where it can be picked up by an orbiting spacecraft for return to Earth. Tenuous issues of contamination of the sample container exterior with Mars dust must be dealt with as well as contamination-free handling of the return sample in the receiving facility.

Receiving Facility Sample Handling Technologies

The items described briefly below would find eventual utilization in a sample receiving facility whose basic functions are to do physical and chemical characterizations, bio-hazard detection, and life detection, within a series of double-walled containment vessels. The facility would be operated with significant utilization of robotics, operated either in situ, or remotely, or both.
• Demonstrate fine-scale manipulations, either in situ or remotely, of a strawman 6-axis ultra-clean robot within the confines of a double-walled containment vessel. The robot can be current state-of-art. Demonstrate the use of different end effectors to manipulate small samples for observation. The task may require use and/or modification of current state-of-the-art control software.

• Demonstrate a sample container/carrier, possibly adapted from a container/carrier currently in use by semiconductor and/or pharmaceutical industries; that has the capability to be identified (labeled) and tracked, for use in cataloging, transporting, and tracking samples of various kinds; generally of approximately 100-micron size, and consisting of fines, dust, individual grains, and very small rocks, or gases; following the certification of these samples for release to a facility for long-term curation and distribution;

• Develop double-walled gloves for use within a double-walled containment vessel. Such gloves would perhaps require self-healing and/or warning systems, in case of a breach, and be compatible with ports developed for double-walled containment vessels; and

• Identify specific sterilization methods and techniques for use in sterilization of extraterrestrial samples. Determine the sterilization levels achieved for sample coupons defined and/or provided by a NASA-sponsored science/biosafety working group.

Miniature Leak Detector

Proposals are sought for the development of a miniature, low-mass, low-power leak detection sensor that can be used to indicate a loss of pressure from a container with a volume of 0.5 liter, that has a pressure of 6 torr, as expected on Mars. Areas of interest include:

• A sensor, driver, and the power source designed for placement inside the container that is made of metal. The metal alloy that will be used will be determined at a later time;

• The sensor and its control electronics that provides power, data processing, and communications should not exceed the volume of 5-cm³;

• The device should be operational at temperatures that are as low as -70°C and as high as room temperature; and

• A miniature battery as power source is acceptable. Preferably, a wireless power transfer mechanism and a rechargeable battery that is designed for placement inside the container, would be preferred.

Sample Containerization and Protection

Proposals are sought for the development of a robust method of sealing a sample that would be acquired from an extraterrestrial surface for possible return to Earth in future NASA missions. Areas of interest include:

• A simple and reliable process of hermetically seaming and sealing a "coffee-cup" size container with a rock or soil sample;

• The process needs to simultaneously perform sterilization of the container sealed area and its external surface while releasing the container into an area that simulates a clean section of a lander;
This process should “break-the-chain” of contact of an acquired soil or rock sample from the original area that simulates the environment of an extraterrestrial planet;

The required process needs to simultaneously seal the contained sample while destroying any potential biological materials that may contaminate the external surface of the container;

The process to sterilize the surface of a grapefruit-sized sample container in Mars orbit (e.g., pyrotechnic paint) requiring minimal power and minimizing effect on the sample container interior;

The contained sample should be protected from any mechanical, chemical, or thermal damage during or after the activation of the "break-the-chain" process;

The process needs to be computer simulated and allow a high degree of control of its parameters; and

Demonstrate probability of success of the feasibility to seal the container while performing sterilization.

Sample Acquisition

Proposals are sought for mechanisms to acquire clean core samples for Mars rocks and regolith including development of low-mass, low-normal-force, 10x1 cm coring tool, low-mass core sampling tool integrated with sample containment, acquire Mars dust samples, and development of six-axis force-torque sensor (ranges about 160 Newtons, 15 N-m) operating in Mars ambient.

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 Science Instruments for Conducting Solar System Exploration**

*Lead Center: JPL*

*Participating Center(s): ARC*

This subtopic supports the development of advanced instruments and instrument technology 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.

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;

- Instruments and components that will rely on, and take advantage of, high power capabilities (up to 100 kW) for measurements of planetary surfaces. The instruments may make direct or indirect use of the power, long duration observations, or extremely high data rates;

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

- 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.

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

S2.02 Extreme High Temperature/High Pressure Environment

Lead Center: JPL
Participating Center(s): GRC

Proposals are sought for technologies to enable operation and survivability in high-temperature/high-pressure space environments. These technologies service the needs of the future in situ exploration of Venus as well as the atmospheric probes for giant planets.

Venus features a dense, CO$_2$ 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 (380°C) and high pressures (>100 bar) is also required for deep atmospheric probes to giant planets.

Technology needs for high-temperature and high-pressure environments include:

- Advanced passive and active thermal control for Venus missions, including lightweight (50 kg/m$^3$), high strength/stiffness, high buckling stress resistant pressure vessels to protect the electronics and instruments for several hours; new lightweight thermal insulation materials with conductivity less than 0.1 W/mK at 486°C, thermal storage systems with 300-1000 kJ/kg energy density, thermal switches with a switching ratio of at least 100:1 between "On" and "Off" modes, and high temperature heat pipe systems operating over a temperature range of 25 to 500°C. Refrigeration systems capable of pumping heat from a 25 to 75°C source to the Venus sink temperature of 486°C;

- 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 Design (CAD) tools for predicting the performance, reliability, and life cycle for high-temperature electronic systems and components;

- High-temperature primary batteries (200 Whr/kg) for operation at 380°C and 486°C;

- 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; and

- Anticorrosive coatings to protect optical systems and spacecraft structures from corrosive agents present in the upper levels of Venus’ atmosphere (sulfuric acid clouds) or near surface (besides carbon oxide and nitrogen, the atmosphere contains sulfuric acid, hydrochloric acid, and hydrofluoric acid).

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

**S2.03 Nanosensors**

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

The subtopic seeks to leverage breakthroughs in the emerging fields of nano-technology and biotechnology to develop advanced sensors and actuators with increased sensitivity and small size for solar system exploration. Technologies should provide enhanced capabilities over the current state-of-the-art and be able to operate in an extreme environment. This harsh environment includes steady operation and cycling in the temperature range of -180 degrees Centigrade to 100 degrees Centigrade, and high radiation. Of particular interest are harsh environment-operable nanosystems for single molecule sensing and manipulation, on-chip biomolecular analysis, and semiconductor laser diodes in the 2-5 um wavelength range, and detectors in the greater than 15 um wavelength range.

**S2.04 Deep Space Power Systems**

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

Innovative concepts using advanced technology are solicited in the areas of energy conversion, power electronics, and power system materials. Power levels of interest range from milliatts to 1 KW. NASA Space Science missions in deep space environments require energy systems with long life capability, high radiation tolerance, reliability, and low overall costs (including operations) which can operate in high and low temperatures and over wide temperature ranges. Advanced technologies are sought in the following areas:
Energy Conversion

All proposed energy conversion technologies must be able to show substantial increases over state-of-the-art in efficiency and specific power (W/kg) and to operate in deep-space environments with high radiation and wide-temperature operations (-200°C to 300°C). Long-life (>14 years), highly reliable advanced energy conversion technologies are sought that keep manufacturability in mind. Advances in photovoltaic technology are sought, including high power solar arrays and ultra lightweight, thin film, and concentrator arrays. Advances in radioisotope thermal to electric power conversion technology (milliwort/multiwatt and 100W-1KW classes with efficiencies (state-of-the-art) are sought. This includes advances in thermophotovoltaics, thermoelectrics, Brayton, Rankine, and Stirling technologies as well as compact heat exchangers. Innovative control methods are also sought.

Power Electronics

Advanced power electronic materials and devices for deep-space power systems are sought. The materials of interest include soft magnetics, dielectrics, insulation, and semiconductors. Devices of interest include transformers, inductors, electrostatic capacitors, high-power semiconductor switches and diodes, and integrated control and driver circuits. Proposed technologies must improve upon the following characteristics: high temperature operation (>200°C), low-temperature (cryogenic) operation, wide-temperature operation (-125°C to 200°C), and/or high levels of space radiation (>150 krad) resistance.

Electronics Packaging and Materials

Advanced electronics packaging technologies that reduce volume and mass capable of either high temperature, cryogenic, wide temperature operation, and/or space radiation resistance for use in space power systems are of interest. Advances are sought in power electronics packaging materials, surfaces, and components that are durable for soft X-ray, electron, proton, and ultraviolet radiation and thermal cycling environments.

S2.05 Astrobiology

Lead Center: ARC
Participating Center(s): JPL

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.

A second element of Astrobiology is the understanding of the evolutionary development of biological processes leading from single-cell organisms to multi-cell specimens and to complex ecological systems over multiple
generations. Understanding of the effects of radiation and gravity on lower organisms, plants, humans, and other animals (as well as elucidation of the basic mechanisms by which these effects occur) will be of direct benefit to the quality of life on Earth. These benefits will occur through applications in medicine, agriculture, industrial biotechnology, environmental management, and other activities dependent on understanding biological processes over multiple generations.

A third component of Astrobiology includes the study of evolution on ecological processes. Astrobiology intersects with NASA Earth Science studies through the highly accelerated rate of change in the biosphere being brought about by human actions. One particular area of study with direct links to Earth Science is microbe-environment interactions.

NASA seeks innovations in the following technology areas:

- For Mars exploration, technologies that would enable to provide a broad survey of areas in the vicinities of a rover or lander to narrow a field of search for biomarkers;

- For Mars exploration, technologies that (using X-ray, neutron, ultrasonic, and other types of tomography) would enable a noninvasive, nondestructive analysis of the subsurface environment and areas inside rocks and ice to depths 10-20 cm with spatial resolutions of 2-10 microns. Such technologies should provide the capability for analysis of structures inside opaque matrices created by endolithic organisms or fossil structures and possible elemental analysis of such structures;

- Technologies that would enable the aseptic acquisition of deep subsurface samples, the detection of aquifers, or enhance the performance of long-distance ground roving, tunneling, or flight vehicles are required;

- For Europa exploration, technologies to enable the penetration of deep ice are required;

- Desirable features for both Mars and Europa exploration include the ability to carry an array of instruments and imaging systems, to provide aseptic operation mode, and to maintain a pristine research environment;

- Low-cost, lightweight systems to assist in the selection and acquisition of the most scientifically interesting samples are also of significant interest;

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

- Advanced miniaturized sample acquisition and handling systems optimized for extreme environment applications;

- 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;

- High spatial resolution (5 angstrom level) electron microscopy techniques to establish details of external morphology, internal structure, elemental composition, and mineralogical composition of potential biogenic structures;

- Innovative software to support studies of the origin and evolution of life. The areas of special interest are (1) biomolecular and cellular simulations, (2) evolutionary and phylogenetic algorithms and interfaces, (3) DNA computation, and (4) image reconstruction and enhancement for remote sensing;
• Technologies capable of measuring a range of volatile compounds at small spatial scales. Improved sensor designs for a wide range of analytes, including oxygen, pH, sulfide, carbon dioxide, hydrogen, and small molecular weight organic acids both on and near surfaces that could serve as habitats for microbes;

• 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;

• Spectral and imaging technology with high resolution and low power requirements;

• Habitat support - technologies for supporting miniature closed ecosystems, data collection, and transmission technologies in concert with the automated chemical instrumentation described above;

• Miniature-to-microscopic, high-resolution, field-worthy, smart sensors, or instrumentation for the accurate and unattended monitoring of environmental parameters that include, but are not limited to, solar radiation (190-800 nm at)

• 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;

• Mathematical models capable of predicting the combined effects of elevated pCO₂ (change in CO₂ over the eons) and solar UV radiation on carbon sequestration and N₂O emissions from experimental data obtained from field and laboratory studies of C-cycling rates, N-cycling rates, as well as diurnal and seasonal changes in solar UV;

• 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; and

• Robotic systems designed to provide access to environments such as deep-ocean hydrothermal vents.

S2.06 Advanced Flexible Electronics

Lead Center: JPL

Electronically steerable L-band, phased array antennas are needed for missions to the Moon, Mars, Titan, and Venus. L-band provides the capability to detect surface and subsurface topology including ice or features hidden by the surface dust. Flexible, lightweight active arrays enable better packaging efficiency for the antenna and are critical for these missions. 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.

Research should be conducted to demonstrate technical feasibility during Phase 1 and show a path toward a Phase 2 hardware and software demonstration, and when possible, deliver a demonstration unit or software package for JPL testing at the completion of the Phase 2 contract.
S2.07 Risk Modeling and Analysis

Lead Center: JPL
Participating Center(s): LaRC

The purpose of this subtopic is to advance the state-of-the-art in risk modeling and analysis, particularly for use in early design (formulation) phases. Of particular interest would be methods for risk characterization and modeling that extend beyond typical technical aspects, including software, programmatic, operations, organization, and management elements. This subtopic includes tools and methods, visualization techniques, and process enhancements. Technical areas to address include:

- Uncertainty modeling including both epistemic and aleatory uncertainties;
- Attribute-driven risk identification;
- Risk reduction modeling that includes both preventative and mitigative activities;
- Methods for aggregation and/or integration of quantitative and qualitative risks;
- Methods for characterization and integration of software, organizational, operations, and other non-physics based risks;
- Integration of risks and risk insights into the trade and formal design processes, including new techniques for risk visualization and new methods for directly trading risk against other design aspects;
- Development of risk model library elements and techniques for selecting, maintaining, and integrating the elements;
- Methods for cost-effective adaptation and utilization of PRA and other probabilistic methods in early design (e.g., conceptual design) which can be integrated directly into the design process (i.e., can be utilized directly by the system designers without additional analyst support); and
- Methods for risk-based margin determination and management.
The NASA Science Missions Directorate seeks to conduct advanced telescope searches for Earth-like planets and habitable environments around neighboring stars. This topic will consider technologies necessary to enable future telescopes and observatories collecting all electromagnetic bands, ranging from X-rays to millimeter waves, and also include gravity waves. The subtopics will consider all technologies associated with the collection and combination of any observable signals.

**Sub Topics:**

**S3.01 Precision Formations for Interferometry**

**Lead Center: JPL**

This subtopic seeks hardware and software technologies necessary to establish, maintain, and operate hyper-precision spacecraft constellations to a level that enables separated spacecraft optical interferometry. Also sought are technologies for analysis, modeling, and visualization of such constellations.

In a constellation for large effective telescope apertures, multiple, collaborative spacecraft in a precision formation collectively form a variable-baseline interferometer. 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.

Innovations that address the above precision requirements are solicited for distributed constellation 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 High Contrast Astrophysical Imaging

Lead Center: JPL

Participating Center(s): ARC

This subtopic addresses the unique problem of imaging and spectroscopic characterization of faint astrophysical objects that are located within the obscuring glare of much brighter stellar sources. Examples include, planetary systems beyond our own and the detailed inner structure of galaxies with very bright nuclei. Contrast ratios of one million to one billion over an angular spatial scale of 0.05-1.5 arcsec are typical of these objects. Achieving a very low background against which to detect a planet 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 any starlight cancellation scheme.

This innovative research focuses on advances in coronagraphic instruments, interferometric 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 Origins Program theme will be similar in character to instruments used for present day space astrophysical observations. The performance and observing efficiency of these 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, coronography, 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 $10^4$ or more actuators (both to further the state-of-the-art towards flight-like hardware and to explore novel concepts). Multiple DM technologies in various phases of development and processes are encouraged to ultimately improve the state-of-the-art in deformable mirror technology. Process improvements are needed to improve repeatability, yield, and performance precision of current devices;

- 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; and

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

**S3.03 Precision Deployable Lightweight Cryogenic Structures for Large Space Telescopes**

*Lead Center: JPL*

*Participating Center(s): MSFC*

Planned future NASA Origins Missions and Vision Missions such as the Single Aperture Far-IR (SAFIR) telescope, Life Finder, and Submillimeter Probe of the Evolution of Cosmic Structure (SPECS), require 10-30 m class telescopes that are diffraction limited at wavelengths between the visible and the near IR, and operate at temperatures from 4-300 K. The desired areal density is 3-10 kg/m$^2$. Wavefront control may be either passive (via a high stiffness system) or active control. Potential architecture implementations must package into an existing launch volume, deploy and be self-aligning to the micron level. The environment is expected to be L2.

This topic solicits proposals to develop enabling component and subsystem technology for these telescopes in the areas of precision deployable structures, i.e., large deployable optics manufacture and test; innovative concepts for packaging integrated actuation systems; metrology systems for direct measurement of the structure; deployment
packaging and mechanisms; active control implemented on the structure (downstream corrective and adaptive optics are not included in this topic area); actuator systems for alignment (2 cm stroke actuators, lightweight, submicron dynamic range, nanometer stability); mechanical and inflatable deployable technologies; new thermally-stable materials for deployables; new approaches for achieving packagable structural depth; etc.

The goal for this effort is to mature technologies that can be used to fabricate 20 m class, lightweight, 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 volume and 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 Large-Aperture Lightweight Cryogenic Telescope Components & Systems**

**Lead Center:** MSFC

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

Planned future NASA infrared, far infrared, and submillimeter missions, such as the Single Aperture Far-IR (SAFIR) telescope, Interferometric Terrestrial Planet Finder (TPF-I), Infrared Origin's Probes, Space Infrared Interferometric Telescope (SPIRIT), and Submillimeter Probe of the Evolution of Cosmic Structure (SPECS) require both 10-30 m and 2-4 m class telescopes that are diffraction limited at 5-20 mm and operate at temperatures from 4-10 K. The desired areal density is 3-10 kg/m². Wavefront control may be either passive (via a high stiffness system) or active control (via mechanisms and deformable mirrors). Potential architecture implementations include 2 m class segments, 4 m class mirrors, or membrane systems. Component and system testing techniques are a particular challenge for low areal density or cryogenic specific architectures. It is anticipated that active cooling will be required. Potential telescope system architectures require transporting 1 W of heat at 15 K with 5 W/K, while others require 100 mW at 4 K with 1 W/K.

This topic solicits proposals to develop enabling component and sub-system technology for cryogenic telescopes, including but not limited to: large-aperture lightweight cryogenic optic manufacture and test; thermal management, distributed cryogenic cooling and multiple heat lift; structure, deployment, and mechanisms; deployable cryogenic coolant lines; active wavefront control; etc. The goal for this effort is to mature technologies that can be used to fabricate 2-4 m and 10-30 m class lightweight cryogenic flight-qualified telescope primary mirror systems at a cost of less than $300,000 per square meter. Proposals to fabricate demonstration components and subsystems with direct scalability to flight will be given preference.
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 powerful missions (beyond Chandra, Spitzer, and Hubble) with larger and better optics and detector systems. Future mission may include optics that fold and deploy and can be assembled on orbit, as well as larger arrays of detectors, bolometers, microcalorimeters (superconducting), and room temperature semiconductors. Our missions cover the full range of the electromagnetic spectrum 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 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 Infrared & Sub-mm Sensors and Detectors**

*Lead Center: JPL*

*Participating Center(s): MSFC*

NASA astrophysics missions currently under development, such as Sofia, Herschel, and Planck ([http://science.hq.nasa.gov/missions/phase.html](http://science.hq.nasa.gov/missions/phase.html)) have been enabled by improvements in sensors and detectors. Beyond 2007, expected advances in detectors, readout electronics, and other technologies, particularly those enabling polarimetry and large format imaging arrays for the far IR/submm and spectroscopy with unprecedented sensitivity. These advances may enable future mission concepts such as the Single Aperture Far Infrared (SAFIR) Observatory ([http://safir.jpl.nasa.gov/technologies.shtml](http://safir.jpl.nasa.gov/technologies.shtml)), SPICA ([http://www.ir.isas.ac.jp/SPICA/](http://www.ir.isas.ac.jp/SPICA/)), and CMBPOL.

Space science sensor and detector technology innovations are sought in the following areas:

**Mid/Infrared, Far Infrared and Submillimeter**

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

**Space Very Long Baseline Interferometry (VLBI)**

The next generations of VLBI missions in space will demand greatly improved sensitivity over current missions. These new missions will also operate at much higher frequencies (at first to 86 GHz and eventually to 600 GHz). These thrusts will require development of improved space-borne, low-power, ultra-low-noise amplifiers and mixers to serve as primary receiving instruments.
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 reducing the UV degradation of flight components including balloon membranes, load carrying members, and parachute components;
- Innovative concepts for the measurement of strain in a thin film during flight;
- Innovative sensor concepts for balloon gas or skin temperature measurements;
- 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 low-mass, high-density, and high-efficiency power systems for terrestrial balloons that produce 2 kW or more continuously;
- Innovative power systems that enable long duration, sunlight independent missions for durations of 30 days or more;
- Innovative floatation systems for water recovery of payloads;
- Innovative guided or gliding parachutes systems for use in thin atmospheres;
- Innovative balloon design concepts for long duration missions that can provide any or all of the following: reduced material strength requirements, increased reliability, enhanced performance, reduced manufacturing time, reduced manufacturing cost, or improved mission flexibility; and
- Smaller scale, but similarly designed, balloons and airships will also 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:

**Aerobot Surface Sample Acquisition Device**

NASA is soliciting concepts and prototypes for surface sample acquisition devices that can be used on aerobots to collect icy material from Titan and Mars. Typical sample volumes range from 1 to 2 cubic centimeters, with preference for a solid ice core as well as possible granular material. Collection depths of 0 to 2 cm are desired. Preferred techniques do not require close proximity of the aerobot balloon skin to the ground to reduce the probability of damaging the vehicle during sample acquisition. Examples include tethered collection devices.
deployed from modest altitudes (10s to 100s of meters) or short duration “touch and go” sampling from directional and/or altitude controlled aerobots. Proposed devices can be disposable (single use), but if reusable must avoid cross-contamination between samples. All devices must include solid sample transfer functionality to an analysis chamber on the aerobot itself. Concepts will be preferred that feature low mass (few kilograms or less), small volume (~1 liter) and low electrical power consumption drawn from the aerobot.

**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 m$^2$), 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 films 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/m$^2$.

**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 and Optical Telescopes (including X-ray, UV, Visual, IR)

Lead Center: GSFC

Participating Center(s): JPL, MSFC

With the reorganization of NASA activities into the Exploration Mission Directorate (EMD) and the Space Mission Directorate (SMD), there is a renewed call for novel optical technologies that extend the state-of-the-art across wavelength bands from far-IR to Gamma-ray. Missions to study the Earth and Sun, the other solar system planets and objects, and the origins and fate of the universe are proposed to operate from low Earth orbit to L2 or drift-away trajectories depending on their system of study and environmental requirements.

Among other areas of study, future planet finder missions will require lightweight optical apertures of tens of square meters with sub-nanometer surface figure errors. Infrared versions will require cooling optics to cryogenic temperatures (to 4 K). Telescopes studying the Sun and its environment in the UV and EUV (20-300 nm wavelength) require novel optical coatings and filters, high precision aspheric optics, and high-density uniform and variable line density diffraction gratings. And high-energy X-ray telescopes will study the origins and fate of the universe with

For all missions, low-mass optics and deployment structures are extremely important. Also, wavefront sensing and control systems are sought that may alleviate the stringent mass and stiffness requirements of such large optics. Finally, advanced, low-cost manufacturing, metrology, and modeling techniques will be required to make these missions possible.

The previous year's Optical Technologies (S2.04) and UV and EUV Optics (S1.06) have been merged to form this year's Optics and Optical Telescopes subtopic. All previously relevant areas of research are invited in this new subtopic including:

Optics
Ultra-smooth (2-3 Angstroms rms) replicated optics that are rigid and lightweight;

Lightweight, high modulus (e.g., silicon carbide) optics and structures;

Ultra-stable optics over time periods from minutes to hours;

Cryogenic optics, structures, and mechanisms for space telescopes and interferometers;

High-performance, diamond turned optics (including freeform optical surfaces);

Large, thin, ultra-lightweight grazing incidence optics for X-ray mirrors with angular resolutions less than 5 arcsec. (>100 cm$^2$, 2 areal density);

Wide field-of-view optics using square pore slumped microchannel plates or equivalent;

Large, ultra-lightweight optical mirrors (2 at near-IR through visible), including membrane optics for very large aperture space telescopes and interferometers;

UV and EUV Imaging mirrors with simultaneously large aperture (1-4 m diameter), low mass (5-20 kg/m$^2$), accurate figure (~0.01 wave rms or better at 632 nm), and low micro-roughness (Smooth sub-mm scale image slicer and microlens array component technologies to allow fabrication of integral field spectrographs in the UV and visible, for simultaneous spectroscopy of two spatial dimensions and one spectral dimension.

Filters

Large area, thin blocking filters with high efficiency at low energy X-ray energies (Ultraviolet filters with deep blocking (5) of longer and shorter wavelengths, including "solar blind" performance; novel near- to far-IR filters with increased bandwidth, stability, and out-of-band blocking performance; FUV and EUV coatings (filters) with improved reflectivity (transmission) and selectivity (narrow bands, broad bands, or edges). Technologies include multilayers, transmission gratings, and Fabry-Perot etalons, among others; and Improved X-ray and Gamma-ray modulation optics and coded aperture masks (sub-arcsecond resolution at 10 keV to 10 arcsecond resolution at 1 MeV).

Gratings

Fabrication techniques for ultra-thin-flat silicon (or like material) for grating substrates for X-ray energies High resolving power diffraction gratings (>4000 lines/mm) at acceptable focal lengths and pixel sizes; and Improvements in grating manufacturing technologies, such as high efficiency/low scatter gratings, variable line spacing, improved echelle gratings, active grating surfaces (gratings replicated onto deformable substrates), and gratings ruled onto concave, aspheric surfaces.

Metrology
• Low-cost, high quality, large optics fabrication processes and test methods including active metrology feedback systems during fabrication, and artificial intelligence controlled systems;

• Portable and miniaturized state-of-the-art optical characterization instrumentation and rapid, large-area surface-roughness characterization techniques are needed. Calibrated processes for determination of surface roughness using replicas made from the actual surface. Traceable surface roughness standards suitable for calibrating profilometers over sub-micron to millimeter wavelength ranges are needed; and

• Instruments capable of rapidly determining the approximate surface roughness of an optical surface, allowing modification of process parameters to improve finish, without the need to remove the optics from the polishing machine. Techniques for testing the figure of large, convex, aspheric surfaces to fractional wave tolerances in the visible.

Wavefront Sensing and Control

• Optical systems with high-precision controls, active and/or adaptive mirrors, shape control of deformable telescope mirrors, and image stabilization systems; and

• Advanced, wavefront sensing and control systems including image based wavefront sensors;

• Nanometer to sub-picometer metrology for space telescopes and interferometers.

Optical Design

• Advanced analytical models, simulations, and evaluation techniques, and new integrations of suites of existing software tools allowing a broader and more in-depth evaluation of design alternatives and identification of optimum system parameters including optical, thermal, structural, and dynamic performance of large space telescopes and interferometers.

S4.05 Sensor and Detector Technology 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 a 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 >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 (~10^6), low noise, fast time response (2 to 10 x 10 mm^2). Focal plane mass must be minimized (≤ g/cm^2 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. We seek 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

S4.06 Technologies for Gravity Wave Detection
Lead Center: GSFC
Participating Center(s): JPL, MSFC

Laser Technologies for Gravitational Wave Detection

NASA is now developing the Laser Interferometer Space Antenna (LISA) mission to search for gravitational waves from astrophysical phenomena such as the Big Bang, mergers of supermassive 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 (of order picometers) and will be measured with laser interferometry. The technology areas below deal with technical problems in these measurements. Because the systems will be deployed in space, the technologies to be considered must have credible paths toward space flight qualification. Background information on LISA, along with preliminary technology discussions, can be found in the Proceedings of the 5th International LISA Symposium, , Penn State University, 19-24 JULY 2002, published in the Classical and Quantum Gravity Journal, Vol 20, Number 10, 21 May 2003.

Issues of Space Qualification of LISA Laser: the LISA laser must produce >1W CW of 1.06 micron light with fiber coupled output (for example, a combination of a lower-power master oscillator (eg, NPRO) with suitable amplifier). The laser will have the following characteristics:

• 10 year lifetime;

• Power stability

• Linewidth

This task will involve investigating the issues of space qualification of the system, experimentally studying the relevant problems, and proposing a realistic plan of development of this system. Given the magnitude of the effort
to develop a space qualified LISA laser, it is not expected that the outcome of this task will result in a space qualified laser; rather, the outcome should be a sufficient understanding of the important technical issues in space qualification (e.g., diode lifetime, thermal and vibrational robustness, etc.) so that a clear path towards the development of a fully space qualified system can be identified.

LISA Electro-optical Modulator: produce a phase modulator for a 1 W continuous laser beam, providing 10% power modulation depth at frequencies from 1.9 to 2.1 GHz. The modulator should be fiber coupled (input and output), at 1.06 micron wavelength. The modulator must be space qualified.

LISA Telescope Articulator: produce a mechanical actuator that can articulate the LISA telescope over a 5 mm dynamic range with a 0.1 nm resolution. The actuator must be space qualified and have noise.

Sun - Solar System Connection Topic S5

The strategic priorities of the Sun-Solar System Connection derive from a stated NASA Strategic Objective, namely: "Explore the Sun-Earth system to understand the Sun and its effects on Earth, the solar system, and the space environmental conditions that will be experienced by human explorers, and demonstrate technologies that can improve future operational systems." SSSC has identified three science and exploration objectives. The program will provide the knowledge needed to: 1) open the frontier to space environment prediction: understand the fundamental physical processes of the space environment - from the Sun to Earth, to other planets, and beyond to the interstellar medium; 2) understand the nature of our home in space: understand how society, technological systems, and the habitability of planets are affected by the variable space environment; 3) safeguard our outbound journey: maximize the productivity and safety of human and robotic explorers by developing predictive capability for the extreme and dynamic conditions in space.

Sub Topics:

S5.01 Low Thrust and Propellantless Propulsion Technologies

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

Spacecraft propulsion technology innovations are sought for upcoming 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, solar sails, aerocapture, and emerging technologies.

Advanced Chemical Propulsion
Innovations in low-thrust chemical propulsion system technologies are being sought for deep-space, scientific, robotic mission applications. Delta Vs for the missions of interest range from 1000 m/sec to 3000 m/sec. Technologies of interest are bipropellant engines with Isp greater than 360 seconds, both pressure-fed and pump-fed, with chamber pressures ranging from 100 to 500 psia. Throttling capability is desired for engines used for planetary ascent, descent, and orbit insertion maneuvers. Passive long-term storage (greater than 5 years) for advanced bipropellant propulsion systems for deep space missions are of interest. Reliable ignition systems are needed for non-hypergolic propellants. Activities in development of lightweight, compact, and low-power propellant management components, such as valves, flow control/regulation, fluid isolation, and lightweight tankage are also solicited. Advanced materials to allow development of systems for use with advanced bipo-propellants (higher Isp, higher pressure) are also solicited.

**Solar Sail Propulsion**

Solar sails have been studied for a variety of missions and have the potential to provide cost-effective, propellantless propulsion that enables longer on-station operation, increased scientific payload mass fraction, and access to previously inaccessible orbits (e.g., non-Keplerian, high solar latitudes, etc.).

NASA missions enabled and enhanced by solar sail propulsion include those that can provide: 1) situational awareness for human and robotic exploration in the Earth-Moon system (e.g., Helioswarm, L1 Diamond); 2) comprehensive monitoring of the inner heliosphere (e.g., Solar Sentinels, Solar Polar Imager, Particle Acceleration Solar Observatory); and 3) pathfinder exploration beyond the solar system (Interstellar Probe). The technology required for these missions can further be classified into two categories: 1) near-term (2; and 2) far-term (>15 years) for use in orbits at 25 AU with a propulsive area of greater than 1 x 10^5 m^2. A solar sail propulsion system includes the sail membrane and support structure, the thrust vector control subsystem, the health and monitoring diagnostic subsystem, and the launch stowage structure. Three parameters that are used as sail performance metrics in mission applications are: sail size, sail durability in its orbital environment, and areal density (ratio of sail system mass to propulsive area of the sail). In addition, important programmatic metrics are cost, benefit, and risk. Innovations are sought that will lower the cost and risk associated with sail system development through advancements in: manufacturing, fabrication, and assembly; durable lightweight materials, structures, and mechanisms; comprehensive simulations of maneuvering, navigation, trajectory control, propulsive performance, and operations; and integrated diagnostic health monitoring.

**Tether Technologies**

This effort focuses on technologies supporting innovative and advanced concepts for propellantless propulsion based upon space tethers concepts. The categories under Tether Technologies include, but are not limited to: ElectroDynamic (ED) tether propulsion, Momentum exchange Electrodynamic Reboost (MXER) tethers or its subsystems, Jovian tether mission concepts, Earth orbiting telescope ED tether reboost, and other innovative in space tether technologies. In general, the electrodynamic tether propulsion method exchanges momentum with a planet's rotational angular momentum through electrodynamic interaction with the planetary magnetic field. Momentum exchange tethers or MXER concepts use orbital energy to provide a high thrust to a payload in LEO. Distinctive variations of existing propulsion methods or chief subsystem component improvements are also suitable for submission. Proposals should provide the development plan of specific innovative technologies or techniques supporting the planned research. Identification of the fundamental technology to be developed is also crucial. A clear plan for demonstrating feasibility, noting any test and experiment requirements, is recommended. Key to each idea is an unambiguous knowledge of past research/concepts conducted on related work and specifically how this new proposal differs from, or enhances, the existing tether roadmaps, particularly for robotic mission support.

**Aeroassist**
Aeroassist is a general term given to various techniques to maneuver a space vehicle within an atmosphere using aerodynamic forces in lieu of propulsive fuel. Aeroassist systems enable shorter interplanetary cruise times, increased payload mass, and reduced mission costs. Subsets of aeroassist are aerocapture and aerogravity assist. 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. Without aerocapture, a substantial propulsion system would be needed on the spacecraft to perform the same reduction of velocity. Aerogravity assist is an extension of the established technique of gravity assist with a planetary body to achieve increases in interplanetary velocities. Aerogravity assist involves using propulsion in conjunction with aerodynamics through a planetary atmosphere to achieve a greater turning angle during planetary fly-by. In particular, this subtopic seeks technology innovations that are in the following areas:

**Aerocapture**

Thermal Protection Systems: development of advanced thermal protection systems and insulators for planetary aerocapture.

Low Temperature/High Temperature Adhesives Trade Study: aerocapture inflatable decelerators are currently proposed to be manufactured from thin film materials and/or high temperature fabrics, stowed during transport, and inflated prior to atmospheric entry for aerocapture applications at planetary destinations.

- Prior to the aerocapture maneuver, the inflatable decelerator will be stowed for many years (up to 10) in an uncontrolled space environment (-130°C) during transport to outer solar system destinations;
- Before atmospheric entry, the inflatable decelerator will be unstowed and inflated; and
- During the aerocapture maneuver, up to 24 hours after the inflation process, the inflatable decelerator will experience temperatures to 500°C (or higher).

Conduct a thorough study of the adhesives trade space and select and test adhesive candidates that will maintain bond strength during the temperature extremes and long-term space exposure experienced by inflatable decelerators. The product of this study will be a report thoroughly documenting sample preparation, test procedures, and test results of all materials investigated. This report will be disseminated to inflatable decelerator developers.

**S5.02 Accommodation and Mitigation of Space Environmental Effects**

*Lead Center: GSFC*

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

This subtopic is concerned with improving the capability to accommodate or mitigate the effects of the space environment on spacecraft design and operations. It will achieve its goal by designing and building flight
investigations, developing models, collecting data from investigations in space and from ground tests, and analyzing data to improve the models, tools, and/or databases used for spacecraft design and operations. The resulting products will reduce the design margins and uncertainties in the induced environment definition (i.e., the environment in the presence of a spacecraft) and its effects on spacecraft design and operations. The environments to be considered include planetary-trapped radiation, solar proton events, cosmic rays, the plasma environment at planets and in the solar wind, magnetic fields, EUV/VUV, and the interplanetary meteoroid environment.

The investigations selected have the opportunity to be integrated on the Space Environment Testbed (SET) Carrier. The SET Project opportunities for flight will be in orbits other than LEO. Investigations do not need to fly with the SET Carrier if an investigator makes arrangements for other access to space.

Examples of investigations and models that would satisfy those requirements are described below. A more detailed description, with examples of investigation needs, can be found at: http://lws-set.gsfc.nasa.gov/Opportunities.htm [5].

Areas for which proposals are sought include:

- Characterization of the space environment, both natural and induced, in the vicinity of a spacecraft;
- Definition of the mechanisms for material and materials applications degradation and the performance characterization of materials (such as coatings, optical properties, composites, etc.) in the space environment;
- Accommodation and/or mitigation of charging/discharging effects on spacecraft and spacecraft components;
- Methods for performance improvement of radiation tolerance of microelectronics used in space, including reduction of single event upsets and other single particle-induced soft errors, and elimination of single event latch-ups and other single particle-induced destructive conditions;
- Development of novel methods for increasing crew safety and system performance relative to the effects of the natural space environment; and
- Development of novel methods of increasing ground-based systems performance and reliability by reducing the effects of the natural space environment on those systems (e.g., space environment-induced soft errors in the power grid).

S5.03 Technologies for Particles and Fields Measurements

Lead Center: GSFC
The SEC theme encompasses the Sun with its surrounding heliosphere carrying its photon and particle emissions and the subsequent responses of the Earth and planets. 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 are 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.

- Miniatrurized, 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 subnanosecond resolution and multiple channels of parallel processing; and
- Miniatrurized, 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
- Miniatrurized, 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-Sun System Instrument and Sensor Technology Topic S6

NASA's Earth-Sun Systems (ESS) 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 ESS 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.

Sub Topics:

S6.01 Passive Optics

Lead Center: LaRC

Participating Center(s): ARC, GSFC, MSFC

The following technologies are of interest to NASA in the remote sensing subtopic “passive optics.” 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. Technical and scientific leads at NASA have given careful consideration to the technology areas described below; responses are solicited for these topics.
- Technology leading to visible/NIR narrowband optical filters exhibiting greatly improved degradation properties over existing filters and minimal spectral drift for long-term space-based applications;

- Technology leading to significant improvements in capability of large format (>1 inch diameter), very narrow band (~1 full-width at half-maximum), polarization insensitive, high-throughput infrared (0.7-15 Åm) optical filters;

- Large format (>1 inch diameter), high-transmission, far infrared filters. Technology and techniques leading to filters operating at wave numbers between 500 and 5 cm\(^{-1}\) with FWHM less than 2 cm\(^{-1}\) are of immediate interest, though technology leading to very high transmission edge filters (long and short pass) is also solicited. The filters must be capable of operating in a vacuum at cryogenic temperatures; and

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

**S6.02 Lidar Remote Sensing**

*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, and high performance. Innovative technologies that can expand current measurement capabilities to airborne, spaceborne, or Unmanned Aerial Vehicle (UAV) 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 lidar, or coherent-detection (heterodyne) lidar, or both;
- Land topography (vegetation, ice, land use); and
- Molecular species (ozone, water vapor, and carbon dioxide).

Innovative component technologies that directly address the measurement needs above will be considered. Dual-use technologies addressing Planetary Exploration are highly desirable (see subtopics X1.03 and S1.04). For the PY05 SBIR, we are soliciting component technologies described below.

- Pulsed, single frequency, diode-based seed laser 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:

- Single frequency 1064 nm operation.
- Small, pinned package(s) that can generate CW powers in the 100's of mW and higher pulse powers yielding at least 10 nJ pulse energies.
- Gaussian pulsewidths between 100 ps and 5 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 Yb: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 is needed, with pulsed lifetimes in the trillion shot regime ($10^{12}$).
- Single mode, PM fiber output is needed.
- Short term drift less than 1 MHz.

- CW, dual frequency, diode-based seed laser systems are desired for high power solid-state laser cavity feedback and locking at 1064 nm. If two wavelengths are produced, one must be 1064 nm and another single wavelength 5 nm or more offline (in either direction). Systems with the following specifications are solicited:

  - Simultaneous dual frequency operation; 1064 nm and a second wavelength at least 5 nm (either plus or minus) from 1064 nm.
  - Small, pinned package(s) that can generate CW powers in the 100s of mW and higher pulse powers.
  - CW output powers of >10 mW in each wavelength. Individual tunability is not required, but tunability of the 1064 nm output is required.
  - Dual PM, single mode fiber output is desired, but not absolutely required.
  - 5 MHz or less short term drift over 30 sec.

- 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.

- Shared aperture, angle-multiplexed holographic or diffractive optical elements having several fields of view, each with angular resolution of 50 µrad or better for the Nd:YAG or Nd:YLF laser harmonics, and diffraction limited resolution for the Ho:YLF fundamental wavelength. Wide, flat, focal planes with low off-axis aberrations is of importance to terrain and vegetation mapping lidar applications. Hybrid designs using both 2053 nm or 1064 nm and 355 nm simultaneously are needed for dual wavelength Doppler wind lidar applications. Materials and technologies are needed that can be scaled up to 1 m apertures and larger and space qualified. Designs using lightweight materials, such as composites or membranes and deployable
folded architectures, are also desired to decrease system size and weight.

- Novel, high-power laser diodes capable suitable for pumping Holmium-based solid state lasers:
  - Quasi-CW laser diode arrays operating in 1939 nm or 1906.8 nm wavelengths with pulse duration of at least 1 msec, peak power in 10s watts regime, and duty cycle of greater than 2%;
  - Quasi-CW fiber-coupled laser diode pump arrays operating in 785 nm or 792 nm wavelengths with pulse duration of at least 1 msec, peak power in 100s watts regime, and duty cycle of greater than 2%; and
  - CW fiber-coupled laser diode pump arrays operating in 1939 nm or 1906.8 nm wavelengths.

- 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 0.5-1.0 m diameter for deployment in space is required.

- Laser beam steering and scanning technologies (such as dual-wedge, diffractive optical elements, and liquid crystal) operating at 1.5 or 2.05 micron with 2 cm to 25-cm aperture diameter meeting the following requirements:
  - 60 deg. field of regard.
  - 90% optical throughput.
  - 1/4-wave single pass optical quality at 632 nm.

**S6.03 Earth In Situ Sensors**

**Lead Center:** GSFC

**Participating Center(s):** ARC

Proposals are sought for the development of *in situ* measurement systems that will enhance the scientific and commercial utility of data products from the Earth Science Enterprise program and that will enable the development of new products of interest to commercial and governmental entities around the world. Technology innovation areas of interest include:

- Autonomous Global Positioning System (GPS)-located platforms (fixed or moving) to measure and transmit to remote terminals upper ocean and lower atmosphere properties including temperature, salinity, momentum, light, precipitation, and biogeochemistry;
• Dynamic stabilization systems for small instruments mounted on moving platforms (e.g., buoys and boats) to maintain vertical and horizontal alignment. Systems capable of maintaining a specified pointing with respect to the Sun are preferred;

• Small, lightweight instruments for measuring clouds, liquid water, or ice content (mass) designed for use on radiosondes, dropsondes, aerosondes, tethered balloons, or kites;

• Wide-band microwave radiometers capable of high-speed characterization of cloud parameters, including liquid and ice phase precipitation, which can operate in harsh environmental conditions (e.g., onboard ships and aircraft);

• Autonomous, GPS-located airborne sensors that remotely sense atmospheric wind profiles in the troposphere and lower stratosphere with high spatial resolution and accuracy;

• Systems for in situ measurement of atmospheric electrical parameters including electric and magnetic fields, conductivity, and optical emissions;

• Systems to measure line- and area-averaged rain rate at the surface over lines of at least 100 m and areas of at least 100x100 m;

• Lightweight, low-power systems that integrate the functions of inertial navigation systems and GPS receivers for characterizing and/or controlling the flight path of remotely piloted vehicles;

• Low-cost, stable (to within 1% over several months), portable radiometric calibration devices in the shortwave spectral region (0.3 to 3 µm) for field characterization of radiance instruments such as sun photometers and spectrometers;

• Miniaturized, low-power (12V DC) instruments especially suited for small boat operations that are capable of adequately resolving, at the appropriate accuracy, the complex vertical structure (optical, hydrographic, and biogeochemical) of the coastal ocean (turbid) water column. Sensors that can be easily integrated within a digital (serial) network to measure the apparent and inherent optical properties of seawater are preferred; and

• Aircraft or UAV instruments for in situ measurements of physical and optical properties of clouds and aerosols with instantaneous measurement volumes ranging from cubic meters up to a maximum of a cubic kilometer, the purpose being to furnish validation for satellite remote sensing at the spatial scales satellites actually provide.

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 multispectral 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 (100 mW), and low power consumption;
- Wideband and ultra-wideband sensors with >15dB cross-pole isolation across the bandwidth;
- Low noise;
- 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.

S6.05 Active Microwave

Lead Center: JPL
Participating Center(s): GSFC

Active microwave sensors have proven to be ideal instruments for many Earth science applications. Examples include global freeze and thaw monitoring, soil moisture mapping, accurate global wind retrieval, and snow inundation mapping, global 3D mapping of rainfall and cloud systems, precise topographic mapping and natural hazard monitoring, global ocean topographic mapping, and glacial ice mapping for climate change studies. 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), scatterometers, sounders, altimeters, and atmospheric radars. 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. Onboard processing techniques will reduce data rates sufficiently to enable global coverage. High performance, yet affordable, radars will provide data products of better quality and deliver them to the users more frequently and in a timelier manner, with benefits for science as well as the civil and defense communities. 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.

The frequency and bandwidth of operation are mission driven and defined by the science objectives. For SAR applications, the frequencies of interest include UHF (100 MHz), P-band (400 MHz), L-band (1.25 GHz), X-band (10 GHz), and Ku-band (12 GHz). The required bandwidth varies from a few megahertz to 20 MHz to 300 MHz to achieve the desired resolution; the larger the bandwidth, the higher the resolution. Ocean altimeters and scatterometers typically operate at L-band (1.2 GHz), C-band (5.3 GHz), and Ku-band (12 GHz). Ka-band (35 GHz) interferometers have applications to river discharge. The atmospheric radars operate at very high frequencies (35 GHz and 94 GHz) with only modest bandwidth requirements on the order of a few megahertz.

The emphasis of this subtopic is on core technologies that will significantly reduce mission cost and increase
performance and utility of future radar systems. There are specific areas in which advances are needed.

- **SAR for surface deformation, topography, soil moisture measurements:**
  - Very large aperture L-band antennas (20 m x 20 m) for Medium Earth Orbit (MEO) or 30m diameter for Geosynchronous SAR applications.
  - Shared aperture, multi-frequency antennas (P/L-band, L/X-band).
  - Lightweight, deployable antenna structures and deployment mechanisms.
  - Rad-hard, high-efficiency, high power, low-cost, lightweight L-band and P-band T/R modules.
  - High-power transmitters (L-band, 50-100 kW).
  - L-band and P-band MMIC single-chip T/R module.
  - Rad-hard, high-power, low-loss RF switches, filters, and phase shifters.
  - Digital true-time delay (TTD) components.
  - Thin-film membrane compatible electronics. This includes: reliable integration of electronics with the membrane, high performance (>1.2 GHz) transistor fabrication on flex material including identifying new materials, process development, and techniques that have the potential to produce large-area passive and active flexible antenna arrays.
  - Advanced transmit and receive module architectures such as optically-fed T/R modules, signal up/down conversion within the module, and novel RF and DC signal distribution techniques.
  - Advanced radar system architectures including flexible, broadband signal generation and direct digital conversion radar systems.
  - Advanced antenna array architectures including scalable, reconfigurable, and autonomous antennas; sparse arrays; and phase correction techniques.
  - Distributed digital beamforming and onboard processing technologies.

- **SAR data processing algorithms and data reduction techniques.**

- **SAR data applications and post-processing techniques.**

- **Low-frequency SAR for subcanopy and subsurface applications:**
  - Lightweight, large-aperture (30 m diameter) reflector and reflectarray antennas.
  - Large, electronically scanning P-band arrays.
  - Shared aperture, dual-polarized, multiple low-frequency (VHF through P-band, 50-500 MHz) antennas with highly shaped beams.
Lightweight, low frequency, low-loss antenna feeds (VHF through P-band, 50-500 MHz).

High-efficiency T/R modules and transmitters (50-500 MHz, 10 kW).

Lightweight, deployable antenna structures and deployment mechanisms.

Data applications and post-processing techniques.

- **Polarimetric ocean/land scatterometer:**
  
  - Multi-frequency (L/Ku-band) lightweight, deployable reflectors.
  
  - Large, lightweight, electronically steerable Ku-band reflectarrays.
  
  - Lightweight L-band and Ku-band antenna feeds.
  
  - Dual-polarized antennas with high polarization isolation.
  
  - Lightweight, deployable antenna structures and deployment mechanisms.
  
  - High efficiency, high power, phase stable L-band and Ku-band transmitters.
  
  - Low-power, highly integrated radar components.
  
  - Calibration techniques, data processing algorithms, and data reduction techniques.
  
  - Data applications and post-processing techniques.

- **Wide swath ocean and surface water monitoring altimeters:**
  
  - Shared aperture, multi-frequency (C/Ku-band) antennas.
  
  - Large, lightweight antenna reflectors and reflectarrays.
  
  - Lightweight C-band and Ku-band antenna feeds.
  
  - Lightweight, deployable antenna structures and deployment mechanisms.
  
  - High-efficiency, high power (1-10 kW) C-band and Ku-band transmitters.
  
  - Real-time onboard radar data processing.
  
  - Calibration techniques, data processing algorithms, and data reduction techniques.

- **Ku-band and Ka-band interferometers for snow cover measurement over land (Ku-band), wetland, and river monitoring (Ka-band):**
  
  - Large, stable, lightweight, deployable structures (10-50 m interferometric baseline).
  
  - Ka-band along and across-track track interferometers with a few centimeters of height accuracy.
  
  - Ku-band interferometric polarimetric SAR.
- Phase-stable Ku-band and Ka-band electronically steered arrays and multibeam antennas.
- Lightweight deployable reflectors (Ku-band and Ka-band).
- Shared aperture technologies (L/Ku-band).
- Phase-stable, Ku-band and Ka-band receive electronics.
- High-efficiency, rad-hard Ku-band and Ka-band T/R modules or >10 kW transmitters.
- Ku-band and Ka-band antenna feeds.
- Calibration and metrology for accurate baseline knowledge.
- Real-time onboard radar data processing.
- Data applications and post-processing techniques.

- Atmospheric radar:
  - Low sidelobe, electronically steerable, millimeter wave, phased-array antennas and feed networks.
  - Low sidelobe, multi-frequency, multi-beam, shared aperture millimeter wave antennas (Ka-band and W-band).
  - Large (~300 wavelength), lightweight, low sidelobe, millimeter wave (Ka-band and W-band) antenna reflectors and reflectarrays.
  - Lightweight deployable antenna structures and deployment mechanisms.
  - High power (10 kW) Ka-band and W-band transmitters.
  - High-power (>1 kW, duty cycle >5%), wide bandwidth (>10%) Ka-band amplifiers.
  - High-efficiency, low-cost, lightweight Ka-band and W-band transmit/receive modules.
  - Advanced transmit/receive module concepts such as optically-fed T/R modules.
  - Onboard (real-time) pulse compression and image processing hardware and/or software.
  - Advanced data processing techniques for real-time rain cell tracking, and rapid 3D rain mapping.
  - Lightweight, low-cost, Ku/Ka band radar system for ground-based rain measurements.
  - Light weight, wideband (>200 MHz), low-sidelobe (Low-power, high-speed, multi-channel single board digital receivers.
  - High-power, high-duty cycle solid state power amplifier from X through W-band.
S6.06 Passive Infrared - Sub Millimeter

Lead Center: JPL

Many NASA future Earth science remote sensing programs and missions require microwave to submillimeter wavelength antennas, transmitters, and receivers operating in the 1-cm to 100-Åμm wavelength range (or a frequency range of 30 GHz to 3 THz). General requirements for these instruments include large-aperture (possibly deployable) antenna systems with RMS surface accuracy of

For these systems, advancement is needed in primarily three areas: 1) the development of frequency-stabilized, low phase noise, tunable, fundamental local oscillator sources covering frequencies between 160 GHz and 3 THz; 2) the development of submillimeter-wave mixers in the 300-3000 GHz spectral region with improved sensitivity, stability, and IF bandwidth capability; and 3) the development of higher-frequency and higher-output-power MMIC circuits.

Specific innovations or demonstrations are required in the following areas:

- Heterodyne receiver system integration at the circuit and/or chip level is needed to extend MMIC capability into the submillimeter regime. MMIC amplifier development for both power amplifiers and low noise amplifiers at frequencies up to several hundred GHz is solicited. Integration of a local oscillator multiplier chain, mixer, and intermediate frequency amplifier is one example. There is also a specific need to demonstrate array radiometer systems using MMIC radiometers from 60 GHz to approximately 500 GHz;

- Solid-state, phase-lockable, local-oscillator sources with flight-qualifiable design approaches are needed with >10 mW output power at 200 GHz and >100 ÅμW at 1 THz; source line widths should be

- Stable local-oscillator sources are needed for heterodyne receiver system laboratory testing and development;

- Multi-channel spectrometers that analyze intermediate frequency signal bandwidths as large as 10 GHz with a frequency resolution of

- Compact and reliable millimeter and submillimeter imaging instrumentation that produces images simultaneously in multiple spectral bands;

- Schottky mixers with high sensitivity at T = 100 K and above;

- Low noise superconducting HEB mixers and SIS mixers;

- Receivers using planar diode or alternative reliable local oscillator technologies in the 300-3000 GHz spectrum;

- Lightweight and compact radiometer calibration references covering 100-800 GHz frequency range;

- Lightweight, field portable, compact radiometer calibration references covering frequencies up to 200 GHz. The reference must be temperature stable to within 1 K with a minimum of three temperature settings between 250 and 350 K;

- Low-cost, special purpose, ground-based receivers to detect signals radiated from active satellites that are in orbit for estimating rain rate, water vapor, and cloud liquid water; and

- Calibrated radiometer systems that can achieve accuracy and stability of 0.1 K.
Future 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:

- Instrument Optical alignment needs, lasers, and detectors that require tight temperature control, often to better than ±1°C. Some new missions, such as LISA and TPF, require methods of temperature measurement and control to micro-Kelvin levels.

- 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 thermal losses across make/break interfaces.

- Future missions will utilize large, distributed structures such as mirrors and detector arrays at both ambient and cryogenic temperatures. These missions will require creative techniques to integrate thermal control functions and minimize weight. Some anticipated technology needs include: advanced thermoelectric coolers capable of providing cooling at ambient and cryogenic temperatures, high conductivity structural materials to minimize temperature gradients and provide high efficiency lightweight radiators, and advanced thermal control coatings such as variable emittance surfaces and coatings with a high emissivity at ambient and cryogenic temperatures.

- The push for miniaturization also drives the need for new thermal technologies towards the MEMS level. Miniaturized heat transport devices, especially those suitable for cooling small sensors, devices, and electronics, include miniaturized mechanical pumps, Loop Heat Pipes (LHPs), and Capillary Pumped Loops (CPLs) which allow multiple heat load sources and multiple sinks.

- The drive towards robotic missions and reconfigurable spacecraft presents engineering challenges for science instruments, which must become more self-sufficient. Some of the technology needs are:
  - Advanced analytical techniques for thermal modeling focusing on techniques that can be easily integrated into existing codes, emphasizing inclusion of LHPs, CPLs, and mechanically pumped system models;
  - Single and two-phase mechanically pumped fluid loop systems, which accommodate multiple heat sources and sinks, and long life, lightweight pumps for these systems; and
  - Efficient, lightweight vapor compression systems for cooling up to 2 KW.
oceans, geology, and atmosphere and the complex interactions of all these systems as a single, connected, end-to-end system. The Directorate's mission is to reap the benefits of Earth and Sun exploration for society by providing accurate, objective scientific data and analysis to help policy makers, businesses, and citizens achieve economic security and to promote environmental stewardship. In this topic, the Directorate wants innovative companies to propose technology and techniques to assist the Directorate in achieving a portion of the mission in the shortest timeframe that is practical. The topic goal is to accelerate the deployment of Sun-Earth science data and understanding into operational decision support tools used by managers concerned with stewardship of the Earth's resources. This goal addresses the development of innovative technology solutions that simplify the processing, analysis, interpretation, and visualization of science data that will allow the routine use of Earth science results in automated decision support tools already in use by a broad user community. Management decision support tools of interest are used daily in management of land/biota, air, water, and emergency issues.

Sub Topics:

S7.01 Geospatial Data Analysis Processing and Visualization Technologies

Lead Center: SSC
Participating Center(s): GSFC

Proposals are sought for the development of advanced technologies in support of scientific, commercial, and educational applications of Earth Science and other remote sensing data. Focus areas are to provide tools for processing, analysis, interpretation, and visualization of remotely sensed data sets. Earth Science data needs to be benchmarked for practical use of NASA-sponsored observations from remote sensing systems and predictions from scientific research and modeling. Specific interest exists in the development of technologies contributing to decision support systems, and model development and operation. For more information on decision support models under evaluation, please visit [http://science.hq.nasa.gov/strategy/index.html][6]. Areas of specific interest include the following:

- Unique, innovative data reduction, rapid analysis, and data exploitation methodologies and algorithms of information from remotely sensed data sets, e.g., automated feature extraction, data mining, etc.;
- Algorithms and approaches to enable the efficient production of data products from active imaging systems, e.g., multipoint data resampling, digital elevation model creation, etc.;
- Data merge and fusion software for efficient production and real-time delivery of digital products of ESE Mission and other remote sensing data sets, e.g., weather observation and land use and land cover data sets;
- Innovative approaches for incorporation of GPS data into in situ data collection operations with dynamic links to spatial databases including environmental models;
- Image enhancement algorithms for improving spatial, spectral, and geometric image attributes;
- Innovative approaches for the querying and assimilation of application-specific datasets from disparate and distributed databases from government, academic, and commercial sources into a common framework for data analysis;
- Innovative approaches for querying of application-specific data sets from disparate, distributed databases in government, academic, and commercial data warehouses into a common framework for data analysis; and
- Innovative visualization technologies contributing to the analysis of data through the display and visualization of some or all of the above data types including providing the linkages and user interface between the cartographic model and attribute database.
S7.02 Innovative Tools and Techniques Supporting the Practical Uses of Earth Science Observations

Lead Center: SSC
Participating Center(s): MSFC

Technical innovations and unique approaches are solicited for the development of new technologies and technical methods that make Earth science observations both useful and easy to use by practitioners. This subtopic seeks proposals that support the development of operational decision support tools that produce information for management or policy decision makers. Proposed applications must use NASA Earth Observations (see [7](http://science.hq.nasa.gov/)). Other remote sensing data and geospatial technologies may also be employed in the solution.

This subtopic focuses on the systems engineering aspect of application development rather than fundamental research. Offerors are, therefore, expected to have the documented proof-of-concept project in hand. Topics of current interest to the Applied Science Directorate may be found at [8](http://www.asd.ssc.nasa.gov). Innovation in processing techniques, include, but are not limited to, automated feature extraction, data fusion, and parallel and distributed computing which are desired for the purpose of facilitating the use of Earth science data by the nonspecialist. Ease of use, fault tolerance, and statistical rigor and robustness are required for confidence in the product by the nonspecialist end user.

Promotion of interoperability is also a goal of the subtopic, so Federal data standards, communication standards, Open Geographic Information Systems (GIS) standards, and industry-standard tools and techniques will be strongly favored over proprietary 'black-box' solutions. Endorsement by the end user of both system requirements and the proposed solution concept is desirable. While the proposed application system may be specific to a particular end user or market, techniques and tools that have broad potential applicability will be favored. An objective assessment of market value or benefit/cost will help reviewers assess the relative potential of proposed projects.

S7.03 Wireless Technologies for Spatial Data, Input, Manipulation and Distribution

Lead Center: SSC

Technical innovation is solicited for the development of wireless technologies for field personnel and robotic platforms to send and receive digital and analog data from sensors such as photography cameras, spectrometers, infrared and thermal scanners, and other sensor systems to collection hubs. The intent of this new innovation is to rapidly, in real time, ingest data sequentially from a variety of input sensors, provide initial field verification of data, and distribute the data to various nodes and servers at collection, processing, and decision hub sites. Data distribution should utilize state-of-the-art wireless, satellite, land carriers, and local area communication networks. The technology's operating system should be compatible with commonly available systems. The operating system should not be proprietary to the offeror. The innovation should include biometric capability for password protection and relational tracking of data to the field personnel inputting the data and/or sensors and platforms sending information. The innovation should contain technologies that recognize multiple personnel and other sources (robotics) so that several personnel and platforms can use the same unit in the field. Biometric identification can be
fingerprint, retina scans, facial, or other methods. The innovation should include geospatial technologies to use digital imagery and have Global Positioning System (GPS) location capabilities. The innovation should be able to display, with sufficient size and resolution, the rendering of vector and raster data and other sensor data for easy understanding. The field capability of the innovation must be fully integrated end to end with computing capabilities that range from mobile computers to servers at distant locations. Field personnel and robotic platforms providing information and support to science investigations, resource managers, and community planners will use the innovative wireless technology. First responders to natural, human-made disasters and emergencies will also be users of this innovation.

Science Spacecraft Systems Technology Topic S8

NASA has combined the Earth and Space Sciences into a new mission directorate called the Science Mission Directorate. The Science Mission Directorate will carry out the scientific exploration of our Earth, the planets, moons, comets, and asteroids of our solar system and beyond; chart the best route of discovery; and reap the benefits of Earth and space exploration for society. A major objective of the NASA science 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. NASA is fostering innovations that support implementation of the Earth Science (ES) and Space Science (SS) integrated international undertaking to study the Earth and space systems. The Science Mission Directorate Programs define the platforms as the host systems for science instruments. That is, they provide the infrastructure for an instrument or suite of instruments. Traditionally, the term 'platform' would be synonymous with 'spacecraft,' and it certainly does include spacecraft. However, 'platform' is intended to be much broader in application than spacecraft and is intended to include non-traditional hosts for sensors and instruments such as airborne platforms (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 and indicate types of platforms for which technology development is required.

Sub Topics:

S8.01 Guidance, Navigation and Control

Lead Center: GSFC
Participating Center(s): JPL

Future science architectures will include observation and sensing platforms of varying type, size and complexity in a number of mission-operational regimes, trajectories and orbits. 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. Novel approaches for the autonomous control of distributed spacecraft and/or the management of large fleets of heterogeneous and/or homogeneous assets are desired. Specific areas of research include:

**GN&C System Technologies**

Innovative GN&C solutions are sought for scientific instrument and laser communication system pointing, tracking, and stabilization. Proposals that exploit and combine recent advances in, spacecraft attitude determination and control, advanced electro-mechanical packaging, MEMS technology, and ultra-low power microelectronics are encouraged. Of particular interest is technology to provide alternative solutions to challenging GN&C problems such as spacecraft relative range and attitude determination while in close formation and/or during rendezvous/proximity operations.

**GN&C Sensors and Actuators**

Advanced technology sensors and actuators are sought such as Sun sensors, Earth sensors, star/celestial object trackers, fine guidance sensors, gyroscopes, accelerometers, inertial measurement units, navigation devices, magnetometers, reaction/momentum wheels, control-moment gyros, magnetic torquers, tethers, attitude control thrusters, etc. These devices should have enhanced capabilities and performance as well as reduced cost, mass, power, volume, and reduced complexity for all platform GN&C system elements.

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, with significantly reduced mass, power, volume, and cost. Technologies having the potential for significantly increased performance without additional mass, power, volume, and cost are also of interest. These resource reduction and/or performance improvement factors should be quantified in the proposal and show a minimum factor of 2 with a goal of 10 or greater. Highly autonomous and robust GN&C devices with multifunctional capabilities are of particular interest.

Innovations in Global Positioning System (GPS) receiver hardware and algorithms that use GPS code and carrier signals to provide spacecraft navigation, attitude, and time. Of particular interest are GPS-based navigation techniques that may employ Wide Area Augmentation System (WAAS) corrections.

Novel approaches to autonomous sensing and navigation of multiple distributed space platforms. Of particular interest are specialized sensors and measurement systems for formation sensing and relative navigation functions.
**S8.02 Command and Data Handling**

**Lead Center: GSFC**

The goal for this subtopic is the development of advanced space technology and concepts to further high-performance science image and data processing. The instrument electronics must operate reliably and effectively for long periods of time in harsh environments. These systems require management of data and products, low power, and radiation.

The objective for this development goal is to elicit novel concepts, architectures, and component technologies that have realistic and achievable potential for flight applications and are responsive to the priority areas of this subtopic. Technologies will be selected based on the potential that their final end products are sustainable (affordable, reliable/safe, and effective) and will advance solutions to the challenges of reusability, modularity, and autonomy.

Priority areas are: reconfigurable/modular implementations; onboard science (data and image) processing and management; and low-power, radiation-resistant electronics. Additional information about the solicited technologies follows:

**Onboard Processing**

- Hardware technologies and architectures that support instrument science (data and image) processing and that are reconfigurable in flight and modular;
- Hardware-based algorithms for onboard data and image processing of raw science into multiple custom data products. The intent is to minimize onboard bandwidth constraints;
- Autonomous capability of hardware and algorithm management without ground intervention;
- Low-power electronics: in order to provide higher capabilities on smaller and/or less expensive instruments and decrease subsequent thermal load; and
- Radiation resistant electronics (hardware or application).

**S8.03 Long Range and Near Earth RF Communications**

**Lead Center: JPL**

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

This subtopic seeks innovative technologies for long-range RF telecommunications supporting the needs of space missions. Proposals are sought in the following areas:
• Ultra-small, low-cost, low-power, modular deep-space transceivers, transponders, and components, incorporating MMICs and Bi-CMOS circuits;

• MMIC modulators with drivers to provide large linear phase modulation (above 2.5 rad), high-data rate (10-200 Mbps), BPSK/QPSK modulation at X-band (8.4 GHz), and Ka-band (32 GHz and 38 GHz);

• High-efficiency (>70 %) Solid-Sate Power Amplifiers (SSPAs), of both medium output power (10-50 W) and high-output power (150 W- 1 KW), using power combining techniques and/or wide-bandgap semiconductor devices at X-band (8.4 GHz) and Ka-band (32 GHz and 38 GHz);

• Traveling Wave Tube Amplifiers (TWTAs), SSPAs, modulators, and MMICs for 26 GHz Ka-band (lunar comm);

• TWTAs operating at millimeter wave frequencies and at data rates of 10 Gbps or higher;

• Ultra low-noise amplifiers (MMICs or hybrid) for RF front-ends;

• MEMS-based RF switches and photonic control devices needed for use in reconfigurable antennas, phase shifters, amplifiers, oscillators, and in-flight reconfigurable filters. Frequencies of interest include S-, X-, Ka-, and V-band (60 GHz). Of particular interest is Ka-band from 25.5-27 GHz and 31.5-34 GHz.

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

S8.04 Spacecraft Propulsion

Lead Center: GRC

Participating Center(s): GSFC, JPL, JSC, 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. Propulsion systems must avoid contamination of instruments from thruster plumes. This subtopic seeks innovations in propulsion technologies to increase the capabilities of SMD spacecraft. Specifically, technology innovations are sought in the areas of solar electric propulsion, monopropellant technology, and miniature/precision propulsion.

Solar Electric Propulsion

Technology advancements are needed 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, electrodeless plasma production, low-erosion materials for ion optics and Hall discharge chambers, high-temperature magnetic circuits, and next-generation thrusters. Innovations sought include, but are not limited to, those that improve performance, increase lifetime, reduce mass, and decrease cost. Improvements are also sought for propellant management system components including storage, distribution, and flow control to support solar electric propulsion applications.
Monopropellant Technology

Advancements are sought for propulsion systems using advanced monopropellants. Spacecraft using high-performance (Isp >275 s), high-density (>1 g/cc) monopropellant formulations will need high-durability catalyst materials or, alternatively, non-catalytic ignition technology for power-limited spacecraft. Critical component materials (e.g., tank bladders, valve seats, and filters) that are compatible with advanced monopropellants need to be developed. Performance and density improvements are sought for applications with very low propulsion requirements.

Miniature/Precision Propulsion

Propulsion technologies for miniature (less than 10 kg) spacecraft and for high-precision (impulse bit

S8.05 Energy Conversion and Storage for Space Applications

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

Earth science observation missions will employ spacecraft, balloons, sounding rockets, surface assets, aircraft, and marine craft. Advanced power technologies are required for each of these platforms that address issues of size, mass, capacity, reliability, and operational costs. A vigorous effort is needed to develop energy conversion technologies that will enable the revolutionary Earth science missions. Exploiting innovative technological opportunities, developing power systems for adverse environments, and implementing system-wide techniques that promote scalability, adaptability, flexibility, and affordability are characteristics of the technological challenges to be faced and are representative of the type of developments required beyond the state-of-the-art.

The energy conversion technologies solicited include photovoltaics and thermophotovoltaic as well as related technologies such as array, concentrator, and thermal technologies. Specific areas of interest include:

- 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, and electrostatically clean spacecraft solar arrays;

- Proposals are sought addressing structural and microbatteries and rechargeable lithium-based batteries with advanced anode and cathode materials and advanced liquid and polymer electrolytes;

- Primary fuel cell systems that can function in high altitude platforms are solicited. These include primary H₂:Air systems that operate at low air pressure and H₂:O₂ systems;
• Future micro-spacecraft require distributed power sources that integrate energy conversion and storage into a hybrid structure with microelectronics devices/instruments; and

• 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.

S8.06 Platform Power Management and Distribution

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

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 Materials and Components

Advanced magnetic, dielectric, and semiconductor materials, devices, and circuits 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. Candidate devices and applications include transformers, inductors, semiconductor switches and diodes, electrostatic capacitors, current sensors, and cables.

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, 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.
Modeling and simulation are being used more pervasively and more effectively throughout the space program for both engineering and science pursuits. 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:

**S9.01 Automation and Planning**

Lead Center: ARC

Participating Center(s): GSFC

The Automation and Planning subtopic solicits proposals that allow either spacecraft or ground systems to robustly perform complex tasks given high-level goals with minimal human direction. Areas of interest include all aspects of data collection, processing analysis, and decision making. NASA wants to go from specifying “how” something is done to specifying “what” is needed and letting the system figure what data and resources best meet the high-level goals under a set of constraints (e.g., cost, time, etc.).

Technology innovations include, but are not limited to: 1) automation and autonomous systems that support high-level command abstraction; 2) efficient and effective techniques for assembling and processing large volumes of data (commonly available on the Internet) into useful information; 3) intelligent searches of large, distributed data archives, and data discovery through searches of heterogeneous data sets and architecture; and 4) automation of routine, labor intensive tasks 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; The Automation and Planning subtopic solicits proposals that allow either spacecraft or ground systems to robustly perform complex tasks given high-level goals with minimal human direction. Areas of interest include all aspects of data collection, processing analysis and decision making. NASA wants to go from specifying “how” something is done to specifying “what” is needed and letting the system figure what data and resources best meet the high level goals under a set of constraints (e.g. cost, time and etc).

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• Search agents that support applications involving the use of NASA data;
• Methods that support the robust production of data products 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;
• Autonomous data logging devices (software, or hardware and software) supporting a variety of weather and climate sensors, capable of ground-based operation in a wide variety of environmental conditions; such systems would probably be solar powered with accurate time stamping;
• Planning and scheduling methods related to Earth Science Mission objectives;
• System and subsystem health and maintenance, both space- and ground-based;
• Distributed decision making, using multiple agents, and/or mixed autonomous systems;
• Automated software testing;
• Verification and validation of automated systems;
• Automatic software generation and processing algorithms; and
• Control of Field Programmable Gate-Arrays (FPGA) to provide real-time products.

Problems address must be relevant to Earth and Solar Sciences including space weather.

S9.02 Distributed Information Systems and Numerical Simulation

Lead Center: ARC
Participating Center(s): GSFC

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 autonomous 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 follow below.

Distributed Information Systems

• Core 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;

- Services for management of distributed, heterogeneous information, including replica management, intuitive interfaces, and instantiation on demand or “virtualized data.” These services would be used, for example, to access and manipulate NASA’s wealth of geospatial and remote sensing data;

- 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; and

- Tools for rapidly porting and hosting science applications in a distributed environment. These applications should be written for an integrated, or workstation, environment using standard programming languages or tools such as Matlab, Interactive Data Language (IDL), or Mathematica.

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 application parallelization and performance analysis;

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

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

S9.03 Data Management and Visualization

Lead Center: GSFC

This subtopic focuses on supporting science analysis through innovative approaches to managing and visualizing large collections of science data. These data sets are extremely large and 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 such as goggles or helmets; and
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; and
- Novel tools for data viewing, real-time data browsing, 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

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

Distributed Data Access

- Dynamically configurable, high-speed access to data stored in Storage Area Networks (SAN) distributed over wide area environments; and
- Technologies for sharing data over newly developed, high-speed, wide area networks such as the National Lambda Rail (NLR).

S9.04 On-Board Science for Decisions and Actions

Lead Center: ARC

Current sensors are stove-piped systems, which can collect more data than is possible to transmit to the ground. Intelligence in the sensor or platform can prioritize or summarize the data and send down high priority or synoptic science data. In the future, a sensor-web capability will demand this remote onboard autonomy and intelligence about the kind and content of data being collected to support rapid decision making and tasking. This subtopic is interested in developing new methods to autonomously understand ES data in support of making rapid decisions and taking actions under three themes:

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

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).

Detection and Reduction of Biological Contamination on Flight Hardware Topic S1.01

As solar system exploration continues, NASA remains committed to the implementation of its planetary protection policy and regulations. A Mars sample return mission is being planned for the next decade. Other missions will seek evidence of life through in situ investigations far from Earth. One of the great challenges, therefore, is to develop or find the technologies or system approaches that will make compliance with planetary protection policy routine and affordable. Planetary protection is directed to 1) the control of terrestrial microbial contamination associated with robotic space vehicles intended to land, orbit, flyby, or otherwise be in the vicinity of extraterrestrial solar system bodies, and 2) the control of contamination of the Earth by extraterrestrial solar system material collected and returned by such missions. The implementation of these requirements will ensure that biological safeguards, to maintain extraterrestrial bodies as biological preserves for scientific investigations, are being followed in NASA’s space program. Methods for the detection and reduction of biological contamination are also frequently applicable to non-biological particulate and molecular contamination. To fulfill its commitment, NASA seeks technologies and systems approaches that will support mission compliance with planetary protection requirements. Examples of such technologies include:
• Techniques for cleaning of organics to the level of nanograms per square centimeter on complex surfaces (nondestructively and without residues) and for validation of cleanliness at this level or better;

• Nonabrasive cleaning techniques for narrow aperture occluded areas on spacecraft;

• Techniques for in situ (i.e., at the exploration site) cleaning and sterilization to prevent cross-contamination between planetary surface samples;

• Nondestructive and highly efficient sampling methods for detection of the remnants of microbial, particles, and molecular contamination on cleaned spacecraft surfaces;

• Methodology for the quantitative detection of viable microbial cells in the interior of non-metallic space-craft materials;

• Rapid cleaning validation methods with ultra high sensitivity for the major classes of biomolecules: proteins, amino acids, DNA/RNA, lipids, polysaccharides, etc.;

• A device or methodology for controlled measurement of microbial reduction at temperatures from 200-300°C to enable generation of microbial lethality curves. Rapid ramp-up and cool-down rates are critical to minimize the microbial killing that occurs during the ramp periods;

• Device or methodology for direct observation and evaluation of particles and biological contamination on spacecraft parts;

• Device or methodology for quantitative and homogeneous deposition of particles, microbial cells, and biomolecules on material surfaces for cleaning, sampling, and contamination transport studies;

• System design concepts to enable facile and rapid use of cleaning and sterilization technologies during flight hardware assembly;

• System design concepts to maintain the integrity of cleaned and sterilized complex flight systems and/or subsystems; and

• System concepts that would facilitate spacecraft sterilization at the system level just before launch or in flight.

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

Sub Topics:
Mars In Situ Robotics Technology Topic S1.02
During future exploration of planets, moons, and small solar system bodies (such as comets and asteroids), developments are needed in new innovative robotic technologies for surface operations, subsurface access, and autonomous software for each. Because of limited spacecraft resources, elements must be robust and have low power, volume, mass, computation, telemetry bandwidth, and operational overhead requirements. Successful technologies will have to operate in environments characterized by extremes of temperatures, pressures, gravity, high-gravity landing impacts, vibration, and thermal cycling. In particular, this subtopic seeks technology innovations in the following areas:
Subsurface Access

Research should be conducted to develop complete, lightweight, dry drilling systems with a penetration depth of 10-50 m and have the capability of penetrating both regolith and rocks. The development should focus on significant reduction in mass from the currently available state-of-the-art interplanetary drilling systems as well as the automation required for real-time control and fault diagnosis and recovery. In addition, because of the lack of water in most of the environments of interest, the drilling should be performed without a lubricant between the bit and rock. Of interest also is the development of ice penetrators, designed with explicit consideration of limited computation and power, which use heat to melt their way through the surface.

Rover Technology

Long-range autonomous navigation systems that focus on long distance (greater than 5 km) traverses through natural terrain, using no a priori knowledge of the subject terrain. Inflatable rover technology with a focus on the development of low-mass, highly capable platforms for exploration of extreme terrain through innovations in novel mechanisms and the automation required for real-time control. Concepts for new mobility systems or components, such as innovative wheel or suspension designs. Instrument placement with a focus on improved tools for the design of manipulation systems, to perform contact and noncontact operations such as drilling, grasping, sample acquisition, sample transfer, and contact and noncontact science instrument placement and pointing. Modular robotic joints that are small (0.5 kg), low power, low mass and can be used to build prototype manipulators and/or legs. Quick changeout mechanisms for planetary manipulators that can enable changing of tools or instruments on the end of a manipulator.

Of particular interest is infrastructure for research, including low-cost, mass producible, research-quality rovers and supporting elements. The development of a low-cost, Rocker-Bogie style, six-wheel steerable, robotic research platform that can drive around in rough terrain is desired.

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

Sub Topics:

Long Range Optical Telecommunications Topic S1.03
This subtopic seeks innovative technologies for long range optical telecommunications supporting the needs of space missions. Proposals are sought in the following areas:

- Space-qualifiable, efficient (greater than 20% wall plug), lightweight, variable repetition-rate (1-60 MHz), tunable (± 0.1 nm) pulsed 1064-nm transmitter sources (diode-pumped fiber amplifier or bulk crystal laser/amplifier) with greater than 1 kW of peak power per pulse (over the entire pulse-repetition rate), and greater than 10 W of average power, and narrow (
external driver) with narrow spectral width (25%);

- Space-qualifiable, reliable (>3 years at 100 Mega photons per second continuous photon flux), photon counting 1064 nm and/or 1550 nm detectors with the gain greater than 1000, detection efficiency greater than 50%, very low (50Mcounts/s. and non-gated (continuous operation);

- Lightweight, compact, high precision (less than 0.1 micro-radian), high bandwidth (0-2kHz), inertial reference sensors (angle sensors, gyros) for use onboard spacecraft;

- Novel schemes for stray-light control and sunlight mitigation, especially for large (>5 m) ground-based optical telescopes that must operate when pointed to within a few (about 3) degrees of the Sun;

- Low-cost, lightweight, efficient, pigtailed laser diode transmitters including compact, high precision (one micro-radian accuracy) star-trackers for spaceflight application that can be integrated with an optical communications terminal;

- Novel techniques and technologies that will enable very low cost, large aperture (>5m equivalent aperture diameter) telescopes for ground or space-borne use;

- High power ground-based, relatively low-cost diode-pumped laser technology capable of reaching 100 kW average power levels in a TEM00 mode, for uplink to spacecraft;

- Artificial laser guide-star and beam compensation techniques capable of removing all significant atmospheric turbulence distortions (tilt and higher-order components) on an uplink laser beam;

- Novel techniques to reduce the development cost and risk of future space-borne optical communications transceivers (e.g. automatic focusing or alignment techniques);

- High BW Intersatellite Links (ISL) in Earth orbit and deep space ISL or possibly satellite to ground communications; and

- Systems and technologies relating to sub-microradian pointing, acquisition, and spacecraft vibration.

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

Sub Topics:

Entry, Descent and Landing Topic S1.04
Entry, Descent, and Landing (EDL) systems are an enabling component of future planetary surface and airborne explorations. EDL systems are naturally comprised of a wide variety of tightly integrated subsystems. These subsystems can include, but are not limited to: entry body, thermal protection, avionics for guidance during entry and/or powered descent (including terrain sensors), aerodynamic decelerators including supersonic or subsonic parachutes, and touch-down systems. In addition to these hardware specific subsystems, algorithms for guidance and hazard detection are an integral element of future EDL systems. Innovations are sought that provide benefits in the following general areas: increased payload delivery mass, improved delivery accuracy, and improved hazard detection and avoidance. The intended outcome of these improvements is to develop the capability to land safely within 100m or less of a preselected landing site and to deliver larger payloads for future Mars missions. In particular, this subtopic seeks technology innovations in the following areas:
• Entry body systems and subsystems including lightweight aeroshells and thermal protection;

• Entry guidance algorithms/methods/techniques capable of reducing uncertainty in parachute deployment altitude, for missions employing bank-only control (i.e., no control of angle of attack) during hypersonic entry;

• Aerodynamic decelerator systems including supersonic and subsonic parachutes. Particular areas of interest include approaches that hold promise for delivering increased mass to the surface (e.g., increasing the Mach-Q deployment envelope beyond Viking-heritage capability) and techniques of reducing the cost of testing/validating the performance of new aerodynamic decelerator systems for use at Mars. Also of interest are para-guidance techniques for pinpoint landing;

• Terrain hazard detection approaches that provide real-time three-dimensional terrain mapping capability during parachute descent and powered terminal descent. In addition, compact, low-mass, high accuracy, and high bandwidth GNC sensors such as attitude and velocity sensors are highly desirable; and

• Lightweight, low-cost, hazard-tolerant touchdown system approaches including (but not limited to) airbag, shock struts, and structural crush zones; allowing landings in moderately cratered terrains with surface rock distribution encountered over a wide variety of Martian landing sites.

Sub Topics:

Sample Return Technologies Topic S1.05
The NASA Mars Exploration Program has recently adopted a plan that includes a Mars Sample Return mission. Such a mission would require breaking the chain of contact with Mars: the exterior of the sample container must not be contaminated with unsterilized Mars material. One mission concept involves placing a grapefruit sized sample container in Mars orbit where it can be picked up by an orbiting spacecraft for return to Earth. Tenuous issues of contamination of the sample container exterior with Mars dust must be dealt with as well as contamination-free handling of the return sample in the receiving facility.

Receiving Facility Sample Handling Technologies

The items described briefly below would find eventual utilization in a sample receiving facility whose basic functions are to do physical and chemical characterizations, bio-hazard detection, and life detection, within a series of double-walled containment vessels. The facility would be operated with significant utilization of robotics, operated either in situ, or remotely, or both.

• Demonstrate fine-scale manipulations, either in situ or remotely, of a strawman 6-axis ultra-clean robot within the confines of a double-walled containment vessel. The robot can be current state-of-art. Demonstrate the use of different end effectors to manipulate small samples for observation. The task may require use and/or modification of current state-of-the-art control software.

• Demonstrate a sample container/carrier, possibly adapted from a container/carrier currently in use by semiconductor and/or pharmaceutical industries; that has the capability to be identified (labeled) and tracked, for use in cataloging, transporting, and tracking samples of various kinds; generally of approximately 100-micron size, and consisting of fines, dust, individual grains, and very small rocks, or gases; following the certification of these samples for release to a facility for long-term curation and distribution;

• Develop double-walled gloves for use within a double-walled containment vessel. Such gloves would
perhaps require self-healing and/or warning systems, in case of a breach, and be compatible with ports developed for double-walled containment vessels; and

- Identify specific sterilization methods and techniques for use in sterilization of extraterrestrial samples. Determine the sterilization levels achieved for sample coupons defined and/or provided by a NASA-sponsored science/biosafety working group.

**Miniature Leak Detector**

Proposals are sought for the development of a miniature, low-mass, low-power leak detection sensor that can be used to indicate a loss of pressure from a container with a volume of 0.5 liter, that has a pressure of 6 torr, as expected on Mars. Areas of interest include:

- A sensor, driver, and the power source designed for placement inside the container that is made of metal. The metal alloy that will be used will be determined at a later time;
- The sensor and its control electronics that provides power, data processing, and communications should not exceed the volume of 5-cm$^3$;
- The device should be operational at temperatures that are as low as -70°C and as high as room temperature; and
- A miniature battery as power source is acceptable. Preferably, a wireless power transfer mechanism and a rechargeable battery that is designed for placement inside the container, would be preferred.

**Sample Containerization and Protection**

Proposals are sought for the development of a robust method of sealing a sample that would be acquired from an extraterrestrial surface for possible return to Earth in future NASA missions. Areas of interest include:

- A simple and reliable process of hermetically seaming and sealing a "coffee-cup" size container with a rock or soil sample;
- The process needs to simultaneously perform sterilization of the container sealed area and its external surface while releasing the container into an area that simulates a clean section of a lander;
- This process should "break-the-chain" of contact of an acquired soil or rock sample from the original area that simulates the environment of an extraterrestrial planet;
- The required process needs to simultaneously seal the contained sample while destroying any potential biological materials that may contaminate the external surface of the container;
- The process to sterilize the surface of a grapefruit-sized sample container in Mars orbit (e.g., pyrotechnic paint) requiring minimal power and minimizing effect on the sample container interior;
- The contained sample should be protected from any mechanical, chemical, or thermal damage during or after the activation of the "break-the-chain" process;
- The process needs to be computer simulated and allow a high degree of control of its parameters; and
• Demonstrate probability of success of the feasibility to seal the container while performing sterilization.

Sample Acquisition

Proposals are sought for mechanisms to acquire clean core samples for Mars rocks and regolith including development of low-mass, low-normal-force, 10x1 cm coring tool, low-mass core sampling tool integrated with sample containment, acquire Mars dust samples, and development of six-axis force-torque sensor (ranges about 160 Newtons, 15 N-m) operating in Mars ambient.

Sub Topics:

Science Instruments for Conducting Solar System Exploration Topic S2.01
This subtopic supports the development of advanced instruments and instrument technology 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.

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;

• Instruments and components that will rely on, and take advantage of, high power capabilities (up to 100 kW) for measurements of planetary surfaces. The instruments may make direct or indirect use of the power, long duration observations, or extremely high data rates;

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

• 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.

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

Sub Topics:

Extreme High Temperature/High Pressure Environment Topic S2.02

Proposals are sought for technologies to enable operation and survivability in high-temperature/high-pressure space environments. These technologies service the needs of the future in situ exploration of Venus as well as the atmospheric probes for giant planets.

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 (380°C) and high pressures (>100 bar) is also required for deep atmospheric probes to giant planets.

Technology needs for high-temperature and high-pressure environments include:
• Advanced passive and active thermal control for Venus missions, including lightweight (50 kg/m³), high strength/stiffness, high buckling stress resistant pressure vessels to protect the electronics and instruments for several hours; new lightweight thermal insulation materials with conductivity less than 0.1 W/mK at 486°C, thermal storage systems with 300-1000 kJ/kg energy density, thermal switches with a switching ratio of at least 100:1 between "On" and "Off" modes, and high temperature heat pipe systems operating over a temperature range of 25 to 500°C. Refrigeration systems capable of pumping heat from a 25 to 75°C source to the Venus sink temperature of 486°C;

• 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 Design (CAD) tools for predicting the performance, reliability, and life cycle for high-temperature electronic systems and components;

• High-temperature primary batteries (200 Whr/kg)) for operation at 380°C and 486°C;

• 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; and

• Anticorrosive coatings to protect optical systems and spacecraft structures from corrosive agents present in the upper levels of Venus' atmosphere (sulfuric acid clouds) or near surface (besides carbon oxide and nitrogen, the atmosphere contains sulfuric acid, hydrochloric acid, and hydrofluoric acid).

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

Sub Topics:

Nanosensors Topic S2.03
The subtopic seeks to leverage breakthroughs in the emerging fields of nano-technology and biotechnology to develop advanced sensors and actuators with increased sensitivity and small size for solar system exploration. Technologies should provide enhanced capabilities over the current state-of-the-art and be able to operate in an extreme environment. This harsh environment includes steady operation and cycling in the temperature range of -180 degrees Centigrade to 100 degrees Centigrade, and high radiation. Of particular interest are harsh environment-operable nanosystems for single molecule sensing and manipulation, on-chip biomolecular analysis, and semiconductor laser diodes in the 2-5 um wavelength range, and detectors in the greater than 15 um wavelength range.

Sub Topics:

Deep Space Power Systems Topic S2.04
Innovative concepts using advanced technology are solicited in the areas of energy conversion, power electronics, and power system materials. Power levels of interest range from milliwatts to 1 KW. NASA Space Science missions in deep space environments require energy systems with long life capability, high radiation tolerance, reliability, and
low overall costs (including operations) which can operate in high and low temperatures and over wide temperature ranges. Advanced technologies are sought in the following areas:

Energy Conversion

All proposed energy conversion technologies must be able to show substantial increases over state-of-the-art in efficiency and specific power (W/kg) and to operate in deep-space environments with high radiation and wide-temperature operations (-200°C to 300°C). Long-life (>14 years), highly reliable advanced energy conversion technologies are sought that keep manufacturability in mind. Advances in photovoltaic technology are sought, including high power solar arrays and ultra lightweight, thin film, and concentrator arrays. Advances in radioisotope thermal to electric power conversion technology (milliwatt/multiwatt and 100W-1KW classes with efficiencies (state-of-the-art) are sought. This includes advances in thermophotovoltaics, thermoelectrics, Brayton, Rankine, and Stirling technologies as well as compact heat exchangers. Innovative control methods are also sought.

Power Electronics

Advanced power electronic materials and devices for deep-space power systems are sought. The materials of interest include soft magnetics, dielectrics, insulation, and semiconductors. Devices of interest include transformers, inductors, electrostatic capacitors, high-power semiconductor switches and diodes, and integrated control and driver circuits. Proposed technologies must improve upon the following characteristics: high temperature operation (>200°C), low-temperature (cryogenic) operation, wide-temperature operation (-125°C to 200°C), and/or high levels of space radiation (>150 krad) resistance.

Electronics Packaging and Materials

Advanced electronics packaging technologies that reduce volume and mass capable of either high temperature, cryogenic, wide temperature operation, and/or space radiation resistance for use in space power systems are of interest. Advances are sought in power electronics packaging materials, surfaces, and components that are durable for soft X-ray, electron, proton, and ultraviolet radiation and thermal cycling environments.

Sub Topics:
Astrobiology Topic S2.05
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.

A second element of Astrobiology is the understanding of the evolutionary development of biological processes leading from single-cell organisms to multi-cell specimens and to complex ecological systems over multiple generations. Understanding of the effects of radiation and gravity on lower organisms, plants, humans, and other animals (as well as elucidation of the basic mechanisms by which these effects occur) will be of direct benefit to the quality of life on Earth. These benefits will occur through applications in medicine, agriculture, industrial
biotechnology, environmental management, and other activities dependent on understanding biological processes over multiple generations.

A third component of Astrobiology includes the study of evolution on ecological processes. Astrobiology intersects with NASA Earth Science studies through the highly accelerated rate of change in the biosphere being brought about by human actions. One particular area of study with direct links to Earth Science is microbe-environment interactions.

NASA seeks innovations in the following technology areas:

- For Mars exploration, technologies that would enable to provide a broad survey of areas in the vicinities of a rover or lander to narrow a field of search for biomarkers;

- For Mars exploration, technologies that (using X-ray, neutron, ultrasonic, and other types of tomography) would enable a noninvasive, nondestructive analysis of the subsurface environment and areas inside rocks and ice to depths 10-20 cm with spatial resolutions of 2-10 microns. Such technologies should provide the capability for analysis of structures inside opaque matrices created by endolithic organisms or fossil structures and possible elemental analysis of such structures;

- Technologies that would enable the aseptic acquisition of deep subsurface samples, the detection of aquifers, or enhance the performance of long-distance ground roving, tunneling, or flight vehicles are required;

- For Europa exploration, technologies to enable the penetration of deep ice are required;

- Desirable features for both Mars and Europa exploration include the ability to carry an array of instruments and imaging systems, to provide aseptic operation mode, and to maintain a pristine research environment;

- Low-cost, lightweight systems to assist in the selection and acquisition of the most scientifically interesting samples are also of significant interest;

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

- Advanced miniaturized sample acquisition and handling systems optimized for extreme environment applications;

- 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;

- High spatial resolution (5 angstrom level) electron microscopy techniques to establish details of external morphology, internal structure, elemental composition, and mineralogical composition of potential biogenic structures;

- Innovative software to support studies of the origin and evolution of life. The areas of special interest are (1) biomolecular and cellular simulations, (2) evolutionary and phylogenetic algorithms and interfaces, (3) DNA computation, and (4) image reconstruction and enhancement for remote sensing;

- Technologies capable of measuring a range of volatile compounds at small spatial scales. Improved sensor designs for a wide range of analytes, including oxygen, pH, sulfide, carbon dioxide, hydrogen, and small molecular weight organic acids both on and near surfaces that could serve as habitats for microbes;
- 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;

- Spectral and imaging technology with high resolution and low power requirements;

- Habitat support - technologies for supporting miniature closed ecosystems, data collection, and transmission technologies in concert with the automated chemical instrumentation described above;

- Miniature-to-microscopic, high-resolution, field-worthy, smart sensors, or instrumentation for the accurate and unattended monitoring of environmental parameters that include, but are not limited to, solar radiation (190-800 nm at

- 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;

- Mathematical models capable of predicting the combined effects of elevated pCO₂ (change in CO₂ over the eons) and solar UV radiation on carbon sequestration and N₂O emissions from experimental data obtained from field and laboratory studies of C-cycling rates, N-cycling rates, as well as diurnal and seasonal changes in solar UV;

- 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; and

- Robotic systems designed to provide access to environments such as deep-ocean hydrothermal vents.

Sub Topics:
Advanced Flexible Electronics Topic S2.06
Electronically steerable L-band, phased array antennas are needed for missions to the Moon, Mars, Titan, and Venus. L-band provides the capability to detect surface and subsurface topology including ice or features hidden by the surface dust. Flexible, lightweight active arrays enable better packaging efficiency for the antenna and are critical for these missions. 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.

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

Sub Topics:
Risk Modeling and Analysis Topic S2.07
The purpose of this subtopic is to advance the state-of-the-art in risk modeling and analysis, particularly for use in early design (formulation) phases. Of particular interest would be methods for risk characterization and modeling that extend beyond typical technical aspects, including software, programmatic, operations, organization, and management elements. This subtopic includes tools and methods, visualization techniques, and process enhancements. Technical areas to address include:

- Uncertainty modeling including both epistemic and aleatory uncertainties;
- Attribute-driven risk identification;
- Risk reduction modeling that includes both preventative and mitigative activities;
- Methods for aggregation and/or integration of quantitative and qualitative risks;
- Methods for characterization and integration of software, organizational, operations, and other non-physics based risks;
- Integration of risks and risk insights into the trade and formal design processes, including new techniques for risk visualization and new methods for directly trading risk against other design aspects;
- Development of risk model library elements and techniques for selecting, maintaining, and integrating the elements;
- Methods for cost-effective adaptation and utilization of PRA and other probabilistic methods in early design (e.g., conceptual design) which can be integrated directly into the design process (i.e., can be utilized directly by the system designers without additional analyst support); and
- Methods for risk-based margin determination and management.

Sub Topics:

**Precision Formations for Interferometry Topic S3.01**

This subtopic seeks hardware and software technologies necessary to establish, maintain, and operate hyper-precision spacecraft constellations to a level that enables separated spacecraft optical interferometry. Also sought are technologies for analysis, modeling, and visualization of such constellations.

In a constellation for large effective telescope apertures, multiple, collaborative spacecraft in a precision formation collectively form a variable-baseline interferometer. 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.
Innovations that address the above precision requirements are solicited for distributed constellation 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:

High Contrast Astrophysical Imaging 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. Examples include, planetary systems beyond our own and the detailed inner structure of galaxies with very bright nuclei. Contrast ratios of one million to one billion over an angular spatial scale of 0.05-1.5 arcsec are typical of these objects. Achieving a very low background against which to detect a planet 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 any starlight cancellation scheme.

This innovative research focuses on advances in coronagraphic instruments, interferometric 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 Origins Program theme will be similar in character to instruments used for present day space astrophysical observations. The performance and observing efficiency of these 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, coronography, 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 $10^4$ or more actuators (both to further the state-of-the-art towards flight-like hardware and to explore novel concepts). Multiple DM technologies in various phases of development and processes are encouraged to ultimately improve the state-of-the-art in deformable mirror technology. Process improvements are needed to improve repeatability, yield, and performance precision of current devices;
- 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; and
- High precision wavefront error sensing and control techniques to improve and advance coronagraphic imaging performance.
Sub Topics:

Precision Deployable Lightweight Cryogenic Structures for Large Space Telescopes Topic S3.03
Planned future NASA Origins Missions and Vision Missions such as the Single Aperture Far-IR (SAFIR) telescope, Life Finder, and Submillimeter Probe of the Evolution of Cosmic Structure (SPECS), require 10-30 m class telescopes that are diffraction limited at wavelengths between the visible and the near IR, and operate at temperatures from 4-300 K. The desired areal density is 3-10 kg/m². Wavefront control may be either passive (via a high stiffness system) or active control. Potential architecture implementations must package into an existing launch volume, deploy and be self-aligning to the micron level. The environment is expected to be L2.

This topic solicits proposals to develop enabling component and subsystem technology for these telescopes in the areas of precision deployable structures, i.e., large deployable optics manufacture and test; innovative concepts for packaging integrated actuation systems; metrology systems for direct measurement of the structure; deployment packaging and mechanisms; active control implemented on the structure (downstream corrective and adaptive optics are not included in this topic area); actuator systems for alignment (2 cm stroke actuators, lightweight, submicron dynamic range, nanometer stability); mechanical and inflatable deployable technologies; new thermally-stable materials for deployables; new approaches for achieving packagable structural depth; etc.

The goal for this effort is to mature technologies that can be used to fabricate 20 m class, lightweight, 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 volume and 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:

Large-Aperture Lightweight Cryogenic Telescope Components & Systems Topic S3.04
Planned future NASA infrared, far infrared, and submillimeter missions, such as the Single Aperture Far-IR (SAFIR) telescope, Interferometric Terrestrial Planet Finder (TPF-I), Infrared Origin's Probes, Space Infrared Interferometric Telescope (SPIRIT), and Submillimeter Probe of the Evolution of Cosmic Structure (SPECS) require both 10-30 m and 2-4 m class telescopes that are diffraction limited at 5-20 mm and operate at temperatures from 4-10 K. The desired areal density is 3-10 kg/m². Wavefront control may be either passive (via a high stiffness system) or active control (via mechanisms and deformable mirrors). Potential architecture implementations include 2 m class segments, 4 m class mirrors, or membrane systems. Component and system testing techniques are a particular challenge for low areal density or cryogenic specific architectures. It is anticipated that active cooling will be required. Potential telescope system architectures require transporting 1 W of heat at 15 K with 5 W/K, while others require 100 mW at 4 K with 1 W/K.

This topic solicits proposals to develop enabling component and sub-system technology for cryogenic telescopes, including but not limited to: large-aperture lightweight cryogenic optic manufacture and test; thermal management, distributed cryogenic cooling and multiple heat lift; structure, deployment, and mechanisms; deployable cryogenic coolant lines; active wavefront control; etc. The goal for this effort is to mature technologies that can be used to fabricate 2-4 m and 10-30 m class lightweight cryogenic flight-qualified telescope primary mirror systems at a cost of less than $300,000 per square meter. Proposals to fabricate demonstration components and subsystems with
direct scalability to flight will be given preference.

Sub Topics:
Infrared & Sub-mm Sensors and Detectors Topic S4.01
NASA astrophysics missions currently under development, such as Sofia, Herschel, and Planck ([http://science.hq.nasa.gov/missions/phase.html](http://science.hq.nasa.gov/missions/phase.html) [2]) have been enabled by improvements in sensors and detectors. Beyond 2007, expected advances in detectors, readout electronics, and other technologies, particularly those enabling polarimetry and large format imaging arrays for the far IR/submm and spectroscopy with unprecedented sensitivity. These advances may enable future mission concepts such as the Single Aperture Far Infrared (SAFIR) Observatory ([http://safir.jpl.nasa.gov/technologies.shtml](http://safir.jpl.nasa.gov/technologies.shtml) [3]), SPICA ([http://www.ir.isas.ac.jp/SPICA/](http://www.ir.isas.ac.jp/SPICA/) [4]), and CMBPOL.

Space science sensor and detector technology innovations are sought in the following areas:

**Mid/Infrared, Far Infrared and Submillimeter**

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

**Space Very Long Baseline Interferometry (VLBI)**

The next generations of VLBI missions in space will demand greatly improved sensitivity over current missions. These new missions will also operate at much higher frequencies (at first to 86 GHz and eventually to 600 GHz). These thrusts will require development of improved space-borne, low-power, ultra-low-noise amplifiers and mixers to serve as primary receiving instruments.

Sub Topics:
Terrestrial and Extra-Terrestrial Balloons and Aerobots Topic S4.02
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 reducing the UV degradation of flight components including balloon membranes, load carrying members, and parachute components;
- Innovative concepts for the measurement of strain in a thin film during flight;
- Innovative sensor concepts for balloon gas or skin temperature measurements;
- 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 low-mass, high-density, and high-efficiency power systems for terrestrial balloons that produce 2 kW or more continuously;
- Innovative power systems that enable long duration, sunlight independent missions for durations of 30 days or more;
- Innovative floatation systems for water recovery of payloads;
- Innovative guided or gliding parachutes systems for use in thin atmospheres;
- Innovative balloon design concepts for long duration missions that can provide any or all of the following: reduced material strength requirements, increased reliability, enhanced performance, reduced manufacturing time, reduced manufacturing cost, or improved mission flexibility; and
- Smaller scale, but similarly designed, balloons and airships will also 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:

**Aerobot Surface Sample Acquisition Device**

NASA is soliciting concepts and prototypes for surface sample acquisition devices that can be used on aerobots to collect icy material from Titan and Mars. Typical sample volumes range from 1 to 2 cubic centimeters, with preference for a solid ice core as well as possible granular material. Collection depths of 0 to 2 cm are desired. Preferred techniques do not require close proximity of the aerobot balloon skin to the ground to reduce the probability of damaging the vehicle during sample acquisition. Examples include tethered collection devices deployed from modest altitudes (10s to 100s of meters) or short duration "touch and go" sampling from directional and/or altitude controlled aerobots. Proposed devices can be disposable (single use), but if reusable must avoid cross-contamination between samples. All devices must include solid sample transfer functionality to an analysis chamber on the aerobot itself. Concepts will be preferred that feature low mass (few kilograms or less), small volume (~1 liter) and low electrical power consumption drawn from the aerobot.

**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 films 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:

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 and Optical Telescopes (including X-ray, UV, Visual, IR) Topic S4.04
With the reorganization of NASA activities into the Exploration Mission Directorate (EMD) and the Space Mission Directorate (SMD), there is a renewed call for novel optical technologies that extend the state-of-the-art across wavelength bands from far-IR to Gamma-ray. Missions to study the Earth and Sun, the other solar system planets and objects, and the origins and fate of the universe are proposed to operate from low Earth orbit to L2 or drift-away trajectories depending on their system of study and environmental requirements.

Among other areas of study, future planet finder missions will require lightweight optical apertures of tens of square meters with sub-nanometer surface figure errors. Infrared versions will require cooling optics to cryogenic temperatures (to 4 K). Telescopes studying the Sun and its environment in the UV and EUV (20-300 nm wavelength) require novel optical coatings and filters, high precision aspheric optics, and high-density uniform and variable line density diffraction gratings. And high-energy X-ray telescopes will study the origins and fate of the universe with

For all missions, low-mass optics and deployment structures are extremely important. Also, wavefront sensing and control systems are sought that may alleviate the stringent mass and stiffness requirements of such large optics. Finally, advanced, low-cost manufacturing, metrology, and modeling techniques will be required to make these missions possible.

The previous year's Optical Technologies (S2.04) and UV and EUV Optics (S1.06) have been merged to form this year's Optics and Optical Telescopes subtopic. All previously relevant areas of research are invited in this new subtopic including:

**Optics**

- Ultra-smooth (2-3 Angstroms rms) replicated optics that are rigid and lightweight;
- Lightweight, high modulus (e.g., silicon carbide) optics and structures;
- Ultra-stable optics over time periods from minutes to hours;
- Cryogenic optics, structures, and mechanisms for space telescopes and interferometers;
- High-performance, diamond turned optics (including freeform optical surfaces);
- Large, thin, ultra-lightweight grazing incidence optics for X-ray mirrors with angular resolutions less than 5 arcsec. (>100 cm², 2 areal density);
- Wide field-of-view optics using square pore slumped microchannel plates or equivalent;
- Large, ultra-lightweight optical mirrors (2 at near-IR through visible), including membrane optics for very large aperture space telescopes and interferometers;
- UV and EUV Imaging mirrors with simultaneously large aperture (1-4 m diameter), low mass (5-20 kg/m²), accurate figure (~0.01 wave rms or better at 632 nm), and low micro-roughness (smooth sub-mm scale image slicer and microlens array component technologies to allow fabrication of integral field spectrographs in the UV and visible, for simultaneous spectroscopy of two spatial dimensions and one spectral dimension.)
Filters

- Large area, thin blocking filters with high efficiency at low energy X-ray energies
- Ultraviolet filters with deep blocking (5) of longer and shorter wavelengths, including "solar blind" performance; novel near- to far-IR filters with increased bandwidth, stability, and out-of-band blocking performance;
- FUV and EUV coatings (filters) with improved reflectivity (transmission) and selectivity (narrow bands, broad bands, or edges). Technologies include multilayers, transmission gratings, and Fabry-Perot etalons, among others; and
- Improved X-ray and Gamma-ray modulation optics and coded aperture masks (sub-arcsecond resolution at 10 keV to 10 arcsecond resolution at 1 MeV).

Gratings

- Fabrication techniques for ultra-thin-flat silicon (or like material) for grating substrates for X-ray energies
- High resolving power diffraction gratings (>4000 lines/mm) at acceptable focal lengths and pixel sizes; and
- Improvements in grating manufacturing technologies, such as high efficiency/low scatter gratings, variable line spacing, improved echelle gratings, active grating surfaces (gratings replicated onto deformable substrates), and gratings ruled onto concave, aspheric surfaces.

Metrology

- Low-cost, high quality, large optics fabrication processes and test methods including active metrology feedback systems during fabrication, and artificial intelligence controlled systems;
- Portable and miniaturized state-of-the-art optical characterization instrumentation and rapid, large-area surface-roughness characterization techniques are needed. Calibrated processes for determination of surface roughness using replicas made from the actual surface. Traceable surface roughness standards suitable for calibrating profilometers over sub-micron to millimeter wavelength ranges are needed; and
- Instruments capable of rapidly determining the approximate surface roughness of an optical surface, allowing modification of process parameters to improve finish, without the need to remove the optics from the polishing machine. Techniques for testing the figure of large, convex, aspheric surfaces to fractional wave tolerances in the visible.

Wavefront Sensing and Control

- Optical systems with high-precision controls, active and/or adaptive mirrors, shape control of deformable telescope mirrors, and image stabilization systems; and
- Advanced, wavefront sensing and control systems including image based wavefront sensors;
- Nanometer to sub-picometer metrology for space telescopes and interferometers.
Optical Design

- Advanced analytical models, simulations, and evaluation techniques, and new integrations of suites of existing software tools allowing a broader and more in-depth evaluation of design alternatives and identification of optimum system parameters including optical, thermal, structural, and dynamic performance of large space telescopes and interferometers.

Sub Topics:
- Sensor and Detector Technology for UV, X-Ray, Gamma-Ray and Cosmic-Ray Instruments Topic S4.05
  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 a 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 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. We seek 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:
Technologies for Gravity Wave Detection Topic S4.06
Laser Technologies for Gravitational Wave Detection

NASA is now developing the Laser Interferometer Space Antenna (LISA) mission to search for gravitational waves from astrophysical phenomena such as the Big Bang, mergers of supermassive 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 (of order picometers)
and will be measured with laser interferometry. The technology areas below deal with technical problems in these measurements. Because the systems will be deployed in space, the technologies to be considered must have credible paths toward space flight qualification. Background information on LISA, along with preliminary technology discussions, can be found in the Proceedings of the 5th International LISA Symposium, Penn State University, 19-24 JULY 2002, published in the Classical and Quantum Gravity Journal, Vol 20, Number 10, 21 May 2003.

Issues of Space Qualification of LISA Laser: the LISA laser must produce >1W CW of 1.06 micron light with fiber coupled output (for example, a combination of a lower-power master oscillator (eg, NPRO) with suitable amplifier). The laser will have the following characteristics:

- 10 year lifetime;
- Power stability
- Linewidth

This task will involve investigating the issues of space qualification of the system, experimentally studying the relevant problems, and proposing a realistic plan of development of this system. Given the magnitude of the effort to develop a space qualified LISA laser, it is not expected that the outcome of this task will result in a space qualified laser; rather, the outcome should be a sufficient understanding of the important technical issues in space qualification (e.g., diode lifetime, thermal and vibrational robustness, etc.) so that a clear path towards the development of a fully space qualified system can be identified.

LISA Electro-optical Modulator: produce a phase modulator for a 1 W continuous laser beam, providing 10% power modulation depth at frequencies from 1.9 to 2.1 GHz. The modulator should be fiber coupled (input and output), at 1.06 micron wavelength. The modulator must be space qualified.

LISA Telescope Articulator: produce a mechanical actuator that can articulate the LISA telescope over a 5 mm dynamic range with a 0.1 nm resolution. The actuator must be space qualified and have noise.

Sub Topics:

Low Thrust and Propellantless Propulsion Technologies Topic S5.01
Spacecraft propulsion technology innovations are sought for upcoming 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, solar sails, aerocapture, and emerging technologies.
Advanced Chemical Propulsion

Innovations in low-thrust chemical propulsion system technologies are being sought for deep-space, scientific, robotic mission applications. Delta Vs for the missions of interest range from 1000 m/sec to 3000 m/sec. Technologies of interest are bipropellant engines with Isp greater than 360 seconds, both pressure-fed and pump-fed, with chamber pressures ranging from 100 to 500 psia. Throttling capability is desired for engines used for planetary ascent, descent, and orbit insertion maneuvers. Passive long-term storage (greater than 5 years) for advanced bipropellant propulsion systems for deep space missions are of interest. Reliable ignition systems are needed for non-hypergolic propellants. Activities in development of lightweight, compact, and low-power propellant management components, such as valves, flow control/regulation, fluid isolation, and lightweight tankage are also solicited. Advanced materials to allow development of systems for use with advanced bipropellants (higher Isp, higher pressure) are also solicited.

Solar Sail Propulsion

Solar sails have been studied for a variety of missions and have the potential to provide cost-effective, propellantless propulsion that enables longer on-station operation, increased scientific payload mass fraction, and access to previously inaccessible orbits (e.g., non-Keplerian, high solar latitudes, etc.).

NASA missions enabled and enhanced by solar sail propulsion include those that can provide: 1) situational awareness for human and robotic exploration in the Earth-Moon system (e.g., Heliostorm, L1 Diamond); 2) comprehensive monitoring of the inner heliosphere (e.g., Solar Sentinels, Solar Polar Imager, Particle Acceleration Solar Observatory); and 3) pathfinder exploration beyond the solar system (Interstellar Probe). The technology required for these missions can further be classified into two categories: 1) near-term (2; and 2) far-term (>15 years) for use in orbits at 25 AU with a propulsive area of greater then 1 x 105 m2. A solar sail propulsion system includes the sail membrane and support structure, the thrust vector control subsystem, the health and monitoring diagnostic subsystem, and the launch stowage structure. Three parameters that are used as sail performance metrics in mission applications are: sail size, sail durability in its orbital environment, and areal density (ratio of sail system mass to propulsive area of the sail). In addition, important programmatic metrics are cost, benefit, and risk. Innovations are sought that will lower the cost and risk associated with sail system development through advancements in: manufacturing, fabrication, and assembly; durable lightweight materials, structures, and mechanisms; comprehensive simulations of maneuvering, navigation, trajectory control, propulsive performance, and operations; and integrated diagnostic health monitoring.

Tether Technologies

This effort focuses on technologies supporting innovative and advanced concepts for propellantless propulsion based upon space tethers concepts. The categories under Tether Technologies include, but are not limited to: ElectroDynamic (ED) tether propulsion, Momentum eXchange Electrodynamic Reboost (MXER) tethers or its subsystems, Jovian tether mission concepts, Earth orbiting telescope ED tether reboost, and other innovative in space tether technologies. In general, the electrodynamic tether propulsion method exchanges momentum with a planet's rotational angular momentum through electrodynamic interaction with the planetary magnetic field. Momentum exchange tethers or MXER concepts use orbital energy to provide a high thrust to a payload in LEO. Distinctive variations of existing propulsion methods or chief subsystem component improvements are also suitable for submission. Proposals should provide the development plan of specific innovative technologies or techniques supporting the planned research. Identification of the fundamental technology to be developed is also crucial. A clear plan for demonstrating feasibility, noting any test and experiment requirements, is recommended. Key to each idea is an unambiguous knowledge of past research/concepts conducted on related work and specifically how this new proposal differs from, or enhances, the existing tether roadmaps, particularly for robotic mission support.

Aeroassist
Aeroassist is a general term given to various techniques to maneuver a space vehicle within an atmosphere using aerodynamic forces in lieu of propulsive fuel. Aeroassist systems enable shorter interplanetary cruise times, increased payload mass, and reduced mission costs. Subsets of aeroassist are aerocapture and aerogravity assist. 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. Without aerocapture, a substantial propulsion system would be needed on the spacecraft to perform the same reduction of velocity. Aerogravity assist is an extension of the established technique of gravity assist with a planetary body to achieve increases in interplanetary velocities. Aerogravity assist involves using propulsion in conjunction with aerodynamics through a planetary atmosphere to achieve a greater turning angle during planetary fly-by. In particular, this subtopic seeks technology innovations that are in the following areas:

**Aerocapture**

Thermal Protection Systems: development of advanced thermal protection systems and insulators for planetary aerocapture.

Low Temperature/High Temperature Adhesives Trade Study: aerocapture inflatable decelerators are currently proposed to be manufactured from thin film materials and/or high temperature fabrics, stowed during transport, and inflated prior to atmospheric entry for aerocapture applications at planetary destinations.

- Prior to the aerocapture maneuver, the inflatable decelerator will be stowed for many years (up to 10) in an uncontrolled space environment (-130°C) during transport to outer solar system destinations;
- Before atmospheric entry, the inflatable decelerator will be unstowed and inflated; and
- During the aerocapture maneuver, up to 24 hours after the inflation process, the inflatable decelerator will experience temperatures to 500°C (or higher).

Conduct a thorough study of the adhesives trade space and select and test adhesive candidates that will maintain bond strength during the temperature extremes and long-term space exposure experienced by inflatable decelerators. The product of this study will be a report thoroughly documenting sample preparation, test procedures, and test results of all materials investigated. This report will be disseminated to inflatable decelerator developers.

**Sub Topics:**

Accommodation and Mitigation of Space Environmental Effects Topic S5.02

This subtopic is concerned with improving the capability to accommodate or mitigate the effects of the space environment on spacecraft design and operations. It will achieve its goal by designing and building flight investigations, developing models, collecting data from investigations in space and from ground tests, and analyzing data to improve the models, tools, and/or databases used for spacecraft design and operations. The resulting products will reduce the design margins and uncertainties in the induced environment definition (i.e., the environment in the presence of a spacecraft) and its effects on spacecraft design and operations. The environments to be considered include planetary-trapped radiation, solar proton events, cosmic rays, the plasma
environment at planets and in the solar wind, magnetic fields, EUV/VUV, and the interplanetary meteoroid environment.

The investigations selected have the opportunity to be integrated on the Space Environment Testbed (SET) Carrier. The SET Project opportunities for flight will be in orbits other than LEO. Investigations do not need to fly with the SET Carrier if an investigator makes arrangements for other access to space.

Examples of investigations and models that would satisfy those requirements are described below. A more detailed description, with examples of investigation needs, can be found at: http://lws-set.gsfc.nasa.gov/Opportunities.htm [5].

Areas for which proposals are sought include:

- Characterization of the space environment, both natural and induced, in the vicinity of a spacecraft;
- Definition of the mechanisms for material and materials applications degradation and the performance characterization of materials (such as coatings, optical properties, composites, etc.) in the space environment;
- Accommodation and/or mitigation of charging/discharging effects on spacecraft and spacecraft components;
- Methods for performance improvement of radiation tolerance of microelectronics used in space, including reduction of single event upsets and other single particle-induced soft errors, and elimination of single event latch-ups and other single particle-induced destructive conditions;
- Development of novel methods for increasing crew safety and system performance relative to the effects of the natural space environment; and
- Development of novel methods of increasing ground-based systems performance and reliability by reducing the effects of the natural space environment on those systems (e.g., space environment-induced soft errors in the power grid).

Sub Topics:

Technologies for Particles and Fields Measurements Topic S5.03
The SEC theme encompasses the Sun with its surrounding heliosphere carrying its photon and particle emissions and the subsequent responses of the Earth and planets. 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 are 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 subnanosecond 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.
Sub Topics:
Passive Optics Topic S6.01
The following technologies are of interest to NASA in the remote sensing subtopic "passive optics." 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. Technical and scientific leads at NASA have given careful consideration to the technology areas described below; responses are solicited for these topics.

- Technology leading to visible/NIR narrowband optical filters exhibiting greatly improved degradation properties over existing filters and minimal spectral drift for long-term space-based applications;
- Technology leading to significant improvements in capability of large format (>1 inch diameter), very narrow band ( \( \pm 1 \) full-width at half-maximum), polarization insensitive, high-throughput infrared (0.7-15 \( \mu m \)) optical filters;
- Large format (>1 inch diameter), high-transmission, far infrared filters. Technology and techniques leading to filters operating at wave numbers between 500 and 5 cm\(^{-1}\) with FWHM less than 2 cm\(^{-1}\) are of immediate interest, though technology leading to very high transmission edge filters (long and short pass) is also solicited. The filters must be capable of operating in a vacuum at cryogenic temperatures; and
- High-performance, four-band two-dimensional (2D) arrays (128x128 elements) in the 0.4 - 2.5 \( \mu m \) wavelength range with high quantum efficiencies (60%-80% or higher) in all spectral bands, low noise, and ambient temperature operation.

Sub Topics:
Lidar Remote Sensing 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, and high performance. Innovative technologies that can expand current measurement capabilities to airborne, spaceborne, or Unmanned Aerial Vehicle (UAV) 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:
Innovative component technologies that directly address the measurement needs above will be considered. Dual-use technologies addressing Planetary Exploration are highly desirable (see subtopics X1.03 and S1.04). For the PY05 SBIR, we are soliciting component technologies described below.

- Pulsed, single frequency, diode-based seed laser 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:
  - Single frequency 1064 nm operation.
  - Small, pinned package(s) that can generate CW powers in the 100's of mW and higher pulse powers yielding at least 10 nJ pulse energies.
  - Gaussian pulsewidths between 100 ps and 5 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 Yb: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 is needed, with pulsed lifetimes in the trillion shot regime ($10^{12}$).
  - Single mode, PM fiber output is needed.
  - Short term drift less than 1 MHz.

- CW, dual frequency, diode-based seed laser systems are desired for high power solid-state laser cavity feedback and locking at 1064 nm. If two wavelengths are produced, one must be 1064 nm and another single wavelength 5 nm or more offline (in either direction). Systems with the following specifications are solicited:
  - Simultaneous dual frequency operation; 1064 nm and a second wavelength at least 5 nm (either plus or minus) from 1064 nm.
  - Small, pinned package(s) that can generate CW powers in the 100s of mW and higher pulse
powers.

- CW output powers of >10 mW in each wavelength. Individual tunability is not required, but tunability of the 1064 nm output is required.
- Dual PM, single mode fiber output is desired, but not absolutely required.
- 5 MHz or less short term drift over 30 sec.

- 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.

- Shared aperture, angle-multiplexed holographic or diffractive optical elements having several fields of view, each with angular resolution of 50 μrad or better for the Nd:YAG or Nd:YLF laser harmonics, and diffraction limited resolution for the Ho:YLF fundamental wavelength. Wide, flat, focal planes with low off-axis aberrations is of importance to terrain and vegetation mapping lidar applications. Hybrid designs using both 2053 nm or 1064 nm and 355 nm simultaneously are needed for dual wavelength Doppler wind lidar applications. Materials and technologies are needed that can be scaled up to 1 m apertures and larger and space qualified. Designs using lightweight materials, such as composites or membranes and deployable folded architectures, are also desired to decrease system size and weight.

- Novel, high-power laser diodes capable suitable for pumping Holmium-based solid state lasers:
  - Quasi-CW laser diode arrays operating in 1939 nm or 1906.8 nm wavelengths with pulse duration of at least 1 msec, peak power in 10s watts regime, and duty cycle of greater than 2%;
  - Quasi-CW fiber-coupled laser diode pump arrays operating in 785 nm or 792 nm wavelengths with pulse duration of at least 1 msec, peak power in 100s watts regime, and duty cycle of greater than 2%; and
  - CW fiber-coupled laser diode pump arrays operating in 1939 nm or 1906.8 nm wavelengths.

- 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 0.5-1.0 m diameter for deployment in space is required.

- Laser beam steering and scanning technologies (such as dual-wedge, diffractive optical elements, and liquid crystal) operating at 1.5 or 2.05 micron with 2 cm to 25-cm aperture diameter meeting the following requirements:
  - 60 deg. field of regard.
  - 90% optical throughput.
  - 1/4-wave single pass optical quality at 632 nm.
Sub Topics: Earth In Situ Sensors Topic S6.03

Proposals are sought for the development of in situ measurement systems that will enhance the scientific and commercial utility of data products from the Earth Science Enterprise program and that will enable the development of new products of interest to commercial and governmental entities around the world. Technology innovation areas of interest include:

- Autonomous Global Positioning System (GPS)-located platforms (fixed or moving) to measure and transmit to remote terminals upper ocean and lower atmosphere properties including temperature, salinity, momentum, light, precipitation, and biogeochemistry;

- Dynamic stabilization systems for small instruments mounted on moving platforms (e.g., buoys and boats) to maintain vertical and horizontal alignment. Systems capable of maintaining a specified pointing with respect to the Sun are preferred;

- Small, lightweight instruments for measuring clouds, liquid water, or ice content (mass) designed for use on radiosondes, dropsondes, aerosondes, tethered balloons, or kites;

- Wide-band microwave radiometers capable of high-speed characterization of cloud parameters, including liquid and ice phase precipitation, which can operate in harsh environmental conditions (e.g., onboard ships and aircraft);

- Autonomous, GPS-located airborne sensors that remotely sense atmospheric wind profiles in the troposphere and lower stratosphere with high spatial resolution and accuracy;

- Systems for in situ measurement of atmospheric electrical parameters including electric and magnetic fields, conductivity, and optical emissions;

- Systems to measure line- and area-averaged rain rate at the surface over lines of at least 100 m and areas of at least 100x100 m;

- Lightweight, low-power systems that integrate the functions of inertial navigation systems and GPS receivers for characterizing and/or controlling the flight path of remotely piloted vehicles;

- Low-cost, stable (to within 1% over several months), portable radiometric calibration devices in the shortwave spectral region (0.3 to 3 Åµm) for field characterization of radiance instruments such as sun photometers and spectrometers;

- Miniaturized, low-power (12V DC) instruments especially suited for small boat operations that are capable of adequately resolving, at the appropriate accuracy, the complex vertical structure (optical, hydrographic, and biogeochemical) of the coastal ocean (turbid) water column. Sensors that can be easily integrated within a digital (serial) network to measure the apparent and inherent optical properties of seawater are preferred; and

- Aircraft or UAV instruments for in situ measurements of physical and optical properties of clouds and aerosols with instantaneous measurement volumes ranging from cubic meters up to a maximum of a cubic kilometer, the purpose being to furnish validation for satellite remote sensing at the spatial scales satellites actually provide.
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 multispectral 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 (100 mW), and low power consumption (100 mW);
- Wideband and ultra-wideband sensors with >15 dB cross-pole isolation across the bandwidth;
- Low noise:
  - 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.

Sub Topics:
Active Microwave Topic S6.05
Active microwave sensors have proven to be ideal instruments for many Earth science applications. Examples include global freeze and thaw monitoring, soil moisture mapping, accurate global wind retrieval, and snow inundation mapping, global 3D mapping of rainfall and cloud systems, precise topographic mapping and natural hazard monitoring, global ocean topographic mapping, and glacial ice mapping for climate change studies. 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), scatterometers, sounders, altimeters, and atmospheric radars. 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. Onboard processing techniques will reduce data rates sufficiently to enable global coverage. High performance, yet affordable, radars will provide data products of better quality and deliver them to the users more frequently and in a timelier manner, with benefits for science as well as the civil and defense communities. 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.

The frequency and bandwidth of operation are mission driven and defined by the science objectives. For SAR applications, the frequencies of interest include UHF (100 MHz), P-band (400 MHz), L-band (1.25 GHz), X-band (10 GHz), and Ku-band (12 GHz). The required bandwidth varies from a few megahertz to 20 MHz to 300 MHz to achieve the desired resolution; the larger the bandwidth, the higher the resolution. Ocean altimeters and scatterometers typically operate at L-band (1.2 GHz), C-band (5.3 GHz), and Ku-band (12 GHz). Ka-band (35 GHz) interferometers have applications to river discharge. The atmospheric radars operate at very high frequencies (35-
GHz and 94 GHz) with only modest bandwidth requirements on the order of a few megahertz.

The emphasis of this subtopic is on core technologies that will significantly reduce mission cost and increase performance and utility of future radar systems. There are specific areas in which advances are needed.

- **SAR for surface deformation, topography, soil moisture measurements:**
  - Very large aperture L-band antennas (20 m x 20 m) for Medium Earth Orbit (MEO) or 30m diameter for Geosynchronous SAR applications.
  - Shared aperture, multi-frequency antennas (P/L-band, L/X-band).
  - Lightweight, deployable antenna structures and deployment mechanisms.
  - Rad-hard, high-efficiency, high power, low-cost, lightweight L-band and P-band T/R modules.
  - High-power transmitters (L-band, 50-100 kW).
  - L-band and P-band MMIC single-chip T/R module.
  - Rad-hard, high-power, low-loss RF switches, filters, and phase shifters.
  - Digital true-time delay (TTD) components.
  - Thin-film membrane compatible electronics. This includes: reliable integration of electronics with the membrane, high performance (>1.2 GHz) transistor fabrication on flex material including identifying new materials, process development, and techniques that have the potential to produce large-area passive and active flexible antenna arrays.
  - Advanced transmit and receive module architectures such as optically-fed T/R modules, signal up/down conversion within the module, and novel RF and DC signal distribution techniques.
  - Advanced radar system architectures including flexible, broadband signal generation and direct digital conversion radar systems.
  - Advanced antenna array architectures including scalable, reconfigurable, and autonomous antennas; sparse arrays; and phase correction techniques.
  - Distributed digital beamforming and onboard processing technologies.

- **SAR data processing algorithms and data reduction techniques.**
- **SAR data applications and post-processing techniques.**
- **Low-frequency SAR for subcanopy and subsurface applications:**
  - Lightweight, large-aperture (30 m diameter) reflector and reflectarray antennas.
- Large, electronically scanning P-band arrays.
- Shared aperture, dual-polarized, multiple low-frequency (VHF through P-band, 50-500 MHz) antennas with highly shaped beams.
- Lightweight, low frequency, low-loss antenna feeds (VHF through P-band, 50-500 MHz).
- High-efficiency T/R modules and transmitters (50-500 MHz, 10 kW).
- Lightweight, deployable antenna structures and deployment mechanisms.
- Data applications and post-processing techniques.

- Polarimetric ocean/land scatterometer:
  - Multi-frequency (L/Ku-band) lightweight, deployable reflectors.
  - Large, lightweight, electronically steerable Ku-band reflectarrays.
  - Lightweight L-band and Ku-band antenna feeds.
  - Dual-polarized antennas with high polarization isolation.
  - Lightweight, deployable antenna structures and deployment mechanisms.
  - High efficiency, high power, phase stable L-band and Ku-band transmitters.
  - Low-power, highly integrated radar components.
  - Calibration techniques, data processing algorithms, and data reduction techniques.
  - Data applications and post-processing techniques.

- Wide swath ocean and surface water monitoring altimeters:
  - Shared aperture, multi-frequency (C/Ku-band) antennas.
  - Large, lightweight antenna reflectors and reflectarrays.
  - Lightweight C-band and Ku-band antenna feeds.
  - Lightweight, deployable antenna structures and deployment mechanisms.
  - High-efficiency, high power (1-10 kW) C-band and Ku-band transmitters.
  - Real-time onboard radar data processing.
  - Calibration techniques, data processing algorithms, and data reduction techniques.

- Ku-band and Ka-band interferometers for snow cover measurement over land (Ku-band), wetland, and river monitoring (Ka-band):
  - Large, stable, lightweight, deployable structures (10-50 m interferometric baseline).
Ka-band along and across-track track interferometers with a few centimeters of height accuracy.

Ku-band interferometric polarimetric SAR.

Phase-stable Ku-band and Ka-band electronically steered arrays and multibeam antennas.

Lightweight deployable reflectors (Ku-band and Ka-band).

Shared aperture technologies (L/Ku-band).

Phase-stable, Ku-band and Ka-band receive electronics.

High-efficiency, rad-hard Ku-band and Ka-band T/R modules or >10 kW transmitters.

Ku-band and Ka-band antenna feeds.

Calibration and metrology for accurate baseline knowledge.

Real-time onboard radar data processing.

Data applications and post-processing techniques.

- Atmospheric radar:

  - Low sidelobe, electronically steerable, millimeter wave, phased-array antennas and feed networks.
  - Low sidelobe, multi-frequency, multi-beam, shared aperture millimeter wave antennas (Ka-band and W-band).
  - Large (~300 wavelength), lightweight, low sidelobe, millimeter wave (Ka-band and W-band) antenna reflectors and reflectarrays.
  - Lightweight deployable antenna structures and deployment mechanisms.
  - High power (10 kW) Ka-band and W-band transmitters.
  - High-power (>1 kW, duty cycle >5%), wide bandwidth (>10%) Ka-band amplifiers.
  - High-efficiency, low-cost, lightweight Ka-band and W-band transmit/receive modules.
  - Advanced transmit/receive module concepts such as optically-fed T/R modules.
  - Onboard (real-time) pulse compression and image processing hardware and/or software.
  - Advanced data processing techniques for real-time rain cell tracking, and rapid 3D rain mapping.
  - Lightweight, low-cost, Ku/Ka band radar system for ground-based rain measurements.
  - Light weight, wideband (>200 MHz), low-sidelobe (Low-power, high-speed, multi-channel single board digital receivers.
  - High-power, high-duty cycle solid state power amplifier from X through W-band.
Many NASA future Earth science remote sensing programs and missions require microwave to submillimeter wavelength antennas, transmitters, and receivers operating in the 1-cm to 100-Åμm wavelength range (or a frequency range of 30 GHz to 3 THz). General requirements for these instruments include large-aperture (possibly deployable) antenna systems with RMS surface accuracy of...

For these systems, advancement is needed in primarily three areas: 1) the development of frequency-stabilized, low phase noise, tunable, fundamental local oscillator sources covering frequencies between 160 GHz and 3 THz; 2) the development of submillimeter-wave mixers in the 300-3000 GHz spectral region with improved sensitivity, stability, and IF bandwidth capability; and 3) the development of higher-frequency and higher-output-power MMIC circuits.

Specific innovations or demonstrations are required in the following areas:

- Heterodyne receiver system integration at the circuit and/or chip level is needed to extend MMIC capability into the submillimeter regime. MMIC amplifier development for both power amplifiers and low noise amplifiers at frequencies up to several hundred GHz is solicited. Integration of a local oscillator multiplier chain, mixer, and intermediate frequency amplifier is one example. There is also a specific need to demonstrate array radiometer systems using MMIC radiometers from 60 GHz to approximately 500 GHz;

- Solid-state, phase-lockable, local-oscillator sources with flight-qualifiable design approaches are needed with >10 mW output power at 200 GHz and >100 ÅμW at 1 THz; source line widths should be

- Stable local-oscillator sources are needed for heterodyne receiver system laboratory testing and development;

- Multi-channel spectrometers that analyze intermediate frequency signal bandwidths as large as 10 GHz with a frequency resolution of

- Compact and reliable millimeter and submillimeter imaging instrumentation that produces images simultaneously in multiple spectral bands;

- Schottky mixers with high sensitivity at T = 100 K and above;

- Low noise superconducting HEB mixers and SIS mixers;

- Receivers using planar diode or alternative reliable local oscillator technologies in the 300-3000 GHz spectrum;

- Lightweight and compact radiometer calibration references covering 100-800 GHz frequency range;

- Lightweight, field portable, compact radiometer calibration references covering frequencies up to 200 GHz. The reference must be temperature stable to within 1 K with a minimum of three temperature settings between 250 and 350 K;

- Low-cost, special purpose, ground-based receivers to detect signals radiated from active satellites that are in orbit for estimating rain rate, water vapor, and cloud liquid water; and

- Calibrated radiometer systems that can achieve accuracy and stability of 0.1 K.
Future 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:

- Instrument Optical alignment needs, lasers, and detectors that require tight temperature control, often to better than \( \pm 1 \text{°C} \). Some new missions, such as LISA and TPF, require methods of temperature measurement and control to micro-Kelvin levels.

- Heat flux levels from lasers and other high power devices are increasing with some projected to go as high as 100 W/cm\(^2\). They will require thermal technologies such as spray and jet impingement cooling. Also, high conductivity, vacuum compatible interface materials will be needed to minimize thermal losses across make/break interfaces.

- Future missions will utilize large, distributed structures such as mirrors and detector arrays at both ambient and cryogenic temperatures. These missions will require creative techniques to integrate thermal control functions and minimize weight. Some anticipated technology needs include: advanced thermoelectric coolers capable of providing cooling at ambient and cryogenic temperatures, high conductivity structural materials to minimize temperature gradients and provide high efficiency lightweight radiators, and advanced thermal control coatings such as variable emittance surfaces and coatings with a high emissivity at ambient and cryogenic temperatures.

- The push for miniaturization also drives the need for new thermal technologies towards the MEMS level. Miniaturized heat transport devices, especially those suitable for cooling small sensors, devices, and electronics, include miniaturized mechanical pumps, Loop Heat Pipes (LHPs), and Capillary Pumped Loops (CPLs) which allow multiple heat load sources and multiple sinks.

- The drive towards robotic missions and reconfigurable spacecraft presents engineering challenges for science instruments, which must become more self-sufficient. Some of the technology needs are:
  - Advanced analytical techniques for thermal modeling focusing on techniques that can be easily integrated into existing codes, emphasizing inclusion of LHPs, CPLs, and mechanically pumped system models;
  - Single and two-phase mechanically pumped fluid loop systems, which accommodate multiple heat sources and sinks, and long life, lightweight pumps for these systems; and
  - Efficient, lightweight vapor compression systems for cooling up to 2 KW.

Sub Topics:
Geospatial Data Analysis Processing and Visualization Technologies Topic S7.01
Proposals are sought for the development of advanced technologies in support of scientific, commercial, and educational applications of Earth Science and other remote sensing data. Focus areas are to provide tools for processing, analysis, interpretation, and visualization of remotely sensed data sets. Earth Science data needs to be benchmarked for practical use of NASA-sponsored observations from remote sensing systems and predictions from scientific research and modeling. Specific interest exists in the development of technologies contributing to decision support systems, and model development and operation. For more information on decision support models under evaluation, please visit [http://science.hq.nasa.gov/strategy/index.html](http://science.hq.nasa.gov/strategy/index.html) [6]. Areas of specific interest include the following:
- Unique, innovative data reduction, rapid analysis, and data exploitation methodologies and algorithms of information from remotely sensed data sets, e.g., automated feature extraction, data mining, etc.;

- Algorithms and approaches to enable the efficient production of data products from active imaging systems, e.g., multipoint data resampling, digital elevation model creation, etc.;

- Data merge and fusion software for efficient production and real-time delivery of digital products of ESE Mission and other remote sensing data sets, e.g., weather observation and land use and land cover data sets;

- Innovative approaches for incorporation of GPS data into in situ data collection operations with dynamic links to spatial databases including environmental models;

- Image enhancement algorithms for improving spatial, spectral, and geometric image attributes;

- Innovative approaches for the querying and assimilation of application-specific datasets from disparate and distributed databases from government, academic, and commercial sources into a common framework for data analysis;

- Innovative approaches for querying of application-specific data sets from disparate, distributed databases in government, academic, and commercial data warehouses into a common framework for data analysis; and

- Innovative visualization technologies contributing to the analysis of data through the display and visualization of some or all of the above data types including providing the linkages and user interface between the cartographic model and attribute database.

Sub Topics:

**Innovative Tools and Techniques Supporting the Practical Uses of Earth Science Observations Topic S7.02**

Technical innovations and unique approaches are solicited for the development of new technologies and technical methods that make Earth science observations both useful and easy to use by practitioners. This subtopic seeks proposals that support the development of operational decision support tools that produce information for management or policy decision makers. Proposed applications must use NASA Earth Observations (see [http://science.hq.nasa.gov](http://science.hq.nasa.gov) [7]). Other remote sensing data and geospatial technologies may also be employed in the solution.

This subtopic focuses on the systems engineering aspect of application development rather than fundamental research. Offerors are, therefore, expected to have the documented proof-of-concept project in hand. Topics of current interest to the Applied Science Directorate may be found at [http://www.asd.ssc.nasa.gov](http://www.asd.ssc.nasa.gov) [8]. Innovation in processing techniques, include, but are not limited to, automated feature extraction, data fusion, and parallel and distributed computing which are desired for the purpose of facilitating the use of Earth science data by the nonspecialist. Ease of use, fault tolerance, and statistical rigor and robustness are required for confidence in the product by the nonspecialist end user.

Promotion of interoperability is also a goal of the subtopic, so Federal data standards, communication standards, Open Geographic Information Systems (GIS) standards, and industry-standard tools and techniques will be strongly favored over proprietary 'black-box' solutions. Endorsement by the end user of both system requirements and the proposed solution concept is desirable. While the proposed application system may be specific to a particular end user or market, techniques and tools that have broad potential applicability will be favored. An
objective assessment of market value or benefit/cost will help reviewers assess the relative potential of proposed projects.

Sub Topics:
Wireless Technologies for Spatial Data, Input, Manipulation and Distribution Topic S7.03
Technical innovation is solicited for the development of wireless technologies for field personnel and robotic platforms to send and receive digital and analog data from sensors such as photography cameras, spectrometers, infrared and thermal scanners, and other sensor systems to collection hubs. The intent of this new innovation is to rapidly, in real time, ingest data sequentially from a variety of input sensors, provide initial field verification of data, and distribute the data to various nodes and servers at collection, processing, and decision hub sites. Data distribution should utilize state-of-the-art wireless, satellite, land carriers, and local area communication networks. The technology's operating system should be compatible with commonly available systems. The operating system should not be proprietary to the offeror. The innovation should include biometric capability for password protection and relational tracking of data to the field personnel inputting the data and/or sensors and platforms sending information. The innovation should contain technologies that recognize multiple personnel and other sources (robotics) so that several personnel and platforms can use the same unit in the field. Biometric identification can be fingerprint, retina scans, facial, or other methods. The innovation should include geospatial technologies to use digital imagery and have Global Positioning System (GPS) location capabilities. The innovation should be able to display, with sufficient size and resolution, the rendering of vector and raster data and other sensor data for easy understanding. The field capability of the innovation must be fully integrated end to end with computing capabilities that range from mobile computers to servers at distant locations. Field personnel and robotic platforms providing information and support to science investigations, resource managers, and community planners will use the innovative wireless technology. First responders to natural, human-made disasters and emergencies will also be users of this innovation.

Sub Topics:
Guidance, Navigation and Control Topic S8.01
Future science architectures will include observation and sensing platforms of varying type, size and complexity in a number of mission-operational regimes, trajectories and orbits. 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. Novel approaches for the autonomous control of distributed spacecraft
and/or the management of large fleets of heterogeneous and/or homogeneous assets are desired. Specific areas of research include:

**GN&C System Technologies**

Innovative GN&C solutions are sought for scientific instrument and laser communication system pointing, tracking, and stabilization. Proposals that exploit and combine recent advances in spacecraft attitude determination and control, advanced electro-mechanical packaging, MEMS technology, and ultra-low power microelectronics are encouraged. Of particular interest is technology to provide alternative solutions to challenging GN&C problems such as spacecraft relative range and attitude determination while in close formation and/or during rendezvous/proximity operations.

**GN&C Sensors and Actuators**

Advanced technology sensors and actuators are sought such as Sun sensors, Earth sensors, star/celestial object trackers, fine guidance sensors, gyroscopes, accelerometers, inertial measurement units, navigation devices, magnetometers, reaction/momentum wheels, control-moment gyros, magnetic torquers, tethers, attitude control thrusters, etc. These devices should have enhanced capabilities and performance as well as reduced cost, mass, power, volume, and reduced complexity for all platform GN&C system elements.

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, with significantly reduced mass, power, volume, and cost. Technologies having the potential for significantly increased performance without additional mass, power, volume, and cost are also of interest. These resource reduction and/or performance improvement factors should be quantified in the proposal and show a minimum factor of 2 with a goal of 10 or greater. Highly autonomous and robust GN&C devices with multifunctional capabilities are of particular interest.

Innovations in Global Positioning System (GPS) receiver hardware and algorithms that use GPS code and carrier signals to provide spacecraft navigation, attitude, and time. Of particular interest are GPS-based navigation techniques that may employ Wide Area Augmentation System (WAAS) corrections.

Novel approaches to autonomous sensing and navigation of multiple distributed space platforms. Of particular interest are specialized sensors and measurement systems for formation sensing and relative navigation functions.

Sub Topics:

Command and Data Handling Topic S8.02
The goal for this subtopic is the development of advanced space technology and concepts to further high-performance science image and data processing. The instrument electronics must operate reliably and effectively for long periods of time in harsh environments. These systems require management of data and products, low power, and radiation.
The objective for this development goal is to elicit novel concepts, architectures, and component technologies that have realistic and achievable potential for flight applications and are responsive to the priority areas of this subtopic. Technologies will be selected based on the potential that their final end products are sustainable (affordable, reliable/safe, and effective) and will advance solutions to the challenges of reusability, modularity, and autonomy.

Priority areas are: reconfigurable/modular implementations; onboard science (data and image) processing and management; and low-power, radiation-resistant electronics. Additional information about the solicited technologies follows:

**Onboard Processing**

- Hardware technologies and architectures that support instrument science (data and image) processing and that are reconfigurable in flight and modular;
- Hardware-based algorithms for onboard data and image processing of raw science into multiple custom data products. The intent is to minimize onboard bandwidth constraints;
- Autonomus capability of hardware and algorithm management without ground intervention;
- Low-power electronics: in order to provide higher capabilities on smaller and/or less expensive instruments and decrease subsequent thermal load; and
- Radiation resistant electronics (hardware or application).

**Sub Topics:**

***Long Range and Near Earth RF Communications Topic S8.03***

This subtopic seeks innovative technologies for long-range RF telecommunications supporting the needs of space missions. Proposals are sought in the following areas:

- Ultra-small, low-cost, low-power, modular deep-space transceivers, transponders, and components, incorporating MMICs and Bi-CMOS circuits;
- MMIC modulators with drivers to provide large linear phase modulation (above 2.5 rad), high-data rate (10-200 Mbps), BPSK/QPSK modulation at X-band (8.4 GHz), and Ka-band (32 GHz and 38 GHz);
- High-efficiency (>70 %) Solid-Sate Power Amplifiers (SSPAs), of both medium output power (10-50 W) and high-output power (150 W- 1 KW), using power combining techniques and/or wide-bandgap semiconductor devices at X-band (8.4 GHz) and Ka-band (32 GHz and 38 GHz);
- Traveling Wave Tube Amplifiers (TWTAs), SSPAs, modulators, and MMICs for 26 GHz Ka-band (lunar comm);
- TWTAs operating at millimeter wave frequencies and at data rates of 10 Gbps or higher;
Ultra low-noise amplifiers (MMICs or hybrid) for RF front-ends (MEMS-based RF switches and photonic control devices needed for use in reconfigurable antennas, phase shifters, amplifiers, oscillators, and in-flight reconfigurable filters. Frequencies of interest include S-, X-, Ka-, and V-band (60 GHz). Of particular interest is Ka-band from 25.5-27 GHz and 31.5-34 GHz.

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

Sub Topics:

Spacecraft Propulsion Topic S8.04
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. Propulsion systems must avoid contamination of instruments from thruster plumes. This subtopic seeks innovations in propulsion technologies to increase the capabilities of SMD spacecraft. Specifically, technology innovations are sought in the areas of solar electric propulsion, monopropellant technology, and miniature/precision propulsion.

Solar Electric Propulsion
Technology advancements are needed 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, electrodeless plasma production, low-erosion materials for ion optics and Hall discharge chambers, high-temperature magnetic circuits, and next-generation thrusters. Innovations sought include, but are not limited to, those that improve performance, increase lifetime, reduce mass, and decrease cost. Improvements are also sought for propellant management system components including storage, distribution, and flow control to support solar electric propulsion applications.

Monopropellant Technology
Advancements are sought for propulsion systems using advanced monopropellants. Spacecraft using high-performance (Isp >275 s), high-density (>1 g/cc) monopropellant formulations will need high-durability catalyst materials or, alternatively, non-catalytic ignition technology for power-limited spacecraft. Critical component materials (e.g., tank bladders, valve seats, and filters) that are compatible with advanced monopropellants need to be developed. Performance and density improvements are sought for applications with very low propulsion requirements.

Miniature/Precision Propulsion
Propulsion technologies for miniature (less than 10 kg) spacecraft and for high-precision (impulse bit
Earth science observation missions will employ spacecraft, balloons, sounding rockets, surface assets, aircraft, and marine craft. Advanced power technologies are required for each of these platforms that address issues of size, mass, capacity, reliability, and operational costs. A vigorous effort is needed to develop energy conversion technologies that will enable the revolutionary Earth science missions. Exploiting innovative technological opportunities, developing power systems for adverse environments, and implementing system-wide techniques that promote scalability, adaptability, flexibility, and affordability are characteristics of the technological challenges to be faced and are representative of the type of developments required beyond the state-of-the-art.

The energy conversion technologies solicited include photovoltaics and thermophotovoltaic as well as related technologies such as array, concentrator, and thermal technologies. Specific areas of interest include:

- 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, and electrostatically clean spacecraft solar arrays;
- Proposals are sought addressing structural and microbatteries and rechargeable lithium-based batteries with advanced anode and cathode materials and advanced liquid and polymer electrolytes;
- Primary fuel cell systems that can function in high altitude platforms are solicited. These include primary \( \text{H}_2: \text{Air} \) systems that operate at low air pressure and \( \text{H}_2: \text{O}_2 \) systems;
- Future micro-spacecraft require distributed power sources that integrate energy conversion and storage into a hybrid structure with microelectronics devices/instruments; and
- 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:
Platform Power Management and Distribution Topic S8.06
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 Materials and Components**

Advanced magnetic, dielectric, and semiconductor materials, devices, and circuits 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. Candidate devices and applications include transformers, inductors, semiconductor switches and diodes, electrostatic capacitors, current sensors, and cables.
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, 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:

Automation and Planning Topic S9.01
The Automation and Planning subtopic solicits proposals that allow either spacecraft or ground systems to robustly perform complex tasks given high-level goals with minimal human direction. Areas of interest include all aspects of data collection, processing analysis, and decision making. NASA wants to go from specifying "how" something is done to specifying "what" is needed and letting the system figure what data and resources best meet the high-level goals under a set of constraints (e.g., cost, time, etc.).

Technology innovations include, but are not limited to: 1) automation and autonomous systems that support high-level command abstraction; 2) efficient and effective techniques for assembling and processing large volumes of data (commonly available on the Internet) into useful information; 3) intelligent searches of large, distributed data archives, and data discovery through searches of heterogeneous data sets and architecture; and 4) automation of routine, labor intensive tasks 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; The Automation and Planning subtopic solicits proposals that allow either spacecraft or ground systems to robustly perform complex tasks given high-level goals with minimal human direction. Areas of interest include all aspects of data collection, processing analysis and decision making. NASA wants to from specifying "how" something is done to specifying "what" is needed and letting the system figure what data and resources best meet this high level goals under a set of constraints (e.g. cost, time and etc).

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- Search agents that support applications involving the use of NASA data;
- Methods that support the robust production of data products 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;
- Autonomous data logging devices (software, or hardware and software) supporting a variety of weather and climate sensors, capable of ground-based operation in a wide variety of environmental conditions; such systems would probably be solar powered with accurate time stamping;
- Planning and scheduling methods related to Earth Science Mission objectives;
- System and subsystem health and maintenance, both space- and ground-based;
- Distributed decision making, using multiple agents, and/or mixed autonomous systems;
- Automated software testing;
- Verification and validation of automated systems;
- Automatic software generation and processing algorithms; and
- Control of Field Programmable Gate-Arrays (FPGA) to provide real-time products.

Problems address must be relevant to Earth and Solar Sciences including space weather.

Sub Topics:
Distributed Information Systems and Numerical Simulation Topic S9.02

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 autonomous 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 follow below.

**Distributed Information Systems**

- Core 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;

- Services for management of distributed, heterogeneous information, including replica management, intuitive interfaces, and instantiation on demand or "virtualized data." These services would be used, for example, to access and manipulate NASA's wealth of geospatial and remote sensing data;

- 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; and

- Tools for rapidly porting and hosting science applications in a distributed environment. These applications should be written for an integrated, or workstation, environment using standard programming languages or tools such as Matlab, Interactive Data Language (IDL), or Mathematica.

### 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 application parallelization and performance analysis;

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

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

**Sub Topics:**

Data Management and Visualization Topic S9.03

This subtopic focuses on supporting science analysis through innovative approaches to managing and visualizing large collections of science data. These data sets are extremely large and 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 such as goggles or helmets; and

- 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; and
- Novel tools for data viewing, real-time data browsing, 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

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

Distributed Data Access

- Dynamically configurable, high-speed access to data stored in Storage Area Networks (SAN) distributed over wide area environments; and
- Technologies for sharing data over newly developed, high-speed, wide area networks such as the National Lambda Rail (NLR).

Sub Topics:
On-Board Science for Decisions and Actions Topic S9.04
Current sensors are stove-piped systems, which can collect more data than is possible to transmit to the ground. Intelligence in the sensor or platform can prioritize or summarize the data and send down high priority or synoptic science data. In the future, a sensor-web capability will demand this remote onboard autonomy and intelligence about the kind and content of data being collected to support rapid decision making and tasking. This subtopic is interested in developing new methods to autonomously understand ES data in support of making rapid decisions and taking actions under three themes:

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

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: