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/ 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.

Subtopics

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 ( 
- Space-qualifiable, high-peak power (> 1.2 W), average-power (> 300 mW), operating wavelength less than 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, 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.
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.
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.