NASA is pursuing technologies to enable robotic exploration of the Solar System including its planets, their moons, and small bodies. NASA has a development program that includes technologies for the atmospheric entry, descent, and landing, mobility systems, extreme environments technology, sample acquisition and preparation for in situ experiments, and in situ planetary science instruments. Robotic exploration missions that are planned include a Europa Jupiter System mission, Titan Saturn System mission, Venus In Situ Explorer, sample return from Comet or Asteroid and lunar south polar basin and continued Mars exploration missions launching every 26 months including a network lander mission, an Astrobiology Field Laboratory, a Mars Sample Return mission and other rover missions. Numerous new technologies will be required to enable such ambitious missions. The solicitation for in situ planetary instruments can be found in the in situ instruments section of this solicitation. See URL: (http://solarsystem.nasa.gov/missions/index.cfm) for mission information. Planetary protection requirements vary by planetary destination, and additional backward contamination requirements apply to hardware with the potential to return to Earth (e.g., as part of a sample return mission). Technologies intended for use at/around Mars, Europa (Jupiter), and Enceladus (Saturn) must be developed so as to ensure compliance with relevant planetary protection requirements. Constraints could include surface cleaning with alcohol or water, and/or sterilization treatments such as dry heat (approved specification in NPR 8020.12; exposure of hours at 115 °C or higher, non-functioning); penetrating radiation (requirements not yet established); or vapor-phase hydrogen peroxide (specification pending).

Subtopics

S4.01 Planetary Entry, Descent and Landing Technology

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

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

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

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

S4.02 Robotic Mobility, Manipulation and Sampling

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

New technologies for robotic mobility, manipulation, and sampling are needed to enable access to sites of interest and acquisition and handling of samples for in-situ analysis or return to Earth from planetary and solar system small bodies including Mars, Venus, comets, asteroids, and planetary moons.

Mobility technologies are needed to enable access to crater walls, canyons, gullies, sand dunes, and high rock density regions for planetary bodies where gravity dominates, such as the Moon and Mars. Trafficability challenges include steep terrain, obstacle size, and low soil cohesion. Tethered systems, non-wheeled systems, and marsupial systems are examples of mobility technologies that are of interest. Technologies to enable mobility on small bodies in micro-gravity environments are also of interest.

Manipulation technologies are needed to enable deployment of sampling tools and handling of samples. Mars
mission sample-handling technologies are needed to enable transfer and storage of a range of rock and regolith cores approximately 1cm long and up to about 10cm long. Small-body mission manipulation technologies are needed to deploy sampling tools to the surface and transfer samples to in-situ instruments and sample storage containers.

Sample acquisition tools are needed to acquire samples on planetary and small bodies. For Mars, a coring tool is needed to acquire rock and regolith cores approximately 1cm diameter and up to 10cm long which also supports transfer of the samples to a sample handling system. Abrading bits for the tool are needed to provide rock-surface abrasion capability to better than 0.2mm scale roughness. A deep drill is needed to enable sample acquisition from the subsurface including rock cores to 3m depth and icy samples from deeper locations. Tools for sampling from asteroids and comets are needed which support transfer of the sample for in-situ analysis or sample return. Tools for acquisition and transfer of icy samples on Europa are also of interest. Minimization of mass and ability to work reliably in the harsh mission environment are important characteristics for the tools. Example environmental conditions include microgravity for small-body missions, high pressure and temperature (460 °C, 93bar) on Venus, and at Europa the radiation environment is estimated at 2.9 Mrad total ionizing dose (TID) behind 100 mil thick aluminum.

Contamination control and planetary protection are important considerations for sample acquisition and handling technologies. Contamination may include Earth-source contaminants produced by the sampling tool, handling system, or deposited on the sampling location from another source on the rover. Consideration should be given to:

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

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

Innovative component technologies for low-mass, low-power, and modular systems tolerant to the in situ environment are of particular interest. Technical feasibility should be demonstrated during Phase I and a full capability unit of at least TRL 4 should be delivered in Phase II. Proposals should show an understanding of relevant science needs and engineering constraints and present a feasible plan to fully develop a technology and infuse it into a NASA program. Specific areas of interest include the following:

- Steep terrain adherence for vertical and horizontal mobility.
- Tether play-out and retrieval systems including tension and length sensing.
- Low-mass tether cables with power and communication.
- Sampling system deployment mechanisms.
- Low mass/power vision systems and processing capabilities that enable faster surface traverse while maintaining safety over a wide range of surface environments.
• Robotics autonomy.
• Modular actuators with 1000:1 scale gear ratios.
• Coring tool for 1cm X 10cm rock and regolith cores.
• Small body sampling tool.
• Cleaning to sterility technologies that will be compatible with spacecraft materials and processes.
• Surface cleaning validation technology to quantify trace amount (~ng/cm^2) of organic contamination and submicron particle (~100nm size) contamination.
• Sample handling technologies that minimize cross contamination and preserve mechanical integrity of samples.

S4.03 Spacecraft Technology for Sample Return Missions

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

NASA plans to perform sample return missions from a variety of targets including Mars, outer planet moons, and small bodies such as asteroids and comets. In terms of spacecraft technology, these types of targets present a variety of challenges. Some targets, such as Mars and some moons, have relatively large gravity wells and will require ascent propulsion. Other targets are small bodies with very complex geography and very little gravity, factors that present difficult navigation and maneuvering challenges. In addition, the spacecraft will be subject to extreme environmental conditions including low temperatures (-270 °C), dust, and ice particles. Technology innovations should either enhance vehicle capabilities (e.g., increase performance, decrease risk, and improve environmental operational margins) or ease mission implementation (e.g., reduce size, mass, power, cost, increase reliability, or increase autonomy). Specific areas of interest are listed below. SMD's In-space Propulsion technology program is a direct customer of this subtopic, and the solicitation is coordinated with the ISPT program each year. The ISPT program views this subtopic as a fertile area for providing possible Phase III efforts. Many of the Planetary Decadal Survey white papers/studies evaluating technologies needed for various planetary, small body, and sample return missions refer to the need for sample return spacecraft technologies.

Small Body Missions:

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

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