



NASA SBIR 2011 Phase I Solicitation

S5 Robotic Exploration Technologies

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. See URL: (<http://marsprogram.jpl.nasa.gov/>) for additional information on Mars Exploration technologies. 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 115C or higher, non-functioning); penetrating radiation (requirements not yet established); or vapor-phase hydrogen peroxide (specification pending).

Subtopics

S5.01 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 the situational awareness during landing by identifying hazards (rocks, craters, slopes), or providing indications of approach velocities and touchdown.
- Substantially reducing the amount of external processing needed to calculate the measurements.
- Significantly reducing the impact of incorporating such sensors on the spacecraft in terms of volume, mass, placement, or cost.
- Providing testbeds (e.g., free-flying vehicles) for closed-loop testing of GNC sensors and technologies used in the powered descent landing phase.

For a sample return mission, monitoring local environmental (weather) conditions on the surface just prior to planetary ascent vehicle launch, 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.

S5.02 Sample Collection, Processing, and Handling

Lead Center: JPL

Participating Center(s): ARC, GSFC, JSC

Robust systems for sample acquisition, handling and processing are critical to the next generation of robotic explorers for investigation of planetary bodies (http://books.nap.edu/openbook.php?record_id=10432&page=R1). Limited spacecraft resources (power, volume, mass, computational capabilities, and telemetry bandwidth) demand innovative, integrated sampling systems that can survive and operate in challenging environments (e.g., extremes in temperature, pressure, gravity, vibration and thermal cycling). Special interest lies in sampling systems and components (actuators, gearboxes, etc.) that are suitable for use in the extremely hot high-pressure environment at the Venusian surface (460°C, 93 bar), as well as for asteroids and comets. Relevant systems could be integrated

on multiple platforms, however of primary interest are samplers that could be mounted on a mobile platform, such as a rover. For reference, current Mars-relevant rovers range in mass from 200 - 800 kg.

Sample Acquisition

Research should be conducted to develop compact, low-power, lightweight subsurface sampling systems that can obtain 1 cm diameter cores of consolidated material (e.g., rock, icy regolith) up to 10 cm below the surface. Systems should be capable of autonomously acquiring and ejecting samples reliably, with minimal physical alteration of samples. Also of interest are methods of autonomously exposing rock interiors from below weathered rind layers. Other sample types of interest are unconsolidated regolith, dust, and atmospheric gas. Asteroid and comet samplers are also of interest.

Sample Manipulation (e.g., core management, sub-sampling/sorting, powder transport)

Sample manipulation technologies are needed to enable handling and transfer of structured and unstructured samples from a sampling device to instruments and sample processing systems. Core, cuttings, and regolith samples may be variable in size and composition, so a sample manipulation system needs to be flexible enough to handle the sample variability. Core samples will be on the order of 1 cm diameter and up to 10 cm long. Soil and rock fragment samples will be of similar volumes.

Sample Integrity (e.g., encapsulation and contamination control)

For a sample return mission, it is critical to find solutions for maintaining physical integrity of the sample during the surface mission (rover driving loads, diurnal temperature fluctuations) as well as the return to Earth (cruise, atmospheric entry and impact). Technologies are needed for characterizing state of sample in situ - physical integrity (e.g., cracked, crushed), sample volume, mass or temperature, as well as retention of volatiles in solid (core, regolith) samples, and retention of atmospheric gas samples.

Also of particular need are means of acquiring subsurface rock and regolith samples with minimum contamination. This contamination may include contaminants in the sampling tool itself, material from one location contaminating samples collected at another location (sample cross-contamination), or Earth-source microorganisms brought to the Martian surface prior to drilling ('clean' sampling from a 'dirty' surface). Consideration should be given to use of materials and processes compatible with 110 - 125°C dry heat sterilization. In situ sterilization may be explored, as well as innovative mechanical or system solutions - e.g., single-use sample "sleeves," or fully-integrated sample acquisition and encapsulation systems.

For a sample return mission, solutions are sought for sample transfer of a payload into a planetary ascent vehicle including automated payload transfer mechanisms and Orbiting Sample (OS) sealing techniques.

Sample Return Facility capabilities

Technologies are needed for terrestrial handling of returned samples, including sample quarantine, biological activity and biohazard assessment, techniques for performing sample science.

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. Technical feasibility should be demonstrated during Phase I and a full capability unit of at least TRL 4 should be delivered in Phase II.

S5.03 Surface and Subsurface Robotic Exploration

Lead Center: JPL

Participating Center(s): ARC, GSFC, JSC, LaRC

Technologies are needed to enable access, mobility, and sample acquisition at surface and subsurface sampling sites of scientific interest on Mars, Venus, small planetary bodies, and the moons of Earth, Mars, Jovian and Saturnian systems.

For planetary bodies where gravity dominates, such as the Moon and Mars, many scientifically valuable sites are accessible only via terrain that is too difficult for state-of-the-art planetary rovers to traverse in terms of ground slope, rock obstacle size, plateaus, and non-cohesive soils types. Sites include crater walls, canyons, gullies, sand dunes, and high rock density regions. Tethered systems, non-wheeled systems, and marsupial systems are examples of mobility technologies that are of interest. Mars is particularly interested in fast traverse capabilities aimed at a fetch rover that would potentially need to travel a long distance to retrieve a sample cache deposited by a prior mission. For small planetary bodies with micro-gravity environments, novel access systems are desired to enable exploration and sample acquisition. Small body missions include Comet Surface Sample Return, Cryogenic Comet Sample Return, and asteroid Trojan Tour and Rendezvous.

For surface and subsurface sampling, advanced manipulation technologies are needed to deploy instruments and tools from spacecraft, landers and rovers. Technologies to enable acquisition of subsurface samples are also needed. Technologies are needed to acquire core samples in the shallow subsurface to about 10cm and to enable subsurface sampling in multiple holes at least 1 - 3 meters deep through rock, regolith, or ice compositions. For Europa, penetrators and deployment systems to allow deep drilling are needed to sample and bore the outer water-ice layer and through 10 to 30km to a potential liquid ocean below.

Innovative component technologies for low-mass, low-power, and modular systems tolerant to the in situ environment are of particular interest, e.g., for Europa, the radiation environment is estimated at 2.9 Mrad total ionizing dose (TID) behind 100 mil thick aluminum. Technical feasibility should be demonstrated during Phase I and a full capability unit of at least TRL level 4 should be delivered in Phase II. 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 such as tethers, booms, and manipulators.
- Low mass/power vision systems and processing capabilities that enable faster surface traverse while

maintaining safety over a wide range of surface environments.

- Modular actuators with 1000:1 scale gear ratios.
- Electro-mechanical couplers to enable change out of instruments at the end of a manipulator.s
- Autonomy to enable adaptation of exploration to new conditions.

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.

S5.04 Spacecraft Technology for Sample Return Missions

Lead Center: GRC

Participating Center(s): AFRC, ARC, 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 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, which present difficult navigational and maneuvering challenges. In addition, the spacecraft will be subject to extreme environmental conditions including low temperatures (120K or below), 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 (ISPT) 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 (and the previous Planetary Ascent Vehicle 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 temperature capable non-contaminating propellants.
 - Surface manipulation technologies (e.g., rakes, drills, etc.).
 - Concept to obtain a stratified subsurface comet core sample.
 - Sample mass, volume, ice content verification.
 - Hermetic sample sealing concepts.
 - Low power long life cryogenic sample storage.
 - Applicable propulsion technologies for ascent vehicles and for the return to Earth.
 - Erection mechanisms for setting azimuth and elevation of the Mars Ascent Vehicle.

S5.05 Extreme Environments Technology

Lead Center: JPL

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

High-Temperature, High-Pressure, and Chemically-Corrosive Environments

NASA is interested in expanding its ability to explore the deep atmosphere and surface of Venus through the use of long-lived (days or weeks) balloons and landers. Survivability in extreme high-temperatures and high-pressures is also required for deep atmospheric probes to giant planets. Proposals are sought for technologies that enable the in situ exploration of the surface and deep atmosphere of Venus and the deep atmospheres of Jupiter or Saturn for future NASA missions. Venus features a dense, CO₂ atmosphere completely covered by sulfuric acid clouds at about 55 km above the surface, a surface temperature of about 486 degrees Centigrade and a surface pressure of about 90 bars. Technologies of interest include high-temperature and acid resistant high strength-to-weight textile materials for landing systems (balloons, parachutes, tethers, bridles, airbags), high-temperature electronics components, high-temperature energy storage systems, light-mass refrigeration systems, high-temperature actuators and gear boxes for robotic arms and other mechanisms, high-temperature drills, phase change materials for short term thermal maintenance, low-conductivity and high-compressive strength insulation materials, high-temperature optical window systems (that are transparent in IR, visible and UV wavelengths) and advanced materials with high-specific-heat-capacity and high-specific-strength for pressure vessel construction, and pressure vessel components compatible with materials such as steel, titanium and beryllium for applications like low leak rate wide-temperature (-50 degrees Centigrade C to 500 degrees Centigrade) seals capable of operating between 0 and 90 bars.

Low-Temperature Environments

Low-temperature survivability is required for surface missions to Titan (-180 degrees Centigrade), Europa (-220 degrees Centigrade), Ganymede (-200 degrees Centigrade) and comets. Also the Earth's Moon equatorial regions experience wide temperature swings from -180 degrees Centigrade to +130 degrees Centigrade during the lunar day/night cycle, and the sustained temperature at the shadowed regions of lunar poles can be as low as -230 degrees Centigrade. Mars diurnal temperature changes from about -120 degrees Centigrade to +20 degrees Centigrade. Also for the baseline concept for Europa Jupiter System Mission (EJSM), with a mission life of 10 years, the radiation environment is estimated at 2.9 Mega-rad total ionizing dose (TID) behind 100 mil thick aluminum. Proposals are sought for technologies that enable NASA's long duration missions to low-temperature and wide-temperature environments. Technologies of interests include low-temperature-resistant high strength-

weight textiles for landing systems (parachutes, air bags), low-power and wide-operating-temperature radiation-tolerant /radiation hardened RF electronics, radiation-tolerant/radiation-hardened low-power/ultra-low-power wide-operating-temperature low-noise mixed-signal electronics for space-borne system such as guidance and navigation avionics and instruments, low-temperature radiation-tolerant/radiation-hardened power electronics, low-temperature radiation-tolerant/radiation-hardened high-speed fiber optic transceivers, low-temperature and thermal-cycle-resistant radiation-tolerant/radiation-hardened electronic packaging (including shielding, passives, connectors, wiring harness and materials used in advanced electronics assembly), low to medium power actuators, gear boxes, lubricants and energy storage sources capable of operating across an ultra-wide temperature range from -230 degrees Centigrade to 200 degrees Centigrade and Computer Aided Design (CAD) tools for modeling and predicting the electrical performance, reliability, and life cycle for wide-temperature electronic/electro-mechanical systems and components.

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

S5.06 Planetary Protection

Lead Center: JPL

Participating Center(s): LaRC

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. NASA seeks innovative technologies to facilitate meeting Forward and Backward Contamination Planetary Protection objectives especially for a potential Mars Sample Return (MSR) mission and to facilitate Forward Planetary Protection implementation for a potential mission to Europa.

Backward Contamination Planetary Protection deals with the possibility that Mars (or other planetary) material may pose a biological threat to the Earth's biosphere. This leads to a constraint that returned samples of Mars material be contained with extraordinary robustness until they can be tested and proved harmless or be sterilized by an accepted method. Achieving this containment goal will require new technology for several functions. Containment assurance requires "breaking the chain of contact" with Mars: the exterior of the sample container must not be contaminated with Mars material. Also, the integrity of the containment must be verified, the sample container and its seals must survive the worst-case Earth impact corresponding to the candidate mission profile, and the Earth entry vehicle (EEV) must withstand the thermal and structural rigors of Earth atmosphere entry - all with an unprecedented degree of confidence.

Backward Contamination Planetary Protection technologies for the following MSR functions are included in this call:

- Container Design, Sealing, & Verification: Options for sealing the sample container include (but are not limited to) brazing, explosive welding, and various types of soft seals, with sealing performed either on the

Mars surface or in orbit. Confirmation of sealing can be provided by observation of sealing system parameters and by leak detection after sealing. Wireless data and power transmission may be needed to support such leak detection technologies. Additional containment using a flexible liner within the EEV that is sealed while in Mars orbit has also been considered. Further validation prior to Earth entry may also be needed.

- **Breaking-the-Chain & Dust Mitigation:** Several paths have been identified that would result in Mars material contaminating the outside of the sealed sample container and/or the Earth return vehicle (ERV). Technology options for mitigation include ejection of containment layers during ascent and orbit and/or capturing a contaminated "Orbiting Sample" into a clean container on the ERV and then ejecting the capture device.
- **Meteoroid Protection & Breach Detection:** Protection is required for both the sample container and the EEV heat shield. New lightweight shielding techniques are needed. Even with these, there may be a requirement for technology to detect a breach of the shield or damage to the EEV.

Forward Contamination Planetary Protection technologies are desired, particularly for Mars and Europa missions that allow sterilization of previously non-sterilizable flight hardware by either i) dry heat processing or ii) gamma/e-beam irradiation. NASA also seeks to use iii) hydrogen peroxide vapor processes for resterilization of assembled flight hardware elements. Proposals are invited for innovative approaches to sterilization of flight hardware in the pre-flight environment using this technology. Note: this call is not for novel sterilization processes. For Europa, products and technologies are sought that can be demonstrated to be compatible with the three identified sterilization processes, as well as the environmental conditions of spaceflight and the Jovian system.

Candidate technologies for the following functions and capabilities are included in this call:

- **Sterilization Process Compatibility:** Options for proving compatibility of novel product elements (materials, parts) with recognized spacecraft sterilization process parameters are desired.
- **Redesign for Sterilization:** Development of alternative solutions for spacecraft hardware is needed where there are known sterilization process incompatibilities. Current planning is to facilitate system-level sterilization of spacecraft, so heat tolerant technology solutions for sensors, seals (battery, valve), optical coatings, etc., are highly desired.
- **Biobarrier Technology:** Demonstration of novel biobarrier and recontamination prevention approaches for spacecraft hardware is needed when applying one or more of these three sterilization processes.

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

