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.

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. Sensing technologies are desired which determine the entry point of the spacecraft in the Mars atmosphere; provide inputs to systems that control spacecraft trajectory, speed, and orientation to the surface; locate the spacecraft relative to the Martian surface; evaluate potential hazards at the landing site; and determine when the spacecraft has touched down. Appropriate sensing technologies for this topic should provide measurements of physical forces or properties that support some aspect of EDL operations. NASA also seeks to use measurements made during EDL to better characterize the Martian atmosphere, providing data for improving atmospheric modeling for future landers. Proposals are invited for innovative sensor technologies that improve the reliability of EDL operations.

Products or technologies are sought that can be made compatible with the environmental conditions of spaceflight and the rigors of landing on the Martian surface. Successful candidate sensor technologies can address this call for additional information on Mars Exploration.
• 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

• 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 > 20cm height, slopes > 0.05 radians, craters > 1m diameter) and distinguishing between favorable and unfavorable landing materials (e.g., differentiate bowls of dust from solid rock)

• Substantially reducing the amount of external processing needed to calculate the measurements or provide high performance flight qualified processing with low mass and power (e.g., 1 GFLOPS processing in

• Decoupling spacecraft attitude from instrument pointing through the development of fast gimbals that are low mass and power (2 rad/s\(^2\) accelerations, 2 rad/s rates with mass

• Improving landing site map accuracy and resolution while also providing a means for validating the generated map (10cm resolution elevation with 5cm height errors and map tie errors

• Providing modular and low mass spacecraft to spacecraft navigation systems that work through all of EDL (e.g. orbiter to lander during entry or lander to surface rover).

• Monitoring local environmental (weather) conditions on the surface to facilitate forecasting of wind velocities up to ~10km altitude above the surface in preparation for landing (for missions targeted to land near previously landed assets)

• Significantly reducing the impact of incorporating such sensors on the spacecraft in terms of volume, mass, placement, or cost.

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.

Other subtopics that could be soliciting entry, descent, and landing related technology developments include S1.01 Laser and Lidar System Components, S3.10 Earth Entry Vehicle Systems, X9.01 Ablative Thermal Protection Systems, and X9.02 Advanced Integrated Hypersonic Entry Systems. Proposals more aligned with exploration mission requirements should be proposed in X9.

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 (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). 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. 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.

**Sample Manipulation** *(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** *(encapsulation and contamination)*

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 Martisan 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, sample transfer of a payload into a planetary ascent vehicle: Automated payload transfer mechanisms; and Orbiting Sample (OS) sealing techniques.

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.
S5.03 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 the Earth, Mars, Jovian and Saturnian systems. 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. These technologies could enable new approaches for deployment, retrieval, access, and mobility.

A variety of mobility system architectures can be considered. Single vehicle systems might utilize a 200 kg class rover and dual vehicle systems might utilize a 500 - 800 kg primary vehicle that provides long traverse to the vicinity of a challenging site and then deployment of a smaller 20 - 50 kg vehicle with steep mobility capability for access and sampling at the site.

For surface and subsurface sampling, advanced manipulation technologies are needed to deploy instruments and tools from landers and rovers. Technologies to enable acquisition of subsurface samples are also needed. For Mars and Venus, 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. Shallow subsurface sampling systems need to be low mass and deeper subsurface sampling solutions need to be integratable onto 500 - 800 kg stationary landers and mobile platforms. For Europa, penetrators and tools 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.

Consideration should be given for potential failure scenarios, such as platform slip and borehole misalignment for integrated systems, and the challenges of dry drilling into mixed media including icy mixtures of rock and regolith. Systems should ensure minimal contamination of samples from Earth-source contaminants and cross-contamination from samples at different locations or depths.

Innovative component technologies for low mass, low power, and modular systems tolerant to the in-situ environment are of particular interest. 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:

- Tether play-out and retrieval systems including tension and length sensing;
- Low-mass tether cables with power and communication;
- Steep terrain adherence for vertical and horizontal mobility;
- Modular actuators with 1000:1 scale gear ratios;
- Electro-mechanical couplers to enable change out of instruments on an arm end-effector;
- Drill, core, penetrator, and boring systems for subsurface sampling to 10cm, 1 m, 3 m, and deep subsurface;
- Shared intelligence allowing systems to collaborate and adapt exploration scenarios to new conditions.

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

S5.04 Rendezvous and Docking Technologies for Orbiting Sample Capture

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

NASA seeks an innovative suite of products or technologies that will enable and enhance the successful tracking and capture of a sample canister in Mars orbit in anticipation of the start of a Mars Sample Return (MSR) mission in the next decade.

The principal means of detection and tracking of the Orbiting Sample Canister (OSC) is optically with visual-band cameras. The challenging technology of long-range optical sensors for detection and distant tracking is not part of this call, however, short-range optical (or other) sensors and an on-sample radio-metric-based back-up detection and tracking method is desired, including a low-power, low-mass illuminator for short-range imaging of up to 0.5km.

Sample capture mechanisms are sought, of very low mass and volume, and of low complexity and extremely high reliability, including detection of contact with the capture mechanism. Appropriate on-sample radio-beacons are sought that are compatible with NASA’s radio systems, in particular, the Electra onboard programmable radio system; requirements for these beacons are for long life, and independent initiation of on-orbit operation. Solutions are sought that are either battery powered or via solar cells that do not reduce the overall OSC outer shell visual albedo below 0.5. Sample capture mechanisms should include close-proximity/contact sensors, including immediate-field imaging.

Methods are sought to provide a practice mechanism for testing rendezvous and proximity operations with a test sample canister in Earth or Mars orbit. The test carrier and release mechanism must be of very low mass and volume, and the test sample canister(s) should carry a radio beacon. Test OSC canisters should be of limited life after release, ceasing broadcast, and degrading in surface reflectance in approximately one month after release to
avoid confusion with the actual canister. The test articles may be deployed and used on a previous mission to MSR, or on the actual MSR mission for operational readiness testing.

Products or technologies are sought that can be made compatible with the environmental conditions of interplanetary spaceflight and the rigors normal Mars orbits. Proposals should show an understanding of proposals and plans for previous NASA-supported Mars Sample Return relevant missions and mission concepts, and present a feasible plan to fully develop a technology and infuse it into a NASA program. Successful candidate products or technologies can address this call by providing one or more of the following functions, and giving estimated expected performance capabilities of the approach, including, but not limited to, accuracies, ranges, limits of operation, references to previous or related flight experience:

- Autonomously actuated mechanisms for orbiting sample capture of the OSC
  - Mechanical capture mechanisms
  - Transfer mechanisms from capture device to containment transfer mechanism

- Optical and contact sensors
  - Near field imagers (optical or other) (e.g. 10m to 1km)
  - Immediate field imagers (optical) (0.25 to 10m)
  - Detection of OSC for triggering capture mechanism
  - Near field illuminator

- Coherent Radio Doppler and range beacon (high-performance)
  - Low power, low mass and long life beacon for detection aid
  - 2-way communication for activation, ranging and coherency via NASA's Electra radio interface
  - Programmable intermittent transmission for power saving and very long dormancy period
  - Battery or solar powered, preserving 0.5 visual albedo of OSC

- Simple Radio beacon (low-performance)
  - Simple 1-way beacon, for long-range detection and 1-way Electra Doppler extraction
  - Timer activated, multi-year dormant life, and long active life battery, or solar powered - preserving 0.5 visual albedo of OSC

- Low-mass, low-cost sample OSC for proximity operations operational readiness tests
A simple, low-cost, low-mass practice sample canister that could be deployed in Earth or Mars orbit and provide low-risk practice runs, either for a precursor mission, or with the actual MSR.

The readiness test exercise would not necessarily capture the test article in the capture mechanism for the actual MSR flight, but only perform the rendezvous and proximity ops operations sufficient to demonstrate very high likelihood of actual OSC capture.

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, CO\(_2\) 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 motors and actuators 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 strength for pressure vessel construction, and pressure vessel components compatible with materials such as steal, titanium and beryllium such as 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 surface (-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 radiation-tolerant / radiation hardened RF electronics, radiation-tolerant / radiation hardened mixed signal electronics, radiation-tolerant / radiation hardened power electronics, radiation-tolerant/ radiation hardened high speed fiber optic transceivers, radiation-tolerant/ radiation hardened electronic packaging (including, shielding, passives, connectors, wiring harness and materials used in advanced electronics assembly), actuators 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 low-
temperature electronic 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

NASA seeks innovative technologies to facilitate meeting Back Planetary Protection objectives for a potential Mars Sample Return mission and to facilitate Forward Planetary Protection implementation for a potential mission to Europa.

Back Planetary Protection deals with the possibility that Mars 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.

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

- **Container Design, Sealing, and Verification:** Options for sealing the sample container include 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 for leak detection. 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 and 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 and Breach Detection:** Protection is required for both the sample container and the EEV heat shield, with the later appearing to be the more challenging technology requirement.
lightweight shielding techniques are needed. Even with these the shield may be excessively heavy leading to a requirement for technology to detect a breach of the shield or damage to the EEV.

- **Entry, Descent, and Landing**: The EEV should be aerodynamically self-righting and should provide shock attenuation for the sample container consistent with the planned no-parachute descent.

- **PRA and Reliability Analysis**: Obtaining approval to proceed with an MSR mission is likely to involve quantitative assessment of the probability of containment loss. This will benefit from advances in the state of the art of probabilistic risk assessment for complex space systems and of reliability analysis of the spacecraft components involved.

Technologies are desired for the Europa mission that allow sterilization of previously non-sterilizable flight hardware by either i) dry heat processing or ii) gamma irradiation. NASA also seeks to use iii) hydrogen peroxide vapor processes for re-sterilization 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, for example for heat tolerant sensors, seals (battery, valve), optical coating applications.

- **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.