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.

Subtopics

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 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 years) 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.

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.

- 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.