The overarching goal of the Sun–Earth Connection (SEC) theme in Space Science is an understanding of how the Sun, heliosphere, and planetary environments are connected in a single system. The three principal science objectives spring from this goal:

1. Understanding the changing flow of energy and matter throughout the Sun, heliosphere, and planetary environments;
2. Exploring the fundamental physical processes of plasma systems in the solar system; and
3. Defining the origins and societal impacts of variability in the Sun–Earth Connection.

SEC missions investigate the physics of the Sun, the heliosphere, the local interstellar medium, and all planetary environments within the heliosphere. They address problems such as solar variability, the responses of the planets to such variability, and the interaction of the heliosphere with the galaxy. Increasingly, SEC investigations have focused upon space weather, the diverse array of dynamic and interconnected space phenomena that affects life, society, and exploration systems. Technology plays an important role in maximizing the science return from all SEC missions.

Subtopics

S1.01 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.
- 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, magnetopause, and auroral arcs.
- 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.
- Miniaturized, radiation-tolerant and autonomous electronic systems for the above, within resource envelopes of 1–2 kg and 1–2 W.

S1.02 Deep Space Propulsion

Lead Center: MSFC
Participating Center(s): GRC, GSFC, JSC

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 solar electric, chemical and thermal, solar sails, aeroassist and aerocapture and emerging technologies.

Solar Electric Propulsion

Innovations in electric propulsion system technologies are being sought for space science applications. One area of emphasis pertains to high-performance propulsion systems capable of delivering specific impulse (Isp) greater than 2000 s, using electrical power from radioisotope or solar energy sources. Thruster technologies include, but are not limited to, ion engines, Hall thrusters, and pulsed electromagnetic devices. Other areas of interest include propellant storage, direct drive and other innovative power processing, power management and distribution, heat-to-electrical power conversion, and waste heat disposal. Innovations considered here may focus on the component, subsystem or system level, and must ultimately result in significant improvements in spacecraft capability, longevity, mass, volume, and/or cost.

Solar Sails

Solar sails are envisioned as a low-cost, efficient transport system for future near-Earth and deep space missions. NASA mission's enabled and enhanced by solar sail propulsion include Tech Pull Missions such as Geotail, Comet Sample and Titan Flyby all to be launched between 2009 and 2012. Another category of NASA missions is the Particle Acceleration Solar Orbiter, including the L1-Diamond and the Solar Polar Imager, both to be launched between 2015 and 2028. Solar Sails are enabling for several strategic missions in the Sun-Earth Connection Science theme, including Solar Polar Imager and Interstellar Probe, the latter being a sail mission to explore interstellar space. Missions in the Exploration of the Solar System theme would be broadly enhanced by the availability of proven sail technology. Innovations are sought that will lower the cost and risk associated with sail development and application, and enhance sail delivery performance. Innovations are sought in the following areas: systems engineering, materials, structures, mechanical systems, fabrication, packaging and deployment, system control (attitude, etc.), maneuvering and navigation, operations, durability and survivability, and sail impact on science. Development of ultra-lightweight inflatable and deployable support structures is of significant interest, including rigidization approaches. Innovations in ultra-light reflective thin films are also sought. Three parameters
have been used as sail performance metrics in mission applications: sail size, sail survivability for close solar approaches, and areal density (ratio of mass of the sail to area of the sail). In addition, important programmatic metrics are cost, benefit, and risk. Technologies of interest should be geared toward a wide range of sail sizes, solar closest approach distances, and aerial densities, and may be optimized for one portion of the range rather than trying to cover the whole range. Sail sizes may range from very small (meter-sized for use with very tiny picosat payloads or for use as auxiliary propulsion), to medium (50–100 m size for achieving high-inclination solar orbits or non-Keplerian near-Earth orbits) and ultimately to the very large (hundreds of meters for levitated orbits, high delta V, and for use in leaving the Solar System at high speed). Sail weight should include, but not be limited to, ultra-lightweight sail materials (Chemical and Thermal Propulsion

Innovations in low-thrust chemical propulsion system technologies are being sought for Space Science missions applications. One area of interest is a bipropellant engine with Isp greater than 360 s. Component, subsystem, or system level technology development will be considered but work must ultimately result in significant reductions in spacecraft system mass, volume, and/or cost. Other areas to be considered include lightweight, compact and low-power propellant management components, such as valves, flow control/regulation, fluid isolation, dependable ignition systems, and lightweight tankage.

Aeroassist

Aeroassist is a general term given to various techniques to maneuver a space vehicle within an atmosphere, using aerodynamic forces in lieu of propulsion 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. Materials need high strength (modulus in the tens of GPa) and very low density (tens of kg/m^3). Improvements needed in materials include having highly anisotropic thermal properties, i.e., high thermal diffusivity tangential to the spacecraft shape and low thermal diffusivity normal to the spacecraft shape.

Sensors for Inflatable Decelerators: Health monitoring method for inflatable thin film systems.

Analytical Tools: Development of advanced tools to perform coupled aeroelastic and aerothermal analysis of inflatable decelerator systems.

Aerogravity Assist

Aerogravity Assist Technology Analysis: Research advancements in leading edge materials and provide CFD analysis of heating environment for aerogravity assist maneuvers at a small planet (e.g., Venus).
Emerging Propulsion Technologies

This effort will focus on technologies supporting innovative and advanced concepts for propellantless propulsion and other revolutionary transportation technologies. The categories under Emerging Propulsion Technologies include, but are not limited to: electrodynamic and momentum-exchange tether propulsion, beamed energy, ultralight solar sails, bimodal sails, and low to medium power electric propulsion (including pulse inductive devices). The electrodynamic tether propulsion uses electromagnetic interaction with a planetary magnetic field to exchange angular momentum. Momentum exchange tethers (such as the MXER tether concept use a strong tether to transfer angular momentum and orbital energy to a payload. Beamed energy propulsion concepts include lasers or microwave energy to directly propel a spacecraft or to supply power that is utilized for propulsion onboard the spacecraft. Ultra-light or bimodal sail propulsion developing conventional solar sails into extremely high-performing systems. The low to medium electric propulsion is a general category for fresh variations of electric thrusters (Hall, MHD, PIT, etc.) that support near or mid-term solar powered spacecraft (e.g., below ~50 kW). Unique, innovative and novel propulsion ideas are sought but with reasonable expectations to progress to hardware prototypes. The concept must be above TRL 2 with rapid demonstration to TRL 4 expected. Distinctive variations of existing propulsion methods or chief subsystem component improvements are also suitable for submission. Proposals should provide development of specific innovative technologies or techniques supporting any of the above approaches. A clear plan for demonstrating feasibility, noting any test and experiment requirements, is also recommended. Key to each idea is an unambiguous knowledge of past research and concepts conducted on related work, and specifically, how this new proposal differs to the extent that it appears to offer a significant benefit. Identification of the fundamental technology to be developed is also crucial.

S1.03 Multifunctional Autonomous Robust Sensor Systems

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

NASA seeks innovative concepts for Multifunctional Autonomous Robust Sensor Systems (MARSS) to increase spacecraft autonomy and robustness. These concepts are intended to lower overall mission costs, reduce reliance on human control and monitoring, and allow for systems that are inherently robust and provide maximum flexibility of the space vehicles throughout mission lifecycle and for various space/planetary exploration missions. The systems should include the ability to couple the data from a variety of distributed sensor technologies to relevant response actuation systems of the vehicle. As we move from 10s of sensors to 1000s of sensors and beyond, new approaches must be investigated that will allow the vehicle to efficiently obtain “knowledge” about the health and optimization of its systems, and the ever changing environment it is in.

Robustness and autonomy in space vehicles are two of the keys to achieving maximum efficiency of missions and increasing the probability of success. Distributed, self-sufficient, reconfigurable sensors are at the heart of this capability. Technologies such as, but not limited to, MEMS, nanotechnology, integrated/distributed processors and fuzzy logic are potential elements of MARSS. These systems should be able to provide their own power by scavenging it from the environment and provide real-time knowledge from large numbers of sensors to various response systems to comprise “sense and respond” systems. In addition, methods are sought to improve radiation shielding of systems components. This includes, but are not limited to, metal and metal matrix materials that may offer better radiation protection properties than the current state-of-the-art aluminum alloys, and high atomic number intercalated graphite composites for light weight strong radiation shielding of electronics to improve their robustness.
Emphasis should be placed on technologies that provide a sense-and-respond capability using technologies that are small, reliable, low-cost, lightweight, and would allow space probes to adapt to a wide range of space missions. Sensing requirements include both intrinsic (relating to the performance and health of the vehicle itself) and extrinsic (relating to the performance of the mission and adapting to the operating environment).

Evaluators will be looking for system concepts and not just individual pieces that could be used for a system. This requires multidiscipline collaboration on various proposals and clear explanations of system functionality, benefit, and improvement over existing technology. In addition, details of how systems will function in relevant space environments should be provided. The Technology Readiness Level (TRL) for submissions should be in the TRL 4-6 range. Please see the SBIR Web site for more details.

S1.04 Spacecraft Technology for Micro- and Nanosats

Lead Center: GSFC

NASA seeks research and development of components, subsystems and systems that enable inexpensive, highly capable small spacecraft for future SEC missions. The proposed technology must be compatible with spacecraft somewhere within the micro-to-nano range of 100 kg down to 1 kg. All proposed technology must have a potential for providing a function at current performance levels with significantly reduced mass, power, and cost, or have a potential for significant increase in performance without additional mass, power, and cost. These reduction and/or improvement factors should be significant and show a minimum factor of 2 with a goal of 10 or higher.

A proposed technology must state the type or types of expected improvements, (performance, mass, power, and cost), list the assumptions for the current state-of-the-art, and indicate the spacecraft range of sizes for which the technology is applicable.

The integration of multiple components into functional units and subsystems is desirable but not a requirement for consideration.

- Avionics and architectures that support command and data handling functions, including input and output, formatting, encoding, processing, storage, and analog-to-digital conversion. System level architecture, software operating systems, low voltage logic switching, radiation-tolerant design, and packaging techniques are also appropriate technologies for consideration.

- Sensors and actuators that support guidance, navigation, and control functions such as Sun–Earth sensors, star trackers, inertial reference units, navigation receivers, magnetometers, reaction wheels, magnetic torquers, and attitude thrusters. Technologies with applications to either spinning or three-axis stable spacecraft are sought.

- Power system elements including those that support the generation, storage, conversion, distribution regulation isolation, and switching functions for spacecraft power. System level architecture, low voltage
buss design, radiation tolerant design, and novel packaging techniques are appropriate technologies for consideration.

- New and novel application of technologies for manufacturing, integration and test of micro and nano size spacecraft are sought. Limited production runs of up to several hundred spacecraft can be considered. Efficiencies can derive from increased reliability, flexibility in the end-to-end production process, as well as cost, labor, and schedule.

- Technologies that support passive and active thermal control suitable for micro and nano size spacecraft are sought. These functions include heat generation, storage, rejection, transport, and the control of these functions. Efficient system level approaches for integrated small spacecraft that may see a wide range of thermal environments are desirable. These environments may range from low heliocentric orbits to 2 hr shadows.

- Elements that support Earth-to-space or space-to-space communications functions are sought. This includes receivers, transmitters, transceivers, transponders, antennas, RF amplifiers, and switches. S and X are the target communications bands.

- System architectures and hardware that lead to greater spacecraft and constellation autonomy and, therefore, reduce operational expenses are desired. Technologies that derive added capability for a fixed bandwidth, efficient utilization of ground systems, status analysis, and situation control or other enhancing performance for operations are sought.

- Structure and mechanism technologies and material applications that support the micro and nano class of spacecraft are desired. Exoskeleton structures, spin release mechanisms, and bi-stable deployment mechanisms are typical of the desired technology.

- Propulsion system elements that provide delta-V capability for spinning and/or three-axis stable spacecraft are sought. This includes solid, cold-gas, and liquid systems, and their components such as igniters, thrust vector control mechanisms, tanks, valves, nozzles, and system control functions.

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**S1.05 Information Technology for Sun-Earth Connection Missions**

*Lead Center: GSFC*

A large number of multiple-spacecraft missions are planned for the future of SEC science. Cost-effective implementation of these missions will require new information technology: tools, systems and architectures for mission planning, implementation, and operations; and science data processing and analysis that facilitate scientific understanding. Specific research areas of interest for these SEC multi-spacecraft missions include the following items below.

**Information Technology for Cost-Effective Mission Planning and Implementation**

Tools or systems are needed that improve the system engineering, integration, test, and synchronous operations of semiautonomous multispacecraft missions with intermittent contact and large communication latencies; automated approaches to onboard science data processing and reactive onboard instrument management and control; and tools that capture and represent scientific objectives as preplanned and reactive onboard autonomous drivers.
Data Analysis

Items of interest in this area focus on innovative approaches and the tools necessary to support space and solar physics virtual observatories (physically distributed heterogeneous science data sources considered as a logical entity).

Tools are needed for enabling automated systematic identification, access, ad hoc science analysis, and distribution of large distributed heterogeneous data sets from space and solar physics data centers; and technologies and tools supporting inclusion of individual researcher provided, ad hoc, science analysis modules as a component of search criteria for remote data mining at space and solar physics data centers.

S1.06 UV and EUV Optics

Lead Center: GSFC
Participating Center(s): MSFC

From the Sun's atmosphere to the Earth's aurora, remote imaging, spectroscopy, and polarimetry at ultraviolet (UV) and extreme ultraviolet (EUV) wavelengths are important tools for studying the Sun-Earth connection. A far ultraviolet (FUV) range is sometimes interposed between UV and EUV, but the terminology is arbitrary: the pertinent full range of wavelength is approximately 20–300 nm.

Proposals should explain specifically how they intend to advance the state-of-the-art in one or more of the following areas.

Imaging Mirrors

- Large aperture: 1–4 m
- Low mass: 5–20 kg m\(^{-2}\)
- Accurate figure: \(~0.01\) wave rms or better at 632 nm. Figure accuracy must be maintained through launch and on orbit (including, for mirrors subjected to direct or concentrated solar radiation, the effects of differential heating)
- Low microroughness: \(~1\) nm rms or better on scales below 1 mm.

Optical Coatings and Transmission Filters
Coatings (filters) with improved reflectivity (transmission) and selectivity (narrow bands, broad bands, or edges). Technologies include (but are not limited to) multilayer coatings, transmission gratings, and Fabry-Pérot étalons.

**Diffraction Gratings**

- High groove density (> 4000 mm\(^{-1}\)) for high spectral resolving power in conjunction with achievable focal lengths and pixel sizes
- High efficiency and low scatter (microroughness)
- Variable line spacing
- Echelle gratings
- Active gratings (replicated onto deformable surfaces)
- Aspherical concave substrates, such as toroids and ellipsoids

Proposals that address detector requirements of Sun-viewing instruments, such as large format, deep wells, fast readout, or “3-D” (spatial-spatial-energy) resolution, should be submitted to Topic S2.05.