The Science Mission Directorate will carry out the scientific exploration of our Earth, the planets, moons, comets, and asteroids of our Solar System and beyond; chart the best route of discovery; and reap the benefits of Earth and space exploration for society. A major objective of the NASA science spacecraft systems development programs is to implement science measurement capabilities using small, affordable spacecraft enabling a single spacecraft to meet multiple mission requirements thus making the best use of our limited resources. To accomplish this objective, NASA is fostering innovations in propulsion, power, and guidance and navigation systems that significantly reduce the mass and cost while maximizing the scientific return for future NASA missions. Innovations are sought in the areas of power generation, energy storage, guidance, navigation, command/control, on-board propulsion (electric propulsion, advanced chemical and propellantless propulsion), on-board power management and distribution (power electronics and packaging), and thermal control technologies for spacecraft, piloted and unpiloted aircraft, balloons, drop sondes, and sounding rockets used for NASA Science Missions.

**Subtopics**

**S3.01 Avionics and Electronics**

**Lead Center:** GSFC

**Participating Center(s):** GRC, JPL, JSC

NASA's space based observatories, fly by spacecraft, orbiters, landers, and robotic and sample return missions, require robust Command and Control capabilities. Advances in technologies relevant to guidance, navigation, command and data handling are sought to support NASA's goals and several missions and projects under development, including the New World Observer, GEO Quick Ride and Radiation Hardened Electronics for Space Environments (RHESE).

The subtopic goals are to: (1) develop high-performance processors and memory architectures and reliable electronic systems and (2) develop precision line-of-sight sensing for large telescopes and spacecraft formations. The subtopic objective is to elicit novel architectural concepts and component technologies that are realistic and operate effectively and credibly in environments consistent with the future vision of the Science Mission Directorate (SMD).
Successful proposal concepts will significantly exceed the present state-of-the-art. Proposals will clearly (1) state what the product is; (2) describe how it targets the technical priorities listed below; and (3) outline the feasibility of the technical and programmatic approach. If a Phase 2 proposal is awarded, the combined Phase 1 and Phase 2 developments shall produce a prototype that is testable by NASA. The technology priorities sought are listed below.

Command and Data Handling

- Processors - General purpose (processor chips and radiation-hardened by design synthesizable IP cores) and special purpose single-chip components (DSPs and FPGAs) with sustainable processing performance (>500 MIPS), power efficiency (>100 MIPS/W) and radiation tolerance, including the tools to support the software flow.
- Radiation hardened: low power memories and Ethernet physical layer components.
- Models for analysis of interplanetary radiation and radiation belts, and technologies enabling in-flight total dose and single event radiation measurements.

Guidance Navigation and Control

- Navigation systems (including multiple sensors and algorithms/estimators, possibly based on existing component technologies) that work collectively on multiple vehicles to enable inertial alignment of the formation of vehicles (i.e., pointing of the line-of-sight defined by fixed points on the vehicles) on the level of milli-arcseconds relative to the background star field.
- Light-weight sensors (gyroscopic or other approach) to enable milli-arcsecond class pointing measurement for individual large telescopes.
- Isolated pointing and tracking platforms (pointing 0.5 arcseconds, jitter to 5 milli-arcsecond), targeted to placing a scientific instrument on GEO communication satellites that can track the sun for > 3 hours/day.

S3.02 Thermal Control Systems

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

Future Spacecraft and instruments for NASA's Science Mission Directorate will require increasingly sophisticated thermal control technology. Research should be conducted to demonstrate technical feasibility during Phase 1 and
show a path toward a Phase 2 demonstration, and when possible, deliver a demonstration unit for functional and environmental testing at the completion of the Phase 2 contract. Innovative proposals for thermal control technologies are sought in the following areas:

- Optical systems, lasers, and detectors require tight temperature control, often to better than +/- 1°C. Some new missions such as CON-X and LISA require thermal gradients held to micro-degree levels. Methods of precise temperature measurement and control to this level are needed.

- Heat flux levels from lasers and other high power devices are increasing, with some projected to go as high as 100 W/cm², especially for proposed wind/Lidar missions. They will require thermal technologies such as spray and jet impingement cooling. Also, high conductivity, vacuum-compatible interface materials will be needed to minimize losses across make/break interfaces.

- Future missions such as TPF will use large structures, like mirrors and detector arrays, at both ambient and cryogenic temperatures. Some anticipated technology needs include: advanced thermoelectric coolers capable of providing cooling at ambient and cryogenic temperatures, high conductivity materials to minimize temperature gradients and provide high efficiency light-weight radiators, and advanced thermal control coatings such as variable emittance surfaces and coatings with a high emissivity at ambient and cryogenic temperatures.

- Future advanced spacecraft present engineering challenges requiring systems which are more self-sufficient.

Some of the technology needs are:

- Single and two-phase mechanically pumped fluid loop systems which accommodate multiple heat sources and sinks, and long life, lightweight pumps for these systems;

- Efficient, lightweight vapor compression systems for cooling up to 2 KW;

- Advanced thermal modeling techniques that can be easily integrated into existing codes, emphasizing inclusion of two-phase system and mechanically pumped system models;

- Integration of standardized formats into existing codes for the representation and exchange of Thermal Network Models and Thermal Geometric Models and results.

**S3.03 Power Generation and Storage**

Lead Center: GRC

Participating Center(s): GSFC, JPL, JSC
Future NASA science missions will employ Earth orbiting spacecraft, planetary spacecraft, balloons, aircraft, surface assets, and marine craft as observation platforms. Proposals are solicited to develop advanced power conversion, energy storage, and power electronics to enable or enhance the capabilities of future science missions. The requirements for the power systems for these missions are varied and include long life capability, high reliability, significantly lower mass and volume, higher mass specific power, and improved efficiency over the state of practice (SOP) components/systems. Other desired capabilities are high radiation tolerance, and ability to operate in extreme environments (high and low temperatures and over wide temperature ranges).

**Advanced Photovoltaic Energy Conversion**

- Photovoltaic cell and array technologies with significant improvements in efficiency (>30%), mass specific power (>600W/kg), stowed volume, cost, radiation resistance, and wide operating conditions are solicited;
- Photovoltaic cell technologies for low intensity, low-temperature operation (LILT) are solicited;
- Array technologies of interest are concentrators, deployable arrays, ultra-lightweight arrays for flexible, thin-film cells, and electrostatically-clean solar arrays.

**Stirling Power Conversion**

Novel methods or approaches for radiation-tolerant, sensorless, autonomous control of the Stirling converters with very low vibration and having low mass, size, and electromagnetic interference (EMI). Technologies of interest include:

- High-temperature, high-performance regenerators;
- High-temperature, lightweight, high-efficiency, low EMI, linear alternators;
- High-temperature heater heads (> 850°C) and joining techniques.

**Energy Storage**

Energy storage requirements for Science mission are:>10,000 charge/discharge cycles for LEO spacecraft, as low as 40K low-temperature storage/operation for planetary missions, and high mass specific power for small spacecraft. Energy storage technologies that enable one or more of the above requirements are of interest. Technologies of interest include:

- Fuel cells;
- Batteries including structural batteries;
- Integrated power systems (generation/storage/control integrated into one module).

**Power Management and Distribution**
Advanced electrical power technologies are required for the electrical components and systems on future platforms to address the size, mass, efficiency, capacity, durability, and reliability requirements. In addition to the above requirements, proposals must address the expected improvements in energy density, speed, efficiency, or wide-temperature operation (-125°C to 200°C) with a high number of thermal cycles. Advancements are sought in power electronic devices, components, and packaging. Technologies of interest include:

- Power electronic components and subsystems;
- Power distribution;
- Fault protection;
- Advanced electronic packaging for thermal control and electromagnetic shielding.

**S3.04 Propulsion Systems**

**Lead Center:** GRC

**Participating Center(s):** JPL, JSC, MSFC

The Science Mission Directorate (SMD) needs spacecraft with ever-increasing propulsive performance and flexibility for ambitious missions requiring high duty cycles and years of operation. Planetary spacecraft need the ability to rendezvous with, orbit, and conduct in situ exploration of planets, satellites and other solar system bodies. Platforms, satellites, and satellite constellations have high-precision propulsion requirements, usually in volume- and power-limited envelopes. This subtopic seeks innovations to meet SMD propulsion requirements, reflecting the goals of NASA’s In-Space Propulsion Technology program to reduce the travel time, mass, and cost of SMD spacecraft. Propulsion areas include chemical and electric propulsion systems, propulsion technologies related to sample return missions to asteroids, comets, and other small bodies, propellantless options (such as aerocapture and solar sails), and less developed but emerging propulsion concepts such as advanced plasma thrusters and momentum exchange/electrodynamic reboost (MXER) tethers.

Specifically, innovations are sought in the following areas:

- Characterization of high strength fibers and compatible resins for composite overwrapped pressure vessels (COPVs) for use in higher-pressure, in-space propulsion systems. Of particular interest are fiber/resin systems exhibiting high uniformity of mechanical properties and high resistance to debonding.
- Improved capability and reduced cost of low- to medium-power electric propulsion systems, including power processing, long-life, high-efficiency cathodes and neutralizers, low-erosion materials for ion optics and Hall discharge chambers, plume mitigation, and next generation thrusters.
Thin film materials, elastomeric materials, and/or high temperature fabrics for inflatable decelerator concepts used in aerocapture applications at planetary destinations. The decelerator will be stowed for many years (up to 10 years) in an uncontrolled space environment (-130°C). The inflatable decelerator will experience temperatures up to 500°C during the aerocapture maneuver. Materials of particular interest include polyimide thin films, polybenzobisoxazole (PBO) thin films, and ceramic fabrics.

S3.05 Terrestrial Balloon Technology

Lead Center: GSFC
Participating Center(s): JPL

The Balloon Program Office (BPO) is soliciting innovations in two specific areas:

(1) Currently, the Balloon Program Office is developing an Ultra Long Duration Balloon (ULDB) vehicle targeting 100 day duration missions in mid-latitude. This added capability will greatly enable new science investigations. The design of the current pumpkin shape vehicle utilizes light weight polyethylene film and high strength tendons made of twisted Zylon® yarn. The in-flight performance and health of the vehicle relies on accurate information on a number of environmental and design parameters. Therefore, NASA is seeking innovations in the following specific areas:

Tendons are the load carrying member in the pumpkin design. During a typical mission, loading on individual tendons should not exceed a critical design limit to insure structural integrity and survival. A key technology challenge is the development of devices or methods to accurately and continuously measure individual axial loading on an array of up to 200 separate tendons during a ULDB mission. Tendons are typically captured at the fitting via individual pins. Loading levels on the tendons can range from ~20 N to ~8,000 N and temperature can vary from room temperature to the troposphere temperatures of -90°C or colder. The devices of interest shall be easily integrated with the tendons or fittings during balloon fabrication and shall have minimal impact on the overall mass of the balloon system.

Ambient air, helium gas, and balloon film temperature measurements are needed to accurately model the balloon performance during a typical flight at altitudes of approximately 120,000 feet. The measurement must compensate for the effects of direct solar radiation through shielding or calculation. Minimal mass and volume are highly desired. For film measurement, a non-invasive and non-contact approach is highly desired for the thin polyethylene film, with film thickness ranging from 0.8 to 1.5 mils, used as the balloon envelope.
(2) The Balloon Program Office is also seeking innovations to reduce the effects of parachute opening shock on gondolas and balloon subsystems. This shock is produced by the rapid opening of a flight system's parachute after the payload is released from the balloon at mission termination.

Innovations may address the problem either by reducing the termination shock via modifications to the recovery system or by attenuating the shock produced by current recovery systems. Proposed technologies will be evaluated for their mass efficiency, ease of integration, effectiveness at reducing shock levels, compatibility with balloon flight environments, and cost effectiveness, among other factors.

Research should be conducted to demonstrate technical feasibility during Phase 1 and show a path toward a Phase 2 hardware/software demonstration, and when possible, deliver a demonstration unit for functional and environmental testing at the completion of the Phase 2 contract.