



## NASA SBIR 2016 Phase I Solicitation

### S3 Spacecraft and Platform Subsystems

The Science Mission Directorate will carry out the scientific exploration of our Earth, the planets, moons, comets, and asteroids of our solar system and the universe beyond. SMD's future direction will be moving away from exploratory missions (orbiters and flybys) into more detailed/specific exploration missions that are at or near the surface (landers, rovers, and sample returns) or at more optimal observation points in space. These future destinations will require new vantage points, or would need to integrate or distribute capabilities across multiple assets. Future destinations will also be more challenging to get to, have more extreme environmental conditions and challenges once the spacecraft gets there, and may be a challenge to get a spacecraft or data back from.

A major objective of the NASA science spacecraft and platform subsystems development efforts are to enable science measurement capabilities using smaller and lower cost spacecraft to meet multiple mission requirements thus making the best use of our limited resources. To accomplish this objective, NASA is seeking innovations to significantly improve spacecraft and platform subsystem capabilities while reducing the mass and cost that would in turn enable increased scientific return for future NASA missions.

A spacecraft bus is made up of many subsystems like: propulsion; thermal control; power and power distribution; attitude control; telemetry command and control; transmitters/antenna; computers/on-board processing/software; and structural elements. Science platforms of interest could include unmanned aerial vehicles, sounding rockets, or balloons that carry scientific instruments/payloads, to planetary ascent vehicles or Earth return vehicles that bring samples back to Earth for analysis. This topic area addresses the future needs in many of these sub-system areas, as well as their application to specific spacecraft and platform needs.

Innovations for 2016 are sought in the areas of:

- Command and Data Handling, and Instrument Electronics
- Power Generation and Conversion
- Propulsion Systems for Robotic Science Missions
- Power Electronics and Management, and Energy Storage
- Unmanned Aircraft and Sounding Rocket Technologies
- Thermal Control Systems
- Guidance, Navigation and Control
- Terrestrial and Planetary Balloons

For planetary missions, 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 115° C or higher, non-functioning); penetrating radiation (requirements not yet established); or vapor-phase hydrogen peroxide (specification pending). The following references discuss some of

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NASA's science mission and technology needs:

- The Astrophysics Roadmap - (<http://nasascience.nasa.gov/about-us/science-strategy>).
- Astrophysics Decadal Survey - "New Worlds, New Horizons: in Astronomy and Astrophysics" ([http://www.nap.edu/catalog.php?record\\_id=12951](http://www.nap.edu/catalog.php?record_id=12951)).
- The Earth Science Decadal Survey - ([http://books.nap.edu/catalog.php?record\\_id=11820](http://books.nap.edu/catalog.php?record_id=11820)).
- The Heliophysics roadmap - "The Solar and Space Physics of a New Era: Recommended Roadmap for Science and Technology 2009 - 2030" ([http://sec.gsfc.nasa.gov/2009\\_Roadmap.pdf](http://sec.gsfc.nasa.gov/2009_Roadmap.pdf)).
- The 2011 Planetary Science Decadal Survey was released March 2011. This decadal survey is considering technology needs - (<http://www.nap.edu/catalog/13117/vision-and-voyages-for-planetary-science-in-the-decade-2013-2022>).

## Subtopics

### S3.01 Power Generation and Conversion

Lead Center: GRC

Participating Center(s): ARC, 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-generation and conversion technologies to enable or enhance the capabilities of future science missions. Requirements for these missions are varied and include long life, high reliability, significantly lower mass and volume, higher mass specific power, and improved efficiency over the state of practice for components and systems. Other desired capabilities are high radiation tolerance and the ability to operate in extreme environments (high and low temperatures and over wide temperature ranges).

While power-generation technology affects a wide range of NASA missions and operational environments, technologies that provide substantial benefits for key mission applications/capabilities are being sought in the following areas:

#### Photovoltaic Energy Conversion

Photovoltaic cell, blanket, and array technologies that lead to significant improvements in overall solar array performance (i.e., conversion efficiency >33%, array mass specific power >300watts/kilogram, decreased stowed volume, reduced initial and recurring cost, long-term operation in high radiation environments, high power arrays, and a wide range of space environmental operating conditions) are solicited. Photovoltaic technologies that provide enhancing and/or enabling capabilities for a wide range of aerospace mission applications will be considered. Technologies that address specific NASA Science mission needs include:

- Photovoltaic cell and blanket technologies capable of low intensity, low-temperature operation applicable to outer planetary (low solar intensity) missions.
- Photovoltaic cell, blanket and array technologies capable of enhancing solar array operation in a high intensity, high-temperature environment (i.e., inner planetary and solar probe-type missions).
- Solar arrays to support Extreme Environments Solar Power type missions, including long-lived, radiation tolerant, cell and blanket technologies capable of operating in environments characterized by varying degrees of light intensity and temperature.
- Lightweight solar array technologies applicable to science missions using solar electric propulsion. Current science missions being studied require solar arrays that provide 1 to 20 kilowatts of power at 1 AU, greater than 300 watts/kilogram specific power, operation in the range of 0.7 to 3 AU, low stowed volume, and the ability to provide operational array voltages up to 300 volts.

**Stirling Power Conversion: advances in, but not limited to, the following**

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- Novel Stirling convertor configurations that provide high efficiency (>25%), low mass, long life (>10 yrs), and high reliability for use in 100-500 We Stirling radioisotope generators.
  - Advanced Stirling convertor components including hot-end heat exchangers, cold-end heat exchangers, regenerators, linear alternators, engine controllers, and radiators.
  - Innovative Stirling generator features that improve the fault tolerance (e.g., heat source backup cooling devices, mechanical balancers) or expand the mission applications (e.g., duplex power and cooling systems).

### **Direct Energy Conversion; advances in, but not limited to, the following**

Recent advancements in alpha/beta-voltaic energy conversion devices have the potential to increase the power level, improve reliability, and increase the lifetime of this power technology. The increased use of cubesat/smallsat technology and autonomous remote sensors in support of NASA Science Mission goals has demonstrated the need for low-power, non-solar energy sources. The area of Direct Energy Conversion seeks technology advancements that address, but are not limited to:

- Experimental demonstration of long life (multiyear) alpha-voltaic and beta-voltaic devices with device-level conversion efficiencies in excess of 10%, high reliability, minimal operational performance degradation, and the ability to scale up to 1-10 W of electrical power output with system-level specific power of 5 W/kg or higher.

### **S3.02 Propulsion Systems for Robotic Science Missions**

**Lead Center:** GRC

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

The Science Mission Directorate (SMD) needs spacecraft with more demanding propulsive performance and flexibility for more ambitious missions requiring high duty cycles, more challenging environmental conditions, and extended operation. Planetary spacecraft need the ability to rendezvous with, orbit, and conduct in-situ exploration of planets, moons, and other small bodies in the solar system ([http://solarsystem.nasa.gov/multimedia/download-detail.cfm?DL\\_ID=742](http://solarsystem.nasa.gov/multimedia/download-detail.cfm?DL_ID=742)). Future spacecraft and constellations of spacecraft will have high-precision propulsion requirements, usually in volume- and power-limited envelopes.

This subtopic seeks innovations to meet SMD propulsion in chemical and electric propulsion systems related to sample return missions to Mars, small bodies (like asteroids, comets, and Near-Earth Objects), outer planet moons, and Venus. Additional electric propulsion technology innovations are also sought to enable low cost systems for Discovery class missions, and low-power, nuclear electric propulsion (NEP) missions. Roadmaps for propulsion technologies can be found from the National Research Council ([http://www.nap.edu/openbook.php?record\\_id=13354&page=168](http://www.nap.edu/openbook.php?record_id=13354&page=168)) and NASA's Office of the Chief Technologist ([http://www.nasa.gov/pdf/501329main\\_TA02-InSpaceProp-DRAFT-Nov2010-A.pdf](http://www.nasa.gov/pdf/501329main_TA02-InSpaceProp-DRAFT-Nov2010-A.pdf)).

Proposals should show an understanding of the state of the art, how their technology is superior, and of one or more relevant science needs. The proposals should provide a feasible plan to fully develop a technology and infuse it into a NASA program.

#### **Advanced Electric Propulsion Components**

This subtopic also seeks proposals that explore uses of technologies that will provide superior performance in for high specific impulse/low mass electric propulsion systems at low cost. These technologies include:

- High thrust-to-power ion thruster component or system technologies. Key characteristics include:
  - Power < 14 kW.

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- T/P > SOA Hall Effect Thrusters at comparable specific impulse ranging from 1500-3000 seconds.
  - Lifetimes > 10,000 hours.
  - Thruster components including, but not limited to, advanced cathodes, rf devices, advanced grids, lower-cost components.
  - Any long-life, electric propulsion technology between 1 to 10 kW/thruster that would enable a low-power nuclear electric propulsion system based on a kilowatt nuclear reactor.
  - Instrumentation and support equipment that will enable or improve ground testing of electric propulsion power processor units.

### Secondary Payload Propulsion

The secondary payload market shows significant promise to enable low cost science missions. Launch vehicle providers, like SLS, are considering a large number of secondary payload opportunities. The majority of small satellite missions flown are often selected for concept or component demonstration activities as the primary objectives. Opportunities are anticipated to select future small satellite missions based on application goals (i.e., science return). However, several technology limitations prevent high value science from low-cost small spacecraft, such as post deployment propulsion capabilities. Additionally, propulsion systems often place constraints on handling, storage, operations, etc. that may limit secondary payload consideration. It is desired to have a wide range of Delta-V capability to provide 100-1000s of m/s.

Specifically, proposals are sought for:

- Chemical and/or electric propulsion systems with green/non-toxic propellants,
- RF devices,
- Improved operational life over SOA propulsion systems, and
- 1U sized solar electric ionized gas propulsion unit with delta V of 1-8 km/s for 6U CubeSat, and a clear plan for demonstrated constellation station keeping capability for 6 months in LEO.

In addressing technology requirements, proposers should identify potential mission applications and quantify the expected advancement over state-of-the-art alternatives.

*Note to Proposer* - Topics under the Human Exploration and Operations Directorate also addresses advanced propulsion. Proposals more aligned with exploration mission requirements should be proposed in H2.

### S3.03 Power Electronics and Management, and Energy Storage

Lead Center: GRC

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

NASA's science

vision ([http://science.nasa.gov/media/medialibrary/2014/05/02/2014\\_Science\\_Plan-0501\\_tagged.pdf](http://science.nasa.gov/media/medialibrary/2014/05/02/2014_Science_Plan-0501_tagged.pdf)) is to use the vantage point of space to achieve with the science community and our partners a deep scientific understanding of the Sun and its effects on the solar system, our home planet, other planets and solar system bodies, the interplanetary environment, and the universe beyond. Scientific priorities for future planetary science missions are guided by the recommendations of the decadal surveys published by the National Academies. The goal of the decadal surveys is to articulate the priorities of the scientific community, and the surveys are therefore the starting point for NASA's strategic planning process in science ([http://science.nasa.gov/media/medialibrary/2014/04/18/FY2014\\_NASA\\_StrategicPlan\\_508c.pdf](http://science.nasa.gov/media/medialibrary/2014/04/18/FY2014_NASA_StrategicPlan_508c.pdf)). The most recent planetary science decadal survey, Vision and Voyages for Planetary Science in the Decade 2013 - 2022, was released in 2011. This report recommended a balanced suite of missions to enable a steady stream of new discoveries and capabilities to address challenges such as sample return missions and outer planet exploration. Under this subtopic, proposals are solicited to develop energy storage and power electronics to enable or enhance the capabilities of future NASA science missions. The unique requirements for the power systems for these missions can vary greatly, with advancements in components needed above the current State of the Art (SOA) for high energy density, high power density, long life, high reliability, low mass/volume, radiation tolerance, and wide temperature operation. Other subtopics which could potentially benefit from these technology

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developments include S4.04 Extreme Environments Technology, and S4.01 Planetary Entry, Descent and Landing Technology. This subtopic is also directly tied to S3.02 Propulsion Systems for Robotic Science Missions for the development of advanced Power Processing Units and associated components.

### **Power Electronics and Management**

NASA's Planetary Science Division is working to implement a balanced portfolio within the available budget and based on the decadal survey that will continue to make exciting scientific discoveries about our solar system. This balanced suite of missions show the need for low mass/volume power electronics and management systems and components that can operate in extreme environment for future NASA Science Missions. In addition, studying the Sun, the heliosphere, and other planetary environments as an interconnected system is critical for understanding the implications for Earth and humanity as we venture forth through the solar system. To that end, the NASA heliophysics program seeks to perform innovative space research missions to understand:

- The Sun and its variable activity.
- How solar activity impacts Earth and the solar system.
- Fundamental physical processes that are important at Earth and throughout the universe by using space as a laboratory.

Heliophysics also seeks to enable research based on these missions and other sources to understand the connections among the Sun, Earth, and the solar system for science and to assure human safety and security both on Earth and as we explore beyond it. Advances in electrical power technologies are required for the electrical components and systems of these future spacecrafts/platforms to address program size, mass, efficiency, capacity, durability, and reliability requirements. Radioisotope power systems (RPS), Advanced Modular Power Systems (AMPS) and In-Space Electric Propulsion (ISP) are several programs of interest which would directly benefit from advancements in this technology area. These types of programs, including Mars Sample Return using Hall thrusters and power processing units (PPUs), require advancements in radiation hardened power electronics, especially tolerant of single event upsets, and systems beyond the state-of-the-art. Of importance are expected improvements in energy density, speed, efficiency, or wide-temperature operation (-125° C to over 450° C) with a number of thermal cycles. Novel approaches to minimizing the weight of advanced PPUs are also of interest. Advancements are sought for power electronic devices, components, packaging and cabling for programs with power ranges of a few watts for minimum missions to up to 20 kilowatts for large missions. In addition to electrical component development, RPS has a need for intelligent, fault-tolerant Power Management and Distribution (PMAD) technologies to efficiently manage the system power for these deep space missions.

Also, in order to maximize functional capability for Earth Observations, operate higher performance instruments and deliver significantly better data and imagery from a small spacecraft, more capable power systems are needed. NASA is interested in a power system (stretch goal of 100w) that can be integrated into a cubesat or nanosat for this purpose. The power system package must be restricted to 6U or 3U volume, and the design should minimize orientation restrictions. The system should be capable of operating for a minimum of 6 months in LEO.

SMD's In-space Propulsion Technology, Radioisotope Power Systems and Cubesat/Nanosat programs are direct customers of this subtopic.

Overall technologies of interest include:

- High power density/high efficiency power electronics and associated drivers for switching elements.
- Non-traditional approaches to switching devices, such as addition of graphene and carbon nano-tubes to material
- Radiation hardened (single event effects), 1200 V (or greater) MOSFETs and high speed diodes for high voltage space missions (300 V average, 600 V peak).
- Lightweight, highly conductive power cables and/or cables integrated with vehicle structures.
- Intelligent power management and fault-tolerant electrical components and PMAD systems.
- Advanced electronic packaging for thermal control and electromagnetic shielding
- Integrated packaging technology for modularity.
- Cubesat/nanosat power systems up to 100 watts

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Patent 6,461,944, Methods for growth of relatively large step-free SiC crystal surfaces Neudeck, et al., October 8, 2002.

A method for growing arrays of large-area device-size films of step-free (i.e., atomically flat) SiC surfaces for semiconductor electronic device applications is disclosed. This method utilizes a lateral growth process that better overcomes the effect of extended defects in the seed crystal substrate that limited the obtainable step-free area achievable by prior art processes. The step-free SiC surface is particularly suited for the heteroepitaxial growth of 3C (cubic) SiC, AlN, and GaN films used for the fabrication of both surface-sensitive devices (i.e., surface channel field effect transistors such as HEMT's and MOSFET's) as well as high-electric field devices (pn diodes and other solid-state power switching devices) that are sensitive to extended crystal defects.

## **Energy Storage**

Future science missions will require advanced primary and secondary battery systems capable of operating at temperature extremes from -100° C for Titan missions to 400 to 500° C for Venus missions, and a span of -230° C to +120° C for Lunar Quest. The Outer Planet Assessment Group and the 2011 PSD Relevant Technologies Document have specifically called out high energy density storage systems as a need for the Titan/Enceladus Flagship and planetary exploration missions. In addition, high energy-density rechargeable electrochemical battery systems that offer greater than 50,000 charge/discharge cycles (10 year operating life) for low-earth-orbiting spacecraft, 20 year life for geosynchronous (GEO) spacecraft, are desired. Advancements to battery energy storage capabilities that address one or more of the above requirements for the stated missions combined with very high specific energy and energy density (>200 Wh/kg for secondary battery systems), along with radiation tolerance are of interest.

In addition to batteries, other advanced energy storage/load leveling technologies designed to the above mission requirements, such as mechanical or magnetic energy storage devices, are of interest. These technologies have the potential to minimize the size and mass of future power systems.

Research should be conducted to demonstrate technical feasibility during Phase I and show a path toward a Phase II, and when possible, deliver a demonstration unit for NASA testing at the completion of the Phase II contract. Phase II emphasis should be placed on developing and demonstrating the technology under relevant test conditions. Additionally, a path should be outlined that shows how the technology could be commercialized or further developed into science-worthy systems.

## **S3.04 Unmanned Aircraft and Sounding Rocket Technologies**

**Lead Center:** GSFC

**Participating Center(s):** AFRC, ARC, GRC, JPL, LaRC

### **Unmanned Aircraft Systems Technologies**

Breakthrough technologies are sought that will enhance performance and utility of NASA's Airborne Science fleet with unmanned aircraft systems (UAS). Novel instrumented platforms or innovative subsystems suitable for addressing specific Earth science research goals are desired. Relevant NASA and FAA requirements must be addressed. Potential concepts include:

- Long endurance (~1 month) small UAS for miniature (~2 lb) instrument packages scalable to larger platforms.
- Fuel cell propulsion and high efficiency airframes for high altitude/long endurance (HALE, target ~50 kft, 2 days endurance with 50 lb payload).
- Harsh environment flight (e.g., for volcanic eruptions, fires) including high density altitude (20 kft asl), high turbulence, high temperature (300 to 500° C), significant icing, or corrosive environments.
- Novel flight management approaches such as dynamic soaring, autonomous mission planning, terrain following, or autonomously linking aircraft.

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- Small UAS for in-situ cloud measurements.
  - Guided dropsondes.
  - Airspace monitoring system for small UAS operations.
  - Over-the-horizon communications systems with increased bandwidth.

### **Sounding Rocket Technologies**

The NASA Sounding Rockets Program provides low-cost, sub-orbital access to space in support of space and Earth sciences research. NASA utilizes a variety of vehicle systems comprised of surplus and commercially available rocket motors, capable of lofting scientific payloads of up to 1300lbs, to altitudes from 100km to 1500km. NASA launches sounding rocket vehicles worldwide, from both land-based and water-based ranges, based on the science needs to study phenomenon in specific locations. Of particular interest are systems that will enable water recovery of payloads from high altitude flights from locations such as launch ranges at Wallops Island VA or Andoya, Norway. New telemetry approaches are also encouraged. Specific elements may include:

- High speed decelerators.
- Steerable high altitude parachute systems.
- Water recovery aids such as floatation devices, location systems, and robotic capabilities.
- Ruggedized over-the-horizon telemetry systems with increased bandwidth.
- Constellation communication for sub-to-main payload data telemetry
- 10 to 50 MB/s for primary data, 1 to 2 MB/s for sub payloads, ~30 cubic inches (without antenna), with C or S band desired

### **S3.05 Guidance, Navigation and Control**

**Lead Center: GSFC**

**Participating Center(s): ARC, JPL**

NASA seeks innovative, ground breaking, and high impact developments in spacecraft guidance, navigation, and control technologies in support of future science and exploration mission requirements. This subtopic covers the technologies enabling significant performance improvements over the state of the art in the areas of spacecraft attitude determination and control, spacecraft absolute and relative orbit and attitude navigation, pointing control, and SmallSat/CubeSat technologies.

Component technology developments are sought for the range of flight sensors, actuators, and associated algorithms and software required to provide these improved capabilities. Technologies that apply to all spacecraft platform sizes will be considered. Special considerations will be given to emerging technologies applicable to SmallSat/CubeSat class spacecraft if they are technology leaps and mission enabling.

Advances in the following areas are sought:

- *Spacecraft Attitude Determination and Control Systems* - Sensors and actuators that enable milli-arcsecond class pointing capabilities for large space telescopes, with improvements in size, weight, and power requirements.
- *Absolute and Relative Navigation Systems* - Autonomous onboard flight navigation sensors and algorithms incorporating both spaceborne and ground-based absolute and relative measurements. For relative navigation, machine vision technologies apply. Special considerations will be given to relative navigation sensors enabling precision formation flying, astrometric alignment of a formation of vehicles, robotic servicing and sample return capabilities, and other GN&C techniques for enabling the collection of distributed science measurements.
- *Pointing Control Systems* - Mechanisms that enable milli-arcsecond class pointing performance on any spaceborne pointing platforms. Active and passive vibration isolation systems, innovative actuation feedback, or any such technologies that can be used to enable other areas within this subtopic apply.
- *SmallSat/CubeSat Technologies* - Lightweight, low power, compact sensors and actuators that push the

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state-of-the-art for SmallSat/CubeSat attitude and orbit controls capabilities. Arcsecond-level pointing performance, non-propulsive orbit control, and radiation hardening technologies apply. NASA would like to utilize SmallSat/CubeSat technologies on missions beyond LEO therefore special considerations would be given to proposals addressing those needs.

Phase I research should be conducted to demonstrate technical feasibility as well as show a plan towards Phase II integration and component/prototype testing in a relevant environment. Phase II technology development efforts shall deliver component/prototype at the TRL 5-6 level consistent with NASA SBIR/STTR Technology Readiness Level (TRL) Descriptions. Delivery of final documentation, test plans, and test results are required. Delivery of a hardware component/prototype under the Phase II contract is preferred.

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

### **S3.06 Terrestrial and Planetary Balloons**

**Lead Center:** GSFC

**Participating Center(s):** JPL

#### **Terrestrial Balloons**

NASA's Scientific Balloons provide practical and cost effective platforms for conducting discovery science, development and testing for future space instruments, as well as training opportunities for future scientists and engineers. Balloons can reach altitudes above 36 kilometers, with suspended masses up to 3600 kilograms, and can stay afloat for several weeks. Currently, the Balloon Program is on the verge of introducing an advanced balloon system that will enable 100 day missions at mid-latitudes and thus resemble the performance of a small spacecraft at a fraction of the cost. In support of this development, NASA is seeking innovative technologies in three key areas:

#### **Power Storage**

Improved and innovative devices to store electrical energy onboard balloon payloads are needed. Long duration balloon flights can experience 12 hours or more of darkness, and excess electrical power generated during the day from solar panels needs to be stored and used. Improvements are needed over the current state of the art in power density, energy density, overall size, overall mass and/or cost. Typical parameters for balloon are 28 VDC and 100 to 1000 watts power consumption. Rechargeable batteries are presently used for balloon payload applications. Lithium Ion rechargeable batteries with energy densities of 60 watt-hours per kilogram are the current state of the art. Higher power storage energy densities, and power generation capabilities of up to 2000 watts are needed for future support.

#### **Satellite Communications**

Improved and innovative downlink bitrates using satellite relay communications from balloon payloads are needed. Long duration balloon flights currently utilize satellite communication systems to relay science and operations data from the balloon to ground based control centers. The current maximum downlink bit rate is 150 kilobits per second operating continuously during the balloon flight. Future requirements are for bit rates of 1 megabit per second or more. Improvements in bit rate performance, reduction in size and mass of existing systems, or reductions in cost of high bit rate systems are needed. TDRSS and Iridium satellite communications are currently used for balloon payload applications. A commercial S-band TDRSS transceiver and mechanically steered 18 dBi gain antenna provide 150 kbps continuous downlink. TDRSS K-band transceivers are available but are currently cost prohibitive. Open port Iridium service is under development, but the operational cost is prohibitive.

#### **UV Protection Technologies**



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Innovative, economic, and applicable processes or materials to protect the balloon flight train subsystems and the balloon components are needed. Long duration balloon missions on the order of 100 days will expose the balloon flight train subsystems such as the parachute, and the balloon components such as the high strength tendons, to the harmful effects of UV exposure. The impact may lead to shorter duration missions and/or severe damage to the science payloads. Innovative concepts are needed for the protection of these subsystems or components to eliminate or minimize these adverse UV effects. The proposed innovative concepts shall be economic and practical. It shall be easy to implement with no major impact on balloon design, fabrication, packaging, or launch operations.

## **Planetary Balloons**

Innovations in materials, structures, and systems concepts have enabled the lifetime of Titan and Venus buoyant vehicles to play an expanding role in NASA's future Solar System Exploration Program. Balloons are expected to carry scientific payloads at Titan and Venus that will perform in-situ investigations of their atmospheres and near surface environments. Both Titan and Venus feature extreme environments that significantly impact the design of balloons for those two worlds and efficient use of energy is critical.

Proposals are sought in the following areas:

### **Floating Platforms for Venus (New)**

NASA is interested in conducting long term monitoring of the Venus atmosphere and the signatures of seismic and volcanic events from the planetary surface using floating vehicles at altitudes of between 30 and 45 km for periods in excess of five years. Concepts that use ammonia or water as a source of buoyancy as well as conventional light gases hydrogen and helium should be considered. A primary focus should be on the design of the flotation device and the materials for achieving long duration operation. The temperature at 45 km is roughly 110° C; at 30 km it is about 225° C. It is expected that a Phase I effort will consist of a system-level design and a proof-of-concept experiment on one or more key components.

### **Altitude and Positional Control for Titan Aerial Vehicles (NEW)**

NASA is interested in Titan aerial vehicles that can both change altitude and also execute controlled movements in latitude and longitude in order to target surface locations of interest. Innovative concepts are sought that can minimize the use of scarce power resources and can achieve controlled motions in latitude under all anticipated atmosphere conditions and in longitude for parts of the Titan year. The targeted capabilities for the system are as follows: altitude range between the surface and 15 km, system mass of payload, power and communications systems of 100 kg; average power usage for horizontal and vertical mobility of less than 50 watts. It is expected that a Phase I effort will consist of a complete system-level design and a proof-of-concept experiment on one or more key components.

## **S3.07 Thermal Control Systems**

**Lead Center:** GSFC

**Participating Center(s):** ARC, GRC, JPL, JSC, LaRC, MSFC

Future Spacecraft and instruments for NASA's Science Mission Directorate will require increasingly sophisticated thermal control technology. Innovative proposals for the cross-cutting thermal control discipline are sought in the following areas:

- Components of advanced small spacecraft such as CubeSat/SmallSat will have very small masses (i.e., small thermal capacitance), and their temperatures are highly sensitive to variations in the component power output and spacecraft environmental temperature. Advanced thermal devices capable of maintaining components within their specified temperature ranges are needed. Some examples are:
  - Phase change systems with high thermal capacity and minimal structural mass.
  - High performance, low cost insulation systems for diverse environments.

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- High flux heat acquisition and transport devices; d) thermal coatings with low absorptance, high emittance, and good electrical conductivity; and e) a miniature pumped fluid loop system that is lightweight, provides radiator turndown, and consumes minimal power (< 2W).
  - Current capillary heat transfer devices require tedious processes to insert the porous wick into the evaporator and to seal the wick ends for liquid and vapor separation. Advanced technology such as additive manufacturing is needed to simplify the processes and ensure good sealing at both ends of the wick, especially for miniature thermal systems for CubeSat/SmallSat applications. Additive manufacturing technology can also be used to produce integrated heat exchangers for pumped fluid loops in order to increase heat transfer performance while significantly reducing mass, labor and cost.
  - Science missions are more dependent on optically sensitive instruments and systems, and effects of thermal distortion on the performance of the system are critical. Current Structural-Thermal-Optical (STOP) analysis has several codes that do some form of integrated analysis, but none that have the capability to analyze any optical system and do a full end-to-end analysis. An improvement of existing code is needed in order to yield software that can integrate with all commonly used programs at NASA for mechanical, structural, thermal and optical analysis. The software should be user-friendly, and allow full STOP analysis for performance predictions based on mechanical design, and structural/thermal material properties.
  - Missions with high sink temperatures require temperature lifting devices in order to dissipate the heat. Some advanced devices having long life, high efficiency are sought for, including absorption/adsorption systems, advanced TECs, etc. The use of heat lift devices can also reduce the radiator area, hence realizing mass and volume savings.
  
  - Current analysis for ablation analysis of re-entry vehicles utilizes various computer codes for predicting the following individual phenomena: aeroheating, ablation, thermal response behind the bond line, thermal radiation, and structural response to thermal and pressure environments. The interfaces between each code lead to potential errors, inaccuracy, and huge computer run time. What is needed is a single code that evaluates the trajectory or input conditions, predicts aeroheating over the surface, does an integrated ablation-thermal analysis, and then uses that thermal and pressure gradient to do a full structural analysis. Even better would be a link back to the aeroheating prediction code to revise the aeroheating based on shape change from structural analysis and ablation.
  - New techniques for measuring the internal pressure of arcjet test samples are sought. Modern ablation codes such as FEAR and CHAR solve the Darcy flow equations to track both the internal pyrolysis gas pressure and mass flow. However, there is currently no data available to validate the internal pressure calculations due to a lack of a reliable and accurate measurement system. The internal pressure calculation becomes even more important when analyzing flexible thermal protection system materials which are highly porous.

Research should be conducted to demonstrate technical feasibility during Phase I and show a path toward a Phase II hardware demonstration. Phase II should deliver a demonstration unit for NASA testing at the completion of the Phase II contract.

### **S3.08 Slow and Fast Light**

**Lead Center: MSFC**

Steep dispersions in engineered media of a wide variety have opened up a new direction of research in optics. A positive dispersion can be used to slow the propagation of optical pulses to extremely small velocities. Similarly, a negative dispersion can lead to conditions where pulses propagate superluminally. These effects have now moved beyond the stage of intellectual curiosity, and have ushered in studies of a set of exciting applications of interest to NASA, ranging from ultraprecise superluminal gyroscopes to spectral interferometers having enhanced resolving power.

This research subtopic seeks slow-light and/or fast-light enhanced sensors for space applications of interest to NASA including:

#### **Superluminal gyroscopes and accelerometers (both passive and active)**

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- Enhanced strain and displacement sensors for non-destructive evaluation and integrated vehicle health management applications.
  - Slow-light-enhanced spectrally-resolved interferometers for astrophysical and Earth science observations, as well as for exploration goals.
  - Other applications of slow and fast light related to NASA's mission areas.

### **Superluminal gyroscopes**

In conventional ring laser gyroscopes, sensitivity increases with cavity size. Fast light, however, can be used to increase gyro sensitivity without having to increase size, for spacecraft navigation systems which are constrained by weight and volume. The increased sensitivity also opens up new science possibilities such as detection of subsurface geological features, tests of Lorentz invariance, improving the bandwidth sensitivity product for gravity wave detection, and tests of general relativity. This research subtopic seeks:

- Prototype fast light gyroscopes, active or passive, that unambiguously demonstrate a scale factor enhancement of at least 10 with the potential for 1000. The minimum or quantum-noise limited angular random walk (ARW) should also decrease.
- Designs for fast light gyros that do not require frequency locking, are not limited to operation at specific frequencies such as atomic or material resonances, and permit operation at any wavelength.
- Fast light gyroscope designs that are rugged, compact, monolithic, rad-hard, and tolerant to variations in temperature and varying G-conditions.

### **Slow-light enhanced spectral interferometers**

Slow light has the potential to increase the resolving power of spectral interferometers such as Fourier transform spectrometers (FTS) for astrophysical applications without increasing their size. Mariner, Voyager, and Cassini all used FTS instruments for applications such as mapping atmospheres and examining ring compositions. The niche for FTS is usually thought to be for large wavelength (IR and beyond), wide-field, moderate spectral resolution instruments. Slow light, however, could help boost FTS spectral resolution making FTS instruments more competitive with grating-based instruments, and opening up application areas not previously thought to be accessible to FTS instruments, such as exoplanet detection. A slow-light FTS could also be hyper-spectral, providing imaging capability. FTS instruments have been employed for remote sensing on NASA Earth Science missions, such as the Atmospheric Trace Molecule Spectroscopy (ATMOS), Cross-track Infrared Sounder (CrIS), and Tropospheric Emission Spectrometer (TES) experiments, and have long been considered for geostationary imaging of atmospheric greenhouse gases. This research subtopic seeks research and development of slow-light-enhanced spectral interferometers that are not restricted by material resonances and can operate at any wavelength. An inherent advantage of FTS systems are their wide bandwidth. It will therefore be of importance to develop slow light FTS systems that can maintain a large operating bandwidth.

## **S3.09 Command, Data Handling, and Electronics**

**Lead Center: GSFC**

**Participating Center(s): JPL, LaRC**

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 command and data handling and instrument electronics are sought to support NASA's goals and several missions and projects under development.

The 2016 subtopic goals are to develop platforms for the implementation of miniaturized highly integrated avionics and instrument electronics that:

- Are consistent with the performance requirements for NASA science missions.

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- Minimize required mass/volume/power as well as development cost/schedule resources.
  - Can operate reliably in the expected thermal and radiation environments.
  - Successful proposal concepts should significantly advance the state-of-the-art. Proposals should clearly:
  - State what the product is.
  - Identify the needs it addresses.
  - Identify the improvements over the current state of the art.
  - Outline the feasibility of the technical and programmatic approach.
  - Present how it could be infused into a NASA program.

Furthermore, proposals developing hardware should indicate an understanding of the intended operating environment, including temperature and radiation. It should be noted that environmental requirements can vary significantly from mission to mission. For example, some low earth orbit missions have a total ionizing dose (TID) radiation requirement of less than 10 krad(Si), while some planetary missions can have requirements well in excess of 1 Mrad(Si). For descriptions of radiation effects in electronics, the proposer may visit (<http://radhome.gsfc.nasa.gov/radhome/overview.htm>).

If a Phase II proposal is awarded, the combined Phase I and Phase II developments should produce a prototype that can be characterized by NASA.

The technology priorities sought are listed below:

- *Spaceflight Multicore Middleware* - Current and emerging spaceflight processors are leveraging multi-core architectures to satisfy the ever increasing onboard processing demands. These architectures can provide increased processing bandwidth, power efficiency, and fault tolerance for onboard processing applications. However, these advantages come at the cost of increased hardware and software complexity. As software development is a major cost driver for missions, this increased complexity has the potential to significantly increase cost for future NASA missions. To address this risk, this subtopic solicits Spaceflight Multicore Middleware technology providing machine management for multicore processing devices. This middleware software layer shall primarily reside between the application layer and the operating system, with extensions into and below the OS as necessary, to provide intelligent resource, fault, and power management. By providing these functions, application software can be largely agnostic to underlying hardware, thereby reducing cost and complexity. It is desired that the middleware software support multiple processor architectures. Examples include, but not limited to, ARM, Freescale, Tilera, and LEON, and those that support a number of cores ranging from 2-32.
- *Advanced Spaceflight Memory* - As spaceflight processor technology advances to provide increased bandwidth, power efficiency, and flexibility, advanced spaceflight memory devices are needed to fully leverage these improvements. This subtopic solicits technologies enabling power efficient, high performance volatile spaceflight memory incorporating high speed, fault tolerant, serial interfaces, internal EDAC, power and fault management, and 2.5/3D manufacturing processes enabling implementation of miniaturized, highly-reliable fault tolerant systems.
- *Point-of-Load Power Converters* - Emerging spaceflight processors require multiple supply voltages, and multiple switched services for many of these voltages. Using currently available point-of-load power converters, an unacceptably large portion of future spaceflight computer boards will need to be dedicated for these devices. To address this concern, this subtopic solicits technologies enabling miniaturized spaceflight point-of-load power conversion and switching.
- *Radiation Shielding* - Innovative additive manufacturing and/or deposition technologies starting at TRL 3 are sought to create integral one-piece surface claddings of graded atomic number (Z) materials for use as radiation shielding for electronics. Shielding thicknesses must be able to achieve up to 3 g/cm<sup>2</sup> for initial shielding applications. At the end of Phase I, delivery of layered slabs and/or half sphere samples is expected with areal densities from 1 -3 g/cm<sup>2</sup>; samples must be able to show a strong interface property to avoid delamination and consistent density and thickness (areal density) uniformity.

This subtopic also solicits technologies enabling the use of COTS micropower/ultra-low power computing devices in highly reliable spacecraft avionics systems.

