



## NASA SBIR 2015 Phase I Solicitation

### S3 Spacecraft and Platform Subsystems

Lead Center: GRC

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.

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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.

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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.

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Innovations for 2015 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

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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 115C or higher, non-functioning); penetrating radiation (requirements not yet established); or vapor-phase hydrogen peroxide (specification pending).

The following references discuss some of 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* - Released March 2011. This decadal survey is considering technology needs. ([http://solarsystem.nasa.gov/multimedia/download-detail.cfm?DL\\_ID=742](http://solarsystem.nasa.gov/multimedia/download-detail.cfm?DL_ID=742)).

## 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.

#### Radioisotope Power Conversion

Radioisotope technology enables a wide range of mission opportunities, both near and far from the Sun and hostile planetary environments including high energy radiation, both high and low temperature and diverse atmospheric chemistries. Technology innovations capable of advancing lifetimes, improving efficiency, highly tolerant to hostile environments are desired for all thermal to electric conversion technologies considered here. Specific systems of interest for this solicitation are listed below:

#### Stirling Power Conversion

Advances in, but not limited to, the following:

- System specific mass greater than 10 We/kg.
- Highly reliable autonomous control.

#### Photovoltaic Energy Conversion

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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).
- Lightweight solar array technologies applicable to solar electric propulsion missions. Current missions being studied require solar arrays that provide 1 to 20 kilowatts of power at 1 AU, are greater than 300 watts/kilogram specific power, can operate in the range of 0.7 to 3 AU, provide operational array voltages up to 300 volts and have a low stowed volume.

Note that submissions for thermoelectrics technologies, formerly solicited by SMD, are now being solicited by STMD.

### **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.
  - 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-

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power nuclear electric propulsion system based on a kilowatt nuclear reactor.

## 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:

- Propulsion systems with green propulsion.
- Micropumps w/ Mon-25/MMH.
- Iodine propellants.
- 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 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

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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) and In-Space Electric Propulsion (ISP) are two 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 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 PPU's are also of interest. Advancements are sought for power electronic devices, components, packaging and cabling/wiring 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 voltage, radiation hardened, high temperature power passive components.
- High power density/high efficiency power electronics and associated drivers for switching elements.
- Radiation hardened, 1200 V (or greater) SiC 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, and nano-wiring for low power 28 V distribution.
- 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 W.

## **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

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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.

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.

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

**Lead Center: GSFC**

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

Breakthrough technologies are sought that will enhance performance and utility of NASA's Airborne Science fleet with expanded use of unmanned aircraft systems (UAS). Novel airborne platforms incorporating tailored sensors and instrumentation suitable for supporting specific NASA Earth science research goals are encouraged. Additionally, innovative subsystem elements that will support existing or future UAS are desired. Concepts should include a clear outline of steps planned to complete all relevant NASA and FAA requirements. Potential concepts include:

- Novel Navigation Systems (terrain following for example).
- Autonomous Mission Planning.
- One month endurance small UAS for miniature (~2 lb) instrument packages scalable to larger platforms.
- Novel propulsion concepts that will expand the flight envelope.
- Small UAS in-situ cloud measurement capabilities.
- Autonomously Linking UAS.
- Novel flight management approaches such as dynamic soaring.
- Guided Dropsondes.
- Airspace monitoring system for small UAS operations.
- Modular air vehicle systems for optimization for specific missions.
- Systems for air/ash sample return from volcanic plumes.
- Miniaturized 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

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recovery of payloads from high altitude flights from locations such as launch ranges at Wallops Island VA or Andoya, Norway. 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.

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

**Lead Center: GSFC**

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

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 positioning, navigation, timing, attitude determination, and attitude control. 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 a range of spacecraft platform sizes, from large, to mid-size, to emerging smallsat-cubesat class spacecraft are desired.

Advances in the following areas are sought:

- Navigation systems - Autonomous onboard flight navigation sensors and algorithms incorporating a range of measurements from GNSS measurements, ground-based optical and RF tracking, and celestial navigation. Also relative navigation sensors enabling precision formation flying and astrometric alignment of a formation of vehicles relative to a background starfield.
- 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. Also lightweight, compact sensors and actuators that will enable pointing performance comparable to large platforms on lower cost, small spacecraft.

Proposals should address the following specific technology needs:

- Precision attitude reference sensors, incorporating optical, inertial, and x-ray measurements, leading to significant increase in accuracy and performance over the current state of the art.
- Autonomous navigation sensors and algorithms applicable to missions in HEO orbits, cis-lunar orbits, and beyond earth orbit. Techniques using above the constellation GNSS measurements, as well as measurements from celestial objects.
- Compact, low power attitude determination and control systems for small satellite platforms, including ESPA (EELV Secondary Payload Adapter) class spacecraft and smaller, university standard cubesat form factors.
- Relative navigation sensors for spacecraft formation flying and autonomous rendezvous with asteroids. Technologies applicable to laser beam steering and pulsed lasers for LIDAR.
- 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,

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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 two 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.

### **Planetary Balloons**

Innovations in materials, structures, and systems concepts have enabled buoyant vehicles to play an expanding role in planning 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. Proposals are sought in the following areas:

#### **Power Systems for Titan Balloons**

NASA is interested in Titan balloons that can fly at an altitude range of 5 to 10 km above the surface for at least 30 days. Innovative concepts are sought for power systems capable of providing 100 Watts of electric power continuously at 28 Volts for a 30 day mission for a total electrical energy output of 72 kW-hrs. The system must be capable of operating within the Titan environment at 85 to 95 K. The Titan atmosphere at this altitude range contains approximately 95% nitrogen and 5% methane gas which may be harvested as an in situ fuel source. Waste heat from the power source can be used to keep the balloon payload at a warm operating temperature to reduce electrical heating requirements. Consideration should also be given to define requirements (e.g., power needs) placed on the host spacecraft during the transit to Titan from Earth, which could be as long as 8 years, for storage and retention of the fuel and oxidizer components. 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. Proposers should include estimates of the mass and volume of their power system concept.

#### **Steerable Antenna for Titan and Venus Telecommunications**

Many concepts for Titan and Venus balloons require high gain antennas mounted on the balloon gondola to transmit data directly back to Earth. This approach requires that the antenna remain mechanically or electronically pointed at the Earth despite the motions experienced during balloon flight. A beacon signal from the Earth will be available to facilitate pointing. Innovative concepts are sought for such an antenna and pointing system with the following characteristics: dish antenna diameter of 0.8 m (or equivalent non-dish gain), total mass of antenna and



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pointing system of d 10 kg, power consumption for the steering system d 5 W (avg.), pointing accuracy d 0.5 deg (continuous), hemispheric pointing coverage (2 pi steradians), azimuthal and rotational slew rates  $\hat{\Delta}^3$  30 deg/sec. It is expected that a Phase I effort will involve a proof-of-concept experiment leading to a plan for full scale prototype fabrication and testing in Phase II. Phase II testing will need to include an Earth atmosphere balloon flight in the troposphere to evaluate the proposed design under real flight conditions.

### 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.
  - High flux heat acquisition and transport devices.
  - Thermal coatings with low absorptance, high emittance, and good electrical conductivity.
  - 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 is user-friendly, integrates with all commonly used programs at NASA for mechanical, structural, thermal and optical analysis, allows full STOP analysis, changes performance predictions based on mechanical design changes, structural or thermal materials or analysis changes, and quickly predicts full system performance.
- Single-phased and two-phase mechanically pumped fluid systems with easily adaptable/reconfigurable architectures are needed in order to accommodate multiple heat sources and multiple heat sinks. In addition, missions with high sink temperatures require vapor compression systems with COP > 5 and high temperature lifts. Such systems must accommodate long duration missions (12+ years) in high radiation environments (e.g., Europa). Areas of focus include high performance working fluids with wide temperature ranges and low freeze points; novel evaporators/heat exchangers that promote isothermality over large areas; lightweight, reliable phase separators; long-life, energy efficient pumps for sub-cooled systems; long-life, energy efficient compressors for vapor compression systems; and miniaturization of pumps, compressors, and control valves.
- 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.

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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**

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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).
- 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-

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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 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 2015 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.
- Minimize required mass/volume/power as well as development cost/schedule resources.
- Can operate reliably in the expected thermal and radiation environments.

Additionally, the development of radiation hardened, high speed memory devices and advanced point-of-load power converters for high performance onboard processing systems is included as a goal.

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 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:

- Technologies enabling the use of COTS micropower/ultra-low power computing devices in highly reliable spacecraft avionics systems.
- Technologies enabling 3-D die stacking using die from different processes and foundries, enabling implementation of miniaturized, highly-reliable fault tolerant systems.
- Radiation hardened, high speed SDRAM memory devices for high performance onboard processing systems (focusing on DDR3 or newer technologies).
- Novel approaches for miniaturized, highly reliable point-of-load converters capable of providing core and I/O power for existing and emerging spaceflight processors and Field Programmable Gate Arrays (FPGAs). These should be capable of:
  - Accepting a nominal 5V input.

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- Sourcing voltages as low as 1V at up to 5A.
  - Providing peak efficiency exceeding 90%.
  - Maintaining stability across a wide range of output loads while requiring a minimal number of external discrete components.
  - Innovative approaches for single event effects mitigation utilizing non-RHBD (Radiation Hardened By Design) FPGA devices for performance (speed, power, mass) that is capable of meeting or exceeding traditional RHBD devices and leveraging commercially available devices.Â