NASA SBIR 2014 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 2014 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 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).
- The Earth Science Decadal Survey - (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 20092030” (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.php?record_id=13117).

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.

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

- Advanced bulk materials enabling demonstration of high efficiency thermoelectric energy conversion (>15%) when using high grade space-qualified heat sources (> 1000 K).
- Advanced thermoelectric couple and module component technologies that will facilitate integration of new high performance materials into high reliability, high temperature long life systems, such as: thermally stable, low resistance and mechanically compliant interface structures, advanced lightweight thermal insulation materials and stable thermoelectric material encapsulation coatings.
- Advanced concepts capable of taking advantage of miniature space-qualified heat sources (~ 1Wth class) and compatible with very high g loadings at the system level (> 10,000 g) as well as operation in extreme environments (temperature, radiation).

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).
- 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.

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). 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 requirements, which are reflected in the goals of NASA's In-Space Propulsion Technology program to reduce the travel time, mass, and cost of SMD spacecraft. Advancements 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 are desired. Additional electric propulsion technology innovations are also sought to enable low cost systems for Discovery class missions, and eventually to enable radioisotope electric propulsion (REP) type 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) and NASA’s Office of the Chief Technologist (http://www.nasa.gov/pdf/501329main_TA02-InSpaceProp-DRAFT-Nov2010-A.pdf).

The focus of this solicitation is for next generation propulsion systems and components, including micropropulsion rocket technologies, and low cost/low mass electric propulsion technologies. Propulsion technologies related specifically to Power Processing Units will be sought under S3.03 Power Electronics and Management, and Energy Storage and should not be submitted to this subtopic.

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.

Electric Propulsion Systems

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

- Long-life thrusters and related system components with efficiencies > 55% and up to 1 kW of input power that operate with a specific impulse between 1600 to 3500 seconds to enable radioisotope electric propulsion.

- 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 kilopower nuclear reactor.

Mini-satellite Propulsion Systems

This subtopic also seeks proposals that address the propulsion for spacecraft 180-1000 kg. It is desired that the capability of plane-changing or de-orbiting in a timely manner be achieved. These system or component technologies would likely be:

- Low mass and low volume fractions.
- Wide range of delta-V capability to provide 100-1000s of m/s.
- Wide range of specific impulses up to 1000s of seconds.
- Precise thrust vectoring and low vibration for precision maneuvering.
- Efficient use of onboard resources (i.e., high power efficiency and simplified thermal and propellant management).
- Affordability.
- Safety for users and primary payloads.

Small Satellite/CubeSat Propulsion

The small satellite (<180kg) 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.

Specifically, proposals are sought for propulsion systems capable of full scale flight demonstration on 12U CubeSats or smaller; to enable science through secondary payloads carried by SLS or other launch vehicles. Mission applications can be extended up to ESPA based or up to 180kg spacecraft.

Proposals are sought that can deliver hardware products and proof-of-concept demonstrations in Phase I. Proposals are sought that can deliver hardware at or greater than TRL 6 suitable for flight demonstration within the Phase II resources provided. Propulsion systems requiring Phase II-E or II-X funding will be considered if justified through enabling mission capabilities.

Specific propulsion technologies of interest to interplanetary small satellites include:

- Moderate to high specific impulse propulsion systems.
- High specific impulse - density solutions.
- Systems that require no pressurization prior to operations.
- Systems that place no demanding storage requirements prior to launch.
- Systems than can remain quiescent under ambient conditions for extended durations (>6 months) prior to launch.

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

Note to Proposer: Topic H2 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

Future NASA science objectives will include missions such as Earth Orbiting, Venus, Europa, Titan/Enceladus Flagship, Lunar Quest and Space Weather. Under this subtopic, proposals are solicited to develop energy storage and power electronics to enable or enhance the capabilities of future 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 Power Electronics and Management, and Energy Storage for the development of advanced Power Processing Units and associated components.

Power Electronics and Management

The 2009 Heliophysics roadmap (http://sec.gsfc.nasa.gov/2009_Roadmap.pdf), the 2010 SMD Science Plan (http://science.nasa.gov/about-us/science-strategy/), the 2010 Planetary Decadal Survey White Papers & Roadmap Inputs (http://www8.nationalacademies.org/ssbsurvey/publicview.aspx), the 2011 PSD Relevant Technologies document, the 2006 Solar System Exploration (SSE) Roadmap (http://nasascience.nasa.gov/about-us/science-strategy), and the 2003 SSE Decadal Survey describe the need for lighter weight, lower power electronics along with radiation hardened, extreme environment electronics for planetary exploration. Radioisotope power systems (RPS) and Power Processing Units (PPUs) for Electric Propulsion (EP) are two programs of interest which would directly benefit from advancements in this technology area. Advances in electrical power technologies are required for the electrical components and systems for these future platforms to address program size, mass, efficiency, capacity, durability, and reliability requirements. In addition, the Outer Planet Assessment Group has called out high power density/high efficiency power electronics as needs for the Titan/Enceladus Flagship and planetary exploration missions. These types of missions, including Mars Sample Return using Hall thrusters and 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 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.

SMD's In-space Propulsion Technology and Radioisotope Power Systems programs are direct customers of this subtopic, and the solicitation is coordinated with the two programs each year.

Overall technologies of interest include:

- High voltage, radiation hardened, high temperature components.
- High power density/high efficiency power electronics and associated drivers for switching elements.
- Lightweight, highly conductive power cables and/or cables integrated with vehicle structures.
- Intelligent management and fault-tolerant electrical components and PMAD systems.
- Advanced electronic packaging for thermal control and electromagnetic shielding; integrated packaging technology for modularity.

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.

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

Unmanned Aircraft Systems

Breakthrough technologies that will enhance performance and utility of NASA’s Airborne Science fleet with expanded use of unmanned aircraft systems (UAS) are sought. Desired performance envelope expansion over existing capabilities includes lower and higher altitudes, longer range and endurance, and flight in hazardous conditions (hurricanes, tornadoes, and volcano plumes, for example). Novel airborne platforms incorporating tailored sensors and instrumentation suitable for supporting NASA’s Earth science research goals are encouraged. Additionally, innovative subsystem elements that will support existing or future UAS are desired. Potential concepts include:

- Coordinated (Matrixed) Platforms: Systems that enable multiple measurements from several vantage points to increase spatial and temporal coverage.
- Optical or radio frequency system networks that will enable multiple unmanned aircraft systems to communicate with a global communication systems.
- Sense and avoid systems that enable flights in the National Airspace System.
- Attitude and navigation control for highly turbulent conditions.
- Low cost, high precision inertial navigation systems (< 0.10 degree accuracy, resolution).
- Small, easily transportable systems requiring a crew of one or two.
- Novel propulsion approaches targeting increased range and endurance, flight in adverse conditions, reduced operating costs, and/or minimum sampling contamination (NASA’s SIERRA requires 25 to 40 hp, for example).
- Guided Dropsondes.

Sounding Rockets

The NASA Sounding Rocket Program (NSRP) provides low-cost, sub-orbital access to space in support of space and Earth sciences research and technology development sponsored by NASA and other users by providing payload development, launch vehicles, and mission support services. NASA utilizes a variety of vehicle systems comprised of military surplus and commercially available rocket motors, capable of lofting scientific payloads, 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.

NASA is seeking innovations to enhance capabilities and operations in the following areas:

- High data rate telemetry and on board recording (greater than 20Mb/s).
- High-accuracy, small, and affordable attitude, acceleration, and rate sensors for guidance, navigation and control systems.
- High capacity, small, light-weight, operationally safe, and affordable batteries for on-board power systems.
- Autonomous vehicle environmental diagnostics system capable of monitoring flight loading (thermal, acceleration, stress/strain) for solid rocket vehicle systems.
- Location determination systems to provide over-the-horizon position of buoyant payloads to facilitate expedient location and retrieval from the ocean.
- Flotation systems, ranging from tethered flotation devices to self-encapsulation systems, for augmenting buoyancy of sealed payload systems launched from water-based launch ranges.

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.
- Autononomous 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, 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 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.
- *Satellite Communications* - Improved 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:

- *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 pointing system of ? 10 kg, power consumption for the steering system ? 5 W (avg.), pointing accuracy ? 0.5 deg (continuous), hemispheric pointing coverage (2 pi steradians), azimuthal and rotational slew rates ? 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.

- *Altitude-Cycling Balloons for Venus* - NASA is interested in Venus balloons that continuously cycle across a wide altitude range without the use of ballast drops. Such balloons not only enable scientific measurements at different altitudes, they also enable the periodic cooling of the payload during the time spent at the highest altitude. Innovative concepts and system-level solutions are sought for such an altitude cycling Venus balloon with the following characteristics: a minimum cycling altitude of 45 km or lower, a maximum cycling altitude of 58 km or higher, a balloon large enough to carry a 100 kg payload, and a flight duration of at least 14 (Earth) days comprising both day and night conditions. 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, 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:

- Future highly integrated electronics for CubeSat/SmallSat will drastically increase the performance per unit volume, mass and power of electronics systems. High flux heat acquisition and transport devices are required. In addition, high conductivity, vacuum-compatible interface materials are needed in order to reduce interface temperature gradients and facilitate efficient heat removal.
- 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, low volume and low mass for endothermic/exothermal thermal management and conditioning.
    - Durable thermal coatings with low absorptance, variable emmittance, and good electrical conductivity.
    - High performance, low cost insulation systems for diverse environments.
    - Passive radiator turn-down devices to enable variation of heat rejection rates.
- Advanced thermal control systems with easily adaptable/reconfigurable thermal management architectures are needed in order to accommodate multiple heat sources and multiple heat sinks, particularly a thermal system that can facilitate heat sharing among on and off components and heat dissipation among multiple radiators placed on various locations on the spacecraft surface. Also needed are improved design and analysis tools for rapid design, integration and testing, and flight operations.
- Thermal control systems for long duration operation are needed, including long life pumps, single-phase and two-phase mechanically pumped fluid systems, components adaptable to distributed heat acquisition and rejection in diverse environments such as high radiation doses (Europa, etc.), and novel heat lift capabilities that enable operation in warm environments.
- Advanced detectors and optical systems at infrared wavelengths require efficient cooling methods to low temperatures. Advanced cryogenic thermal devices for precision temperature measurement and control over much larger sensor areas than currently possible are needed.

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.

Note to Proposer: Subtopic H3.01 Thermal Control for Future Human Exploration Vehicles, under the Human Exploration and Operations Mission Directorate, also addresses thermal control technologies. Proposals more aligned with exploration mission requirements should be proposed in H3.01.