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# Funding and Strategic Alignment Guidance for Infusing Small Business Innovation Research Technology Into NASA Programs Associated With the Science Mission Directorate

*Hung D. Nguyen and Gynelle C. Steele*
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September 2015

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# Contents

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## Abstract

This report is intended to help NASA program and project managers incorporate Small Business Innovation Research/Small Business Technology Transfer (SBIR/STTR) technologies that have gone through Phase II of the SBIR program into NASA Science Mission Directorate (SMD) programs. Other Government and commercial project managers can also find this information useful.

## Introduction

Incorporating Small Business Innovation Research (SBIR)-developed technology into NASA programs is important, especially given the Agency's limited resources for technology development. The SBIR program's original intention was for technologies that completed Phase II to be ready for integration into NASA programs, however, in many cases there is a gap between Technology Readiness Levels (TRLs) 5 and 6 that needs to be closed.

After Phase II projects are completed, the technology is evaluated against various parameters and a TRL rating is assigned. Most programs tend to adopt more mature technologies—at least TRL 6 to reduce the risk to the mission rather than adopt TRLs between 3 and 5 because those technologies perceived as too risky. The gap between TRLs 5 and 6 is often called the "Valley of Death" (Fig. 1) and historically it has been difficult to close because of a lack of funding support from programs. Several papers already have suggested remedies on how to close the gaps (Refs. 1 to 4).

To address the TRL gap, NASA's SBIR program has made a considerable effort to strengthen the critical connection between SBIR and NASA programs through post-Phase II initiatives. As a result NASA SBIR now supports its small business partners with three post-Phase II options that focus on creating opportunities for technology infusion and commercialization. The Phase II Enhancement (Phase II-E), Phase II Expanded (Phase II-X), and the Commercialization Readiness Program (CRP) options provide opportunities for Phase II technologies to be integrated and tested in the NASA system platform or in the space environment.

## Aligning SBIR Technologies Into SMD Programs

This section discusses how NASA program managers can incorporate SBIR technologies into Science Mission Directorate (SMD) programs by showing where there is relevant alignment. This information also will be helpful for other Government agencies or commercial entities that pursue related fields.

| | | TRL | Description |
|---|---|---|---|
| SBIR Phases I and II | Basic research | 1 | Basic scientific/engineering principles observed and reported |
| | Feasibility research | 2 | Technology concept, application, and potential benefits formulated (candidate system selected) |
| | Feasibility research | 3 | Analytic and/or experimental proof-of-concept completed (breadboard test) |
| | Technology development | 4 | System concept observed in laboratory environment (candidate system selected) |
| Technology demonstration "Valley of Death" | Technology development | 5 | System concept tested and potential benefits substantiated in a controlled relevant environment |
| | System development | 6 | Prototype of system concept is demonstrated in a relevant environment |
| System development | System development | 7 | System prototype is tested and potential benefits substantiated more broadly in a relevant environment |
| | Operational verification | 8 | Actual system constructed and demonstrated with benefits substantiated in a relevant environment |
| | Operational verification | 9 | Operational use of actual system tested with benefits proven |

Figure 1.—Technology Readiness Levels (TRLs).

SMD research focuses on conducting scientific exploration enabled by the use of space observatories and space probes that view the Earth from space, observe and visit other bodies in the solar system, and peer out into our Galaxy and beyond. SMD is structured into the following four operations:

(1) Earth Science: Develops a scientific understanding of the Earth system and its response to natural and human-induced changes to enable improved prediction of climate, weather, and natural hazards for present and future generations.
(2) Planetary Science: Advances the scientific understanding of the solar system in extraordinary ways, while pushing the limits of spacecraft and robotic engineering design and operations.
(3) Astrophysics: Discovers how the universe works, explore how it began and evolved, and search for life on planets around other stars.
(4) Heliophysics: Explores the full system of complex interactions that characterize the relationship of the Sun with the solar system.

Figure 2 shows the SMD operations structure and programs that focus on exploring the solar system for scientific purposes while supporting safe robotic and human exploration of space, and programs that focus on improving national capabilities to predict climate, weather, and natural hazards; manage resources; and supporting the development of environmental policy. Table 1 shows NASA's funding request from fiscal years (FY) 2015 to 2019 for SMD programs.

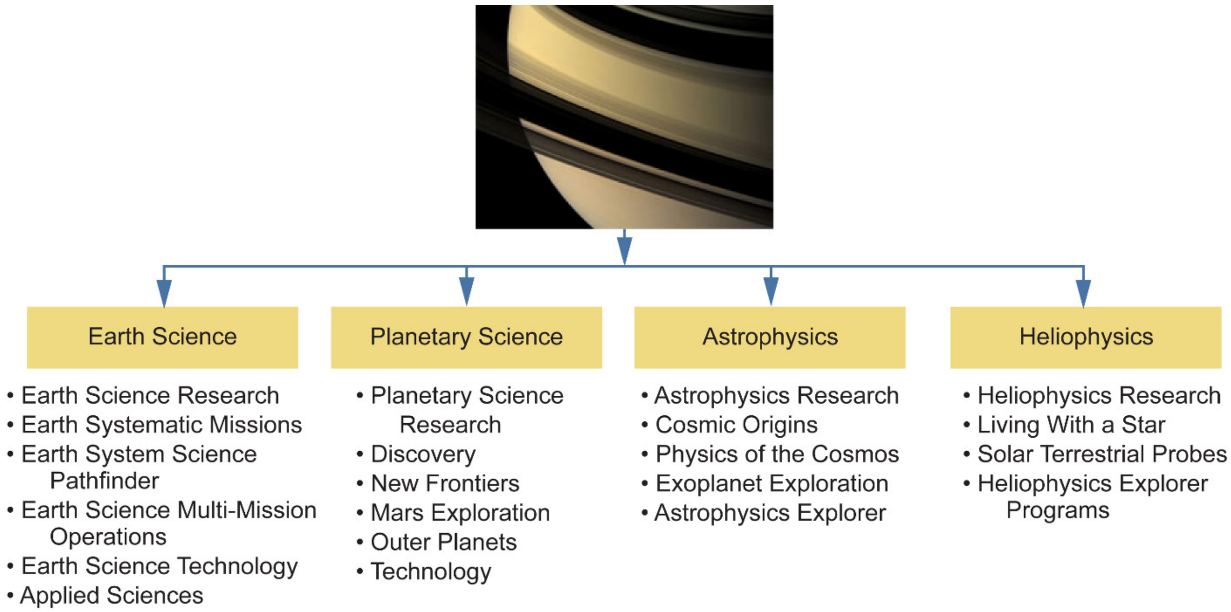


Figure 2.—Science Mission Directorate (SMD) operations and programs.

TABLE 1.—FISCAL YEAR (FY) BUDGET REQUEST SUMMARIES FOR SMD PROGRAMS (IN MILLIONS OF DOLLARS) (REF. 5)

| Program | Actual | Projected | | | |
|---|---|---|---|---|---|
| | FY 2015 | FY 2016 | FY 2017 | FY 2018 | FY 2019 |
| Earth Science Operations | | | | | |
| Earth Science Research | 449 | 477 | 453 | 445 | 448 |
| Earth Systematic Missions | 786 | 856 | 880 | 894 | 927 |
| Earth System Science Pathfinder | 266 | 209 | 227 | 243 | 231 |
| Earth Science Multi-Mission | 176 | 179 | 181 | 183 | 183 |
| Earth Science Technology | 55 | 54 | 55 | 55 | 55 |
| Applied Sciences | 36 | 38 | 39 | 39 | 39 |
| Planetary Science Operations | | | | | |
| Planetary Science Research | 255 | 280 | 284 | 283 | 278 |
| Discovery | 230 | 163 | 174 | 280 | 377 |
| New Frontiers | 281 | 254 | 110 | 51 | 45 |
| Mars Exploration | 279 | 381 | 547 | 573 | 518 |
| Outer Planets | 95 | 82 | 84 | 27 | 9 |
| Technology | 137 | 142 | 136 | 140 | 144 |
| Astrophysics Operations | | | | | |
| Astrophysics Research | 191 | 216 | 221 | 234 | 261 |
| Cosmic Origins | 120 | 106 | 108 | 114 | 105 |
| Physics of the Cosmos | 108 | 100 | 86 | 89 | 142 |
| Exoplanet Exploration | 47 | 46 | 60 | 89 | 237 |
| Astrophysics Explorer | 139 | 163 | 174 | 168 | 186 |
| Heliophysics Operations | | | | | |
| Heliophysics Research | 217 | 158 | 167 | 169 | 169 |
| Living With a Star | 266 | 355 | 378 | 398 | 282 |
| Solar Terrestrial Probes | 61 | 41 | 42 | 30 | 129 |
| Heliophysics Explorers | 123 | 91 | 88 | 74 | 93 |

# SMD Operation and Program Summaries

## Earth Science Operations

- Earth Science Research: Develops a scientific understanding of Earth and its response to natural or human-induced changes. This addresses complex, interdisciplinary Earth science problems in pursuit of a comprehensive understanding of the Earth system. This strategy involves six interdisciplinary and interrelated science focus areas, including (1) Climate variability and change, (2) Atmospheric composition, (3) Carbon cycle and ecosystems, (4) Water and energy cycle, (5) Weather, and (6) Earth surface and interior.
- Earth Systematic Missions: Focus on a broad range of multi-disciplinary science investigations aimed at understanding the Earth system and its response to natural and human induced forces and changes. Develops Earth-observing research satellite missions, manages the operation of these missions once on orbit, and produces mission data products in support of research, applications, and policy communities.
- Earth System Science Pathfinder: The Earth System Science Pathfinder (ESSP) program provides an innovative approach to Earth science research by providing frequent, regular, competitively selected opportunities that accommodate new and emerging scientific priorities and measurement capabilities. ESSP projects include space missions and remote sensing instruments for space-based missions of opportunity or extended duration airborne science missions. The ESSP program also supports the conduct of science research utilizing data from these missions.
- Earth Science Multi-Mission: Acquires, preserves, and distributes observational data from operating spacecraft to support Earth Science research focus areas. This is accomplished primarily by the Earth Observing System Data and Information System (EOSDIS), which has been in operations since 1994. EOSDIS acquires, processes, archives, and distributes Earth Science data and information products.
- Earth Science Technology: Enables previously infeasible science investigations; improves existing measurement capabilities; and reduces the cost, risk, and/or development times for Earth science instruments. EST will develop new remote-sensing and information systems technologies for infusion into future science missions and airborne campaigns. These technologies will enable or enhance measurements and data system capabilities.
- Applied Sciences: Leverages NASA Earth Science satellite measurements and new scientific knowledge to provide innovative and practical uses for public and private sector organizations. It also enables near-term uses of Earth science knowledge, discovers and demonstrates new applications, and facilitates adoption of applications by non-NASA stakeholder organizations.

## Planetary Science Operations

- Planetary Science Research: Provides the scientific foundation for unique data sets returned from NASA missions exploring the solar system. Focuses on five key research goals: Explore and observe the objects in the solar system to understand how they formed and evolve; Advance the understanding of how the chemical and physical processes in our solar system operate, interact, and evolve; Explore and find locations where life could have existed or could exist today; Improve our understanding of the origin and evolution of life on Earth to guide our search for life elsewhere; Identify and characterize objects in the solar system that pose threats to Earth or offer resources for human exploration.

- Discovery: Supports innovative, relatively low-cost, competitively selected Planetary Science missions. The Discovery program currently has two operational spacecraft: MErcury Surface, SpaceENvironment, GEochemistry, and Ranging (MESSENGER) and Dawn. The program also has one instrument in operations: the Analyzer of Space Plasma and Energetic Atoms (ASPERA-3) on the ESA Mars Express mission; one flight mission in development: the Interior Exploration using Seismic Investigations, Geodesy and Heat Transport (InSight); and one instrument in spacecraft integration: Strofio on the ESA BepiColombo mission to Mercury.
- New Frontiers: Seeks to contain total mission cost and development time and improve performance through the use of validated new technologies, efficient management, and control of design, development and operations costs while maintaining a strong commitment to flight safety. The program objective is to launch high-science-return planetary science investigations twice per decade.
- Mars Exploration: Seeks to understand whether Mars was, is, or can be, a habitable world and whether it ever supported life. The four broad, overarching goals for Mars Exploration are to determine whether life ever arose on Mars; characterize the climate of Mars; characterize the geology of Mars; and prepare for human exploration.
- Outer Planets: Enables science investigations spanning the diverse geography and disciplines of the outer solar system. The strategic missions in this portfolio investigate a broad array of science disciplines with more depth than is possible for smaller, tightly focused missions in the Discovery and New Frontiers programs. The science discoveries made by these strategic missions provide answers to long-held questions and theories about life beyond Earth and the origin and evolution of outer planets.
- Technology: Supports multimission capabilities and technology developments in key spacecraft systems, and mission operations. Additionally, it includes the Radioisotope Power Systems (RPS), Plutonium Production, RPS Production Operations infrastructure and Advanced Multi-Mission Operations System (AMMOS) projects.

## Astrophysics Operations

- Astrophysics Research: Analyzes the data from NASA missions to understand astronomical events such as the explosion of a star, the birth of a distant galaxy, or the nature of planets circling other stars. The program also enables the early development of new technologies for future missions, and suborbital flights of experimental payloads on balloons and sounding rockets.
- Cosmic Origins: Supports a number of operating facilities includes Hubble Space Telescope (HST), Spitzer Space Telescope (SST), and the Stratospheric Observatory for Infrared Astronomy (SOFIA). Focus on advanced future instruments for SOFIA and studies of a UV-optical successor to HST. Advances in key technologies will enable the building of powerful future facilities.
- Physics of the Cosmos: Incorporates cosmology, high energy astrophysics, and fundamental physics projects that address central questions about the nature of complex astrophysical phenomena such as black holes, neutron stars, dark matter and dark energy, cosmic microwave background, and gravitational waves.
- Exoplanet Exploration: Focuses on advancing along a path of discovery leading to a point where scientists can directly study the atmospheres and surface features of habitable, rocky planets, like Earth, around other stars in the solar neighborhood. It also develops systems that will allow

scientists to take the pivotal step from identifying an exoplanet as Earth-sized, to determining whether it is truly Earth-like, and possibly even detecting if it bears the fingerprints of life.

- Astrophysics Explorer: Provides frequent flight opportunities for world-class astrophysics investigations using innovative and streamlined management approaches for spacecraft development and operations. The program is highly responsive to new knowledge, new technology, and updated scientific priorities by launching smaller missions that can be conceived and executed in a relatively short development cycle.

### Heliophysics Operations

- Heliophysics Research: To understand the Sun, heliosphere, and planetary environments as a single connected system and to answer these fundamental questions about this system’s behavior. It also advances knowledge of solar processes and the interaction of solar plasma and radiation with Earth, the other planets and the Galaxy.
- Living with a Star: Targets specific aspects of the Sun-Earth-planetary system that affect life and society. LWS provides a predictive understanding of the Sun-Earth system, the linkages among the interconnected systems, and specifically of the space weather conditions at Earth and the interplanetary medium. LWS products measure and therefore may mitigate impacts to technology associated with space systems, communications and navigation, and ground systems such as power grids.
- Solar Terrestrial Probes: Focuses on understanding the fundamental physics of the space environment, from the Sun to Earth, other planets, and beyond to the interstellar medium. STP provides insight into the fundamental processes of plasmas (fluid of charged particles) inherent in all astrophysical systems. STP missions focus on processes such as the variability of the Sun, the responses of the planets to those variations, and the interaction of the Sun and solar system.
- Heliophysics Explorers: Provides frequent flight opportunities for world-class scientific investigations on focused and timely science topics. Explorers use a suite of smaller, fully competed missions that address these topics to complement the science of strategic missions of the Living with a Star and Solar Terrestrial Probes (STP) programs.

## Fiscal Year 2015 Topics and Subtopics Related to SMD

The annual NASA-wide SBIR solicitation is divided up into several topics and subtopics; Figure 4(a) and (b) illustrate those topics and subtopics for the FY 2015 solicitation. These SBIR topics and subtopics are carefully developed to strategically align with SMD programs, thereby supporting the directorate’s current needs and objectives.

The annual NASA-wide SBIR solicitation contains several topics and subtopics that are developed to strategically align with SMD programs, thereby supporting the directorate’s current needs and objectives. To help the small business principal investigators (PIs) and SMD program managers, it is important to understand how the SBIR topics and subtopics are mapped to SMD programs. Figure 3 shows the FY 2015 solicitation topics and subtopics for SMD programs and Figure 4 maps the FY 2015 solicitation subtopics to SMD programs.

S1 Sensors, Detectors, and Instruments

- S1.01 Lidar Remote Sensing Technologies
- S1.02 Microwave Technologies for Remote Sensing
- S1.03 Sensor and Detector Technology for Visible, IR, Far IR and Submillimeter
- S1.04 Detector Technologies for UV, X-Ray, Gamma-Ray, and Cosmic-Ray Instruments
- S1.05 Particles and Field Sensors and Instrument Enabling Technologies
- S1.06 In-situ Sensors and Sensor Systems for Lunar and Planetary Science
- S1.07 Airborne Measurement Systems
- S1.08 Surface and Subsurface Measurement Systems
- S1.09 Atomic Interferometry
- S1.10 Cryogenic Systems for Sensors and Detectors

S2 Advanced Telescope Systems

- S2.01 Proximity Glare Suppression for Astronomical Coronagraphy
- S2.02 Precision Deployable Optical Structures and Metrology
- S2.03 Advanced Optical Systems and Fabrication/Testing/Control Technologies for EUV/Optical and IR Telescope
- S2.04 X-Ray Mirror Systems Technology, Coating Technology for X-Ray-UV-OIR, and Free-Form Optics

S3 Spacecraft and Platform Subsystems

- S3.01 Power Generation and Conversion
- S3.02 Propulsion Systems for Robotic Science Missions
- S3.03 Power Electronics and Management, and Energy Storage
- S3.04 Unmanned Aircraft and Sounding Rocket Technologies
- S3.05 Guidance, Navigation, and Control
- S3.06 Terrestrial and Planetary Balloons
- S3.07 Thermal Control Systems
- S3.08 Slow and Fast Light
- S3.09 Command, Data Handling, and Electronics

S4 Robotic Exploration Technologies

- S4.01 Planetary Entry, Descent and Landing, and Small Body Proximity Operation Technology
- S4.02 Robotic Mobility, Manipulation, and Sampling
- S4.03 Spacecraft Technology for Sample Return Missions
- S4.04 Extreme Environments Technology
- S4.05 Contamination Control and Planetary Protection

S5 Information Technologies

- S5.01 Technologies for Large-Scale Numerical Simulation
- S5.02 Earth Science Applied Research and Decision Support
- S5.03 Algorithms and Tools for Science Data Processing, Discovery and Analysis, in State-of-the-Art Data Environments
- S5.04 Integrated Science Mission Modeling
- S5.05 Fault Management Technologies

Figure 3.—Fiscal year 2015 SBIR SMD topics and subtopics.

**SMD programs**

**S1 Sensors, Detectors, and Instruments**

- S1.01 Lidar Remote Sensing Technologies
- S1.02 Microwave Technologies for Remote Sensing
- S1.03 Sensor and Detector Technology for Visible, IR, Far IR, and Submillimeter
- S1.04 Detector Technologies for UV, X-Ray, Gamma-Ray, and Cosmic-Ray Instruments
- S1.05 Particles and Field Sensors and Instrument Enabling Technologies
- S1.06 In-situ Sensors and Sensor Systems for Lunar and Planetary Science
- S1.07 Airborne Measurement Systems
- S1.08 Surface and Subsurface Measurement Systems
- S1.09 Atomic Interferometry
- S1.10 Cryogenic Systems for Sensors and Detectors

SMD programs:

- Earth System Science Pathfinder
- Earth Science Technology
- Planetary Science Research
- Discovery
- New Frontiers
- Exoplanet Exploration
- Living With a Star

**S2 Advanced Telescope Systems**

- S2.01 Proximity Glare Suppression for Astronomical Coronagraphy
- S2.02 Precision Deployable Optical Structures and Metrology
- S2.03 Advanced Optical Systems and Fabrication/Testing/Control Technologies for EUV/Optical and IR Telescope
- S2.04 X-Ray Mirror Systems Technology, Coating Technology for X-Ray-UV-OIR, and Free-Form Optics

SMD programs:

- Planetary Science Research
- Mars Exploration
- Astrophysics Research

**S3 Spacecraft and Platform Subsystems**

- S3.01 Power Generation and Conversion
- S3.02 Propulsion Systems for Robotic Science Missions
- S3.03 Power Electronics and Management, and Energy Storage
- S3.04 Unmanned Aircraft and Sounding Rocket Technologies
- S3.05 Guidance, Navigation, and Control
- S3.06 Terrestrial and Planetary Balloons
- S3.07 Thermal Control Systems
- S3.08 Slow and Fast Light
- S3.09 Command, Data Handling, and Electronics

SMD programs:

- New Frontiers
- Mars Exploration

**S4 Robotic Exploration Technologies**

- S4.01 Planetary Entry, Descent and Landing, and Small Body Proximity Operation Technology
- S4.02 Robotic Mobility, Manipulation, and Sampling
- S4.03 Spacecraft Technology for Sample Return Missions
- S4.04 Extreme Environments Technology
- S4.05 Contamination Control and Planetary Protection

SMD programs:

- Planetary Science Research
- New Frontiers
- Heliophysics Research

**S5 Information Technologies**

- S5.01 Technologies for Large-Scale Numerical Simulation
- S5.02 Earth Science Applied Research and Decision Support
- S5.03 Algorithms and Tools for Science Data Processing, Discovery and Analysis, in State-of-the-Art Data Environments
- S5.04 Integrated Science Mission Modeling
- S5.05 Fault Management Technologies

SMD programs:

- Earth Science Research
- Earth Systematic Missions
- Earth Science Multi-Mission Operations
- Earth Science Technology
- Applied Sciences
- LIving With a Star

Figure 4.—Fiscal year 2015 SBIR subtopics mapped to SMD programs.

# Summary of SBIR Topics and Subtopics for SMD

## Topic S1 Sensors, Detectors, and Instruments

### S1.01 Lidar Remote Sensing Technologies

Focus on new capabilities or enhancements over current measurements of atmospheric and topographic parameters from ground, airborne, and space-based platforms. Innovative lidar subsystem and component technologies that directly address the measurement of atmospheric constituents and surface topography of the Earth, Mars, the Moon, and other planetary bodies will be considered under this subtopic. Compact, high-efficiency lidar instruments for deployment on unconventional platforms, such as balloon, small sat, and CubeSat are also considered.

### S1.02 Microwave Technologies for Remote Sensing

Focus on active (radar) and passive (radiometer) microwave sensors for a wide range of remote sensing applications. These sensors include low frequency (less than 10 MHz) sounders to G-band (160 GHz) radars for measuring precipitation and clouds, for planetary landing, upper atmospheric monitoring, and global snow coverage, topography measurement and other Earth and planetary science applications.

### S1.03 Sensor and Detector Technology for Visible, IR, Far IR, and Submillimeter

Focus on new technologies or improvements to existing technologies to meet the detector needs of future missions, as described in the most recent decadal surveys for Earth science. These detectors include development of un-cooled or cooled infrared detectors and development of a robust wafer-level integration technology that will allow high-frequency capable interconnects and allow two dis-similar substrates.

### S1.04 Detector Technologies for UV, X-Ray, Gamma-Ray, and Cosmic-Ray Instruments

Focus on detector requirements for a broad range of wavelengths from UV through to gamma ray for applications in Astrophysics, Earth Science, Heliophysics, and Planetary Science. Requirements across the board are for greater numbers of readout pixels, lower power, faster readout rates, greater quantum efficiency, and enhanced energy resolution.

### S1.05 Particles and Field Sensors and Instrument Enabling Technologies

Focus on advanced sensors for the detection of elementary particles (atoms, molecules and their ions) and electric and magnetic fields in space and associated instrument technologies. Improvements in particles and fields sensors and associated instrument technologies enable further scientific advancement for upcoming NASA missions such as CubeSats, Explorers, and planetary exploration missions. Technology developments that result in a reduction in size, mass, power, and cost will enable these missions to proceed. Of interest are advanced magnetometers, electric field booms, ion/atom/molecule detectors, and associated support electronics and materials.

### S1.06 In-Situ Sensors and Sensor Systems for Lunar and Planetary Science

Development of advanced instrument technologies and components suitable for deployment on planetary and lunar missions. These technologies must be capable of withstanding operation in space and planetary environments, including the expected pressures, radiation levels, launch and impact stresses, and range of survival and operational temperatures. Technologies that reduce mass, power, volume, and data rates for instruments and instrument components without loss of scientific capability are of particular importance.

### S1.07 Airborne Measurement Systems

Measurement system miniaturization and/or increased performance is needed to support for NASA's airborne science missions, particularly those utilizing the Global Hawk, SIERRA-class, Dragon Eye or other unmanned aircraft. The subject airborne instruments are intended as calibration/validation systems. Complete instrument systems are desired, including features such as remote/unattended operation and data acquisition, low power consumption, and minimum size and weight. Desired sensors include miniaturized, high performance instrument suites for multidisciplinary applications.

### S1.08 Surface and Sub-surface Measurement Systems

Surface & Sub-surface Measurement Systems are sought with relevance to future space missions such as Active Sensing of CO2 Emissions over Nights, Days, and Seasons (ASCENDS), Orbiting Carbon Observatory - 2 (OCO-2), Global Precipitation Measurement (GPM), Geostationary Coastal and Air Pollution Events (GEO-CAPE), Hyperspectral InfraRed Imager (HyspIRI), Aerosol, Cloud, and Ecosystems (ACE, including Pre-ACE/PACE). Sensor system innovations with significant near-term commercial potential that may be suitable for NASA's research after full development are of interest.

### S1.09 Atomic Interferometry

Recent developments of laser control and manipulation of atoms have led to new types of precision inertial force and gravity sensors based on atom interferometry. Atom interferometers exploit the quantum mechanical wave nature of atomic particles and quantum gases for sensitive interferometric measurements. Ground-based laboratory experiments and instruments have already demonstrated beyond the state of the art performances of accelerometer, gyroscope, and gravity measurements. Currently the most mature development of atom interferometers as measurement instruments are those based on light pulsed atom interferometers with freefall cold atoms. There remain a number of technical challenges to infuse this technology in space applications.

### S1.10 Cryogenic Systems for Sensors and Detectors

Cryogenic cooling systems often serve as enabling technologies for detectors and sensors flown on scientific instruments as well as advanced telescopes and observatories. As such, technological improvements to cryogenic systems further advance the mission goals of NASA through enabling performance (and ultimately science gathering) capabilities of flight detectors and sensors. The topic areas are as follows: Miniaturized/Efficient Cryocooler Systems, Miniaturized/Efficient Cryocooler Systems, Magnetic Cooling Systems, High Capacity/Efficiency Cryocooler Systems, Low Temperature/Input Power Cooling Systems, Sub-Kelvin Cooling Technologies, and Continuous Flow Distributed Cooling Systems.

## Topic S2 Advanced Telescope Systems

### S2.01 Proximity Glare Suppression for Astronomical Coronagraphy

Addresses the unique problem of imaging and spectroscopic characterization of faint astrophysical objects that are located within the obscuring glare of much brighter stellar sources. Examples include planetary systems beyond our own, the detailed inner structure of galaxies with very bright nuclei, binary star formation, and stellar evolution. This innovative research focuses on advances in coronagraphic instruments, starlight cancellation instruments, and potential occulting technologies that operate at visible and near infrared wavelengths. The ultimate application of these instruments is to operate in space as part of a future observatory mission. Measurement techniques include imaging, photometry, spectroscopy, and polarimetry.

### S2.02 Precision Deployable Optical Structures and Metrology

Mission concepts for New Worlds science would require 10 to 30 m class, cost-effective telescope observatories that are diffraction limited at wavelengths from the visible to the far IR, and operate at temperatures from 4 to 300 K. In addition, ground based telescopes such as the Cerro Chajnantor Atacama Telescope (CCAT) requires similar technology development. Potential architecture implementations must package into an existing launch volume, deploy and be self-aligning to the micron level. This subtopic solicits proposals to develop enabling, cost effective component and subsystem technology for deploying large aperture telescopes with low cost.

### S2.03 Advanced Optical Systems and Fabrication/Testing/Control Technologies for EUV/Optical and IR Telescopes

Focus on components and systems for potential EUV, UV/O & IR missions as well as technology to fabricate, test and control potential UUV, UV/O & IR telescopes. This subtopic's emphasis is to mature technologies needed to affordably manufacture, test or operate complete mirror systems or telescope assemblies. An ideal Phase 1 deliverable would be a precision optical system of at least 0.25 m, or a relevant sub-component of a system, or a prototype demonstration of a fabrication, test or control technology. An ideal Phase 2 project would further advance the technology to produce a space-qualifiable optical system greater than 0.5 m or relevant sub-component (with a TRL in the 4 to 5 range).

### S2.04 X-Ray Mirror Systems Technology, Coating Technology for X-Ray-UV-OIR, and Free-Form Optics

Focus on three areas of technology development (1) X-Ray manufacturing, coating, testing, and assembling complete mirror systems in addition to maturing the current technology; (2) Coating technology for wide range of wavelengths from X-Ray to IR (X-Ray, EUV, Visible, and IR); and (3) Free-form Optics design, fabrication, and metrology for CubeSat, SmallSat and Visible Nulling Coronagraph (VNC).

## Topic S3 Spacecraft and Platform Subsystems

### S3.01 Power Generation and Conversion

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).

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

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. 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.

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

Focus on developing 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. 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.

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

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, Novel propulsion concepts that will expand the flight envelope, Small UAS in-situ cloud measurement capabilities, and Autonomously Linking UAS.

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

Focus on 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 small sat-cubesat class spacecraft are desired.

### S3.06 Terrestrial and Planetary 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 km, with suspended masses up to 3600 kg, and can stay afloat for several weeks. In support of this development, NASA is seeking innovative technologies in two key areas: Power Storage and satellite communications.

### S3.07 Thermal Control Systems

Focus on components of advanced small spacecraft such as CubeSat/SmallSat which 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: (a) phase change systems with high thermal capacity and minimal structural mass; (b) high performance, low cost insulation systems for diverse environments; (c) high flux heat acquisition and transport devices; and (d) thermal coatings with low absorptance, high emmittance, and good electrical conductivity.

### S3.08 Slow and Fast Light

Focus on 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 nondestructive 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.

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

Focus on developing platforms for the implementation of miniaturized highly integrated avionics and instrument electronics that (a) are consistent with the performance requirements for NASA science missions, (b) minimize required mass/volume/power as well as development cost/schedule resources, and (c) 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.

## Topic S4 Robotic Exploration Technologies

### S4.01 Planetary Entry, Descent and Landing and Small Body Proximity Operation Technology

Focuses on sensor technologies to enhance success for entry, descent and landing (EDL) operations on missions to other planetary bodies, including Earth's Moon, Mars, Venus, Titan, Europa, and proximity operations (including sampling and landing) on small bodies such as asteroids and comets. Sensing technologies are desired that determine any number of the following (1) Terrain relative translational state (altimetry/3-axis velocimetry), (2) Spacecraft absolute state in planetary/small-body frame (either attitude, translation, or both), (3) Terrain point cloud (for hazard detection, absolute state estimation, landing/sampling site selection, and/or body shape characterization), and (4) Atmosphere-relative measurements (velocimetry, pressure, temperature, flow-relative orientation).

### S4.02 Robotic Mobility, Manipulation, and Sampling

Focuses on technologies for robotic mobility, manipulation, and sampling which are needed to enable access to sites of interest and acquisition and handling of samples for in-situ analysis or return to Earth from planetary and solar system small bodies including Mars, Venus, comets, asteroids, and planetary moons. Mobility technologies are needed to enable access to steep and rough terrain for planetary bodies where gravity dominates, such as the Moon and Mars. Tethered systems, nonwheeled systems, and marsupial systems are examples of mobility technologies that are of interest. Technologies to enable mobility on small bodies in micro-gravity environments and access to liquid bodies below the surface such as in conduits and deep oceans are needed.

### S4.03 Spacecraft Technology for Sample Return Missions

Focuses on technology innovations that should either enhance vehicle capabilities (e.g., increase performance, decrease risk, and improve environmental operational margins) or ease sample return mission implementation (e.g., reduce size, mass, power, cost, increase reliability, or increase autonomy). NASA plans to perform sample return missions from a variety of scientifically important targets including Mars, small bodies such as asteroids and comets, and outer planet moons. These types of targets present a variety of spacecraft technology challenges.

### S4.04 Extreme Environments Technology

Focuses on technologies that are suitable for remote sensing applications at cryogenic temperatures, and in-situ atmospheric and surface explorations in the high-temperature high-pressure environment at the Venusians surface (485 ýC, 93 atmospheres), or in low-temperature environments such as Titan (–180 ýC), Europa (–220 ýC), Ganymede (–200 ýC), Mars, the Moon, asteroids, comets and other small bodies. Also Europa-Jupiter missions may have a mission life of 10 years and the radiation environment is estimated at 2.9 Mega-rad total ionizing dose (TID) behind 0.1 in. thick aluminum. Also focus on technologies that enable NASA’s long duration missions to extreme wide-temperature and cosmic radiation environments. High reliability, ease of maintenance, low volume, low mass, and low out-gassing characteristics are highly desirable.

### S4.05 Contamination Control and Planetary Protection

Develops technologies to implement Contamination Control and Planetary Protection requirements has emerged in recent years with increased interest in investigating bodies with the potential for life detection such as Europa, Enceladus, Mars, etc. and the potential for sample return from such bodies. Planetary Protection is concerned with both forward and backward contamination. Forward contamination is the transfer of viable organisms from Earth to another body. Backward contamination is the transfer of material posing a biological threat back to Earth's biosphere. Focus on innovative technologies or applications of technologies to facilitate meeting portions of forward and backward contamination Planetary Protection requirements as well as analytical technologies that can ensure hardware and instrumentation can meet organic contamination requirements in an effort to preserve sample science integrity.

## Topic S5 Information Technologies

### S5.01 Technologies for Large-Scale Numerical Simulation

Focus on an increasing of the mission impact of NASA's investments in supercomputing systems and associated operations and services. Specific objectives are to decrease the barriers to entry for prospective supercomputing users, minimize the supercomputer user's total time-to-solution (e.g., time to discover, understand, predict, or design), increase the achievable scale and complexity of computational analysis, data ingest, and data communications, reduce the cost of providing a given level of supercomputing performance on NASA applications, and enhance the efficiency and effectiveness of NASA's supercomputing operations and services.

### S5.02 Earth Science Applied Research and Decision Support

Focus on innovative and unique approaches to increase the utilization and extend the benefit of Earth Science research data to better meet societal needs. One area of interest is new decision support tools and systems for a variety of ecological applications such as managing coastal environments, natural resources or responding to natural disasters. Currently, creating decision support tools (DST) that effectively utilize remote sensing data requires significant efforts by experts in multiple domains. This creates a barrier to the widespread use of Earth observations by state and local governments, businesses, and the public. This subtopic aims to democratize the creation of Earth science driven decision support tools and to unleash a creative explosion of DST development that significantly increases the return on investment for Earth science missions.

### S5.03 Algorithms and Tools for Science Data Processing, Discovery and Analysis, in State-of-the-Art Data Environments

Focus on innovation and unique approaches to solve issues associated around the use of "Big Data" within NASA. The emphasis of this subtopic is on tools that leverage existing systems, interfaces, and infrastructure, where it exists and where appropriate. Reuse of existing NASA assets is strongly encouraged. Specifically, innovations are being sought in the following areas: (1) Parallel Processing for Data Analytics, (2) High Performance File System Abstractions, and (3) Data Management of Large-Scale Scientific Repositories.

### S5.04 Integrated Science Mission Modeling

Focuses on innovative systems modeling methods and tools to (1) Define, design, develop and execute future science missions, by developing and utilizing advanced methods and tools that empower more comprehensive, broader, and deeper system and subsystem modeling, while enabling these models to be developed earlier in the lifecycle. The capabilities should also allow for easier integration of disparate model types and be compatible with current agile design processes; and (2) Enable disciplined system analysis for the design of future missions, including modeling of decision support for those missions and integrated models of technical and programmatic aspects of future missions. Such models might also be made useful to evaluate technology alternatives and impacts, science valuation methods, and programmatic and/or architectural trades.

**S5.05 Fault Management Technologies**

Focus on fault Management (FM) which is one of the key components of system autonomy. FM consists of the operational mitigations of spacecraft failures. It is implemented with spacecraft hardware, on-board autonomous software that controls hardware, software, information redundancy, and ground-based software and operations procedures. Specific objectives are to (1) Improve the ability to predict FM system complexity and estimate development and operations costs, (2) Enable cost-effective FM design architectures and operations, (3) Determine completeness and appropriateness of FM designs and implementations, and (4) Decrease the labor and time required to develop and test FM models and algorithms.

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