NASA recognizes the potential of lidar technology in meeting many of its science objectives by providing new capabilities or offering enhancements over current measurements of atmospheric and topographic parameters from ground, airborne, and space-based platforms. To meet NASA’s requirements for remote sensing from space, advances are needed in state-of-the-art lidar technology with an emphasis on compactness, efficiency, reliability, lifetime, and high performance. 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 and encouraged.

Proposals must show relevance to the development of lidar instruments that can be used for NASA science-focused measurements or to support current technology programs. Meeting science needs leads to four primary instrument types:

- **Backscatter** - Measures beam reflection from aerosols to retrieve the opacity of a gas.
- **Ranging** - Measures the return beams time-of-flight to retrieve distance.
- **Doppler** - Measures wavelength changes in the return beam to retrieve relative velocity.
- **Differential absorption** - Measures attenuation of two different return beams (one centered on a spectral line of interest) to retrieve concentration of a trace gas.

Phase I research should demonstrate technical feasibility and show a path toward a Phase II prototype unit. Phase II prototypes should be capable of laboratory demonstration and preferably suitable for operation in the field from a ground-based station, an aircraft platform, or any science platform amply defended by the proposer. For the 2018 SBIR Program, NASA is soliciting the component and subsystem technologies described below:

- Compact and rugged single-frequency continuous-wave and pulsed lasers operating between 290-nm and 2050-nm wavelengths suitable for lidar. Specific wavelengths are of interest to match absorption lines or atmospheric transmission: 290 to 320-nm (ozone absorption), 450 to 490-nm (ocean sensing), 532-nm, 817-nm (water vapor), 750 to 950-nm (aerosol sensing), 935-nm (water line), 1064-nm, 1570-nm (CO₂ line), 1650-nm (methane line), and 2050-nm (Doppler wind). Architectures involving new developments in diode laser, quantum cascade laser, and fiber laser technology are especially encouraged. Additionally, novel solid-state laser materials are sought for reaching infrared wavelengths of 2500-nm to 10,000-nm. For pulsed lasers two different regimes of repetition rate and pulse energies are desired: from 1-kHz to 10-kHz with pulse energy greater than 1-mJ and from 20-Hz to 100-Hz with pulse energy greater than 100-mJ.
- Optical amplifiers for increasing the energy of pulsed lasers in the wavelength range of 300-nm to 2050-nm. Also, amplifier and modulator combinations for converting continuous-wave lasers to a pulsed format are

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**NASA SBIR 2018 Phase I Solicitation**

**Science**

**S1.01 Lidar Remote Sensing Technologies**

Lead Center: JPL

Participating Center(s): GSFC, JPL

**Technology Area: TA15 Aeronautics**

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Proposals must show relevance to the development of lidar instruments that can be used for NASA science-focused measurements or to support current technology programs. Meeting science needs leads to four primary instrument types:

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- **Doppler** - Measures wavelength changes in the return beam to retrieve relative velocity.
- **Differential absorption** - Measures attenuation of two different return beams (one centered on a spectral line of interest) to retrieve concentration of a trace gas.

Phase I research should demonstrate technical feasibility and show a path toward a Phase II prototype unit. Phase II prototypes should be capable of laboratory demonstration and preferably suitable for operation in the field from a ground-based station, an aircraft platform, or any science platform amply defended by the proposer. For the 2018 SBIR Program, NASA is soliciting the component and subsystem technologies described below:

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- Optical amplifiers for increasing the energy of pulsed lasers in the wavelength range of 300-nm to 2050-nm. Also, amplifier and modulator combinations for converting continuous-wave lasers to a pulsed format are
encouraged. Amplifier designs must preserve the wavelength stability and spectral purity of the input laser.

- Ultra-low noise photoreceiver modules, operating at 1600-nm or 2050-nm wavelength, consisting of the
detection device, complete Dewar/cooling systems, and associated amplifiers. General requirements are:
large single-element active detection diameter (>100 micron), high quantum efficiency (>85%), noise
equivalent power of the order of $10^{-14}$ W/$\sqrt{\text{Hz}}$, and bandwidth greater than 10-MHz.
- Novel approaches and components for lidar receivers such as: new approaches for high-efficiency
measurement of high spectral resolution lidar (HSRL) aerosol properties at 1064, 532 and/or 355 nm;
compact and lightweight Cassegrain telescopes compatible with existing differential absorption lidar (DIAL)
and HSRL lidar systems; frequency agile solar blocking filters at 817-nm and/or 935-nm, and scanners for
large apertures of telescope of at least 10-cm diameter and scalable to 50-cm diameter.

S1.02 Technologies for Active Microwave Remote Sensing

Lead Center: JPL

Participating Center(s): GSFC

Technology Area: TA15 Aeronautics

NASA employs active microwave sensors for a wide range of remote sensing applications (for example, see
http://www.nap.edu/catalog/11820.html [1]). These sensors include low frequency (less than 10 MHz) radar
sounders to G-band (160 GHz) radars for measuring precipitation and clouds, for planetary landing, upper
atmospheric monitoring, surface water monitoring, soil moisture and global snow coverage, topography
measurement and other Earth and planetary science applications. We are seeking proposals for the development
of innovative technologies to support future radar missions and applications. The areas of interest for this call are
listed below.

Deployable High-Frequency Antenna Technologies for CubeSats, NanoSats or SmallSats

Novel technologies are sought that enable X, Ku, Ka, W-band deployable antennas for small spacecraft, exceeding
an effective deployed area of 3U or 30 cm x 30 cm. Techniques, hardware, electronics, materials, etc. are sought
to advance the state of art in deployable high-frequency antennas for CubeSats, NanoSats or SmallSats.

Deployable Low-Frequency Antenna Technologies for CubeSats, NanoSats or SmallSats

Novel technologies are sought that enable HF, VHF, UHF deployable, electrically large antennas (half-wavelength
or greater) for small spacecraft. Techniques, hardware, electronics, materials, etc. are sought to advance the state
of art in deployable low frequency antennas for CubeSats, NanoSats or SmallSats.

Deployable Cylindrical Parabolic Antenna:

- Up to a four square meter aperture.
- Performance up to 36 GHz desired.

SoOp (Signal of Opportunity) Power Reduction Technologies

Technology to reduce the power consumption of Signal of Opportunity (SoOp) instruments, such as a correlator
ASIC with >20 MHz BW, on-board ADCs, and differential delay and Doppler compensation.

V-band Power Amplifiers:

- Frequency: 65-70 GHz.
- Output Power > 1.5W.
- Or >2W over smaller bandwidth 67-69 GHz.
Compact mm-Wave phase array (Active or Passive) for Landing/Hazard Detection:

- Mm-Wave phased array antenna design.
- Low-Power TRMs/Solid State.
- Output Power > 20 dBm.
- Beam width < 8 mrad.

Large Aperture, High Aspect Ratio Antenna Technologies for MicroSats

Novel technologies that enable antenna designs between L and X band with > 4 m² effective area aspect ratios > 4:1 stowing volume < 18,000 cm³.

VHF/P-band Dual-band dual-polarization antenna elements for small satellites or CubeSats:

- Needed for signals-of-opportunity remote sensing.
- Specifications: 137 MHz and 255 MHz.
- ~10% bandwidth, dual polarization.
- Stowable in <1U.
- Deployable in zero gravity (1-G also desired).
- Gain > 0 dBi - Combine into 2-element end-fire array.

VHF/P-band Dual-band Dual-Polarization Antenna Elements for Small Satellites or CubeSats

VHF/P-band Dual-band dual-polarization antenna elements for small satellites or CubeSats are needed for signals-of-opportunity remote sensing. Specifications: 137 MHz and 255 MHz with ~10% bandwidth, dual polarization, stowable in <1U, deployable in zero gravity (1-G also desired), gain > 0 dBi. Combine into 2-element end-fire array.

Deployable Cylindrical Antennas

Deployable cylindrical parabolic antenna with up to a four square meter aperture. Performance up to 36 GHz desired.

Deployable W-band (94 GHz) antenna suitable for CubeSats and SmallSats

Aperture up to 1 square meter desired.

Surface Mount Non-Intrusive Hall Effect Current Sensor:

- Current Sensing: > 10-100 mA.
- Based on Hall Effect.
- Devices should sense current indirectly on PCB without being part of the circuit.

Technologies/Techniques for Super Resolution Radar Imaging

Hardware and algorithms required to apply physics-based super resolution techniques to acquire and/or analyze data.

S1.03 Technologies for Passive Microwave Remote Sensing

Lead Center: JPL

Participating Center(s): JPL
Technology Area: TA15 Aeronautics

NASA employs passive microwave and millimeter-wave instruments for a wide range of remote sensing applications from measurements of the Earth's surface and atmosphere to cosmic background emission. Proposals are sought for the development of innovative technology to support future science and exploration missions MHz to THz sensors. Technology innovations should either enhance measurement capabilities (e.g., improve spatial, temporal, or spectral resolution, or improve calibration accuracy) or ease implementation in spaceborne missions (e.g., reduce size, weight, or power, improve reliability, or lower cost). Specific technology innovations of interest are listed below, however other concepts will be entertained:

- **Microwave integrated photonic components to demonstrate feasibility and utility for future microwave instruments.** Components used in spectrometers, beam forming arrays, correlation arrays and other active or passive microwave instruments are sought.
- **A focal plane array antenna design to enable large aperture microwave radiometers** (e.g., 6 meters operating at 37 GHz), conical scanning reflector antennas fed by focal plane arrays are needed. Designs are desired for 4.6, or 12-meter apertures operating at 36.5 GHz and 18.7/23.8 GHz.
- **Low power RFI mitigating receiver back ends for broad band microwave radiometers.** NASA requires a low power, low mass, low volume, and low data rate RFI mitigating receiver back-end that can be incorporated into existing and future radiometer designs. The system should be able to channelize up to 1 GHz with 16 sub bands and be able to identify RFI contamination using tools such as kurtosis.
- **Calibration Targets for water vapor radiometers operating in the frequency range from 18 to 37 GHz.** Return loss of > 40 dB and relative emission characterized over physical temperature to 0.1%.
- **Components for addressing gain instability in LNA based radiometers from 100 and 600 GHz.** NASA requires low insertion loss solutions to the challenges of developing stable radiometers and spectrometers operating above 100 GHz that employ LNA based receiver front ends. This includes noise diodes with ENR>10dBm with better than ? 0.01 dB/K thermal stability, Dicke switches with better than 30 dB isolation, phase modulators, and low loss isolators along with fully integrated state-of-art receiver systems operating at room and cryogenic temperatures.
- **Technology for low-power, rad-tolerant broad band spectrometer back ends for microwave radiometers.** Includes: digitizers starting at 20 Gsps, 20 GHz bandwidth, 4 or more bit and simple interface to FPGA; ASIC implementations of polyphase spectrometer digital signal processing with ~1 Watt/GHz.
- **5-GHz bandwidth polarimetric-spectrometer with 512 channels.** Two simultaneously sampled ADC inputs. Spectrometer filterbanks and either polarization combiners or cross correlators for computing all four Stokes parameters (any Stokes vector basis is acceptable: e.g., IQUV, vhUV, vhpmlr). Kurtosis detectors on at least the two principal channels. Rad-hard and minimized power dissipation.
- **Local Oscillator technologies for THz instruments.** This can include: GaN based frequency multipliers that can work in the 200-400 GHz range (output frequency) with input powers up to 1 W. Graphene based devices that can work as frequency multipliers in the frequency range of 1-3 THz with efficiencies in the 10% range and higher.
- **Low DC power correlating radiometer front-ends and low 1/f-noise detectors for 100-700 GHz.** Correlating radiometers and low 1/f-noise tunnel diode detectors have been demonstrated at frequencies below 100 GHz. 180 GHz correlating radiometer with high DC power LO system demonstrated.
- **A radiometer-on-a-chip of either a switching or pseudo-correlation architecture with internal calibration sources is needed.** Designs with operating frequencies at the conventional passive microwave bands of 36.6 GHz (priority) and 19.7/22.3 GHz enabling dual-polarization inputs. Interfaces include, waveguide input, power, control, and digital data output. Design features allowing subsystems of multiple (10’s of) integrated units to be efficiently realized.
- **GaAs based Schottky diode with low junction capacitance and finger inductance to operate in the 2-5 THz.** The diodes should be integrated with waveguide coupling probes and other circuitries to develop 2-5 THz harmonic-mixers with low conversion loss and noise temperature.

S1.04 Sensor and Detector Technology for Visible, IR, Far IR and Submillimeter

Lead Center: JPL

Participating Center(s): ARC, GSFC, LaRC
Technology Area: TA15 Aeronautics

NASA is seeking new technologies or improvements to existing technologies to meet the detector needs of future missions, as described in the most recent decadal surveys:

- Earth science - [http://www.nap.edu/catalog/11820.html](http://www.nap.edu/catalog/11820.html) [1].
- Planetary science - [http://www.nap.edu/catalog/10432.html](http://www.nap.edu/catalog/10432.html) [2].
- Astronomy and astrophysics - [http://www.nap.edu/books/0309070317/html](http://www.nap.edu/books/0309070317/html) [3].

In pixel digital readout integrated circuit (DROIC) for high dynamic range infrared focal plane arrays to circumvent the limitations in charge well capacity, by using in-pixel digital counters that can provide orders of magnitude larger effective well depth, thereby affording longer integration times. Longer integration times provide improved signal-to-noise ratio and/or higher operating temperature, which reduces cooler capacity, resulting in savings in size, weight, power and cost.

Compact, low power, ASICs for readout of Kinetic Inductance Detector arrays each with a low operating power and capable of operation at both room temperature and cryogenic temperatures to perform one of the following functions.

- 8192 point FFT processor with 5 bits of depth using a polyphase oversampling or a Hanning window. Input format would be SERDES (2-4Gsamples/sec) and output format USB2.0 or similar and Power <=2W.
- >10bit ADC at >1GHz sampling rate with >2000 bands, ~5kHz bandwidth, power <0.3W.

Two-dimensional row and column, cryogenic, multiplexing readout system for hybridization to two dimensional Far IR and Submillimeter bolometer arrays. Of particular interest are SQUID based systems with a first stage operating at sub-Kelvin temperatures and compatible with 32X40 detector array format.

New or improved technologies leading to measurement of trace atmospheric species (e.g., CO, CH₄, N₂O) or broadband energy balance in the IR and far-IR from geostationary and low-Earth orbital platforms. Of particular interest are SQUID based systems with a first stage operating at sub-Kelvin temperatures and compatible with 32X40 detector array format.

Development of a robust wafer-level integration technology that will allow high-frequency capable interconnects and allow two dis-similar substrates (i.e., Silicon and GaAs) to be aligned and mechanically 'welded' together. Specially develop ball grid and/or Through Silicon Via (TSV) technology that can support submillimeter-wave arrays. Initially the technology can be demonstrated at 1-inch die level but should be do-able at 4-inch wafer level.

Single photon avalanche diode or silicon photomultiplier photon-counting detector technology for high-speed, non-imaging lidar applications. Detector(s) (single or array) to provide ~ 10E10 ph/s linear counting dynamic range, < 5x10E5 dark count rate at non-cryogenic temperatures, > 30% detection efficiency at 532 nm.

Space qualify a commercial 2k x 2k polarization camera for a solar coronograph for low Earth orbit and Earth-Sun lagrange point environments.

Higher power THz local oscillators and backend electronics for high resolution spectroscopy for astrophysics. Local Oscillator capable of spectral coverage 2-5 THz; Output power up to >2 mW; Frequency agility with > 1GHz near chosen THz frequency; Continuous phase-locking ability over the THz laser tunable range with <100 kHz line width. Backend ASIC capable of binning >1GHz intermediate frequency bandwidth into 0.1-0.5 MHz channels with low power dissipation <0.5W.

Development of an un-cooled broadband photon detector with average QE>50% over the spectral range from 3um to 50um. The Detectivity D* must be greater than 5x10⁹. The detector may have electrically tunable spectral range.
S1.05 Detector Technologies for UV, X-Ray, Gamma-Ray and Cosmic-Ray Instruments

Lead Center: JPL

Participating Center(s): GSFC, MSFC

Technology Area: TA15 Aeronautics

This subtopic covers 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.

The proposed efforts must be directly linked to a requirement for a NASA mission. These include Explorers, Discovery, Cosmic Origins, Physics of the Cosmos, Solar-Terrestrial Probes, Vision Missions, and Earth Science Decadal Survey missions. Details of these can be found at the following URLs:

- General Information on Future NASA Missions - [http://www.nasa.gov/missions](http://www.nasa.gov/missions [4]).
- Future planetary programs - [https://solarsystem.nasa.gov/2013decadal/](https://solarsystem.nasa.gov/2013decadal/ [5]).
- Earth Science Decadal missions - [http://www.nap.edu/catalog/11820.html](http://www.nap.edu/catalog/11820.html [1]).
  - [http://foxsi.ssl.berkeley.edu/](http://foxsi.ssl.berkeley.edu/ [8]).
- X-ray Astrophysics - [http://sites.nationalacademies.org/bpa/BPA_049810](http://sites.nationalacademies.org/bpa/BPA_049810 [9]).
  - [http://wwwastro.msfc.nasa.gov/xrs/](http://wwwastro.msfc.nasa.gov/xrs/ [10]).
  - [http://x-ifu.irap.omp.eu/](http://x-ifu.irap.omp.eu/ [11]).

Specific technology areas are:

- Significant improvement in wide band gap semiconductor materials, such as AlGaN, ZnMgO and SiC, individual detectors, and detector arrays for operation at room temperature or higher for missions such as GEO-CAPE, NWO, ATLAST and planetary science composition measurements.
- Highly integrated, low noise (< 300 electrons rms with interconnects), low power (< 100 uW/channel) mixed signal ASIC readout electronics as well as charge amplifier ASIC readouts with tunable capacitive inputs to match detector pixel capacitance. See needs of National Research Council's Earth Science Decadal Survey (NRC, 2007): Future Missions include GEO-CAPE, HyspIRI, GACM, future GOES and SOHO programs and planetary science composition measurements.
- Visible-blind SiC Avalanche Photodiodes (APDs) for EUV photon counting are required. The APDs must show a linear mode gain >10E6 at a breakdown reverse voltage between 80 and 100V. The APD's must demonstrate detection capability of better than 6 photons/pixel/s down to 135nm wavelength. See needs of National Research Council's Earth Science Decadal Survey (NRC, 2007): Tropospheric ozone.
- Visible-blind UV and EUV detectors with small (< 10 $\mu$m) pixels, large format, photon-counting sensitivity and detectivity, low voltage and power requirements, and room-temperature operation suitable for mission concepts such as the EUV Spectrograph on the ESA-NASA Solar Orbiter.
- Large area (3 m$^2$) photon counting near-UV detectors with 3 mm pixels and able to count at 10 MHz. Array with high active area fraction (>85%), 0.5 megapixels and readout less than 1 mW/channel. Future instruments are focal planes for JEM-EUSO and OWL ultra-high energy cosmic ray instruments and ground Cherenkov telescope arrays such as CTA, and ring-imaging Cherenkov detectors for cosmic ray instruments such as BESS-ISO. As an example, (JEM-EUSO and OWL), imaging from low-Earth orbit of air fluorescence, UV light generated by giant air showers by ultra-high energy (E >10E19 eV) cosmic rays require the development of high sensitivity and efficiency detection of 300-400 nm UV photons to measure signals at the few photon (single photo-electron) level. A secondary goal minimizes the sensitivity to photons with a wavelength greater than 400 nm. High electronic gain (10E4 to 10E6), low noise, fast time response (<10 ns), minimal dead time (<5% dead time at 10 ns response time), high segmentation with low dead area (<20% nominal, <5% goal), and the ability to tailor pixel size to match that dictated by the imaging optics. Optical designs under consideration dictate a pixel size ranging from approximately 2 x 2 mm$^2$ to 10 x 10 mm$^2$. Focal plane mass must be minimized (2g/cm$^2$ goal). Individual pixel readout is required. The entire focal plane detector can be formed from smaller, individual sub-arrays.
• Neutral density filter for hard x-rays (> 1 keV) to provide attenuation by a factor of 10 to 1000 or more. The filter must provide broad attenuation across a broad energy range (from 1 keV to ~100 keV or more) with a flat attenuation profile of better than 20%.
• Solar X-ray detectors with small independent pixels (< 250 μm) and fast read-out (>10,000 count/s/pixel) over an energy range from < 5 keV to 300 keV.
• Proposals that address the development of supporting technologies that would help enable X-ray Surveyor mission that requires the development of X-ray microcalorimeter arrays with much larger field of view, ~10^5-10^6 pixels, of pitch ~ 25-100 μm, and ways to read out the signals. For example, modular superconducting magnetic shielding is sought that can be extended to enclose a full scale focal plane array. All joints between segments of the shielding enclosure must also be superconducting.
• For missions such as ATHENA X-IFU and X-ray Surveyor, improved long-wavelength blocking filters are needed for large-area, x-ray microcalorimeters. Filters with supporting grids are sought that, in addition to increasing filter strength, also enhance EMI shielding (1 - 10 GHz) and thermal uniformity for decontamination heating. X-ray transmission of greater than 80% at 600 eV per filter is sought, with infrared transmissions less than 0.01% and ultraviolet transmission of less than 5% per filter. Means of producing filter diameters as large as 10 cm should be considered.

S1.06 Particles and Field Sensors and Instrument Enabling Technologies

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

Technology Area: TA15 Aeronautics

While the size distribution of matter in space that ranges from large-scale (planets – moons – asteroids – dust) objects is quite well characterized down to micron-sized dust particles, below that there is a significant, largely unobserved gap down to single ions/electrons/ENAs. To cover the observational gap between 10^{-6} m and 10^{-10} m in particle size that includes nano-dust and molecules in space, new technology investment is needed. Advanced sensors for the detection of elementary particles (atoms, molecules and their ions) and electric and magnetic fields in space and associated instrument technologies are often critical for enabling transformational science from the study of the sun's outer corona, to the solar wind, to the trapped radiation in Earth's and other planetary magnetic fields, and to the atmospheric composition of the planets and their moons. Improvements in particles and fields sensors and associated instrument technologies enable further scientific advancement for upcoming NASA missions such as CubeSats, Explorers, STP, LWS, 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, dust particle detectors, and associated support electronics and materials. Specific areas of interest include:

• High Voltage Optocoupler / Optoisolator or isolation transformers:
  ○ Need Horizon: 1 to 3 years, 3 to 5 years.
  ○ Low energy particle instruments often require significant high voltage in the range 5KV to 20KV. Floating the electronics is an attractive for low noise. A high reliability radiation hardened device for transferring power, signal and commands across a high voltage is a very useful component. Typical specifications 3.3V and 5V up to 1A, speed up to 1MHz, -55° C to +85° C, and 300 krads.
  ○ Importance: High – Critical need for next generation particle instruments.
• Curved microchannel plates (MCPs):
  ○ Need Horizon: 1 to 3 years.
  ○ It is highly desirable for MCP channel angles to match MCP curvature. This will make MCP gain and imaging quality independent of incident particle angle. This property will be very useful for particle
imaging instruments using MCPs.
- Importance: Very High for future flagship and Cubesat and SmallSat missions.

- Micro machined particle collimators:
  - Explorer missions, Decadal survey missions IMAP, MEDICI, GDC, DYNAMICS, DRIVE Initiative, DISCOVERY, New Frontiers, and CubeSat, SmallSat missions, Sub-orbitals.
  - Need Horizon: 1 to 3 years, 3 to 5 years.
  - State of art: Light weight vibration reliable, particle collimators from thin metal or other material with FOV to be made in the range of 2deg x 2 deg to 20x20 deg with physics transparency >=70.
  - Importance: High: Critical need for next generation particle instruments.

**S1.07 In Situ Instruments/Technologies for Planetary Science**

Lead Center: JPL

Participating Center(s): ARC, GRC, GSFC, MSFC

Technology Area: TA15 Aeronautics

This subtopic solicits development of advanced instrument technologies and components suitable for deployment on in-situ planetary 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. In addition, technologies that can increase instrument resolution and sensitivity or achieve new & innovative scientific measurements are solicited. For example missions, see [http://www.nasa.gov/missions](http://www.nasa.gov/missions) [4]. For details of the specific requirements see the National Research Council's, Vision and Voyages for Planetary Science in the Decade 2013-2022 ([http://solarsystem.nasa.gov/2013decadal/](http://solarsystem.nasa.gov/2013decadal/)) [6]. Technologies that support NASA’s New Frontiers and Discovery missions to various planetary bodies are of top priority.

In-situ technologies are being sought to achieve much higher resolution and sensitivity with significant improvements over existing capabilities. In-situ technologies amenable to CubeSats and SmallSats are also being solicited. Atmospheric probe sensors and technologies that can provide significant improvements over previous missions are also sought. Specifically, this subtopic solicits instrument development that provides significant advances in the following areas, broken out by planetary body:

- **Mars** - Sub-systems relevant to current in-situ instrument needs (e.g., lasers and other light sources from UV to microwave, X-ray and ion sources, detectors, mixers, mass analyzers, etc.) or electronics technologies (e.g., FPGA and ASIC implementations, advanced array readouts, miniature high voltage power supplies). Technologies that support high precision in-situ measurements of elemental, mineralogical, and organic composition of planetary materials are sought. Conceptually simple, low risk technologies for in-situ sample extraction and/or manipulation including fluid and gas storage, pumping, and chemical labeling to support analytical instrumentation. Seismometers, mass analyzers, technologies for heat flow probes, and atmospheric trace gas detectors. Improved robustness and g-force survivability for instrument components, especially for geophysical network sensors, seismometers, and advanced detectors (iCCDs, PMT arrays, etc.). Instruments geared towards rock/sample interrogation prior to sample return are desired.

- **Venus** - Sensors, mechanisms, and environmental chamber technologies for operation in Venus's high temperature, high-pressure environment with its unique atmospheric composition. Approaches that can enable precision measurements of surface mineralogy and elemental composition and precision measurements of trace species, noble gases and isotopes in the atmosphere are particularly desired.

- **Small Bodies** - Technologies that can enable sampling from asteroids and from depth in a comet nucleus, improved in-situ analysis of comets. Imagers and spectrometers that provide high performance in low light environments. Dust environment measurements & particle analysis, small body resource identification, and/or quantification of potential small body resources (e.g., oxygen, water and other volatiles, hydrated minerals, carbon compounds, fuels, metals, etc.). Advancements geared towards instruments that enable elemental or mineralogy analysis (such as high-sensitivity X-ray and UV-fluorescence spectrometers,
UV/fluorescence systems, scanning electron microscopy with chemical analysis capability, mass spectrometry, gas chromatography and tunable diode laser sensors, calorimetry, imaging spectroscopy, and LIBS) are sought.

- **Saturn, Uranus and Neptune** - Components, sample acquisition, and instrument systems that can enhance mission science return and withstand the low-temperatures/high-pressures of the atmospheric probes during entry.
- **The Moon** - Note that there is one subtopic, "Lunar Resources (H2.01)" in the HEOMD list. The emphasis of that subtopic is on in-situ resource utilization (ISRU). All proposers are encouraged to submit any proposal related to ISRU to the HEOMD subtopic. However, proposals with pure science objectives and without ISRU application may be submitted to this SMD subtopic. One example is a seismometer.

Proposers are strongly encouraged to relate their proposed development to:

- NASA's future planetary exploration goals.
- Existing flight instrument capability, to provide a comparison metric for assessing proposed improvements.

Proposed instrument architectures should be as simple, reliable, and low risk as possible while enabling compelling science. Novel instrument concepts are encouraged particularly if they enable a new class of scientific discovery.

Technology developments relevant to multiple environments and platforms are also desired.

Proposers should show an understanding of relevant space science needs, and present a feasible plan to fully develop a technology and infuse it into a NASA program.

**S1.08 In-situ Sensors and Sensor Systems for Earth Science**

*Lead Center: JPL*

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

*Technology Area: TA15 Aeronautics*

NASA seeks measurement capabilities that support current satellite and model validation as well as targeted airborne science program field campaign activities as discussed in the ROSES solicitation. Data from such sensors not only validates models, but informs process studies, and is used to improve models. Topics include air quality, aerosol absorption and optical properties (e.g., brown carbon), and cloud probes suitable for discriminating and characterizing ice and liquid particles in super-cooled and mixed-phase clouds.

In-situ sensor systems can comprise stand-alone instrument and data packages; instrument systems configured for integration on NASA’s Airborne Science aircraft fleet or commercial providers, UAS, or balloons, ground networks; or end-to-end solutions providing needed data products from mated sensor and airborne/surface/subsurface platforms. An important goal is to create sustainable measurement capabilities to support NASA’s Earth science objectives, with infusion of new technologies and systems into current/future NASA research programs. Instrument prototypes as a deliverable in Phase II proposals and/or field demonstrations are encouraged.

Complete instrument systems are desired, including features such as remote/unattended operation and data acquisition, and minimum size, weight, and power consumption. Desired sensors or mated platform/sensors include:

- Spectrally resolved absorption and extinction of atmospheric aerosols (size 0.1 to 10 micron).
- Aerosol scattering as a function of scattering angle (phase function).
- Aerosols refractive index.
- Aerosols and cloud particle number and size distribution covering the diameter size range of 0.01 micron to 200 micron with 10% accuracy. Probes targeting cloud particles in the lower end of this size range (0.01-5 micron) are particularly encouraged.
- Cloud probes able to differentiate and quantify non-sphericity and phase of particles.
- Liquid and ice water content in clouds with calibrated accuracy and precision.
- Spectrally resolved cloud extinction.
- Static air temperature to better than 0.1°C accuracy.
- Liquid and ice water path, precipitable water path.
- Ice nucleating particle (INP) concentration suitable for airborne deployment.
- Innovative, high-value sensors directly targeting a stated NASA need may also be considered.

S1.09 Cryogenic Systems for Sensors and Detectors

Lead Center: JPL

Participating Center(s): ARC, JPL, MSFC

Technology Area: TA15 Aeronautics

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. There are four potential investment areas that NASA is seeking to expand state of the art capabilities for possible use on future programs such as the Europa Jupiter System Science missions (http://www.nasa.gov/multimedia/podcasting/jpl-europa20090218.html [12]), and flagship missions under consideration for the 2020 Astrophysics Decadal Survey (http://cor.gsfc.nasa.gov/docs/PCOS_facility_missions_report_final.pdf [13]). The topic areas are:

Cryocooler Systems and Components:

- **Miniaturized/Efficient Cryocooler Systems** - Cryocooler systems are sought for application on SmallSat and small low power instrument space platforms. Present state-of-the-art capabilities provide 0.4 W of cooling at 77 K with approximately 5 W input power, while rejecting heat at 300 K, and having a system mass of 400 grams. Desired performance specifications for cryocoolers include a cooling capability on the order of 0.2 W at a temperature of approximately 30 K. For application on missions to outer planets, cryocoolers are needed with a cooling power of 0.3 W at approximately 35 K, with a heat rejection temperature as low as 150 K. Desired masses and input powers in both cases are < 400 grams and < 5W respectively. Component level improvements are also desirable.

- **Low Temperature/High Efficiency Cryocoolers** - High efficiency, multi-stage coolers with a low temperature stage capable of reaching 4 to 10 K will be needed for future astrophysics missions. Current state-of-the-art coolers include a device providing 0.04 W at 4.5 K and another providing 0.09 W at 6 K. Cryocoolers are sought that provide higher cooling power, for example >0.3 W at 10 K and ~ 200 mW at 4 K, with high efficiency. Devices that produce extremely low vibration, particularly at frequencies below a few hundred Hz are of special interest. Component level improvements are also desirable.

- **Cryogenic/Rad-Hard Accelerometers** - Accelerometers that can operate at 150 K, withstand a 0.01 Tesla magnetic field and are radiation hard to mega-rad level doses are needed for cryocooler control and monitoring in missions to outer planets.

Sub-Kelvin Cooling Systems:

- **Magnetic Cooling Systems** - Sub-Kelvin cooling systems include Adiabatic Demagnetization Refrigerators (ADRs) and Active Magnetic Regenerative Refrigerators (AMRRs). The ADR in the Soft X-ray Spectrometer instrument on the Hitomi mission represents the state of the art in sub-Kelvin cooling systems for space application. Future missions requiring sub-Kelvin coolers will need devices that provide lower operating temperature (<50 mK), higher (preferably 100%) duty cycle, higher heat rejection temperature (preferably > 10K), higher overall system efficiency, and lower mass. Improvements at the component level are needed to achieve these goals. Specific components sought include:
Compact, lightweight, low current superconducting magnets capable of producing a field of at least 4 Tesla while operating at a temperature of at least 10 K, and preferably above 15 K. Desirable properties include:

- A high engineering current density, preferably > 300 Amp/mm².
- A field/current ratio of >0.33 Tesla/Amp, and preferably >0.66 Tesla/Amp.
- Low hysteresis heating.
- Lightweight Active/Passive magnetic shielding (for use with 4 Tesla magnets) with low hysteresis and eddy current losses, and low remanence.
- Heat switches with on/off conductance ratio > 3 \(10^4\) and actuation time of <10 s. Materials are also sought for gas gap heat switch shells: these are tubes with extremely low thermal conductance below 1 K; they must be impermeable to helium gas, have high strength, including stability against buckling, and have an inner diameter > 20 mm.
- High cooling power density magnetocaloric materials, especially single crystals with volume > 20 cm³.
- Superconducting leads (10K - 90K) capable of 10 A operation with 1 mW conduction.
- 10 mK- 300 mK high resolution thermometry.

Proposals considered viable for Phase I award will seek to validate hypotheses through proof of concept testing at relevant temperatures.

S1.10 Atomic Interferometry

Lead Center: JPL

Participating Center(s): JPL

Technology Area: TA15 Aeronautics

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. The microgravity environment in space provides opportunities for further drastic improvements in sensitivity and precision. Such inertial sensors will have great potential to provide new capabilities for NASA Earth and planetary gravity measurements, for spacecraft inertial navigation and guidance, and for gravitational wave detection and test of properties of gravity in space.

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. Some of the identified key challenges are (but not limited to):

- Compact high flux ultra-cold atom sources for free space atom interferometers (Example: >1x10^6 total useful free-space atoms, <1 nK, Rb, K, Cs, Yb, Sr, and Hg. Performance and species can be defined by offerors). Other related innovative methods and components for cold atom sources are of great interest, such as a highly compact and regulatable atomic vapor cell.
- Ultra-high vacuum technologies that allow completely sealed, non-magnetic enclosures with high quality optical access and the base pressure maintained <1x10^{-9} torr. Consideration should be given to the inclusion of cold atom sources of interest.
- Beyond the state-of-the-art photonic components at wavelengths for atomic species of interest, particularly at NIR and visible: efficient acousto-optic modulators (low RF power d ~ 200 mW, low thermal distortion, ~80% or greater diffraction efficiency); efficient electro-optic modulators (low bias drift, residual AM, and return loss, fiber-coupled preferred), miniature optical isolators (~30 dB isolation or greater, ~ -2 dB loss or less), robust high-speed high-extinction shutters (switching time < 1 ms, extinction > 60 dB are highly desired).
- Flight qualifiable lasers or laser systems of narrow linewidth, high tunability, and/or higher power for clock and cooling transitions of atomic species of interest. Cooling and trapping lasers: 10 kHz linewidth and ~ 1 W or greater total optical power. Compact clock lasers: 5x10^{15} Hz/?1/2 near 1 s (wavelengths for Yb+, Yb,
Sr clock transitions are of special interest).

- Analysis and simulation tool of a cold atom system in trapped and freefall states relevant to atom interferometer and clock measurements in space.

All proposed system performances can be defined by offerors with sufficient justification. Subsystem technology development proposals should clearly state the relevance, define requirements, relevant atomic species and working laser wavelengths, and indicate its path to a space-borne instrument.

S1.11 In Situ Instruments/Technologies and Sample Processing for Ocean Worlds Life Detection

Lead Center: JPL

Participating Center(s): ARC, GRC, GSFC, MSFC

Technology Area: TA15 Aeronautics

This subtopic solicits development of in-situ instrument technologies and components to advance the maturity of science instruments focused on the detection of evidence of life, especially extant of life, in the Ocean Worlds (e.g., Europa, Enceladus, Titan, Ganymede, Callisto, Ceres, etc.). 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. In addition, technologies that can increase instrument resolution and sensitivity or achieve new & innovative scientific measurements are solicited.

In addition, this subtopic solicits development of innovative sample processing technologies (methodologies and hardware) for the purposes of improving the resolution and sensitivity of life detection measurements and supporting habitability assessment of environmental samples from Ocean Worlds (e.g., Europa, Enceladus, Titan, etc.). Samples are expected to contain water, minerals, salts, etc. that may complicate measurements or interfere with interpretations. Thus, samples are expected to require separation of components as a preparatory step to analysis. Analytes of interest (e.g., organic molecules including biomolecules, cells, and inorganic solutes and particulates) in samples may also be too dilute and could escape detection unless concentration technologies are applied as a preparatory step. These technologies must be capable of operation under space and planetary conditions, including the extreme pressures, temperatures, radiation levels, stress from launch and impact. Technologies should be of low mass, power, volume; capable of radiation-hardening and sterilization; and require low data rates. Technologies that minimize biological and analytical contamination of the sample stream in order to meet planetary protection requirements and can maintain sample integrity for mission-science investigations and support integration of contamination and/or analyte monitoring are solicited.

For synergistic NASA technology solicitation, see ROSES 2016/C.20 Concepts for Ocean worlds Life Detection Technology (COLDTECH) call:

- [https://nspires.nasaprs.com/external/solicitations/summary.do?method=init&solId=%7B5C43865B-0C93-6ECA-BCD2-A3783CB1AAC8%7D&path=init](https://nspires.nasaprs.com/external/solicitations/summary.do?method=init&solId=%7B5C43865B-0C93-6ECA-BCD2-A3783CB1AAC8%7D&path=init) [14].

Specifically, this subtopic solicits instrument technologies and components that provide significant advances in the following areas, broken out by planetary body:

- **Europa, Enceladus, Titan and other Ocean Worlds in general** - Technologies and components relevant to life detection instruments (e.g., microfluidic analyzer, MEMS chromatography/mass spectrometers, laser-ablation mass spectrometer, fluorescence microscopic imager, Raman spectrometer, tunable laser system, liquid chromatography/mass spectrometer, X-ray fluorescence, digital holographic microscope-fluorescence microscope, Antibody microarray biosensor, nanocantilever biodetector etc.) Technologies for high radiation environments, e.g., radiation mitigation strategies, radiation tolerant detectors, and readout electronic components, which enable orbiting instruments to be both radiation-hard and undergo the planetary
protection requirements of sterilization (or equivalent).

- **Technologies and components relevant to sample processing of water and ice samples from plumes, surface ice, subsurface ice, or sub-ice waters** - Examples of such technologies include, but are not limited to: sonic processing; subcritical and critical solvent extraction; solid-phase extraction; cell isolation, concentration, and lysing; filtering, separation by osmosis and dialysis; chemical hydrolysis and derivatization; novel substrates or adaptives to enhance sensitivity or selectivity of target analytes; total organic carbon, pressure, temperature, pH, eH, dissolved ion monitoring and regulation components; miniaturized components such as microfluidic valves and pumps; and other fluid and solid handling systems following separation and concentration processing components.

- **Europa** - Life detection approaches optimized for evaluating and analyzing the composition of ice matrices with unknown pH and salt content. Instruments capable of detecting and identifying organic molecules (in particular biomolecules), salts and/or minerals important to understanding the present conditions of Europa’s ocean are sought (such as high-resolution gas chromatograph or laser desorption mass spectrometers, dust detectors, organic analysis instruments with chiral discrimination, etc.). These developments should be geared towards analyzing and handling very small sample sizes (mg to mg) and/or low column densities/abundances. Also of interest are imagers and spectrometers that provide high performance in low-light environments (visible and NIR imaging spectrometers, thermal imagers, etc.), as well as instruments capable of providing improving our understanding Europa’s habitability by characterizing the ice, ocean, and deeper interior and monitoring ongoing geological activity such as plumes, ice fractures, and fluid motion (e.g., seismometers, magnetometers). Improvements to instruments capable of gravity (or other) measurements that might constrain properties such as ocean and ice shell thickness will also be considered.

- **Sample-processing approaches optimized for particulate, inorganic chemicals, and organic molecules of possible biological origin in aerosols and surface materials** - Mechanical and electrical components and subsystems that work in cryogenic (95 K) and hydrocarbon-rich environments; sample extraction from liquid methane/ethane and/or hydrogen cyanide, sampling from organic ‘dunes’ at 95 K and robust sample preparation and handling mechanisms that feed into spectral and mass analyzers, as well as X-ray detection devices are solicited.

- **Enceladus** - Life detection approaches optimized for analyzing plume particles, as well as for determining the chemical state of Enceladus’ icy surface materials (particularly near plume sites). Instruments capable of detecting and identifying organic molecules (in particular biomolecules), salts and/or minerals important to understand the present conditions of the Enceladus ocean are sought (such as high resolution gas chromatograph or laser desorption mass spectrometers, dust detectors, organic analysis instruments with chiral discrimination, etc.). These developments should be geared towards analyzing and handling very small sample sizes (mg to mg) and/or low column densities/abundances. Also of interest are imagers and spectrometers that provide high performance in low-light environments (visible and NIR imaging spectrometers, thermal imagers, etc.), as well as instruments capable of monitoring the bulk chemical composition and physical characteristics of the plume (density, velocity, variation with time, etc.). Improvements to instruments capable of gravity (or other) measurements that might constrain properties such as ocean and ice shell thickness will also be considered.

- **Titan** - Life detection approaches optimized for searching for biosignatures and biologically relevant compounds in Titan’s lakes, including the presence of diagnostic trace organic species, and also for analyzing Titan’s complex aerosols and surface materials. Mechanical and electrical components and subsystems that work in cryogenic (95 K) environments; sample extraction from liquid methane/ethane, sampling from organic ‘dunes’ at 95 K and robust sample preparation and handling mechanisms that feed into mass analyzers are sought. Balloon instruments, such as IR spectrometers, imagers, meteorological instruments, radar sounders, solid, liquid, air sampling mechanisms for mass analyzers, and aerosol detectors are also solicited. Low mass and power sensors, mechanisms and concepts for converting terrestrial instruments such as turbidimeters and echo sounders for lake measurements, weather stations, surface (lake and solid) properties packages, etc. to cryogenic environments (95 K).

Other Ocean Worlds targets may include Ganymede, Callisto, Ceres, etc. Proposers are strongly encouraged to relate their proposed development to: NASA’s future Ocean Worlds exploration goals. Existing flight instrument capability, to provide a comparison metric for assessing proposed improvements.

Proposed instrument architectures should be as simple, reliable, and low risk as possible while enabling compelling science. Novel instrument concepts are encouraged particularly if they enable a new class of scientific discovery. Technology developments relevant to multiple environments and platforms are also desired.
Proposers should show an understanding of relevant space science needs, and present a feasible plan to fully develop a technology and infuse it into a NASA program.

**S2.01 Proximity Glare Suppression for Astronomical Direct Detection**

Lead Center: JPL

Participating Center(s): ARC, GSFC

**Technology Area: TA15 Aeronautics**

This subtopic 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. Contrast ratios of one million to ten billion over an angular spatial scale of 0.05-1.5 arcsec are typical of these objects. Achieving a very low background requires control of both scattered and diffracted light. The failure to control either amplitude or phase fluctuations in the optical train severely reduces the effectiveness of starlight cancellation schemes.

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. There is interest in component development and innovative instrument design, as well as in the fabrication of subsystem devices to include, but not limited to, the following areas:

**Starlight Suppression Technologies:**

- Image plane hybrid metal/dielectric, and polarization apodization masks in linear and circular patterns.
- Transmissive holographic masks for diffraction control and PSF apodization.
- Sharp-edged, low-scatter pupil plane masks.
- Low-scatter, low-reflectivity, sharp, flexible edges for control of scatter in starshades.
- Systems to measure spatial optical density, phase inhomogeneity, scattering, spectral dispersion, thermal variations, and to otherwise estimate the accuracy of high-dynamic range apodizing masks.
- Pupil remapping technologies to achieve beam apodization.
- Techniques to characterize highly aspheric optics.
- Methods to distinguish the coherent and incoherent scatter in a broad band speckle field.
- Coherent fiber bundles consisting of up to 10,000 fibers with lenslets on both input and output side, such that both spatial and temporal coherence is maintained across the fiber bundle for possible wavefront/amplitude control through the fiber bundle.

**Wavefront Measurement and Control Technologies:**

- Small stroke, high precision, deformable mirrors and associated driving electronics scalable to 10,000 or more actuators (both to further the state-of-the-art towards flight-like hardware and to explore novel concepts). Multiple deformable mirror technologies in various phases of development and processes are encouraged to ultimately improve the state-of-the-art in deformable mirror technology. Process improvements are needed to improve repeatability, yield, and performance precision of current devices.
- Instruments to perform broad-band sensing of wavefronts and distinguish amplitude and phase in the wavefront.
- Integrated mirror/actuator programmable deformable mirror.
- Multiplexers with ultra-low power dissipation for electrical connection to deformable mirrors.
- Low-order wavefront sensors for measuring wavefront instabilities to enable real-time control and post-processing of aberrations.
- Thermally and mechanically insensitive optical benches and systems.
Optical Coating and Measurement Technologies:

- Instruments capable of measuring polarization cross-talk and birefringence to parts per million.
- Highly reflecting, uniform, broadband coatings for large (> 1 m diameter) optics.
- Polarization-insensitive coatings for large optics.
- Methods to measure the spectral reflectivity and polarization uniformity across large optics.
- Methods to apply carbon nanotube coatings on the surfaces of the coronagraphs for broadband suppression from visible to NIR.

Other:

- Methods to fabricate diffractive patterns on large optics to generate astrometric reference frames.
- Artificial star and planet point sources, with 1e10 dynamic range and uniform illumination of an f/25 optical system, working in the visible and near infrared.
- Deformable, calibrated, collimating source to simulate the telescope front end of a coronagraphic system undergoing thermal deformations.
- Technologies for high contrast integral field spectroscopy, in particular for microlens arrays with or without accompanying mask arrays, working in the visible and NIR (0.4 - 1.8 microns), with lenslet separations in the 0.1 -0.4 mm range, in formats of ~140x140 lenslets.

S2.02 Precision Deployable Optical Structures and Metrology

Lead Center: JPL

Participating Center(s): GSFC, LaRC

Technology Area: TA15 Aeronautics

Planned future NASA Missions in astrophysics, such as the Wide-Field Infrared Survey Telescope (WFIRST) and the New Worlds Technology Development Program (coronagraph, external occulter and interferometer technologies) will push the state of the art in current optomechanical technologies. Mission concepts for New Worlds science would require 10 - 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 - 300 K. In addition, ground based telescopes such as the Cerro Chajnantor Atacama Telescope (CCAT) requires similar technology development.

The desired areal density is 1 - 10 kg/m² with a packaging efficiency of 3-10 deployed/stowed diameter. Static and dynamic wavefront error tolerances to thermal and dynamic perturbations may be achieved through passive means (e.g., via a high stiffness system, passive thermal control, jitter isolation or damping) or through active opto-mechanical control. Large deployable multi-layer structures in support of sunshades for passive thermal control and 20m to 50m class planet finding external occulters are also relevant technologies. Potential architecture implementations must package into an existing launch volume, deploy and be self-aligning to the micron level. The target space environment is expected to be the Earth-Sun L2.

This subtopic solicits proposals to develop enabling, cost effective component and subsystem technology for deploying large aperture telescopes with low cost. Research areas of interest include:

- Precision deployable structures and metrology for optical telescopes (e.g., innovative active or passive deployable primary or secondary support structures).
- Architectures, packaging and deployment designs for large sunshields and external occulters.
- In particular, important subsystem considerations may include:
  - Innovative concepts for packaging fully integrated subsystems (e.g., power distribution, sensing, and control components).
  - Mechanical, inflatable, or other precision deployable technologies.
  - Thermally-stable materials (CTE < 1ppm) for deployable structures.
  - Innovative systems, which minimize complexity, mass, power and cost.
  - Innovative testing and verification methodologies.
The goal for this effort is to mature technologies that can be used to fabricate 16 m class or greater, lightweight, ambient or cryogenic flight-qualified observatory systems. Proposals to fabricate demonstration components and subsystems with direct scalability to flight systems through validated models will be given preference. The target launch volume and expected disturbances, along with the estimate of system performance, should be included in the discussion. Proposals with system solutions for large sunshields and external occulters will also be accepted. A successful proposal shows a path toward a Phase II delivery of demonstration hardware scalable to 5-meter diameter for ground test characterization.

Before embarking on the design and fabrication of complex space-based deployable telescopes, additional risk reduction in operating an actively controlled telescope in orbit is desired. To be cost effective, deployable apertures that conform to a cubesat (up to 3-U) or ESPA format are desired. Consequently, deployment hinge and latching concepts, buildable for these missions and scalable to larger systems are desired. Such a system should allow <25-micron deployment repeatability and sub-micron stability for both thermal and mechanical on-orbit disturbances. A successful proposal would deliver a full-scale cubesat or ESPA ring compatible deployable aperture with mock optical elements.

Proposals should show an understanding of one or more relevant science needs, and present a feasible plan to fully develop the relevant subsystem technologies and to transition into future NASA program(s).

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

Lead Center: JPL

Participating Center(s): GRC, GSFC, JPL, LaRC

Technology Area: TA15 Aeronautics

Proposals must show an understanding of one or more relevant science needs, and present a feasible plan to develop the proposed technology for infusion into a NASA program: sub-orbital rocket or balloon; competed SMEX or MIDEX; or, Decadal class mission.

An ideal Phase I deliverable would be a precision optical system of at least 0.25 meters; or a relevant sub-component of a system; or a prototype demonstration of a fabrication, test or control technology leading to a successful Phase II delivery; or a reviewed preliminary design and manufacturing plan which demonstrates feasibility. While detailed analysis will be conducted in Phase II, the preliminary design should address how optical, mechanical (static and dynamic) and thermal designs and performance analysis will be done to show compliance with all requirements. Past experience or technology demonstrations which support the design and manufacturing plans will be given appropriate weight in the evaluation.

An ideal Phase II project would further advance the technology to produce a flight-qualifiable optical system greater than 0.5 meters or relevant sub-component (with a TRL in the 4 to 5 range); or a working fabrication, test or control system. Phase I and Phase II mirror system or component deliverables would be accompanied by all necessary documentation, including the optical performance assessment and all data on processing and properties of its substrate materials. A successful mission oriented Phase II would have a credible plan to deliver for the allocated budget a fully assembled and tested telescope assembly which can be integrated into the potential mission; and, demonstrate an understanding of how the engineering specifications of their system meets the performance requirements and operational constraints of the mission (including mechanical and thermal stability analysis).

Successful proposals will demonstrate an ability to manufacture, test and control ultra-low-cost optical systems that can meet science performance requirements and mission requirements (including processing and infrastructure issues). Material behavior, process control, active and/or passive optical performance, and mounting/deploying issues should be resolved and demonstrated.

Technical Challenges

To accomplish NASAs high-priority science requires low-cost, ultra-stable, large-aperture, normal incidence mirrors
with low mass-to-collecting area ratios. After performance, the most important metric for an advanced optical system is affordability or areal cost (cost per square meter of collecting aperture). Current normal incidence space mirrors cost $4 million to $6 million per square meter of optical surface area. This research effort seeks a cost reduction for precision optical components by 5 to 50 times, to between $100K/m² to $1M/m².

Specific metrics are defined for each wavelength application region:

Aperture Diameter for all wavelengths:

- Monolithic: 1 to 8 meters.
- Segmented: > 12 meters.

For UV/Optical:

- Areal Cost < $500K/m².
- Wavefront Figure < 5 nm RMS.
- Wavefront Stability < 10 pm/10 min.
- First Mode Frequency 250 to 500 Hz.
- Actuator Resolution < 1 nm RMS.

For Far-IR:

- Areal Cost for Far-IR < $100K/m².
- Cryo-deformation for Far-IR < 100 nm RMS.

For EUV:

- Slope < 0.1 micro-radian.

Also needed is ability to fully characterize surface errors and predict optical performance.

1. Optical Components and Systems for potential UV/Optical Missions

Large UV/Optical (LUVOIR) and Habitable Exoplanet (HabEx) Missions

Potential UV/Optical missions require 4 to 16 meter monolithic or segmented primary mirrors with < 5 nm RMS surface figures. Active or passive alignment and control is required to achieve system level diffraction limited performance at wavelengths less than 500 nm (< 40 nm RMS wavefront error, WFE). Additionally, potential Exoplanet mission, using an internal coronagraph, requires total telescope wavefront stability on order of 10 picometers RMS per 10 minutes. This stability specification places severe constraints on the dynamic mechanical and thermal performance of 4 meter and larger telescope. To meet this requirement requires active thermal control systems, ultra-stable mirror support structures, and vibration compensation.

Mirror areal density depends upon available launch vehicle capacities to Sun-Earth L2 (i.e., 15 kg/m² for a 5 m fairing EELV vs. 150 kg/m² for a 10 m fairing SLS). Regarding areal cost, a good goal is to keep the total cost of the primary mirror at or below $100M. Thus, an 8-m class mirror (with 50 m² of collecting area) should have an areal cost of less than $2M/m². And, a 16-m class mirror (with 200 m² of collecting area) should have an areal cost of less than $0.5M/m².

Key technologies to enable such a mirror include new and improved:

- Mirror substrate materials and/or architectural designs.
- Processes to rapidly fabricate and test UVO quality mirrors.
Mirror support structures that are ultra-stable at the desired scale.
Mirror support structures with low-mass that can survive launch at the desired scale.
Mechanisms and sensors to align segmented mirrors to < 1 nm RMS precisions.
Thermal control (< 1 mK) to reduce wavefront stability to < 10 pm RMS per 10 min.
Dynamic isolation (> 140 dB) to reduce wavefront stability to < 10 pm RMS per 10 min.

Also needed is ability to fully characterize surface errors and predict optical performance via integrated opto-mechanical modeling.

Potential solutions for substrate material/architecture include, but are not limited to: ultra-uniform low CTE glasses, silicon carbide, nanolaminates or carbon-fiber reinforced polymer. Potential solutions for mirror support structure material/architecture include, but are not limited to: additive manufacturing, nature inspired architectures, nano-particle composites, carbon fiber, graphite composite, ceramic or SiC materials, etc. Potential solutions for new fabrication processes include, but are not limited to: additive manufacture, direct precision machining, rapid optical fabrication, roller embossing at optical tolerances, slumping or replication technologies to manufacture 1 to 2-meter (or larger) precision quality components. Potential solutions for achieving the 10 pico-meter wavefront stability include, but are not limited to: metrology, passive, and active control for optical alignment and mirror phasing; active vibration isolation; metrology, passive, and active thermal control;

Ultra-Stable Balloon Telescopes and Telescope Structures

Multiple potential balloon and space missions to perform Astrophysics, Exoplanet and Planetary science investigations require a complete optical telescope system with 0.5 meter or larger of collecting aperture. 1-m class balloon-borne telescopes have flown successfully, however, the cost for design and construction of such telescopes can exceed $6M, and the weight of these telescopes limits the scientific payload and duration of the balloon mission. A 4X reduction in cost and mass would enable missions which today are not feasible. Space-based gravitational wave observatories (eLISA) need a 0.5-meter class ultra-stable telescope with an optical path length stability of a picometer over periods of roughly one hour at temperatures near 230K in the presence of large applied thermal gradients. The telescope will be operated in simultaneous transmit and receive mode, so an unobstructed design is required to achieve extremely low backscatter light performance.

Balloon Planetary Telescope

Astronomy from a stratospheric balloon platform offers numerous advantages for planetary science. At typical balloon cruise altitudes (100,000 to 130,000 ft.), 99%+ of the atmospheric is below the balloon and the attenuation due to the remaining atmosphere is small, especially in the near ultraviolet band and in the infrared bands near 2.7 and 4.25 µm. The lack of atmosphere nearly eliminates scintillation and allows the resolution potential of relatively large optics to be realized, and the small amount of atmosphere reduces scattered light and allows observations of brighter objects even during daylight hours.

For additional discussion of the advantages of observations from stratosphere platforms, refer to “Planetary Balloon-Based Science Platform Evaluation and Program Implementation - Final Report,” Dankanich et. al. (NASA/TM-2016-218870, available from https://ntrs.nasa.gov/ [15]).

To perform Planetary Science requires a 1-meter class telescope 500 nm diffraction limited performance or Primary Mirror System that can maintain < 10 nm rms surface figure error for elevation angles ranging from 0 to 60 degrees over a temperature range from 220K to 280K.

Phase I will produce a preliminary design and report including initial design requirements such as wave-front error budget, mass allocation budget, structural stiffness requirements, etc. trade studies performed and analysis that compares the design to the expected performance over the specified operating range. Development challenges shall be identified during Phase I including trade studies and challenges to be addressed during Phase II with subsystem proof of concept demonstration hardware. If Phase II can only produce a sub-scale component, then it should also produce a detailed final design, including final requirements (wave-front error budget, mass allocation, etc.) and performance assessment over the specified operating range.

Additional information about Scientific Balloons can be found at https://www.csbf.nasa.gov/docs.html [16].

Telescope Specifications:
• Diameter                             > 1 meter
• System Focal Length          14 meter (nominal)
• Diffraction Limit                 < 500 nm
• Mass                                   < 300 kg
• Shock                                 10G without damage
• Elevation                            0 to 60 degrees
• Temperature                       220 to 280 K

Primary Mirror Assembly Specifications:

• Diameter                             > 1 meter
• Radius of Curvature           3 meters (nominal)
• Surface Figure Error          < 10 nm rms
• Mass                                   < 150 kg
• Shock                                 10G without damage
• Elevation                            0 to 60 degrees
• Temperature                       220 to 280 K

2.0 Optical Components and Systems for potential Infrared/Far-IR missions

Large Aperture Far-IR Surveyor Mission

Potential Infrared and Far-IR missions require 8 m to 24-meter class monolithic or segmented primary mirrors with 
~ 1 µm RMS surface figure error which operates at < 10 K. There are three primary challenges for such a mirror system:

• Areal Cost of < $100K per m².
• Areal Mass of < 15 kg per m² substrate (< 30 kg per m² assembly).
• Cryogenic Figure Distortion < 100 nm RMS from 300K to <10K.

Infrared Interferometry Balloon Mission Telescope

A balloon-borne interferometry mission requires 0.5-meter class telescopes with siderostat steering flat mirror. There are several technologies which can be used for production of mirrors for balloon projects (aluminum, carbon fiber, glass, etc.), but they are high mass and high cost.

3.0 NIR LIDAR Beam Expander Telescope

Potential airborne coherent LIDAR missions need compact 15-cm diameter 20X magnification beam expander telescopes. Potential space based coherent LIDAR missions need at least 50-cm 65X magnification beam expander telescopes. Candidate coherent LIDAR systems (operating with a pulsed 2-micrometer laser) have a narrow, almost diffraction limited field of view, close to 0.8 lambda/D half angle. Aberrations, especially spherical aberration, and surface roughness in the optical telescope can kill the signal. Additionally, the telescope beam expander must maintain the laser beam’s circular polarization. The incumbent telescope technology is a Dahl-Kirkham beam expander. Technology advance is needed to make the beam expander more compact while retaining optical performance.

4.0 Fabrication, Test and Control of Advanced Optical Systems

Finally, this sub-topic also encourages proposals to develop technology which makes a significant advance the ability to fabricate, test or control an optical system.
S2.04 X-Ray Mirror Systems Technology, Coating Technology for X-Ray-UV-OIR, and Free-Form Optics

Lead Center: JPL

Participating Center(s): JPL, MSFC

Technology Area: TA15 Aeronautics

This subtopic focuses on three areas of technology development:

- X-Ray manufacturing, coating, testing, and assembling complete mirror systems in addition to maturing the current technology.
- Coating technology including Carbon Nanotubes (CNT) for wide range of wavelengths from X-Ray to IR: X-Ray, EUV (extreme ultraviolet), LUV (Lyman ultraviolet), VUV (vacuum ultraviolet), Visible, and IR (infrared) telescopes.
- Free-form Optics design, fabrication, and metrology for CubeSat, SmallSat and various coronagraphic instruments.

A typical Phase I proposal for X-Ray technology would address the relevant optical sub-component of a system with necessary coating and stray light suppression for X-Ray missions or prototype demonstration of a fabricated system and its testing. Similarly, a Coating technology proposal would address fabrication and testing of optical surfaces for a wide range of wavelengths from X-Ray, EUV, LUV, VUV, Visible and IR. The Free-form Optics proposals tackle the challenges involved in design, fabrication, and metrology of non-spherical surfaces for small-size missions such as CubeSat, NanoSat, and coronagraphic instruments.

In a nutshell, a successful proposal demonstrates a low-cost ability to address NASA science mission needs and technical challenges specified under each category with feasible plan to develop the technology for infusion into NASA Decadal class missions and sub-orbital rockets and/or balloon for IR-class telescopes.

The National Academy Astro2010 Decadal Report identifies studies of optical components and ability to manufacture, coat, and perform metrology needed to enable future X-Ray observatory missions such as Next Generation of X-Ray Observatories (NGXO). The Astrophysics Decadal specifically calls for optical coating technology investment for future UV, Optical, Exoplanet, and IR missions while Heliophysics 2009 Roadmap identifies the coating technology for space missions to enhance rejection of undesirable spectral lines, improve space/solar-flux durability of EUV optical coatings, and coating deposition to increase the maximum spatial resolution.

Future optical systems for NASAs low-cost missions, CubeSat and other small-scale payloads, are moving away from traditional spherical optics to non-spherical surfaces with anticipated benefits of freeform optics such as fast wide-field and distortion-free cameras.

X-Ray Optical Component, Systems, and Technologies

NASA large X-Ray observatory requires low-cost, ultra-stable, light-weight mirrors with high-reflectance optical coatings and effective stray light suppression. The current state-of-art of mirror fabrication technology for X-Ray missions is very expensive and time consuming. Additionally, a number of improvements such as 10 arc-second angular resolutions and 1 to 5 m$^2$ collecting area are needed for this technology. Likewise, the stray-light suppression system is bulky and ineffective for wide-field of view telescopes.

In this area, we are looking to address the multiple technologies including: improvements to manufacturing (machining, rapid optical fabrication, slumping or replication technologies), improved metrology, performance prediction and testing techniques, active control of mirror shapes, new structures for holding and actively aligning of mirrors in a telescope assembly to enable X-Ray observatories while lowering the cost per square meter of collecting aperture and effective design of stray-light suppression in preparation for the Decadal Survey of 2020. Currently, X-Ray space mirrors cost $4 million to $6 million per square meter of optical surface area. This research effort seeks a cost reduction for precision optical components by 5 to 50 times, to less than $1M to $100 K/m$^2$.

Coating Technologies for X-Ray, EUV, LUV, UV, Visible, and IR Telescopes
The optical coating technology is a mission-enabling feature that enhances the optical performance and science return of a mission. Lowering the areal cost of coating determines if a proposed mission could be funded in the current cost environment. The most common forms of coating used on precision optics are anti-reflective (AR) coating and high reflective coating. The current coating technology of optical components needs to achieve TRL-6 by approximately 2018 to support the 2020 Astrophysics Decadal process. A number of optical coating metrics specific to each wavelength are desired such as:

**The Optical Coating Metrics**

The telescope optical coating needs to meet low temperature operation requirement. Its desirable to achieve 35 K in future.

**X-Ray Metrics:**

- Multilayer high-reflectance coatings for hard X-Ray mirrors similar to NuSTAR.
- Multilayer depth gradient coatings for 5 to 80 KeV with high broadband reflectivity.
- Zero-net-stress coating for iridium or other high-reflectance elements on thin substrates (< 0.5 mm).

**EUV Metrics:**

- Reflectivity > 90% from 6 nm to 90 nm and the ability to be applied onto a < 2-meter mirror substrate.

**LUVOIR Metrics:**

- Broadband reflectivity > 70% from 90 nm to 120 nm (LUV); > 90% from 120 nm to 2500 nm (VUV/Visible/IR); Reflectivity non-uniformity < 1% from 90 nm to 2500 nm. Induced polarization aberration < 1% from 400 nm to 2500 nm and depositable onto 1 to 8 m substrates.

**Non-Stationary Metric:**

- Non-uniform optical coating to be used in both reflection and transmission that vary with location and optical surface. Variation pertains to ratio of reflectivity to transmissivity, optical field amplitude, phase, and polarization change. The optical surface area ranges from 1/2 to 6 cm.

**Scattered Light Suppression Using Carbon Nanotube (CNT) Coating**

A number of future NASA missions require suppression of scattered light. For instance, the precision optical cube utilized in a beam-splitter application forms a knife-edge that is positioned within the optical system to split a single beam into two halves. The scattered light from the knife-edge could be suppressed by CNT coating. Similarly, the scattered light for gravitational-wave application and lasercom system where the simultaneous transmit/receive operation is required, could be achieved by highly absorbing coating such as CNT. Ideally, the application of CNT coating needs to achieve:

- Broadband (visible plus Near IR), reflectivity of 0.1% or less.
- Resist bleaching of significant albedo changes over a mission life of at least 10 years.
- Withstand launch conditions such vibe, acoustics, etc.
- Tolerate both high continuous wave (CW) and pulsed power and power densities without damage. ~10 W for CE and ~ 0.1 GW/cm² density, and 1 kW/nanosecond pulses.
- Adhere to the multi-layer dielectric or protected metal coating including Ion Beam Sputtering (IBS) coating.

**Freeform Optics Design, Fabrication, and Metrology**

Future NASA missions with alternative low-cost science and small-size payload are constrained by the traditional spherical form of optics. These missions could benefit greatly by the freeform optics as they provide non-spherical
optics with better aerodynamic characteristics for spacecraft with lightweight components to meet the mission requirements. Currently, the design and utilization of conformal and freeform shapes are costly due to fabrication and metrology of these parts. Even though various techniques are being investigated to create complex optical surfaces, small-size missions highly desire efficient small packages with lower cost that increase the field of view and expand operational temperature range of unobscured systems. For the coronagraphic applications, freeform optical components allow coronagraphicnulling without shearing and increase the useful science field of view. In this category, freeform optical prescription for surfaces of 0.5 cm to 6 cm diameters with tolerances of 1 to 2 nm rms are needed. In this respect, the freeform refers to either 2nd order conic prescription with higher order surface polished onto it or without underlying conic prescription with no steps in the surface. The optics with underlying conic prescription would need to be in F/# range of F/2 to F/20. In addition to the freeform fabrication, the metrology of freeform optical components is difficult and challenging due to the large departure from planar or spherical shapes accommodated by conventional interferometric testing. New methods such as multibeam low-coherence optical probe and slope sensitive optical probe are highly desirable.

Ultra-Stable X-Ray Grazing-Incident Telescopes for Sub-Orbital Balloons and Rocket-Borne Missions

Technology maturation to build complete low-cost, lightweight X-ray telescopes with grazing-incident optics that can be flown on potential long duration high-altitude balloon-borne or rocket-borne missions. The focus here is to reduce the areal cost of telescope by 2x such that the larger collecting area can be produced for the same cost or half the cost.

S3.01 Power Generation and Conversion

Lead Center: GRC

Participating Center(s): ARC, JPL, JSC

Technology Area: TA15 Aeronautics

Photovoltaic Energy Conversion: advances in, but not limited to, the following:

- 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 low-intensity, high-temperature environment (such as the Venus surface).
- Solar arrays to support Extreme Environments Solar Power type missions, including long-lived, radiation tolerant, cell and blanket technologies applicable to Jupiter missions.
- Lightweight solar array technologies applicable to science missions using solar electric propulsion.

Current missions being studied require solar arrays that provide 1 to 20 kilowatts of power at 1 AU, greater than 300 watts/kilogram specific power, operation in the range of 0.7 to 3 AU, low stowed volume, and the ability to provide operational array voltages up to 300 volts to enable direct drive electric propulsion systems for science missions.

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

- Novel Stirling, Brayton or Rankine convertors that can be integrated with one or more 250 watt-thermal General Purpose Heat Source modules to provide high thermal-to-electric efficiency (>25%), low mass, long life (>10 years), and high reliability for planetary spacecraft, landers, and rovers.
- Micro-miniature dynamic power convertors that can be integrated with one or more 1 watt-thermal Radioisotope Heater Units to provide long duration electric power for planetary smallsats and distributed instruments.
- Advanced dynamic conversion components including hot-end heat exchangers, cold-end heat exchangers, regenerators/recuperators, alternators, engine controllers, heat pipes and radiators that improve system performance, reliability and fault tolerance.
Direct Energy Conversion; advances in, but not limited to, the following: Recent advancements in alpha/beta-voltaic energy conversion devices have the potential to increase the power level, improve reliability, and increase the lifetime of this power technology. The development of continuous, low-power generation technology for autonomous remote sensors and other specialized applications would support NASA Science Mission goals and enhance/enable new mission capabilities. The area of Direct Energy Conversion seeks technology advancements that address, but are not limited to experimental demonstration of long life (years) alpha-voltaic, beta-voltaic, and other non-solar conversion concepts with device-level conversion efficiencies in excess of 10% and the ability to scale up to 1-10 W of electrical power output with system-level specific power of 5 W/kg or higher.

S3.03 Power Electronics and Management, and Energy Storage

Lead Center: GRC

Participating Center(s): ARC, GSFC, JPL

Technology Area: TA15 Aeronautics

Power Electronics and Management

NASA's Planetary Science Division is working to implement a balanced portfolio within the available budget and based on a decadal survey that will continue to make exciting scientific discoveries about our solar system. This balanced suite of missions shows the need for low mass/volume power electronics and management systems and components that can operate in extreme environment for future NASA Science Missions.

Advances in electrical power technologies are required for the electrical components and systems of these future spacecrafts/platforms to address program size, mass, efficiency, capacity, durability, and reliability requirements. Radioisotope power systems (RPS), Advanced Modular Power Systems (AMPS) and In-Space Electric Propulsion (ISP) are several programs of interest which would directly benefit from advancements in this technology area. These types of programs, including Mars Sample Return using Hall thrusters and power processing units, require advancements in components and control systems beyond the state-of-the-art. Of importance are expected improvements in system robustness, 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 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, the Science Mission Directorate has a need for intelligent, fault-tolerant Power Management and Distribution (PMAD) technologies to efficiently manage the system power for deep space missions.

Overall technologies of interest include:

- High power density/high efficiency power electronics and associated drivers for switching elements.
- Non-traditional approaches to switching devices, such as addition of graphene and carbon nanotubes to material.
- Lightweight, highly conductive power cables and/or cables integrated with vehicle structures.
- Intelligent power management and fault-tolerant electrical components and PMAD systems.
- Advanced electronic packaging for thermal control and electromagnetic shielding.
- Integrated packaging technology for modularity.

Energy Storage

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

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

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

S3.04 Guidance, Navigation and Control

Lead Center: MSFC

Participating Center(s): ARC, JPL, LaRC, MSFC

Technology Area: TA15 Aeronautics

NASA seeks innovative, groundbreaking, and high impact developments in spacecraft guidance, navigation, and control technologies in support of future science and exploration mission requirements. This subtopic covers mission enabling technologies that have significant Size, Weight and Power, Cost, and Performance (SWaP-CP) improvements over the state of the art COTS in the areas of Spacecraft Attitude Determination and Control Systems, Absolute and Relative Navigation Systems, and Pointing Control Systems, and Radiation-Hardened GN&C Hardware.

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 most spacecraft platform sizes will be considered.

Advances in the following areas are sought:

- **Spacecraft Attitude Determination and Control Systems** - Sensors and actuators that enable <0.1 arcsecond level pointing knowledge and arcsecond level control capabilities for large space telescopes, with improvements in size, weight, and power requirements.

- **Absolute and Relative Navigation Systems** - Autonomous onboard flight navigation sensors and algorithms incorporating both spaceborne and ground-based absolute and relative measurements. For relative navigation, machine vision technologies apply. Special considerations will be given to relative navigation sensors enabling precision formation flying, astrometric alignment of a formation of vehicles, robotic servicing and sample return capabilities, and other GN&C techniques for enabling the collection of distributed science measurements.

- **Pointing Control Systems** - Mechanisms that enable milli-arcsecond class pointing performance on any spaceborne pointing platforms. Active and passive vibration isolation systems, innovative actuation feedback, or any such technology that can be used to enable other areas within this subtopic applies.

- **Radiation-Hardened Hardware**: GN&C sensors that could operate in a high radiation environment, such as the Jovian environment.

- **Fast light Gyroscopes and Accelerometers** - In conventional ring laser gyro's, precision increases with cavity size and measurement time. Fast-light media, however, can be used to increase gyro precision without having to increase size or decrease measurement frequency, thereby increasing the time for standalone spacecraft navigation. (The increased precision also opens up new science possibilities such as measurements of fundamental physical constants, improving the sensitivity-bandwidth product for gravity wave detection, and tests of general relativity.) Prototype fast-light gyro's are sought that can be
implemented in a compact rugged design that is tolerant to variations in temperature and G-conditions, with the ultimate goal of demonstrating decreased angular random walk.

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

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

**S3.05 Terrestrial Balloons and Planetary Aerial Vehicles**

*Lead Center: JPL*

*Participating Center(s): JPL*

**Technology Area: TA15 Aeronautics**

**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 also currently being used.

**Balloon Sensors and Instrumentation**

Improved and innovative devices to make measurements of the balloon and the ambient flight environment are needed. Devices or methods to accurately and continuously measure ambient air, helium gas, balloon film temperatures, ambient wind velocity and film strain are desired. These measurements are needed to accurately model the balloon performance during a typical flight at altitudes of approximately 120,000 feet. The measurements must compensate for the effects of direct solar radiation through shielding or calculation. Minimal mass and volume are highly desired. For film measurements, a non-invasive and non-contact approach is highly desired for the thin polyethylene film, with film thickness ranging from 0.8 to 1.5 mil, used as the balloon envelope. Devices for these measurements must be compatible with existing NASA systems and operations.

**Planetary Aerial Vehicles**

Innovations in materials, structures, and systems concepts have enabled aerial vehicles to play an expanding role in NASA’s future Solar System Exploration Program. Aerial vehicles are expected to carry scientific payloads at Venus that will perform in-situ investigations of its atmosphere, surface and interior. Venus features extreme environments that significantly impact the design of aerial vehicles. Proposals are sought in the following areas:

- **Aerial Vehicle Platforms for Venus** - NASA is interested in conducting long term monitoring of the Venus atmosphere and planetary surface using aerial vehicles at altitudes around 50 to 60 km. Concepts for Lighter-than-Air (e.g., balloons, airships) and Heavier-than-Air (e.g., fixed wing, rotary wing) vehicles are encouraged. The aerial platforms should be capable of operation through daylight and/or night time observations on Venus. The proposal should describe how the vehicle concept would be deployed into the atmosphere and operated for its mission. Concepts for any of the following capabilities of aerial vehicle are
encouraged:

- Technology demonstration with science payload less than 10 kg.
- Pathfinder mission with science payload less than 50 kg.
- Flagship mission with science payload up to 100 kg.

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.

**S3.08 Command, Data Handling, and Electronics**

Lead Center: JPL

Participating Center(s): JPL, LaRC

Technology Area: TA15 Aeronautics

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 2018 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.
- Successful proposal concepts should significantly advance the state-of-the-art. Proposals should clearly:
  - State what the product is.
  - Identify the needs it addresses.
  - Identify the improvements over the current state of the art.
  - Outline the feasibility of the technical and programmatic approach.
  - Present how it could be infused into a NASA program.

Furthermore, proposals developing hardware should indicate an understanding of the intended operating environment, including temperature and radiation. It should be noted that environmental requirements can vary significantly from mission to mission. For example, some low earth orbit missions have a total ionizing dose (TID) radiation requirement of less than 10 krad(Si), while some planetary missions can have requirements well in excess of 1 Mrad(Si). For descriptions of radiation effects in electronics, the proposer may visit [http://radhome.gsfc.nasa.gov/radhome/overview.htm](http://radhome.gsfc.nasa.gov/radhome/overview.htm) [17].

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:

- **I/O Expansion Chip for next generation spaceflight processor devices, including the High-Performance Spaceflight Computing (HPSC) Chiplet** - This ASIC interfaces to a radiation hardened space processor, via a XAUI port and acts as an I/O expansion and protocol converter. Desired interfaces include TIA/EIA-422, SpaceWire, SpaceFiber, MIL-STD-1553, SPI, CameraLink, PCI-e, and Time Triggered Ethernet (TTE)/Time-Triggered Gigabit Ethernet (TTGbE). The offeror should survey the market and develop a list of I/O interconnects that will accelerate adoption of next generation processors into the broader space, and potentially terrestrial, markets, then design the device and implement it in a form suitable for use in
spacecraft, and cyber-physical/robotics or autonomous systems in both terrestrial and natural space radiation environments. The I/O Expansion Chip hardware design and associated software will facilitate interfacing the processor to the I/O Expansion Chip in a manner that is transparent to the rest of the processor and will make the Expansion Chip seem an integral part of the processor architecture.

- **Serial RapidIO (SRIO) Hub/Switch** - This module, preferably implemented as an ASIC, provides switching and routing of SRIO Version 4 Harsh Device Class links. The SRIO Hub will provide the necessary routing of SRIO links onboard spacecraft, and other platforms to enable use of SRIO as the system interconnect. The full SRIO Version 4 speed need not be supported. The Offeror should determine what levels of radiation tolerance vs baud rate are achievable, perform a survey of anticipated spacecraft interconnect needs, and propose an implementation that is compatible with spacecraft systems envisioned for the near-mid future.

- **Smart, multi-output high efficiency POL (point of load) converter** - This module, preferably implemented utilizing one or more controller ASICs, will source a minimum of 3 settable output voltages when provided with standard spacecraft power bus input. Output voltages should be independently settable to any voltage between 5 and .5 V with efficiency of at least 95%. Regulation, noise filtering and other operational specifications should be commensurate with industry standards for space-based systems. The module should provide standard spacecraft power supply features, including over voltage protection, fault tolerance, load monitoring, and should allow control and status monitoring by a remote power system controller. There is also interest in a capability to provide data over powerline communication to the converter for control and monitoring functions. The offeror should determine radiation tolerance levels achievable utilizing commercially available processes and indicate, in the proposal, the radiation tolerance capability to be achieved.

- **System-In-Package Integrated Assemblies** – Technologies are sought enabling highly integrated System-In-Package (SIP) assemblies integrating multiple die from different processes and foundries, enabling implementation of miniaturized, highly-reliable embedded processing, sensor readout, or motor/actuator control modules. The offeror should propose both the SIP technology to be developed, as well as a proof of concept application (relevant to spaceflight subsystems or instruments) that demonstrates the technology. The offeror should address key technical issues in the SIP implementation including thermal management, reliability, and signal integrity.


Please see Z8.03 for a related topic of potential interest.

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

Lead Center: JPL

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

Technology Area: TA15 Aeronautics

Technologies for robotic mobility, manipulation, and sampling are needed to enable access to sites of interest and acquisition and handling of samples for in-situ analysis or return to Earth from planets and small bodies including Mars, Venus, comets, asteroids, and planetary moons. Application to Ocean Worlds is of increasing importance.

Mobility technologies are needed to enable access to steep and rough terrain for planetary bodies where gravity dominates, such as the Moon and Mars. Wheeled, legged, and aerial solutions are of interest. Wheel concepts with good tractive performance in loose sand while being robust to harsh rocky terrain are of interest. Technologies to enable mobility on small bodies and access to liquid bodies below the surface such as in conduits and deep oceans are desired, as well as associated sampling technologies. Manipulation technologies are needed to deploy sampling tools to the surface and transfer samples to in-situ instruments and sample storage containers, as well as hermetic sealing of sample chambers. Sample acquisition tools are needed to acquire samples on planetary and small bodies through soft and hard materials, including ice. Minimization of mass and ability to work reliably in the harsh mission environment are important characteristics for the tools. Design for planetary protection and contamination control is important for sample acquisition and handling systems.
Component technologies for low-mass and low-power systems tolerant to the in-situ environment are of particular interest. Technical feasibility should be demonstrated during Phase I and a full capability unit of at least TRL 4 should be delivered in Phase II. Proposals should show an understanding of relevant science needs and engineering constraints and present a feasible plan to fully develop a technology and infuse it into a NASA program. Specific areas of interest include the following:

- Surface and subsurface mobility and sampling systems for planets, small bodies, and moons.
- Small body anchoring systems.
- Low mass/power vision systems and processing capabilities that enable fast surface traverse.
- Electro-mechanical connectors enabling tool change-out in dirty environments.
- Tethers and tether play-out and retrieval systems.
- Miniaturized flight motor controllers.
- Sample handling technologies that minimize cross contamination and preserve mechanical integrity of samples.

S4.03 Spacecraft Technology for Sample Return Missions

Lead Center: JPL

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

Technology Area: TA15 Aeronautics

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.

Some targets, such as Mars and some moons, have relatively large gravity wells and will require ascent propulsion. Includes propellants that are transported along with the mission or propellants that can be generated using local resources.

Other targets are small bodies with very complex geography and very little gravity, which present difficult navigational and maneuvering challenges.

In addition, the spacecraft will be subject to extreme environmental conditions including low temperatures (-270° C), dust, and ice particles.

Technology innovations 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).

S4.04 Extreme Environments Technology

Lead Center: JPL

Participating Center(s): ARC, GRC, GSFC, LaRC, MSFC

Technology Area: TA15 Aeronautics

NASA is interested in expanding its ability to explore the deep atmosphere and surface of giant planets, asteroids, and comets through the use of long-lived (days or weeks) balloons and landers. Survivability in extreme high-temperatures and high-pressures is also required for deep atmospheric probes to planets. Proposals are sought for 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 Venusian surface (485° C, 93
atmospheres), or in low-temperature environments such as Titan (-180° C), Europa (-220° C), Ganymede (-200° C), 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-inch-thick aluminum. Proposals are sought for 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. Special interest lies in development of following technologies that are suitable for the environments discussed above:

- Wide temperature range precision mechanisms i.e., beam steering, scanner, linear and tilting multi-axis mechanisms.
- Radiation-tolerant/radiation hardened low-power low-noise mixed-signal mechanism control electronics for precision actuators and sensors.
- Wide temperature range feedback sensors with sub-arc-second/nanometer precision.
- Long life, long stroke, low power, and high torque/force actuators with sub-arc-second/nanometer precision.
- Long life Bearings/tribological surfaces/lubricants.
- High temperature energy storage systems.
- High-temperature actuators and gear boxes for robotic arms and other mechanisms.
- Low-power and wide-operating-temperature radiation-tolerant /radiation hardened RF electronics.
- Radiation-tolerant/radiation-hardened, low-power/ultra-low-power, wide-operating-temperature, low-noise, mixed-signal electronics for space-borne system such as guidance and navigation avionics and instruments.
- Radiation-tolerant/radiation-hardened power electronics.
- Radiation-tolerant/ radiation-hardened electronic packaging (including, shielding, passives, connectors, wiring harness and materials used in advanced electronics assembly).

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

Please see subtopic Z8.03 for related topics of potential interest.

S4.05 Contamination Control and Planetary Protection

Lead Center: JPL

Participating Center(s): GSFC

Technology Area: TA15 Aeronautics

A need to develop 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. NASA is seeking 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.

For contamination control efforts, analytical technologies and techniques for quantifying submicron particle and organic contamination for validating surface cleaning methods are needed. In particular, capabilities for measuring Total Organic Carbon (TOC) at <<40 ppb or <<20 ng/cm² on a surface and detection of particles <0.2 microns in size are being sought. In addition, techniques for detection of one or more of the following molecules and detection level are needed:
- DNA (1 fmole).
- Dipicolinic acid (1 pg).
- N-acetylglucosamine (1 pg).
- Glycine and alanine (1 pg).
- Palmitic acid (1 pg).
- Squalene (1 pg).
- Pristane (1 pg).
- Chlorobenzene (<1 pg).
- Dichloromethane (<1 pg).
- Naphthalene (1 pg).

For many missions, Planetary Protection requirements are often implemented in part by processing hardware or potentially entire spacecraft with one or more sterilization processes. These processes are often incompatible with particular materials or components on the spacecraft and extensive effort is made to try to mitigate these issues. Innovative new or improved sterilization/re-sterilization processes are being sought for application to spacecraft hardware to increase effectiveness of reducing bio-load on spacecraft or increase process compatibility with hardware (e.g., toxicity to hardware, temperature, duration, etc.). Accepted processes currently include heat processing, gamma/electron beam irradiation, cold plasma, and vapor hydrogen peroxide. Options to improve materials and parts (e.g., sensors, seals, in particular, batteries, valves, and optical coatings) to be compatible with currently accepted processes, in particular heat tolerance, are needed. NASA is seeking novel technologies for preventing recontamination of sterilized components or spacecraft as a whole (e.g., biobarriers). In addition, active in-situ recontamination/decontamination approaches (e.g., in-situ heating of sample containers to drive off volatiles prior to sample collection) and in-situ sterilization approaches (e.g., UV or plasma) for surfaces are desired.

Missions planning sample return from bodies such as Mars, Europa, and Enceladus are faced with developing technologies for sample return functions to assure containment of material from these bodies. Thus far, concepts have been developed specifically for Mars sample return but no end-to-end concepts have been developed that do not have technical challenges remaining in one or more areas. Options for sample canisters with seal(s) (e.g., brazing, explosive welding, soft) with sealing performed either on surface or in orbit and capability to verify seal(s), potentially by leak detection are needed. In addition, capability is needed for opening seals while maintaining sample integrity upon Earth return. These technologies need to be compatible with processes the materials may encounter over the lifecycle of the mission (e.g., high temperature heating). Containment assurance also requires technologies to break-the-chain of contact with the sampled body. Any native contamination on the returned sample container and/or Earth return vehicle must be either be fully contained, sterilized, or removed prior to return to Earth, therefore, technologies or concepts to mitigate this contamination are desired. Lightweight shielding technologies are also needed for meteoroid protection for the Earth entry vehicle and sample canister with capability to detect damage or breach to meet a 10-6 probability of loss of containment.

**S4.06 Sample Collection For Life Detection in Outer Solar System Ocean World Plumes**

Lead Center: JPL

Participating Center(s): ARC, GSFC

Technology Area: TA15 Aeronautics

This subtopic solicits development of technologies for sample collection from plumes in the Ocean Worlds (e.g., Europa, Enceladus, Titan, Ganymede, Callisto, Ceres, etc.). This sample collection system would be used as the front-end system in conjunction with in-situ instruments developed under subtopic S1.11. This fly-through sampling subtopic is distinct from S4.02, which solicits sample collection technologies from surface platforms. 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 allow collection during high speed (>1 km/sec) velocity passes through a plume are of interest as are technologies that can maximize total sample mass collected while passing through tenuous plumes. Technologies that reduce mass, power, volume, and data rates without loss of scientific capability are of particular importance.
For synergistic NASA technology solicitation, see ROSES 2016/C.20 Concepts for Ocean worlds Life Detection Technology (COLDTECH) call:

- [https://nspires.nasaprs.com/external/solicitations/summary.do?method=init&solId=%7B5C43865B-0C93-6ECA-BCD2-A3783CB1AAC8%7D&path=init](https://nspires.nasaprs.com/external/solicitations/summary.do?method=init&solId=%7B5C43865B-0C93-6ECA-BCD2-A3783CB1AAC8%7D&path=init) [14].

For the NASA Roadmap for Ocean World Exploration see:

- [http://www.lpi.usra.edu/opag/ROW](http://www.lpi.usra.edu/opag/ROW) [18].

The icy moons of the outer Solar System are of astrobiological interest. The most dramatic target for sampling from a plume is for Enceladus. Enceladus is a small icy moon of Saturn, with a radius of only 252km. Cassini data have revealed about a dozen or so jets of fine icy particles emerging from the south polar region of Enceladus. The jets have also been shown to contain organic compounds, and the south-polar region is warmed by heat flow coming from below.

As a target for future missions, Enceladus rates high because fresh samples of interest are jetting into space ready for collection. Indeed, Enceladus has been added to the current call for New Frontiers missions with a focus on habitability and life detection. Particles from Enceladus also form the E-ring around Saturn. The particles in the E-ring are known to contain organics and are thus also an important target for sample collection and analysis. Recent data have indicated a possible plume at Europa that may also be carrying ocean water from that world into space. In addition to plumes, there are other energetic processes that can spray material from the surface of these low-gravity worlds into space where they could also be collected in-flight and analyzed.

Collecting samples for a variety of science purposes is required. These include samples that allow for determination of the chemical and physical properties of the source ocean, samples for detailed characterization of the organics present in the gas and particle phases, and samples for analysis for biomarkers indicative of life. Thus, these Ocean Worlds of the outer Solar System offer the opportunity for a conceptually new approach to life detection focusing on in-flight sample collection of material freshly injected into space. Technologies of particular interest include sample collection systems and subsystems capable of:

- Capture, containment, and/or transfer of gas, liquid, ice, and/or mineral phases from plumes to sample processing and/or instrument interfaces.
- Technologies for characterization of collected sample parameters including mass, volume, total dissolved solids in liquid samples, and insoluble solids.
- Sample collection and sample capture for in-situ imaging.
- Systems capable of high-velocity sample collection with minimal sample alteration to allow for habitability and life detection analyses.
- Microfluidic sample collection systems that enable sample concentration and other manipulations.
- Plume material collection technologies that minimize risk of terrestrial contamination, including organic chemical and microbial contaminates.

Proposers are strongly encouraged to relate their proposed development to NASA’s future Ocean Worlds exploration goals. Proposed instrument architectures should be as simple, reliable, and low risk as possible while enabling compelling science. Novel instrument concepts are encouraged particularly if they enable a new class of scientific discovery. Technology developments relevant to multiple environments and platforms are also desired.

Proposers should show an understanding of relevant space science needs, and present a feasible plan to fully develop a technology and infuse it into a NASA program.

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

Lead Center: GSFC
NASA scientists and engineers are increasingly turning to large-scale numerical simulation on supercomputers to advance understanding of complex Earth and astrophysical systems, and to conduct high-fidelity aerospace engineering analyses. The goal of this subtopic is to increase 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 for NASA applications.
- Enhance the efficiency and effectiveness of NASA's supercomputing operations and services.

Expected outcomes are to improve the productivity of NASA's supercomputing users, broaden NASA's supercomputing user base, accelerate advancement of NASA science and engineering, and benefit the supercomputing community through dissemination of operational best practices.

The approach of this subtopic is to seek novel software and hardware technologies that provide notable benefits to NASA's supercomputing users and facilities, and to infuse these technologies into NASA supercomputing operations. Successful technology development efforts under this subtopic would be considered for follow-on funding by, and infusion into, NASA's high-end computing (HEC) projects - the High-End Computing Capability project at Ames and the Scientific Computing project at Goddard. To assure maximum relevance to NASA, funded SBIR contracts under this subtopic should engage in direct interactions with one or both HEC projects, and with key HEC users where appropriate. Research should be conducted to demonstrate technical feasibility and NASA relevance during Phase I and show a path toward a Phase II prototype demonstration.

Offerors should demonstrate awareness of the state-of-the-art of their proposed technology, and should leverage existing commercial capabilities and research efforts where appropriate. Open source software and open standards are strongly preferred. Note that the NASA supercomputing environment is characterized by:

- HEC systems operating behind a firewall to meet strict IT security requirements.
- Communication-intensive applications.
- Massive computations requiring high concurrency.
- Complex computational workflows and immense datasets.
- The need to support hundreds of complex application codes - many of which are frequently updated by the user/developer.

Projects need not benefit all NASA HEC users or application codes, but demonstrating applicability to an important NASA discipline, or even a key NASA application code, could provide significant value. For instance, a GPU accelerated (or multi-core) planetary accretion code such as LIPAD (Lagrangian Integrator for Planetary Accretion and Dynamics) could be one possible project.

The three main technology areas of S5.01 are aligned with three objectives of NSCI, the National Strategic Computing Initiative, announced by the White House in July 2015. The overarching goal of NSCI is to coordinate and accelerate U.S. activities in HEC, including hardware, software, and workforce development, so that the U.S. remains the world leader in HEC technology and application. NSCI charges every agency that is a significant user of HEC to make a significant contribution to this goal. This SBIR subtopic is an important part of NASA’s contribution to NSCI. See https://www.nitrd.gov/nsci/index.aspx [19] for more information about NSCI. The three main elements of S5.01 are:

- Many NASA science applications demand much faster supercomputers. This area seeks technologies to accelerate the development of an efficient and practical exascale computing system (10^18 operations per...
Innovative file systems that leverage node memory and a new exascale operating system geared toward NASA applications are two possible technologies for this element. At the same time, this area calls for technology to support co-design (i.e., concurrent design) of NASA applications and exascale supercomputers, enabling application scaling to billion-fold parallelism while dramatically increasing memory access efficiency. This supports NSCI Objective 1 (Accelerating delivery of a capable exascale computing system that integrates hardware and software capability to deliver approximately 100 times the performance of current 10 petaflop systems across a range of applications representing government needs.).

- Data analytics is becoming a bigger part of the supercomputing workload, as computed and measured data expand dramatically, and the need grows to rapidly utilize and understand that data. This area calls for technologies that support convergence of computing systems optimized for modeling & simulation and those optimized for data analytics (e.g., data assimilation, data compression, image analysis, machine learning, visualization, and data mining). In-situ data analytics that can run in-memory side-by-side with the model run is another possible technology for this element. This supports NSCI Objective 2 (Increasing coherence between the technology base used for modeling and simulation and that used for data analytic computing.).

- Presently it is difficult to integrate cyberinfrastructure elements (supercomputing system, data stores, distributed teams, instruments, mobile devices, etc.) into an efficient and productive science environment. This area seeks technologies to make elements of the supercomputing ecosystem much more accessible and composable, while maintaining security. This supports NSCI Objective 4 (Increasing the capacity and capability of an enduring national HPC ecosystem by employing a holistic approach that addresses relevant factors such as networking technology, workflow, downward scaling, foundational algorithms & software, accessibility, and workforce development.).

S5.02 Earth Science Applied Research and Decision Support

Lead Center: GSFC

Participating Center(s): JPL, MSFC

Technology Area: TA15 Aeronautics

The NASA Earth (http://science.nasa.gov/earth-science/) and Applied Science (http://appliedsciences.nasa.gov/) programs seeks innovative and unique approaches to increase the utilization and extend the benefit of Earth Science research data to better meet societal needs. The main focus of this subtopic is improving the pipeline from NASA Earth Science data and products to a range of end user communities to support decision making. To that end, one area of interest is new or improved decision support tools for a variety of applications areas (http://appliedsciences.nasa.gov/sites/default/files/ar2014/index.html#/applications-areas), including but not limited to, disaster response, agricultural and food security, water resource management, ecological forecasting, land surface modeling, air quality and health.

Under this subtopic, NASA also invites proposals from companies that provide innovative data science tools to extract new insights from applicable NASA Earth science dataset that can support emerging commercial activities. State-of-the-art geospatial data analytics such as automated image classification, feature extraction, or change detection deployed at scale can reveal new insights and drive increased utilization of publicly available NASA Earth science data. NASA Earth science data may be fused with non-NASA remote sensing data or even non-remote sensing data to provide context or other added value and unlock new information products. Areas of commercial focus (not all inclusive) include agricultural, financial services, transportation, logistics, oil, gas, resource extraction, land management, water resource management, and leisure industries.

This subtopic aims to connect and demonstrate the integration of NASA Earth science data and models into societal benefit areas and commercial applications. This solicitation encourages project teams to consider products from recently-launched NASA Missions, as well as simulated products from upcoming, planned missions (e.g., SMAP, GPM, Landsat, GRACE, GRACE-FO, IceSat-2, SWOT), and field campaigns or other observatories (e.g., Airborne Snow Observatory (http://aso.jpl.nasa.gov/), SnowEx (https://snow.nasa.gov/snowex/)). Projects may consider connecting with NASA-sponsored activities including, but not limited to SPoRT
The NASA Applied Science Program sponsors several Capacity Building Programs, including SERVIR (http://www.nasa.gov/mission_pages/servir/ [27]), DEVELOP (https://develop.larc.nasa.gov/ [28]) and ARSET (https://arset.gsfc.nasa.gov/ [29]); proposed projects may find it valuable to leverage resources and relationships with these capacity building activities. Proposed projects should also note that NASA hosts a broad range of modeling systems and related that have been highly valuable to operational and end user communities, including MERRA-2 (https://gmao.gsfc.nasa.gov/reanalysis/MERRA-2/ [30]), climate project information from GISS GCMs (http://www.giss.nasa.gov/projects/gcm/ [31]) and Land Data Assimilation Systems (LDAS (http://ldas.gsfc.nasa.gov/gldas/ [32]).

Currently, creating decision support tools (DST) that effectively utilize remote sensing data requires significant efforts by experts in multiple domains. NASA Earth Science data, while accessible, is massive in breadth and scope – a true “Big Data” problem. However, the formatting of the data is not easily accessed or readily usable beyond remote sensing experts and the research community, suggesting that application by commercial users is even more challenging. While the data has commercial use, it is underutilized due to accessibility and translation issues. 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.

Specifically, this subtopic develops core capabilities that can be integrated to build multiple remote sensing driven DSTs customized to the requirements of different users in varied fields. Proven development and commercialization strategies will be used to meet these objectives. The goal of this solicitation is to directly link what is being done at NASA with the end user community to support decision making. The outcomes of this work could include new tools, integration systems, visualization interfaces, among others. Responsive proposals must include a clear identification of a data product(s), modeling tools, or NASA activities that will be used and a clear end user or business application to which the tools, systems, etc. are intended to support for applied research and decision support. Proposals should explain how the proposed capabilities will address an end user need, business opportunity or gap area in decision support capabilities. Proposals should also outline existing capabilities, including software, models, and data that are already implemented at NASA or through related NASA activities and how the proposed activities may leverage, complement, or expand from existing infrastructure. Projects must be mindful of NASA security restrictions in the development of new activities.

Ultimately, this subtopic aims to provide commercial analytics firms and other data-driven companies with improved access to, and translation of, NASA data. The subtopic supports research and technology focused on innovative data science tools and information products that will improve business productivity, reduce the cost of operations, and provide for better informed decision making. Research proposed to this subtopic should demonstrate technical feasibility during Phase I, and in partnership with Commercial customers, show a path toward a Phase II prototype demonstration, with significant communication with commercial stakeholders to increase the potential for non-governmental market penetration.

**S5.03 Machine Learning and Deep Learning for Science and Engineering**

Lead Center: GSFC

Participating Center(s): ARC, JPL, LaRC

Technology Area: TA15 Aeronautics

NASA research and engineering has begun exploring the application of Machine Learning and Deep Learning (ML/DL) within Science and Engineering. While there are many problems that can be addressed with ML/DL, the adoption of these techniques and technologies are slow due to the large learning curve associated with the application of this technology and the applicability of commercial and open source tools to specific problems of interest for NASA.

This subtopic area seeks to close those gaps and accelerate the use of ML/DL across NASA Science and Engineering. The emphasis of this subtopic will be on the application of ML/DL to solve challenging Science and
Engineering problems and also for new technologies to enable and accelerate the use of ML/DL within NASA.

Proposals MUST be in alignment with existing and/or future NASA programs and address or extend a specific need or question for those programs. It is therefore incumbent upon the proposers to have discussions with NASA scientists and engineers to receive feedback prior to submission and to adequately show the alignment of the proposed innovation to NASA.

Specifically, innovative proposals are being sought to assist NASA Science and Engineering in the following two areas:

- Application of ML/DL to solve challenging and unique problems in order to significantly advance NASA’s Science and Engineering.
- New algorithms, methods, or tools to accelerate the use and adoption of ML/DL within NASA.

Research proposed to this subtopic should demonstrate technical feasibility during Phase I, and in partnership with scientists, show a path toward a Phase II prototype demonstration, with significant communication with missions and programs to later plan a potential Phase III infusion. It is highly desirable that the proposed projects lead to solutions that will be infused into NASA programs and projects.

Tools and products developed under this subtopic may be developed for broad public dissemination or used within a narrow scientific community. These tools can be plug-ins or enhancements to existing software, on-line data/computing services, or new stand-alone applications or web services, provided that they promote interoperability and use standard protocols, file formats, and Application Programming Interfaces (APIs).

S5.04 Integrated Science Mission Modeling

Lead Center: GSFC

Participating Center(s): GSFC, KSC

Technology Area: TA15 Aeronautics

The focus for the coming year is on the integration of model-based approaches into NASA’s life-cycle processes: Design, Build, Assemble, Integrate and Operate. Specific areas of interest supporting one or more of these life-cycle processes are listed below. Proposers are encouraged to be familiar with the State-of-the-art in these areas. Proposers are also encouraged to address more than one of these areas with an approach that emphasizes integration with others on the list.

Visualization and tool interaction

Techniques and tools for:

- Using MBSE to support trade evaluation and capabilities for visualization and comprehension of results/options. NASA needs the ability to engage the intuition and experience of those without significant tool expertise.
- Enabling SysML profiles to be more easily created, integrated and compared with other profiles. NASA has a wide variety of users and use cases and the ability to better manage profiles (or the equivalent) is important.
- Enabling early phase agility. In the early phases, rapid trade space exploration presents challenges in utilizing typical models or library elements, trade space navigation, rationale capture, and archival/retrieval of options.

Model Management:
- Methods for archiving/storing, retrieving and integrating model fragments. The approach should be easy to use and not require significant new infrastructure investment.
- Approaches for defining and utilizing permission/access control in a collaborative environment.

**Training and Engagement**

As NASA continues down the Model-based approach to the engineering disciplines it will be imperative to engage and develop the skilled engineers necessary to achieve our desired end state. To that end, NASA seeks approaches for initial engagement with MBSE/SysML that are “lightweight” without onerous costs and complexity. This must include approaches for transitioning to “full featured” tool sets without significant retraining. Proposers encouraged, but not required, to consider utilizing plug-ins to existing tool sets.

**Tool and Process integration**

As MBSE continues to develop at NASA, it is critical to explore and develop tools and techniques for better integration at the boundaries of Systems Engineering both breadth (other disciplines) and depth (detailed information). Integration (breadth) includes integration with other discipline tools and processes (e.g., Finite Element Modeling, Circuit Analysis) as well as business and programmatic processes. Integration (depth) includes integration, or at least interfacing, with lower-level information (e.g., Piece part data, assembly process specifications). It is critical that we understand the nature of these interfaces, and reduce the complexity and difficulty of developing and maintaining these interfaces.

**S5.05 Fault Management Technologies**

**Lead Center:** ARC

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

**Technology Area:** TA15 Aeronautics

As science missions are given increasingly complex goals and have more pressure to reduce operations costs, system autonomy increases. Fault Management (FM) 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.

Many recent Science Mission Directorate (SMD) missions have encountered major cost overruns and schedule slips during test and verification of FM functions. These overruns are due to a lack of understanding of FM functions early in the mission definition cycles and to FM architectures that do not provide attributes of transparency, verifiability, fault isolation capability, or fault coverage. The NASA FM Handbook is under development to improve the FM design, development, verification and validation and operations processes. FM approaches, architectures, and tools are needed to improve early understanding of needed FM capabilities by project managers and FM engineers and to improve the efficiency of implementing and testing FM.

Specific objectives are to:

- Improve the ability to predict FM system complexity and estimate development and operations costs.
- Enable cost-effective FM design architectures and operations.
- Determine completeness and appropriateness of FM designs and implementations.
- Decrease the labor and time required to develop and test FM models and algorithms.
- Improve visualization of the full FM design across hardware, software, and operations procedures.
- Determine extent of testing required, completeness of verification planned, and residual risk resulting from incomplete coverage.
- Increase data integrity between multi-discipline tools.
- Standardize metrics and calculations across FM, SE, S&MA and operations disciplines.
- Increase reliability of FM systems.
Expected outcomes are better estimation and control of FM complexity and development costs, improved FM designs, and accelerated advancement of FM tools and techniques. The approach of this subtopic is to seek the right balance between sufficient reliability and cost appropriate to the mission type and risk posture. Successful technology development efforts under this subtopic would be considered for follow-on funding by, and infusion into, SMD missions. Research should be conducted to demonstrate technical feasibility and NASA relevance during Phase I and show a path toward a Phase II prototype demonstration. Offerors should demonstrate awareness of the state-of-the-art of their proposed technology, and should leverage existing commercial capabilities and research efforts where appropriate.

Specific technology in the forms listed below is needed to increase delivery of high quality FM systems. These approaches, architectures and tools must be consistent with and enable the NASA FM Handbook concepts and processes:

- **FM Design Tools** - System modeling and analyses significantly contributes to the quality of FM design; however, the time it takes to translate system design information into system models often decreases the value of the modeling and analysis results. Examples of enabling techniques and tools are modeling automation, spacecraft modeling libraries, expedited algorithm development, sensor placement analyses, and system model tool integration.

- **FM Visualization Tools** - FM systems incorporate hardware, software, and operations mechanisms. The ability to visualize the full FM system and the contribution of each mechanism to protecting mission functions and assets is critical to assessing the completeness and appropriateness of the FM design to the mission attributes (mission type, risk posture, operations concept, etc.). Fault trees and state transition diagrams are examples of visualization tools that could contribute to visualization of the full FM design.

- **FM Operations Approaches** - The goal of current FM processes is to preserve the asset, by safing the vehicle and relying on mission operations to determine how to proceed. But as greater autonomy is required - flying through failures in order to complete science objectives that require timely operations, for example – the spacecraft must be able to make decisions about how to recover from failures or degradations and continue the mission. FM designs must enable flexible operations that can integrate onboard and mission operations decision-making.

- **FM Verification and Validation Tools** - As complexity of spacecraft and systems increases, the extensiveness of testing required to verify and validate FM implementations can be resource intensive. Automated test case development, false positive/false negative test tools, model verification and validation tools, and test coverage risk assessments are examples of contributing technologies.

- **FM Design Architectures** - FM capabilities may be implemented through numerous system, hardware, and software architecture solutions. The FM architecture trade space includes options such as embedded in the flight control software or independent onboard software; on board versus ground-based capabilities; centralized or distributed FM functions; sensor suite implications; integration of multiple FM techniques; innovative software FM architectures implemented on flight processors or on Field Programmable Gate Arrays (FPGAs); and execution in real-time or off-line analysis post-operations. Alternative architecture choices such as model-based approaches could help control FM system complexity and cost and could offer solutions to transparency, verifiability, and completeness challenges.

- **Multi-discipline FM Interoperation** - FM designers, Systems Engineering, Safety and Mission Assurance, and Operations perform analyses and assessments of reliabilities, failure modes and effects, sensor coverage, failure probabilities, anomaly detection and response, contingency operations, etc. The relationships between multi-discipline data and analyses are inconsistent and misinterpreted. Resources are expended either in effort to resolve disconnects in data and analyses or worse, reduced mission success due to failure modes that were overlooked. Solutions that address data integrity, identification of metrics, and standardization of data products, techniques and analyses will reduce cost and failures.

All submissions must show how proposed technologies are relevant to SMD missions and objectives. For further information on SMD Science Strategy go to: [https://science.nasa.gov/about-us/science-strategy](https://science.nasa.gov/about-us/science-strategy) [33].
NASA’s role under the NSWAP is to provide increased understanding of the fundamental physics of the Sun-Earth system through space-based observations and modeling, develop new space-based technologies and missions, and monitor space weather for NASA’s space missions. This SBIR subtopic is intended to solicit new enabling technologies as part of NASA’s response to this national objective. While this subtopic will consider all concepts demonstrably related to NASA’s Research-to-Operations/Operations-to-Research (R2O/O2R) responsibilities outlined in the NSWAP, four broad areas have been identified for priority development:

- NASA supports the Community Coordinated Modeling Center (CCMC), located at GSFC, as a centralized government-run facility that hosts, maintains, and validates heliophysics models, some of which will become suitable for use by the space weather operations and forecasting community. Innovations solicited include modernization of the CCMC core infrastructure, the preparation and validation of existing science models in preparation for transition to operations, and ideas for future models tied to space weather forecasting needs. Proposals directly tied to NASA’s NSWAP activities may be given priority. Infrastructure improvement proposals should be coordinated with NASA CCMC requirements and needs, and outline the process for implementation, mitigations to ensure continued community access to CCMC resources throughout the transition process, and flexibilities that allow for future integration of additional modeling tools, archives, or repositories. For example, the CCMC is interested in technologies that enable utilization of high-end computing architectures to optimize system performance for tasks such as "runs on request (RoR)."

- The Heliophysics System Observatory (HSO) data archives include a vast array of spacecraft observations suitable for the development of space weather benchmarks, which are the set of characteristics against which space weather events are measured. Baseline benchmarks have been established or are nearing completion. Innovations to further refine these benchmarks are solicited, as are concepts for future creative approaches utilizing new data types or models that could become available. Proposals should address the feasibility and utility of establishing any newly proposed functional benchmarks, preferably in coordination with one or more of the participating NSWAP agencies.

- A particular challenge is to combine the sparse, vastly distributed data sources with realistic models of the near-Earth space environment. Innovations across the broad range of data assimilation techniques are solicited, with the long-term goal of enabling future tools and protocols for the operations community. Proposals should address requirements that:
  - Develop space weather applications or technologies desired by operational organizations that augment existing and future needs.
  - Include the ability to integrate data from assets which typically do not share similar time series, utilize different measurement techniques (e.g., imaging vs in-situ particles and fields), and are distributed throughout the heliosphere.
  - Specify that new forecasting tools which can be straightforwardly validated by the CCMC or other equally robust validation methodology.
  - Examine the potential for integrating additional resources, such as ground based instrumentation e.g., USGS ground conductivity measurements which can be used to calculate geomagnetically induced currents.

- Heliophysics science relies on a wide variety of instrumentation for its research and often makes its data available in near-real-time for space weather forecasting purposes. Concepts are solicited for instrumentation concepts, flight architectures, and reporting systems that may be suitable for data assimilation into space weather monitoring and forecasting systems. This includes the miniaturization of existing systems and/or technologies deployable as an array of CubeSats. In order to be considered for investment, SBIR technologies should demonstrate comparable, or better, precision and accuracy when compared to the current state-of-the art. Further, SBIR instrument designs should avoid duplicating current NASA research spacecraft arrays or detector systems including those currently in formulation (e.g., SDO, Van Allen Probes, MMS, IMAP).

Proposals should demonstrate an understanding of the current state-of-the-art, describe how the proposed innovation is superior, and provide a feasible plan to develop the technology and infuse into a specific NSWAP activity.