NASA SBIR 2008 Phase I Solicitation

Science

Sensors, Detectors and Instruments Topic S1

NASA's Science Mission Directorate (SMD) (http://nasascience.nasa.gov/ [1]) encompasses research in the areas of Astrophysics (http://nasascience.nasa.gov/astrophysics [2]), Earth Science (http://nasascience.nasa.gov/earth-science [3]), Heliophysics (http://nasascience.nasa.gov/heliophysics [4]), and Planetary Science (http://nasascience.nasa.gov/planetary-science [5]). A major objective of SMD instrument development programs is to implement science measurement capabilities with smaller or more affordable spacecraft so development programs can meet multiple mission needs and therefore make the best use of limited resources. The rapid development of small, low-cost remote sensing and in situ instruments is essential to achieving this objective. For Earth Science needs, in particular, the subtopics reflect a focus on instrument development for airborne and Unmanned Aerial Vehicle (UAV) platforms. Astrophysics has a critical need for sensitive detector arrays with imaging, spectroscopy, and polarimetric capabilities which can be demonstrated on ground, airborne, balloon, or suborbital rocket instruments. Heliophysics, which focuses on measurements of the sun and its interaction with the Earth and the other planets in the solar system, needs a significant reduction in the size, mass, power, and cost for instruments to fly on smaller spacecraft. Planetary Science has a critical need for miniaturized instruments with in situ sensors that can be deployed on surface landers, rovers, and airborne platforms. For the 2008 program year, two new subtopics have been added. One subtopic solicits technology for geodetic instruments and instruments to enable global navigation and very long baseline interferometry. A second new subtopic requests proposals for technology to enable new lunar science instruments. A key objective of this SBIR topic is to develop and demonstrate instrument component and subsystem technologies that reduce the risk, cost, size, and development time of SMD observing instruments and to enable new measurements. Proposals are sought for development components that can be used in planned missions or a current technology program. Research should be conducted to demonstrate feasibility during Phase 1 and show a path towards a Phase 2 prototype demonstration. The following subtopics are concomitant with these objectives and are organized by technology.
Sub Topics:

S1.01 Lidar System Components

Lead Center: LaRC

Participating Center(s): ARC, GSFC

Accurate measurements of atmospheric parameters with high spatial resolution from ground, airborne, and space-based platforms require advances in the state-of-the-art lidar technology with emphasis on compactness, efficiency, reliability, lifetime, and high performance. Innovative lidar component technologies that directly address the measurements of the atmosphere and surface topography of the Earth, Mars, the Moon, and other planetary bodies will be considered under this subtopic. Innovative technologies that can expand current measurement capabilities to spaceborne or Unmanned Aerial Vehicle (UAV) platforms are particularly desirable. Development of components that can be used in planned missions or current technology program is highly encouraged. Examples of planned missions and technology programs are: Ice, Cloud and land Elevation Satellite (ICESat, http://icesat.gsfc.nasa.gov [6]), Laser Interferometer Space Antenna (LISA, http://lisa.nasa.gov/index.html [7]), Doppler Wind Lidar, Lidar for Surface Topography (LIST), and Earth and planetary atmospheric composition (ASCENDS).

Research should be conducted to demonstrate technical feasibility during Phase 1 and show a path toward a Phase 2 prototype demonstration. For this Program year, we are soliciting only the specific component technologies described below.

- High speed fiber multiplexers for multimode fiber (200 micron core, 0.22 NA) operating at 1064 nm wavelength. We require an N by M multiplexer (where N is 1 or more and M is 10 to 100 or more) capable of switching at speeds on the order of 10 microseconds with low insertion loss (<2 dB). The unit must be small, lightweight, capable of long life, and low power consumption.
- Space-qualifiable high reliability frequency-stabilized CW laser source with 1 W output power. A master oscillator power amplifier (MOPA) configuration is desirable since the source must be phase-modulated.
- Development of polarization-maintaining Er and/or Yb doped optical fiber amplifiers that are optimized for suppression of stimulated Brillouin scattering (SBS). Resulting fiber amplifier must be capable of single frequency (< 1MHz linewidth), peak power of > 1 kW, and M2 beam quality < 1.3.
- Efficient and compact single frequency, near diffraction limited fiber lasers operating in near infrared (1.0 -1.7 ?m) and mid-infrared (3 - 4 ?m). Requirements include: polarization maintaining output (better than 100:1), M2 beam quality < 1.5, wavelength stability <50 pm over one hour. Both pulsed lasers with repetition rates of the order of 10 KHz and pulse energies greater than 0.5 mJ, and CW lasers in multiwatts regimes are applicable. Wavelength tunability over 10s of nanometers is desirable for certain applications.
- Efficient and compact single mode solid state or fiber lasers operating at 1.5 and 2.0 micron wavelength regimes suitable for coherent lidar applications. These lasers must meet the following general requirements: pulse energy 0.5 mJ to 50 mJ, repetition rate 10 Hz to 1 kHz, and pulse duration of approximately 200 nsec.
- Single frequency semiconductor or fiber laser generating CW power in 1.5 or 2.0 micron wavelength regions with less than 50 kHz linewidth. Frequency modulation with about 5 GHz bandwidth and wavelength tuning over several nanometers are desirable.
- Development of efficient, compact, and space qualifiable laser absorption spectrometry-related technologies for measuring atmospheric pressure and density. Components of interest include but not limited to fiber based Raman amplifier-based transmitter architecture. Remote sensing of oxygen in the 1.26-micron spectral region for measuring atmospheric pressure is of particular interest.

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

S1.02 Active Microwave Technologies

Lead Center: JPL

Participating Center(s): GSFC

NASA employs active sensors (radars) for a wide range of remote sensing applications (http://www.nap.edu/catalog/11820.html [8]). These sensors include low frequency (less than 10 MHz) sounders to G-band (160 GHz) radars for measuring precipitation and clouds and for planetary landing. We are seeking proposals for the development of innovative technologies to support future radar missions. The areas of interest for this call are listed below (with applications and/or mission concept names):

- Lightweight deployable L-band antenna structures and deployment mechanisms suitable for large aperture (reflectors or phased array of $50m^2$ and larger) systems. (Solid Earth Science , http://solidearth.jpl.nasa.gov/ [9])
- Compact wide bandwidth L-band and S-band (200 MHz) array antennas for airborne real aperture and synthetic aperture radar remote sensing applications.
- Rad-hard, high-efficiency, low-cost, lightweight L- and P-band Transmit/Receive (TR) modules (~250 W peak RF output power at ~100 us pulsewidth and 20% duty cycle) with respective energy storage units to provide pulsed DC power to the power amplifier while minimizing ripple on the primary DC power source. (DESDynI, http://desdyni.jpl.nasa.gov/ [10]; SES, hydrology

- Low Power 10-bit, 1.5 GHz analog bandwidth ADCs and digital filtering with an emphasis on rad-tolerance and space-qualification. (Ice Topography (GLISTIN), planetary landing)
- Lightweight deployable reflectors (Ku-band and Ka-band) and active feed electronics.
- High efficiency Ka-band (34-36GHz) TR modules with output power of 5-10W. The Low Noise Amplifiers (LNAs) should have a NF less than 3dB and gain better than 30dB. Included in the TR module is a low loss phase shifter. (GPM, Clouds and precipitation, planetary landing)
- Power amplifier and associated LNA for a Ka-band (34-36GHz) radar system with a peak output power of 2KW to 10KW (duty cycle of 10%) and system bandwidth of up to 1 GHz and LNA NF of less than 1.5dB. The LNA needs to have enough isolation and power handling capability to operate in this high power transmission environment. (SWOT, GLISTIN, clouds and precipitation)
- 140-160 GHz planar frequency-scanned antenna with scan range +/- 16 degrees, beamwidth 0.5 degrees, and bandwidth 400 MHz per beam. (planetary landing, atmospheric radar)
- Dual or tri-frequency (Ku/Ka/W band), matched beam antennas with high cross-polarization isolation (>32 dB). (Cloud and precipitation)
- Innovative approaches to realizing a low-cost instrument (sub-system).

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

S1.03 Passive Microwave Technologies

Lead Center: GSFC

Participating Center(s): JPL, MSFC

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 (http://www.nap.edu/catalog.php?record_id=11820 [12]) to cosmic background emission. Proposals are sought for the development of innovative technology to support future science and exploration missions employing 450 MHz to 5 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). While other concepts will be entertained, specific technology innovations of interest are listed below for missions including decadal survey missions (http://www.nap.edu/catalog/11820.html [8]) such as PATH, SCLP, and GACM and the Beyond Einstein Inflation Probe (Inflation Probe (cosmic microwave background, http://universe.nasa.gov/program/probes/inflation.html [13])

- Low power >200 Mb/s 1-bit A/D converters and cross-correlators for microwave interferometers. Earth Science Decadal survey missions which apply: PATH, SCLP.
- Automated assembly of 180 GHz direct conversion I-Q receiver modules. This technology applies to both the Beyond Einstein Inflation probe and the Decadal Survey PATH concept.
- Low DC power spectrometer (channelizer) covering >500 MHz with 125 kHz resolution for planetary radiometer missions and covering 4 GHz with 1 MHz resolution for Earth observing missions. Also RFI mitigation approaches employing channelizers for broad band radiometers. Earth Science Decadal Survey mission which applies: GACM.
- RF (GHz to THz) MEMS switches with low insertion loss (< 0.5 dB), high isolation (>18 dB), capable of switching with speeds of >100 Hz at cryogenic temperatures (below 10 K) for 10^8 or more cycles. Technology applies to Beyond Einstein Probe.
- High emissivity (>40 dB return loss) surfaces/structures for use as onboard calibration targets that will reduce the weight of aluminum core targets, while reliably improving the uniformity and knowledge of the calibration target temperature. Earth Science Decadal survey missions which apply: SCLP and PATH.
- MMIC Low Noise Amplifiers (LNA). Room temperature LNAs for 165 to 193 GHz with low 1/f noise, and a noise figure of 6.0 dB or better; and cryogenic LNAs for 180 to 270 GHz with noise temperatures of less than 150K. Earth Science Decadal Survey missions that apply: PATH and GACM.

- Low loss, low RF power waveguide SPDT diode switches and active noise sources for frequencies above 90 GHz to support calibration of SWOT and other atmospheric temperature and humidity measurements.

In addition to the technologies listed above, proposals for innovative passive microwave instruments for a wide range of remote sensing applications from measurements of the Earth's surface and atmosphere to cosmic background emission would also be welcome.

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

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

Lead Center: JPL

Participating Center(s): ARC, GSFC, LaRC

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 for Earth science (http://www.nap.edu/catalog/11820.html [8]), planetary science (http://www.nap.edu/catalog/10432.html [14]), and astronomy & astrophysics (http://www.nap.edu/books/0309070317/html/ [15]).

The following technologies are of interest for Earth and planetary science instrument concepts such as Scanning Microwave Limb Sounder (http://mls.jpl.nasa.gov/index-cameo.php [16]) on the Global Atmospheric Chemistry Mission, Climate Absolute Radiance and Refractivity Observatory (http://science.hq.nasa.gov/earth-sun/docs/Volz4_CLARREO.pdf [17]), Methane Trace Gas Sounder, and Lunar Atmosphere Dust Environment Explorer:

- New or improved technologies leading to measurement of trace atmospheric species (e.g., CO, CH4, N_2O) from geostationary and low-Earth orbital platforms. Of particular interest are new techniques in gas filter correlation spectroscopy, Fabry-Perot spectroscopy, or improved component technologies.

- Uncooled or passively cooled detectors with specific detectivity (D*) ? 10^{10} cm $Hz^{1/2}$/W in the operating wavelength ranges 6-14 ?m and 10-100 ?m.

- Efficient, flight qualifiable, spur free, local oscillators for SIS mixers operating in low Earth orbit. Two bands: (1) tunable from 200 to 250 GHz, and (2) tunable from 610 to 650 GHz, phase-locked to or derived from an ultra-stable 5 MHz reference.
- Technologies for calibrating millimeter wave spectrometers for spaceborne missions, including low power, flight qualifiable comb generators for gain, linearity, and sideband calibration of microwave spectrometers covering the bands from 180 to 270 GHz and from 600 to 660 GHz; flight qualifiable low noise diodes for the bands from 180 to 270 and 600 to 660 GHz; very low return loss (70 dB or better) calibration targets and techniques for quantifying and calibrating out the impact of standing waves in broadband heterodyne submillimeter spectrometers.
- Low power, stable, linear, spectrometers capable of measuring the band from 6-18 GHz with ~120 100 MHz wide channels.
- Digital spectrometers with ~4 GHz bandwidth and 10 MHz resolution. Components for these digital spectrometers including high speed digitizers, efficient spectrometer firmware, and ASIC implementations.

Detector technologies for future astrophysics mission concepts, such as the Single Aperture Far Infrared (SAFIR) Observatory (http://safir.jpl.nasa.gov/technologies.shtml [18]), the Space Infrared Telescope for Cosmology and Astrophysics (SPICA) (http://www.ir.isas.ac.jp/SPICA/ [19]), and Inflation Probe (cosmic microwave background,

http://universe.nasa.gov/program/probes/inflation.html [13]).

- Innovative detector designs, readout electronics, or new sensor materials (e.g. novel dopants for extrinsic Si detectors) are of interest, as is development of a photo-definable version of parylene to aid the fabrication of thermally isolated structures of bolometers (and x-ray microcalorimeters).
- Spatial Filter Array (SFA) consisting of a monolithic array of up to 1200 coherent, polarization preserving, single mode fibers that operate over a large fraction of the spectral range from 0.4 - 1.0 microns and such that each input and output lenslet is mapped to a single fiber. Uniformity of output intensity and high throughput is desired and fiber-to-fiber placement accuracies of < 2.0 microns are required with < 1.0 microns desired. Â Applications include active and passive wavefront and amplitude control, and relevant missions include Terrestial Planet Finder (http://planetquest.jpl.nasa.gov/TPF/tpf_index.cfm [20]) and Stellar Imager (http://hires.gsfc.nasa.gov/si/ [21]).

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

S1.05 Detector Technologies for UV, X-Ray, Gamma-Ray and Cosmic-Ray Instruments

Lead Center: GSFC

Participating Center(s): JPL, MSFC

This subtopic covers detector requirements for a broad range of wavelengths from UV through to gamma ray. As would be expected, requirements across the board are for greater numbers of readout pixels, lower power, faster readout rates, greater quantum efficiency, and enhanced energy resolution. Typical semiconductor devices in this energy range are based on silicon or germanium. However, proposals for other detector materials are welcomed if a compelling case is made.

The proposed efforts must be directly linked to a requirement for a NASA mission. Details of these can be found at the following URLs:

- General Information on Future NASA Missions: http://nasascience.nasa.gov/missions [22]
- Specific Mission pages:
    - ConX: http://constellation.gsfc.nasa.gov [23]
    - LBTI: http://planetquest.jpl.nasa.gov/lbti/lbti_index.cfm [24]
- Future Mars Programs: http://marsprogram.jpl.nasa.gov/missions/future/futureMissions.html [25]
- Solar Probes: http://science.hq.nasa.gov/missions/sun.html [26]

Specific technologies are listed below. Highly desirable are developments that satisfy multiple requested parameters:

- Large-format focal plane detectors for use in UV and X-ray imaging and spectrometry:
    - UV-sensitive CCD and active pixel sensors with large formats: to 6k x 6k abuttable; extended UV response below 0.2 nm;
    - X-ray-sensitive CCD and active pixel sensors: up to 4k x 4k formats, 4-side abuttable; power levels of 0.1 W / megapixel; resolutions less than 120 eV; readout rates of at least 30 Hz; extended x-ray response above 6 keV.

Very-large-area X-ray detectors for survey instruments: square-meter area capability; response from 3-30 keV; ultra-low power (10 microW/channel).

- Significant improvements in wide band gap materials, individual detectors, and detector arrays for UV and X-ray applications.
- Photon counting detectors with capability to resolve single photon arrival for use in space applications.
- Mega-to-giga-channel analogue electronic systems for very-large-area X- and gamma-ray detectors as follows: up to 108 channel capability; less than 10 microW/channel power requirement; less than 100 electron rms noise level with interconnects.
- Technology to accomplish X-ray and gamma-ray imaging spectroscopy and polarimetry at the arcsecond level in the energy range from 1 keV to 20 MeV.

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

S1.06 Particles and Field Sensors and Instrument Enabling Technologies

Lead Center: GSFC

Participating Center(s): ARC, JPL, MSFC

Advanced sensors and instrument enabling technologies for the measurement of the physical properties of space plasmas and energetic charged particles, mesospheric-thermospheric neutral species, energetic neutral atoms created by charge exchange, and electric and magnetic fields in space are needed to achieve NASA's transformational science advancements in Heliophysics. The Heliophysics discipline has as its primary strategic goal the understanding of the physical coupling between the sun's outer corona, the solar wind, the trapped radiation in Earth's and other planetary magnetic fields, and to the upper atmospheres of the planets and their moons. This understanding is of national importance not only because of its intrinsic scientific worth, but also because it is the necessary first step toward developing the ability to measure and forecast the "space weather" that affects all human crewed and robotic space assets. Improvements in particles and fields sensors and associated instrument technologies will enable further scientific advancement for upcoming NASA missions such as Solar Probe (http://solarprobe.gsfc.nasa.gov/ [27]), Solar Orbiter (http://www.rssd.esa.int/index.php?project=SOLARORBITER [28]), Solar Sentinels (http://www.lws.nasa.gov/missions/sentinels/solar_sentinels_orbiter.htm [29]), GEC, Magnetospheric Constellation (http://stp.gsfc.nasa.gov/missions/mc/mc.htm [30]), IT-SP (http://www.lws.nasa.gov/missions/geospace/geospace.htm [31]) and some planetary exploration missions. Technology developments that result in expanded measurement capabilities and a reduction in size, mass, power, and cost are necessary in order for some of these missions to proceed. Of special interest are magnetometers, fast high voltage stepping power supplies for charged particle analyzers, electric field booms and other supporting sensor electronics. Specific areas of interest include:

- Low cost, low power, low current, high voltage power supplies which allow ultra-fast stepping (t < 100- ?s) over the full voltage range (0 < V < 5-15 kV).
- Self-calibrating scalar-vector magnetometer for future Earth and space science missions. Performance goals: dynamic range: +/-100,000 nT, accuracy with self-calibration: 1 nT, sensitivity: 5 pT / sqrtHz, max sensor unit size: 6 x 6 x 12 cm, max sensor mass: 0.6 kg, max electronics unit size: 8 x 13 x 5 cm, max electronics mass: 1 kg, and max power: 5 W operation, 0.5 W standby, including, but not limited to "sensors on a chip".
- Strong, lightweight, thin, compactly-stowed electric field booms possibly using composite materials that deploy sensors to distances of 10 m or more and/or long wire boom (> 50 m) deployment systems for the deployment of very lightweight tethers or antennae on spinning spacecraft.
- Low power charge sensitive preamplifiers on a chip.
- Radiation hardened ASIC spectrum analyzer module that determines mass spectra using fast algorithm

deconvolution to produce ion counts for specific ion species.

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

S1.07 Cryogenic Systems for Sensors and Detectors

Lead Center: GSFC

Participating Center(s): ARC, JPL, MSFC

Cryogenic cooling systems are often enabling technologies for cutting edge science from infrared imaging and spectroscopy to x-ray calorimetry. Improvements in cryogenic technologies enable further scientific advancement at lower cost, lower risk, reduced volume, and/or reduced mass. Lifetime, reliability, and power requirements of the cryogenic systems are critical performance concerns. Of interest are cryogenic technologies for cooling detectors for scientific instruments and sensors on advanced telescopes and observatories (http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20070018750_2007018830.pdf [32]) as well as on instruments for lunar and planetary exploration such as missions to Europa, Titan, or Enceladus (http://sci.esa.int/science-e/www/object/index.cfm?fobjectid=42337 [33]). Active coolers should have long life, low vibration, low mass, low cost, and high efficiency. Specific areas of interest include:

- Essentially vibration-free cooling systems such as Pulse Tube or reverse Brayton cycle cooler technologies with cooling capability of 20 mW at 4K.
- Low temperature cooling systems, operating and rejecting heat at 150K, providing 0.3W of cooling at 35K with input power on the order of 10W.
- Distributed cooling systems using circulators for larger systems including helium circulators. The temperature range is 20-100K, with flowrates of up to 1 gram/sec and a maximum pressure drop of 50 psi.
- Heat switches for redundant cryocoolers with a temperature range of 20-100K and a capacity of 20W.
- Highly efficient magnetic and dilution cooling technologies under 1 Kelvin.
- Components for advanced magnetic coolers (adiabatic demagnetization refrigerators) including:
  - Small (few cm bore), lightweight, low current (under 10A, goal under 5A) superconducting magnets capable of producing at least 3 Tesla central field while operating at least 10 Kelvin. Higher temperature superconductor (HTS) magnets operating at significantly higher temperatures are of particular interest.
  - Lightweight (relative to standard ferromagnetic flux guides) active and/or passive magnetic shielding for 3 to 4 Tesla magnets that reduces the stray field to tens of microTesla at a distance of several cm from the outside of the shield.
  - Large (>1 cubic cm) single crystal or polycrystalline magnetocaloric materials.
  - Superconducting current leads operating between 90 Kelvin down to 10 Kelvin, capable of carrying up to 10 amperes while allowing only approximately 1 mW of heat to be conducted.
  - Compact, accurate, easy to use thermometers that operate down to 10 milliKelvin.

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

S1.08 In Situ Airborne, Surface, and Submersible Instruments for Earth Science

Lead Center: GSFC

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

There are new platform systems that have the potential to benefit Earth science research activities. To capitalize on these emerging capabilities, proposals are sought for the development of in situ instruments for use on radiosondes, dropsondes, tethered balloons, kites, Unmanned Aerial Vehicles (UAVs), Unmanned Surface Vehicles (USVs), or Unmanned Underwater Vehicles (UUVs). Both miniaturization of current techniques, as well as innovative new methods that lead to compact and lightweight systems are important. Details of complete instrument systems are desired, including data acquisition, power, and platform integration. Instrument performance goals such as resolution, accuracy, and response time should be discussed, as well as maintenance and reliability considerations. An outline of potential use by NASA and a plan for commercial production and marketing should be included as well. Technology innovation areas of interest include:

- Atmospheric measurements including aerosol properties, temperature, humidity, solar radiation, clouds, liquid water, ice, precipitation, and chemical composition (carbon dioxide, methane, reactive gases and radicals, dynamical tracer species).
- Three-dimensional wind measurements near the Earth's surface, and within the troposphere and lower stratosphere.
- Oceanic and coastal measurements including inherent and apparent optical properties, temperature, salinity, chemical composition, nutrient distribution, and currents.

Instrument systems to support field studies of fundamental processes are of interest, as well as for satellite measurement calibration and validation. Applicability to NASA's Airborne Science, Ocean Biology and Biogeochemistry, and Applied Sciences programs, including support of the Integrated Ocean Observing System (IOOS), is a priority.

S1.09 In Situ Sensors and Sensor Systems for Planetary Science

Lead Center: JPL

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

This subtopic solicits development of advanced instruments and instrument components that are tailored to the demands of planetary instrument deployment on a variety of space platforms (orbiters, flyby spacecraft, landers, rovers, balloon or other aerial vehicles, subsurface penetrators or impactors, etc.) accessing the wide variety of bodies in our solar system (inner and outer planets and their moons, comets, asteroids, etc.). For example missions see: http://science.hq.nasa.gov/missions/solar_system.html [34].

Specifically, this subtopic solicits instrument development that provides significant advances in the following areas:

- Reduced mass, power, volume, data rates for instruments or instrument components that could be achieved in optomechanical components (e.g., room temperature lasers, detectors, mixers, microvalves, optical components and structures, gas and liquid pumps, ion sources, light sources from UV to microwave, seismometers, etc.) or electronics (e.g., FPGA, ASIC implementations, advanced array readouts);
- Improved g-force survivability for rough landings on Mars, Moon, or comet/asteroid bodies;
- Mitigation strategies for tolerance to high-radiation environments like that around Europa;
- High temperature and/or high pressure lifetime improvement for instruments landed on Venus;
- Low temperature survivability or lifetime improvement for instruments landed on cryogenic outer planet bodies or deployed to the subsurface;
- Advanced sample handling and manipulation technologies for challenging environments and planetary protection.

Proposers are strongly encouraged to relate their proposed development to (a) future planetary exploration goals of NASA; and (b) existing flight instrument capability to provide a comparison metric for assessing proposed improvements.

Instruments for both remote sensing and in situ investigations are required for NASA's planned and potential solar system exploration missions. Instruments are required for the characterization of the atmosphere, surface, and subsurface regions of planets, satellites, and small bodies. These instruments may be deployed for remote sensing, on orbital or flyby spacecraft, or for in situ measurements, on surface landers and rovers, subsurface penetrators, and airborne platforms. In situ instruments cover spatial scales from surface reconnaissance to microscopic investigations. These instruments must be capable of withstanding operation in space and planetary environmental extremes, which include temperature, pressure, radiation, and impact stresses.

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

S1.10 Space Geodetic Observatory Components

Lead Center: GSFC

Participating Center(s): JPL, LaRC

NASA is working with the international community to develop the next generation of geodetic instruments and networks to determine the terrestrial reference frame with accuracy better than one part per billion (http://science.hq.nasa.gov/strategy/roadmaps/surface.html [35]). These instruments include Global Navigation Satellite System (GNSS) receivers, Very Long Baseline Interferometry (VLBI) systems, and Next Generation Satellite Laser Ranging (SLR) stations. The development of these instruments and the needed integrating technology will require contributions from a broad variety of optical, microwave, antenna and survey engineering suppliers. These needs include but are not limited to:

- Broadband (2 - 14 GHz) feeds capable of receiving GNSS signals, Ka-band (32 - 36 GHz) feeds integrated with broadband feeds, and matching antennas that meet or exceed the slewing and duty cycle requirements of the IVS VLBI2010 specifications.
- VLBI system components including > 4 Gbps recorders, phase/cable calibrators, and frequency standards / distribution systems that meet or exceed the requirements of the IVS VLBI2010 specifications.
- Cost-effective data transmission for e-VLBI from a global network of 30 VLBI stations operating up to 8 Gbps.
- Compact, low mass, space-qualified for MEO, SLR retroreflector arrays with greater than 100 million square meter lidar cross section, with a design that assures the ability to determine the array center to the center of mass of the spacecraft to a millimeter.
- A very high quantum efficiency (>50% at 532nm), low instrument noise, multi-pixilated detector for SLR use in the automated tracking.
- Geodetic GNSS software receivers and antenna systems capable of receiving all signals from the GPS, GLONASS, Galileo and Beidou/Compass GNSS.
- Continuous, reliable co-location monitoring and control system for the relative 3-D displacement of geodetic instruments within a geodetic observatory to better than 1 mm.

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

S1.11 Lunar Science Instruments and Technology

Lead Center: MSFC

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

NASA lunar robotic science missions support the high-priority goals identified in the 2007 National Research Council report, The Scientific Context for Exploration of the Moon: Final Report (hwttp://ww.nap.edu/catalog.php?record_id=11954 [36]). Future missions will characterize the lunar exosphere and surface environment; field test new equipment, technologies, and approaches for performing lunar science; identify landing sites and emplace infrastructure to support robotic and human exploration; demonstrate and validate heritage systems for exploration missions; and provide operational experience in the harsh lunar environment.

Space-qualified instruments are required to perform remote and in situ lunar science investigations, to include measurements of lunar dust composition, reactivity and transport, searching for water ice, assessing the radiation environment, gathering long period measurements of the lunar exosphere, and conducting surface and subsurface geophysical measurements.

In support of these requirements, this subtopic seeks advancements in the following areas:

Geophysical Measurements

  Systems, subsystems, and components for seismometers and heat flow sensors capable of long-term continuous operation over multiple lunar day/night cycles with improved sensitivity at lower mass and reduced power consumption compared to the Apollo Lunar Surface Experiments Package (ALSEP) instruments (http://www.hq.nasa.gov/alsj/frame.html [37]). Instrument deployment options include robotic deployment from soft landers, as well as emplacement by hard landers or penetrators. Also of interest are portable surface ground penetrating radars with antenna frequencies of 250-MHz, 500-MHz, and 1000-MHz to characterize the thickness of the lunar regolith.

In Situ Lunar Surface Measurements

  Light-weight and power efficient instruments that enable elemental and/or mineralogy analysis using techniques such as high-sensitivity X-ray and UV-fluorescence spectrometers, UV/fluorescence flash lamp/camera systems, scanning electron microscopy with chemical analysis capability; time-of-flight mass spectrometry, gas chromatography and tunable diode laser (TDL) sensors for in situ isotopic and elemental analysis of evolved volatiles, calorimetry, and Laser Induced Breakdown Spectroscopy (LIBS). Instruments shall have the potential to provide isotope ratio measurements and/or hydrogen distributions to ±10 ppm locally. Instrument deployment options include robotic deployment from soft landers, as well as emplacement by hard landers or penetrators.

Lunar Atmosphere and Dust Environment Measurements

  Low-mass and low-power instruments that measure the local lunar surface environment which includes but is not limited to the characterization of: the plasma environment, surface electric field, and dust concentrations and its diurnal dynamics. Instrument deployment options include robotic deployment from soft landers, as well as emplacement by hard landers or penetrators.

Research should be conducted to demonstrate technical feasibility during Phase 1 and show a path toward a Phase 2 hardware and software demonstration, and when possible, deliver a demonstration unit or software package for NASA testing at the completion of the Phase 2 contract.

Advanced Telescope Systems Topic S2

The NASA Science Missions Directorate seeks technology for cost-effective high-performance advanced space telescopes for astrophysics and Earth science. Astrophysics applications require large aperture light-weight highly reflecting mirrors, deployable large structures and innovative metrology, control of unwanted radiation for high-contrast optics, precision formation flying for synthetic aperture telescopes, and cryogenic optics to enable far infrared telescopes. A few of the new astrophysics telescopes and their subsystems will require operation at cryogenic temperatures as cold a 4-degrees Kelvin. This topic will consider technologies necessary to enable future telescopes and observatories collecting electromagnetic bands, ranging from UV to millimeter waves, and also include gravity waves. The subtopics will consider all technologies associated with the collection and combination of observable signals. Earth science requires modest apertures in the 2 to 4 meter size category that are cost effective. New technologies in innovative mirror materials, such as silicon, silicon carbide and nanolaminates, innovative structures, including nanotechnology, and wavefront sensing and control are needed to build telescope for Earth science that have the potential to cost between $50 to $150M.
Sub Topics:

S2.01 Precision Spacecraft Formations for Telescope Systems

Lead Center: JPL

Participating Center(s): GSFC

This subtopic seeks hardware and software technologies necessary to establish, maintain, and operate precision spacecraft formations to a level that enables cost effective large aperture and separated spacecraft optical telescopes and interferometers (e.g., http://constellation.gsfc.nasa.gov/ [23], http://lisa.gsfc.nasa.gov/ [38]). Also sought are technologies (analysis, algorithms, and testbeds) to enable detailed analysis, synthesis, modeling, and visualization of such distributed systems.

Formation flight can synthesize large effective telescope apertures through, multiple, collaborative, smaller telescopes in a precision formation. Large effective apertures can also be achieved by tiling curved segments to form an aperture larger than can be achieved in a single launch, for deep-space high resolution imaging of faint astrophysical sources. These formations require the capability for autonomous precision alignment and synchronized maneuvers, reconfigurations, and collision avoidance. The spacecraft also require onboard capability for optimal path planning and time optimal maneuver design and execution.

Innovations are solicited for: (a) sensor systems for inertial alignment of multiple vehicles with separations of 10,000 - 100,000 km to accuracy of 1 - 50 milli-arcseconds (b) development of nanometer to sub-nanometer metrology for measuring inter-spacecraft range and/or bearing for space telescopes and interferometers (c) control approaches to maintain line-of-sight between two vehicles in inertial space near Sun-Earth L2 to milli-arcsecond levels accuracy (d) development of combined cm-to-nanometer-level precision formation flying control of numerous spacecraft and their optics to enable large baseline, sparse aperture UV/optical and X-ray telescopes and interferometers for ultra-high angular resolution imagery. Proposals addressing staged-control experiments which combine coarse formation control with fine-level wavefront sensing based control are encouraged.

Innovations are also solicited for distributed spacecraft systems in the following areas:

- Distributed, multi-timing, high fidelity simulations;
- Formation modeling techniques;
- Precision guidance and control architectures and design methodologies;
- Centralized and decentralized formation estimation;
- Distributed sensor fusion;
- RF and optical precision metrology systems;
- Formation sensors;
- Precision microthrusters/actuators;
- Autonomous reconfigurable formation techniques;
- Optimal, synchronized, maneuver design methodologies;
- Collision avoidance mechanisms;
- Formation management and station keeping.

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

S2.02 Proximity Glare Suppression for Astronomical Coronagraphy

Lead Center: JPL

Participating Center(s): ARC, GSFC

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 and innovative advanced wavefront sensing and control for cost-effective space telescopes. 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 infrared wavelengths. The ultimate application of these instruments is to operate in space as part of a future observatory mission. Much of the scientific instrumentation used in future NASA observatories for the astrophysical sciences will require control of unwanted radiation (thermal and scattered) across a modest field of view. The performance and observing efficiency of astrophysics instruments, however, must be greatly enhanced. The instrument components are expected to offer much higher optical throughput, larger fields of view, and better detector performance. The wavelengths of primary interest extend from the visible to the thermal infrared. 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

- Advanced starlight canceling coronagraphic instrument concepts;
- Advanced aperture apodization and aperture shaping techniques;
- Pupil plane masks for interferometry;
- Advanced apodization mask or occulting spot fabrication technology controlling smooth density gradients to 10-4 with spatial resolutions ~1 μm, low dispersion, and low dependence of phase on optical density;
- Metrology for detailed evaluation of compact, deep density apodizing masks, Lyot stops, and other types of graded and binary mask elements. Development of a system to measure spatial optical density, phase in homogeneity, scattering, spectral dispersion, thermal variations, and to otherwise estimate the accuracy of masks and stops is needed;
- Interferometric starlight cancellation instruments and techniques to include aperture synthesis and single input beam combination strategies;
- Single mode fiber filtering from visible to 20 μm wavelength;
- Methods of polarization control and polarization apodization; and
- Components and methods to insure amplitude uniformity in both coronagraphs and interferometers, specifically materials, processes, and metrology to insure coating uniformity.

Wavefront Control Technologies

- Development of small stroke, high precision, deformable mirrors (DM) and associated driving electronics scalable to 10^4 or more actuators (both to further the state-of-the-art towards flight-like hardware and to explore novel concepts). Multiple DM 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;
- Development of instruments to perform broad-band sensing of wavefronts and distinguish amplitude and

phase in the wavefront;

- Adaptive optics actuators, integrated mirror/actuator programmable deformable mirror;
- Reliability and qualification of actuators and structures in deformable mirrors to eliminate or mitigate single actuator failures;
- Multiplexer development for electrical connection to deformable mirrors that has ultra-low power dissipation;
- High precision wavefront error sensing and control techniques to improve and advance coronagraphic imaging performance; and
- Highly reflecting broadband coatings.

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

S2.03 Precision Deployable Optical Structures and Metrology

Lead Center: JPL

Participating Center(s): GSFC, LaRC

Planned future NASA Missions in astrophysics, such as the Single Aperture Far-IR (SAFIR) telescope, James Webb Space Telescope (JWST, http://www.jwst.nasa.gov/ [39]), Terrestrial Planet Finder (TPF, http://planetquest.jpl.nasa.gov/TPF/tpf_index.cfm [20]) missions: Coronagraph, External Occulter and Interferometer, ATLAST, Life Finder, and Submillimeter Probe of the Evolution of Cosmic Structure (SPECS), and the UV Optical Imager (UVOIR) 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. The desired areal density is 1 - 10 kg/m^2. 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 L2.

This topic solicits proposals to develop enabling, cost effective component and subsystem technology for these telescopes. Research areas of particular interest include precision deployable structures and metrology (i.e., innovative active or passive deployable primary or secondary support structures); innovative concepts for packaging fully integrated (i.e., including power distribution, sensing, and control components); distributed and localized actuation systems; deployment packaging and mechanisms; active opto-mechanical control distributed on or within the structure; actuator systems for alignment of reflector panels (order of cm stroke actuators, lightweight, nanometer stability); innovative architectures, materials, packaging and deployment of large sunshields and external occulters; mechanical, inflatable, or other deployable technologies; new thermally-stable materials (CTE < 1ppm) for deployables; innovative ground testing and verification methodologies; and new approaches for achieving packagable depth in primary mirror support structures.

Also of interest are innovative metrology systems for direct measurement of the optical elements or their supporting structure; requirements for micron level absolute and subnanometer relative metrology for multiple locations on the primary mirror; measurement of the metering truss; and innovative systems which minimize complexity, mass, power and cost. The goal for this effort is to mature technologies that can be used to fabricate 20 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. A successful proposal shows a path toward a Phase 2 delivery of demonstration hardware scalable to 3 m for characterization.

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

S2.04 Optical Devices for Starlight Detection and Wavefront Analysis

Lead Center: MSFC

Participating Center(s): GSFC, JPL

The planned Ares V vehicle will enable the launch of extremely large and/or extremely massive space telescopes. Potential systems include 12 to 30 meter class segmented primary mirrors for UV/optical or infrared wavelengths and 8 to 16 meter class segmented x-ray telescope mirrors. UV/optical telescopes require 1 to 3 meter class mirrors with < 5 nm rms surface figures. IR telescopes require 2 to 3 meter class mirrors with cryo-deformations < 100 nm rms. X-ray telescopes require 1 to 2 meter long grazing incidence segments with angular resolution < 5 arc-sec down to 0.1 arc-sec and surface micro-roughness < 0.5 nm rms. Additionally, missions such as EUSO and OWL need 2 to 9 meter diameter UV-transparent refractive, double-sided Fresnel or diffractive lenses.

In view of the very large total mirror or lens collecting aperture required, affordability or areal cost (cost per square meter of collecting aperture) rather than areal density is probably the single most important system characteristic of an advanced optical system. For example, both x-ray and normal incidence space mirrors currently cost $3M to $4M per square meter of optical surface area. This research effort seeks a cost reduction for precision optical components by 20X to 100X to less than $100K per square meter.

The primary purpose of this subtopic is to develop and demonstrate technologies to manufacture ultra-low-cost precision optical systems for very large x-ray, UV/optical or infrared telescopes. Potential solutions include but are not limited to direct precision machining, rapid optical fabrication, slumping or replication technologies to manufacture 1 to 2 meter (or larger) precision quality mirror or lens segments (either normal incidence for uv/optical/infrared or grazing incidence for x-ray).

An additional key enabling technology for UV/optical telescopes is a broadband (from 100 nm to 2500 nm) high-reflectivity mirror coating with extremely uniform amplitude and polarization properties which can be deposited on 1 to 3 meter class mirrors.

Successful proposals will demonstrate prototype manufacturing of a precision mirror or lens system or precision replicating mandrel in the 0.25 to 0.5 meter class with a specific scale up roadmap to 1 to 2+ meter class space qualifiable flight optics systems. Material behavior, process control, optical performance, and mounting/deploying issues should be resolved and demonstrated. The potential for scale-up will need to be addressed from a processing and infrastructure point of view.

The Phase 1 deliverable will be at least a 0.25 meter near UV, visible or x-ray precision mirror or lens or replicating mandrel, its optical performance assessment and all data on the processing and properties of its substrate materials. This effort will allow technology to advance to TRL 3-4.

The Phase 2 deliverable will be at least a 0.50 meter near UV, visible or x-ray space-qualifiable precision mirror or lens system with supporting documentation, optical performance assessment, all data on materials and processing, and thermal and mechanical stability analysis. Effort will advance technology to TRL 4-5.

The proposal must address the technical need of a recognized future NASA space science mission, science measurement objective or science sensor for a Discovery, Explorer, Beyond Einstein, Origins, GOESS, New Millennium, Landmark-Discovery, or Vision mission. Missions of interest include the following: Constellation-X (http://constellation.gsfc.nasa.gov/ [23]); Generation-X (http://www.cfa.harvard.edu/hea/genx.html [40]); Single Aperture Far-Infrared (http://safir.jpl.nasa.gov/technologies.shtml [18]); Terrestrial Planet Finder (http://planetquest.jpl.nasa.gov/_TPF/tpf_index.cfm [41]); Orbiting Wide Angle Light Collector (http://owl.gsfc.nasa.gov/ [42]); Extreme Universe Space Observatory (http://hena.lbl.gov/EUSO/ [43]).

Proposals should show an understanding of one or more relevant science needs, and present a feasible plan to

fully develop a technology and infuse it into a NASA program.

S2.05 Optics Manufacturing and Metrology for Telescope Optical Surfaces

Lead Center: GSFC

Participating Center(s): JPL, MSFC

This year's subtopic focuses primarily on manufacturing and metrology of optical surfaces, especially for very small or very large and/or thin optics. Missions of interest include JDEM concepts (http://universe.nasa.gov/program/probes/jdem.html [44]), Constellation-X (http://constellation.gsfc.nasa.gov/ [23]), TPF (http://planetquest.jpl.nasa.gov/TPF/tpf_index.cfm [20]) and SAFIR (http://safir.jpl.nasa.gov/technologies.shtml [18]). Optical systems currently being researched for these missions are large area aspheres, requiring accurate figuring and polishing across six orders of magnitude in period (i.e., 1st and 2nd order errors through micro-roughness). Technologies are sought that will enhance the figure quality of optics in any range as long as the process does not introduce artifacts in other ranges (i.e., mm-period polishing should not introduce waviness errors at the 20 mm or 0.05 mm periods in the power spectral density). Also, novel metrological solutions that can measure figure errors over a large fraction of the PSD range are sought, especially techniques and instrumentation that can perform measurements while the optic is mounted to the figuring/polishing machine.

By the end of a Phase 2 program, technologies must be developed to the point where the technique or instrument can dovetail into an existing optics manufacturing facility producing optics at the R&D stage. Metrology instruments should have 10 nm or better surface height resolution and span at least 3 orders of magnitude in lateral spatial frequency.

Examples of technologies and instruments of interest include:

- Interferometric nulling optics for very shallow conical optics used in x-ray telescopes;
- Segmented systems commonly span 60 degrees in azimuth and 200 mm axial length and cone angles vary from 0.1 to 1 degree;
- Low stress metrology mounts that can hold very thin optics without introducing mounting distortion;
- Low normal force figuring/polishing systems operating in the 1 mm to 50 mm period range with minimal impact at significantly smaller and larger period ranges;
- In situ metrology systems that can measure optics and provide feedback to figuring/polishing instruments without removing the part from the spindle;
- Innovative mirror substrate materials or manufacturing methods that produce thin mirror substrates that are stiffer and/or lighter than existing materials or methods;
- Extreme aspheric and/or anamorphic optics for pupil intensity amplitude apodization (PIAA).

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

Spacecraft and Platform Subsystems Topic S3

The Science Mission Directorate will carry out the scientific exploration of our Earth, the planets, moons, comets, and asteroids of our Solar System and beyond; chart the best route of discovery; and reap the benefits of Earth and space exploration for society. A major objective of the NASA science spacecraft systems development programs is to implement science measurement capabilities using small, affordable spacecraft enabling a single spacecraft to meet multiple mission requirements thus making the best use of our limited resources. To accomplish this objective, NASA is fostering innovations in propulsion, power, and guidance and navigation systems (including advanced avionics for low cost small spacecraft and technology) that significantly reduce the mass and cost while maximizing the scientific return for future NASA missions. Innovations are sought in the areas of power generation, energy storage, guidance, navigation, command/control, on-board propulsion (electric propulsion, advanced chemical and propellantless propulsion), propulsion technologies related to sample return missions, and on-board power management and distribution (power electronics and packaging). Also sought for NASA Science Missions are thermal control technologies for spacecraft, piloted and unpiloted aircraft, and terrestrial and planetary balloons.
Sub Topics:

S3.01 Avionics and Electronics

Lead Center: GSFC

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

NASA's space based observatories, fly by spacecraft, orbiters, landers, and robotic and sample return missions, require robust command and control capabilities. Advances in technologies relevant to guidance, navigation, command and data handling are sought to support NASA's goals and several missions and projects under development (http://nasascience.nasa.gov/search?SearchableText=missions+under+development [45], http://www.nap.edu/catalog.php?record_id=10432 [46]).

The subtopic goals are to: (1) develop high-performance processors and memory architectures and reliable electronic systems, (2) develop an avionics architecture that is flexible, scalable, extensible, adaptable, and reusable, (3) develop precision line-of-sight sensing for large telescopes and spacecraft formations, and (4) mass and technology improvements in guidance, navigation and control for low cost small spacecraft use. The subtopic objective is to elicit novel architectural concepts and component technologies that are realistic and operate effectively and credibly in environments consistent with the future vision of the Science Mission Directorate.

Successful proposal concepts will significantly exceed the present state-of-the-art. Proposals will clearly (1) state what the product is; (2) describe how it targets the technical priorities listed below; and (3) outline the feasibility of the technical and programmatic approach. If a Phase 2 proposal is awarded, the combined Phase 1 and Phase 2 developments shall produce a prototype that is testable by NASA. The technology priorities sought are listed below.

Command and Data Handling

- Processors - General purpose (processor chips and radiation-hardened by design synthesizable IP cores) and special purpose single-chip components (DSPs) with sustainable processing performance and power efficiency (>500 MIPS at >100 MIPS/W for general purpose processing platforms, >5 GMACs at >5 GMACS/W for computationally-intensive processing platforms), and tolerance to total dose and single-event radiation effects. Concepts must include tools required to support an integrated hardware/software development flow.
- Radiation-hardened non-volatile low power memories and Ethernet physical layer components.
- Tunable, scalable, reconfigurable, adaptive fault-tolerant avionics.

Guidance, Navigation and Control

- Navigation systems (including multiple sensors and algorithms/estimators, possibly based on existing component technologies) that work collectively on multiple vehicles to enable inertial alignment of the formation of vehicles (i.e., pointing of the line-of-sight defined by fixed points on the vehicles) on the level of milli-arcseconds relative to the background star field.
- Light-weight sensors (gyroscopic or other approach) to enable milli-arcsecond class pointing measurement for individual large telescopes and low cost small spacecraft.
- Isolated pointing and tracking platforms (pointing 0.5 arcseconds, jitter to 5 milli-arcsecond), targeted to placing a scientific instrument on GEO communication satellites that can track the sun for > 3 hours/day.
- Working prototypes of GN&C actuators (e.g., reaction or momentum wheels) that advance mass and technology improvements for small spacecraft use. Such technologies may include such non-contact approaches such as magnetic or gas. Superconducting materials, driven by temperature conditioning may also be appropriate provided that the net power used to drive and condition the "frictionless" wheels is comparable to traditional approaches.

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

The Small Spacecraft Build effort highlighted in Topic S4 (Low-cost Small Spacecraft and Technologies) of the solicitation participates in this subtopic. Offerors are encouraged to take this in consideration as a possible flight opportunity when proposing work to this subtopic.

S3.02 Thermal Control Systems

Lead Center: GSFC

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

Future Spacecraft and instruments for NASA's Science Mission Directorate will require increasingly sophisticated thermal control technology (http://nasascience.nasa.gov/search?SearchableText=missions+under+development [45], http://www.nap.edu/catalog.php?record_id=10432 [46]). Some of these requirements include:

- Optical systems, lasers (ICESAT 2), and detectors which require tight temperature control, often to better than +/- 1°C. Some new missions such as CON-X and LISA, and upcoming Earth Science missions require thermal gradients held to even tighter micro-degree levels.
- Exploration science missions to the Moon and Mars present engineering challenges requiring systems which are more self-sufficient and reliable.
- The introduction of low-cost, small, rapidly configured spacecraft as described in Topic S4 requires the development of new thermal technologies to reduce the time and costs typically required for analysis, design, integration, and testing of the spacecraft. The Small Spacecraft Build effort highlighted in Topic S4 (Low-cost Small Spacecraft and Technologies) participates in this subtopic and offerors are encouraged to take this in consideration as a possible flight opportunity when proposing work to this subtopic.

Innovative proposals for the cross-cutting thermal control discipline are sought in the following areas:

- Methods of precise temperature measurement and control to tight temperature levels.
- High conductivity, vacuum-compatible interface materials to minimize losses across make/break interfaces.
- High conductivity materials to minimize temperature gradients and provide high efficiency light-weight radiators, including interfaces to heat pipes and fluid loops that overcomes issues with CTE mismatch.
- Advanced more efficient thermoelectric coolers capable of providing cooling at ambient and cryogenic temperatures.
- Advanced thermal control coatings or process technologies including variable emittance surfaces applicable

to small spacecraft.
- Single and two-phase mechanically pumped fluid loop systems which accommodate multiple heat sources and sinks, and long life, lightweight pumps for these systems. Also includes advanced fluid system components such as accumulators, valves, pumps, flow rate sensors, etc. optimized for improved reliability, long life, and low resource needs.
- Efficient, lightweight, oil-less, high lift vapor compression systems for cooling up to 2 KW.
- Advanced thermal modeling techniques that can be easily integrated into existing codes, emphasizing inclusion of two-phase systems and mechanically pumped system models.
- Integration of standardized formats into existing codes for the representation and exchange of Thermal Network Models and Thermal Geometric Models and results.

Research should be conducted to demonstrate technical feasibility during Phase 1 and show a path toward a Phase 2 hardware and software demonstration. Phase 2 should deliver a demonstration unit or software package for NASA testing at the completion of the Phase 2 contract.

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

S3.03 Power Generation and Storage

Lead Center: GRC

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

Future NASA science missions will employ Earth orbiting spacecraft, planetary spacecraft, balloons, aircraft, surface assets, and marine craft as observation platforms.

(http://nasascience.nasa.gov/search?SearchableText=missions+under+development [45], http://www.nap.edu/catalog.php?record_id=10432 [46])

Proposals are solicited to develop advanced power conversion, energy storage, and power electronics to enable or enhance the capabilities of future science missions. The requirements for the power systems for these missions are varied and include long life capability, high reliability, significantly lower mass and volume, higher mass specific power, and improved efficiency over the state of practice (SOP) components/systems. Other desired capabilities are high radiation tolerance, and ability to operate in extreme environments (high and low temperatures and over wide temperature ranges).

Advanced Photovoltaic Energy Conversion

Photovoltaic cell, blanket, and array technologies that lead to significant improvements in overall solar array performance (i.e. efficiency (>30%), mass specific power (>300W/kg), decreased stowed volume, reduced initial and recurring cost, long-term operation in high radiation environments, high power arrays, and a wide range of space environmental operating conditions):

- Photovoltaic cell and blanket technologies capable of low intensity, low-temperature (LILT) operation applicable to the Outer Planets Mission;
- Photovoltaic cell, blanket and array technologies for high intensity high-temperature operation applicable to the Solar Probe mission;
- Thermophotovoltaic technologies applicable to the Outer Planets Mission;
- Component technologies of interest include advanced solar cell designs, space-durable coatings, designs capable of high voltage operation within the space environment, and technologies that reduce fabrication/testing costs while maintaining high reliability;

- Array technologies of interest include concentrators, large reliably-deployable arrays, ultra-lightweight arrays for use with flexible, lightweight cells. Of particular interest are lightweight array technologies that are electrostatically-clean and can operate at voltages up to 1000 volts, enabling direct drive electric propulsion for deep space missions.

Stirling Power Conversion

Novel methods or approaches for radiation-tolerant, sensorless, autonomous control of the Stirling converters with very low vibration and having low mass, size, and electromagnetic interference (EMI). Other technologies of interest include:

- High-temperature, high-performance regenerators;
- High-temperature, lightweight, high-efficiency, low EMI, linear alternators;
- High-temperature heater heads (> 850°C) and joining techniques and regenerators applicable to Venus surface missions (~1200°C);
- Combined electrical power generation and cooling systems applicable to Venus surface missions (~1200°C).

Energy Storage

Future science missions will require lithium-based or other advanced rechargeable electrochemical battery systems that offer greater than 40,000 charge/discharge cycles (7 year operating life) for low-Earth-orbiting (LEO) spacecraft, 20 year life for geosynchronous (GEO) spacecraft, and as low as -80°C storage and operation temperatures for planetary missions. Energy storage technologies that enable one or more of the above requirements combined with very high specific energy and energy density are of interest.

Power Management and Distribution

Advanced electrical power technologies are required for the electrical components and systems on future platforms to address the size, mass, efficiency, capacity, durability, and reliability requirements. In addition to the above requirements, proposals must address the expected improvements in energy density, speed, efficiency, or wide-temperature operation (-125°C to 200°C) with a high number of thermal cycles. Advancements are sought in power electronic devices, components, and packaging. Technologies of interest include:

- Power electronic components and subsystems;
- Power distribution;
- Fault protection;
- Advanced electronic packaging for thermal control and electromagnetic shielding.

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

S3.04 Propulsion Systems

Lead Center: GRC

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

The Science Mission Directorate (SMD) needs spacecraft with ever-increasing propulsive performance and flexibility for ambitious missions requiring high duty cycles and years of operation. Planetary spacecraft need the ability to rendezvous with, orbit, and conduct in situ exploration of planets, satellites and other solar system bodies

(http://www.nap.edu/catalog.php?record_id=10432 [46]). Platforms, satellites, and satellite constellations have high-precision propulsion requirements, usually in volume- and power-limited envelopes. This subtopic seeks innovations to meet SMD propulsion requirements, reflecting the goals of NASA's In-Space Propulsion Technology program to reduce the travel time, mass, and cost of SMD spacecraft. Propulsion areas include chemical and electric propulsion systems, propulsion technologies related to sample return missions to asteroids, comets, and other small bodies, propellantless options (such as aerocapture and solar sails), and less developed but emerging propulsion concepts such as advanced plasma thrusters and momentum exchange/electrodynamic reboost (MXER) tethers.

Specific sample return propulsion technologies include, but are not limited to, ascent vehicle propulsion, pumps for pressure-fed propulsion systems, long-term storage capable solid rocket propulsion technologies, lightweight propulsion components, Earth-return propulsion systems, Earth-EDL systems, and Earth Entry Vehicle heat shield materials.

This subtopic also seeks proposals that explore uses of technologies that will provide superior performance in attitude control and overall orbit control. The Small Spacecraft Build effort highlighted in Topic S4 (Low-cost Small Spacecraft and Technologies) of the solicitation participates in this subtopic. Offerors are encouraged to consider this possible flight opportunity when proposing work to this subtopic.

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

S3.05 Balloon Technology, Terrestrial and Planetary

Lead Center: GSFC

Participating Center(s): JPL

Innovations to advance terrestrial (http://sites.wff.nasa.gov/code820/ [47]) and planetary balloons and aerobots are being solicited. The technologies proposed shall have a clear path for infusion into the current flight systems within the next few years.

Currently, NASA is developing a superpressure terrestrial vehicle targeting 100 day duration missions in mid-latitude. This added capability will greatly enable new science investigations. The design of the current pumpkin shape vehicle utilizes light weight polyethylene film and high strength tendons made of twisted Zylon® yarn. The in-flight performance and health of the vehicle relies on accurate information on a number of environmental and design parameters. Therefore, NASA is seeking innovations in the following specific areas:

Devices or methods to accurately and continuously measure individual axial loading on an array of up to 200 separate tendons during a superpressure balloon mission. Tendons are the load carrying member in the pumpkin design. During a typical mission, loading on individual tendons should not exceed a critical design limit to insure structural integrity and survival. Tendons are typically captured at the fitting via individual pins. Loading levels on the tendons can range from ~20 N to ~8,000 N and temperature can vary from room temperature to the troposphere temperatures of -90°C or colder. The devices of interest shall be easily integrated with the tendons or fittings during balloon fabrication and shall have minimal impact on the overall mass of the balloon system. Support telemetry and instrumentation is not part of the this initiative; however, data from any sensors (devices) that are selected from this initiative must be able to be telemetered in-flight using single-channel (two-wire) interface into existing NASA balloon flight support systems.

Devices or methods to accurately and continuously measure ambient air, helium gas, and balloon film temperature. The measurements are needed to accurately model the balloon performance during a typical flight at altitudes of approximately 120,000 feet. The measurement must compensate for the effects of direct solar radiation through shielding or calculation. Minimal mass and volume are highly desired. For film measurement, 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 measurement of helium gas and balloon film temperature must be compatible with existing NASA balloon packaging, inflation and launch methods. Devices and/or methods must be able to interface with existing NASA balloon flight support systems or alternatively, a definition of a telemetry solution be provided.

Innovations in materials, structures, and systems concepts have also enabled buoyant vehicles to play an expanding role in planning NASA's future Solar System Exploration Program. Balloons and airships are expected to carry scientific payloads on Mars, Venus, and Titan in order to investigate their atmospheres in situ and their surfaces from close proximity. Their envelopes will be subject to extreme environments and must support missions with a range of durations. Proposals are sought in the following areas:

Metal Balloons for High Temperature Venus Exploration

Balloons made of metals are a potential solution to the problem of enabling long duration flight in the hot lower atmosphere of Venus. Proposals are sought for metal balloon concepts and prototypes that provide 1-5 m^3 of fully inflated volume, areal densities of 1 kg/m^2 or less, sulfuric acid compatibility at 85% concentration, and operation at 460 °C for a period of up to 1 year. (http://newfrontiers.nasa.gov/program_plan.html [48])

Cryogenic Testing of Titan Aerobots (http://www.nap.edu/catalog.php?record_id=10432 [46])

Aerobots at Titan must operate at cryogenic temperatures in the range of 85 to 95 K. There is a need for inexpensive test facilities to conduct experiments on sub-scale and full scale prototype balloons ranging in size from 1 to 15 m in their largest dimension. Proposals are sought for the development and validation of innovative, low cost test facilities that can be used to conduct light gas and Montgolfiere balloon experiments with time scales ranging from hours to weeks.

Gas Management Systems for Titan Aerobots

Hydrogen-filled aerobots at Titan must contend with the problem of gas leakage over long duration (1 year or more) flights. Proposals are sought for the development and testing of two kinds of prototype devices that can be carried on the aerobot to compensate for these gas leakage problems: one device is to produce make-up hydrogen gas from atmospheric methane; the other device is to remove atmospheric gas (mostly nitrogen) that leaks from the ballonets into the hydrogen-filled blimp. Both kinds of devices will need to operate on no more than 15 W of electrical power each while compensating for a leakage rate of at least 40 g/week of hydrogen or 500 g/week of nitrogen.

Ground-launched Mars Balloons

NASA is interested in small balloons with very light payloads (< 1 kg) that can be autonomously launched on the Martian surface from a lander or large rover. Proposals are sought for balloon designs and systems concepts to enable this. It is important that proposals directly address the difficult problem of not damaging the balloon despite proximity to landed equipment and surface rocks. Preference will be given to proposals that include proof-of-concept experiments addressing key feasibility questions for the proposed approach.

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

Low-cost Small Spacecraft and Technologies Topic S4

The Low-Cost Small Spacecraft and Technologies Topic focuses on the technologies, subsystems, methodologies, and mission concepts for space missions which lower the over-all cost for scientific exploration. The "Small" of spacecraft and missions refers to small spacecraft that have "wet" masses below 500 Kg. (compared to micro satellites 10-100kg, nano satellite 1-10kg, or pico satellite <1kg), are substantially less expensive, and will require different approaches to solve traditional problems in development, operations and capability. The goal of these low-cost missions is not to replace the major missions, but rather to reduce the risks to, as well as the costs of, future major missions. Low-Cost Small Spacecraft and Technologies Missions will be used as test beds for new technologies, provide flight "heritage" for new instruments and components. Increasing the number of flight opportunities per year enables missions to be designed and flown during typical graduate and post-doctoral tenures, provide training for a new generation of scientists and engineers. These small spacecraft missions can also accomplish specific scientific investigations that would be too narrow for a major mission but still scientifically important. This topic is divided into two categories of subtopics: Small Spacecraft Technologies and Enablers and Small Spacecraft Build.

Small Spacecraft Technologies and Enablers: These subtopics will lower the barrier to entry for small spacecraft missions by encouraging launch opportunities and creating open design and spacecraft management tools. These subtopics include: 1. Nanosat launch vehicles and technologies, 2. Rapid End-to-end Mission Design and Simulation 3. Cost modeling.

Small Spacecraft Build: When used together, SBIR subtopics could create a small spacecraft mission. The subtopics required to accomplish this effort extend beyond the Low-cost Small Spacecraft and Technologies topic, and definition for such an effort is in progress (see 2.0, Mission Concept). In FY08, there will be multiple subtopics across the topic portfolio participating toward this mission concept.

Mission Concept: NASA announced a mission concept at a Mission Concept Review (MCR) held February 8, 2008. The spacecraft is a modular spacecraft that operates using standard protocols (high speed: Ethernet, SpacewireTM; low speed: RS-422, I2C) and at 28V +/- 6V. With this modularity, a requirement for the Low-Cost Small Spacecraft and Technologies, components can be interchanged from a basic spacecraft design to tailor for specific missions.

The Low-Cost Small Spacecraft and Technologies topic will invite to subsequent reviews those awardees current at the time of the review; review titles and respective tentative dates follow: a) System Requirements Review (SRR), tentatively August 2008; b) Mission Definition Review (MDR), tentatively November 2008; c) Preliminary Design Review (PDR), tentatively August 2009; Critical Design Review (CDR), tentatively September 2010. NASA intends to make SBIR Phase 1 and Phase 2 awards to this effort, which NASA understands are a best effort by the SBIR awardees and NASA alike. By 1QFY11, all Phase 2 and Phase 3 SBIR teams are encouraged to deliver to NASA the hardware to be integrated and ready for launch in 4QFY11. The Low-Cost Small Spacecraft and Technologies topic is envisioned to launch one satellite per year or every other year, starting in FY11, kicking off a new team at each cycle. NASA cannot direct SBIR awardees to conform to the provisional schedule outlined above, however when brought together this could create the opportunity for a spacecraft build. This topic will give significant priority to offerors that take full advantage of standard interfaces, protocols, methodologies, open source software and Commercial off the Shelf (COTS)-derivative hardware.

Sub Topics:

S4.01 NanoSat Launch Vehicle Technologies

Lead Center: ARC

The space transportation industry is in need of low-cost, reliable, on-demand, routine space access. Both government and private entities are pursuing various launch systems and architectures aimed at addressing this market need. Significant technical risk and cost exists in new system development and operations - reducing incentive for private capital investment in this still-nascent industry. Public and private sector goals are aligned in reducing these risks and enabling the development of launch systems capable of reliably delivering payloads to low Earth orbit. The NanoSat Launch Vehicle Technology subtopic will particularly focus on higher risk entrepreneurial projects for dedicated nano and small spacecraft launch vehicles. This subtopic is seeking proposals in the

following, but not limited, areas:

- Conceptual designs of system/architectures capable of reducing the mission costs associated with small payload delivery to LEO.
- Maturation of hypersonic and small launch vehicle design and analysis tools or tool-sets aimed at increasing the state-of-the-art while reducing the required design cycle time and human interaction.
- Maturation of key technologies/processes for hypersonic and small launch vehicles including, but not limited to:
    - Thermal protection systems;
    - Airframe and subsystem structures that increase system performance and propellant mass fraction;
    - Vehicle sensor networks.
- Novel, low-cost modular adapters and release mechanisms.
- Lightweight interstage designs.

Applications of wireless networking technologies for small launch vehicles are also specifically of interest to this subtopic. This technology could be used for vehicle to ground communications (spread-spectrum and non-licensed technologies), as well as within the vehicle itself. We desire new architectures for intelligent on-board communications as well as satellite-to-satellite communication using machine-to-machine (M2M) solutions. The traditional wire harness architecture could be replaced by the wireless technology for command and control, which would reduce vehicle mass and improve reliability. Also stage-to-stage interfaces and vehicle-payload interfaces are of interest. These wireless technologies can include but are not limited to WIMAXTM and ZIGBEETM.

Non-propulsive approaches and architectures for new launch vehicles can also achieve increases in launch vehicle payload mass delivered to orbit for small spacecraft missions. Offerors should consider development, test, and operational factors to show improvements in development and operational costs, payload mass fraction, and mission assurance. Special attention should be given to improved integration between the launch vehicle and payloads to further reduce operational costs. Furthermore, non-propulsive launch vehicle technologies have a dramatic impact on launch vehicle performance and constitute a large percentage of development and operational costs.

They include, but are not limited to:

- Robust on-board Guidance, Navigation and Control (GN&C) avionics. GN&C should be modular (including modular software architectures) and make use of modern architectures, including high-performance low-weight avionics hardware, and modern software tools. Emphasis is on low-weight architecture to allow maximum payload capacity.
- Range safety solutions and operational concepts to lower costs. These may include alternative solutions to expensive explosive destruct packages, including, but not limited to propulsion-cutoff systems, autonomous flight-abort systems, etc.

Research should be conducted to demonstrate technical feasibility during Phase 1 and show a path toward a Phase 2 hardware and software demonstration, and when possible, deliver a demonstration unit or software package for NASA testing at the completion of the Phase 2 contract.

Phase 2 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 space-worthy systems.

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

S4.02 Rapid End-to-End Mission Design and Simulation

Lead Center: ARC

Participating Center(s): GSFC

This subtopic addresses the need to rapidly and efficiently analyze, design, simulate, and evaluate competing mission concepts.

The traditional mission design process involves multiple tools and trades, resulting in design data being generated and stored in various proprietary formats, making iterative trades cumbersome. Current mission design and simulation environments require dedicated personnel that execute mission simulations for mission projects, but at a significant cost to project budgets. For efficient mission design and simulation activities, particularly for small satellites and other missions with small budgets and cost margins, there is a need for user-friendly tools that will provide seamless data flow between simulation environments with little overhead.

This subtopic seeks proposals for a toolset that shall integrate legacy engineering software with user-generated design and simulation tools into a single, user-friendly environment. The toolset shall automate the flow of data between analysis, design, and simulation applications with minimal user manipulation. The data shall also be preserved through the various design phases from initial concept to execution.

Data resources to be linked include cost tracking spreadsheets, task plans, risk management databases, requirements databases, technical performance metrics and margins sheets, top level and WBS element schedules, and standard monthly status reports from WBS elements. The tool should be easily scalable for large or small projects and the number of WBS elements and features included or excluded for a given project should be user-selectable. User and group permission and access controls are required.

Research should be conducted to demonstrate technical feasibility during Phase 1 and show a path toward a Phase 2 hardware and software demonstration, and when possible, deliver a demonstration application for NASA testing at the completion of the Phase 2 contract.

Phase 2 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.

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

S4.03 Cost Modeling

Lead Center: ARC

Participating Center(s): GSFC, JPL

An integrated cost-design model is required, one that incorporates the regression analysis and statistical validity of historical parametric cost models with the flexibility and relevance of a ground-up, or grassroots, cost model. By explicitly focusing on the prime cost determinant, labor, as opposed to the spacecraft parameters, and determining the historic relationships between the tasks on the WBS and cost for a given institution/firm, as opposed to space industry in general, a cost model can be produced that is specific to the production process used by an institution. Such a cost model would predict the cost of individual tasks at sub-system and component levels within a given institution, enabling cost to be included as an endogenously determined variable in the design process.

Such an integrated cost-design model is currently embodied only as human capital in individual managers who have, through their personal experience, accumulated knowledge of cost-design relationships. When these experienced managers leave, the institution loses the understanding of the relationship between cost and design choices that the manager had built up through years of experience. Without this experience, ground-up cost models can be wildly inaccurate and as a result, only parametric cost models such as the NASA/Air Force Cost Model (NAFCOM) and the Small Satellite Cost Model (SSCM) are accepted for Technical Management and Cost (TMC) reviews. This is particularly problematic for small low-cost spacecraft where designs are rapidly evolving, management structures are more varied, and the entire purpose is to provide spacecraft at costs lower than what has historically been considered possible.

This subtopic seeks proposals to define management system requirements and develop software that would enable cost (and schedule) data at the task-level to be collected and centralized creating a base dataset for institution-based cost models and cost management research. The system would codify cost information of projects ensuring it is preserved beyond the careers of individual managers and would, over time, accumulate long time-series of task-level cost information that would enable ground-up institution-based cost models to stand on a rigorous statistical framework. This would enable the development of a generic institution-based design-cost model that can then be tailored for individual institutions and used across the industry.

Research should be conducted to demonstrate technical feasibility during Phase 1 and show a path toward a Phase 2 hardware and software demonstration, and when possible, deliver a demonstration unit or software package for NASA testing at the completion of the Phase 2 contract.

In Phase 1, research should provide examples of proven cost benefits and project successes based on the use of integrated management tools for management of multiple simultaneous distributed projects. Architectures should be proposed for implementation of an integrated multi-project management tool.

In Phase 2, a management tool set will be implemented and demonstrated as part of an actual small satellite management project. The tool will be evaluated for ease of use, effectiveness as a NASA project set-up tool, management information tool, and reporting tool. Feasibility for a single manager to effectively manage and report on multiple simultaneous projects will be assessed. Project users from the WBS elements of the satellite project will evaluate ease of use of uploading data.

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

S4.04 Reusable Flight Software

Lead Center: ARC

Participating Center(s): GSFC

There is a need to rapidly develop and deploy small satellites and easily adapt new payloads in a cost effective manner. The cost of flight software, including algorithms and data management, is continuing to increase and multiply in complexity.

Spacecraft software applications are typically customized, however, development costs can be driven down and a plug-and-play capability can be fostered through repeated use of reusable software and functional libraries that are developed once and updated only to enhance performance or correct deficiencies.

Small satellites can be effectively designed for multiple uses of the same nominal hardware set to perform multiple missions. Interfaces between differing payloads are anticipated to be "plug-and-play", where the interface between hardware elements is transparent across the interface. This implies that and allows the software to be reusable from mission to mission. An analogy would be a reusable core executive operating system that controls central satellite functions. Each payload or special hardware element will have subservient applications, written by the element developed that provides special needs. In order to be most economical, the subservient applications should be capable of utilizing an extensive library of modules.

This subtopic calls for the definition and development of a common core executive software and library modules that can be utilized repeatedly for many small satellite missions. The software shall be portable between several types of core processors. The executive and libraries shall provide robust functionality, based on open standards that can be utilized by specialized payload and component developers. In this manner, a minimum amount of custom software, limited to basic functional control of certain hardware elements, will be required. Library functions within the reusable core executive shall be capable of performing computation intense work. The intent is to not modify the reusable core executive except as experience dictates from previous missions.

The Reusable Flight Software subtopic encourages offerors to utilize open source software and hardware solutions to be utilized for other actors, including entrepreneurial and university teams, for reusability.

Research should be conducted to demonstrate technical feasibility during Phase 1 and show a path toward a Phase 2 hardware and software demonstration, and when possible, deliver a demonstration unit or software package for NASA testing at the completion of the Phase 2 contract.

Phase 2 emphasis should be placed on developing and demonstrating the software technology under relevant test conditions. Additionally, a path should be outlined that shows how the technology could be commercialized or further developed into space-worthy systems.

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

Robotic Exploration Technologies Topic S5
NASA is pursuing technologies to enable robotic exploration of the Solar System including its planets, their moons, and small bodies. NASA has a development program that includes technologies for the atmospheric entry, descent,

and landing, mobility systems, extreme environments technology, sample acquisition and preparation for in situ experiments, and in situ planetary science instruments. Robotic exploration missions that are planned include a Europa Jupiter System mission, Titan Saturn System mission, Venus In Situ Explorer, sample return from Comet or Asteroid and lunar south polar basin and continued Mars exploration missions launching every 26 months including a network lander mission, an Astrobiology Field Laboratory, a Mars Sample Return mission and other rover missions. Numerous new technologies will be required to enable such ambitious missions. The solicitation for in situ planetary instruments can be found in the in situ instruments section of this solicitation. See URL: http://solarsystem.nasa.gov/missions/index.cfm [49] for mission information. See URL: http://marstech.jpl.nasa.gov/ [50] for additional information on Mars Exploration technologies.
Sub Topics:

S5.01 Planetary Entry, Descent, Ascent, Rendezvous and Landing Technology

Lead Center: JPL

Participating Center(s): ARC, JSC, LaRC

NASA seeks innovative sensor technologies to enhance success for entry, descent and landing (EDL) operations on missions to Mars. This call is not for sensor processing algorithms. Sensing technologies are desired which determine the entry point of the spacecraft in the Mars atmosphere; provide inputs to systems that control spacecraft trajectory, speed, and orientation to the surface; locate the spacecraft relative to the Martian surface; evaluate potential hazards at the landing site; and determine when the spacecraft has touched down. Appropriate sensing technologies for this topic should provide measurements of physical forces or properties that support some aspect of EDL operations. NASA also seeks to use measurements made during EDL to better characterize the Martian atmosphere, providing data for improving atmospheric modeling for future landers. Proposals are invited for innovative sensor technologies that improve the reliability of EDL operations.

Products or technologies are sought that can be made compatible with the environmental conditions of spaceflight and the rigors of landing on the Martian surface. Successful candidate sensor technologies can address this call by:

- Providing critical measurements during the entry phase (e.g., pressure and/or temperature sensors embedded into the aeroshell);
- Improving the accuracy on measurements needed for guidance decisions (e.g., surface relative velocities, altitudes, orientation, localization);
- Extending the range over which such measurements are collected (e.g., providing a method of imaging through the aeroshell, or terrain-relative navigation that does not require imaging through the aeroshell);
- Enhancing the situational awareness during landing by identifying hazards (rocks, craters, slopes), or providing indications of approach velocities and touchdown;
- Substantially reducing the amount of external processing needed to calculate the measurements; and
- Significantly reducing the impact of incorporating such sensors on the spacecraft in terms of volume, mass, placement, or cost.

For a sample return mission, rendezvous technologies for capture of an Orbiting Sample (OS) with the return spacecraft:

- Remotely actuated mechanisms for automated OS capture;
- Optical and contact sensors.

For a sample return mission, monitoring local environmental (weather) conditions on the surface just prior to Planetary Ascent Vehicle (PAV) launch, via appropriate low-mass sensors.

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

S5.02 Sample Collection, Processing, and Handling

Lead Center: JPL

Participating Center(s): ARC, GSFC, JSC

Robust systems for sample acquisition, handling and processing are critical to the next generation of robotic explorers for investigation of planetary bodies (http://books.nap.edu/openbook.php?record_id=10432&page=R1 [51]). Limited spacecraft resources (power, volume, mass, computational capabilities, and telemetry bandwidth) demand innovative, integrated sampling systems that can survive and operate in challenging environments (extremes in temperature, pressure, gravity, vibration and thermal cycling). Relevant systems could be integrated on multiple platforms, however of primary interest are samplers that could be mounted on a mobile platform, such as a rover. For reference, current Mars-relevant rovers range in mass from 200 – 800 kg.

Sample Acquisition

Research should be conducted to develop compact, low-power, lightweight subsurface sampling systems that can obtain 1 cm diameter cores of consolidated material (e.g., rock, icy regolith) up to 10 cm below the surface. Systems should be capable of autonomously acquiring and ejecting samples reliably. Other sample types of interest are unconsolidated regolith, dust, and atmospheric gas.

Sample Manipulation (core management, sub-sampling/sorting)

Sample manipulation technologies are needed to enable handling and transfer of structured and unstructured samples from a sampling device to instruments and sample processing systems. Core and regolith samples may be variable in size and composition, so a sample manipulation system needs to be flexible enough to handle the sample variability. Core samples will be on the order of 1 cm diameter and up to 10 cm long. Soil and rock fragment samples will be of similar volumes.

System Robustness and Reliability

Consideration should be given to potential failure scenarios for integrated systems. For example, recovery and mitigation techniques for platform slip and borehole misalignment should be addressed. Significant attention should be given to the sensing and automation required for real-time control, fault diagnosis and recovery. In the case of rover-mounted subsurface sampling systems, the ability to release under load will be critical to mitigate risk of losing mobility if unexpected subsurface conditions are encountered.

Sample Integrity (encapsulation and contamination)

For a sample return mission, it is critical to find solutions for maintaining physical integrity of the sample during the surface mission (rover driving loads, diurnal temperature fluctuations) as well as the return to Earth (cruise, atmospheric entry and impact). Technologies are needed for characterizing state of sample in situ – physical integrity (e.g., cracked, crushed), sample volume, mass or temperature, as well as retention of volatiles in solid (core, regolith) samples, and retention of atmospheric gas samples.

Also of particular need are means of acquiring subsurface rock and regolith samples with minimum contamination. This contamination may include contaminants in the sampling tool itself, material from one location contaminating samples collected at another location (sample cross-contamination), or Earth-source microorganisms brought to the Martian surface prior to drilling ('clean' sampling from a 'dirty' surface). Consideration should be given to use of materials and processes compatible with 110-125°C dry heat sterilization. In situ sterilization may be explored, as well as innovative mechanical or system solutions – e.g., single-use sample "sleeves," or fully-integrated sample acquisition and encapsulation systems.

For a sample return mission, sample transfer of a payload into a Planetary Ascent Vehicle (PAV)

- Automated payload transfer mechanisms;

- Orbiting Sample (OS) sealing techniques.

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

S5.03 Surface and Subsurface Robotic Exploration

Lead Center: JPL

Participating Center(s): ARC, GSFC, JSC

Technologies are needed to enable access and sample acquisition at surface and subsurface sampling sites of scientific interest on Mars (http://books.nap.edu/openbook.php?record_id=10432&page=R1 [51]). Mobility technology is needed to enable access to difficult-to-reach sites such as access through steep terrain. Many scientifically valuable sites are accessible only via terrain that is too steep for state-of-the-art planetary rovers to traverse. Sites include crater walls, canyons, and gullies. Tethered systems, non-wheeled systems, and marsupial systems are examples of mobility technologies that are of interest. Tether technology could enable new approaches for deployment, retrieval and mobility. Innovative marsupial systems could allow a pair of vehicles with different mobility characteristics to collaborate to enable access to challenging terrain. Single vehicle systems might utilize a 200 kg class rover and dual vehicle systems might utilize a 500-800 kg primary vehicle that provides long traverse to the vicinity of a challenging site and then deployment of a smaller 20-50 kg vehicle with steep mobility capability for access and sampling at the site.

Technologies to enable acquisition of subsurface samples are also needed. Technologies are needed to acquire core samples in the shallow subsurface to about 10cm and to enable subsurface sampling in multiple holes at least 1 - 3 meters deep through rock, regolith or ice compositions. Shallow subsurface sampling systems need to be low mass and deeper subsurface sampling solutions need to be integratable onto 500-800 kg stationary landers and mobile platforms. Consideration should be given for potential failure scenarios, such as platform slip and borehole misalignment for integrated systems, and the challenges of dry drilling into mixed media including icy mixtures of rock and regolith. Systems should ensure minimal contamination of samples from Earth-source contaminants and cross-contamination from samples at different locations or depths.

Innovative low-mass, low-power, and modular systems and subsystems are of particular interest. Technical feasibility should be demonstrated during Phase 1 and a full capability unit of at least TRL level 4-6 should be delivered in Phase 2. Specific areas of interest include the following:

- Tether play-out and retrieval systems including tension and length sensing;
- Low-mass tether cables with power and communication;
- Steep terrain adherence for vertical and horizontal mobility;
- Modular actuators with 1000:1 scale gear ratios;
- Electro-mechanical couplers to enable change out of instruments on an arm end-effector;
- Drill, core, and boring systems for subsurface sampling to 10cm or 1 to 3 meters.

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

S5.04 Technologies for Low Mass Mars Ascent Vehicles (PAV)

Lead Center: JPL

Participating Center(s): AFRC, ARC, MSFC

NASA aims to design, build and test vehicles that will be launched from the surface of other planets and place a payload, Orbiting Sample (OS), into orbit (http://marsprogram.jpl.nasa.gov/missions/future/futureMissions.html [25]). We are seeking proposals for the development of innovative technologies to support future Payload Ascent Vehicles (PAVs) and associated sample operations. Technology innovations should either enhance vehicle capabilities (e.g., increased payload, launch success probability, mission success) or ease implementation in spaceborne missions (e.g., reduce size, weight, power, improve reliability, or lower cost). The areas of interest for this call are listed below.

Alternate propellants, thrusters and propulsion feed system technologies for the PAV:

- Higher performing monopropellants with specific impulse >240 secs;
- High chamber pressure thrusters > 500 psia;
- Pressurization component technologies to reduce system mass (filters, solenoid valves, latch valves, tanks, fill & drain and check valves);
- Small lightweight pump technologies to operate at >500 psi output pressure;
- Non-pyrotechnic isolation valves.

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

Information Technologies Topic S6

Modeling and simulation are being used more pervasively and more effectively throughout NASA, for both engineering and science pursuits, than ever before. These are tools that allow high fidelity simulations of systems in environments that are difficult or impossible to create on Earth, allow removal of humans from experiments in dangerous situations, and provide visualizations of datasets that are extremely large and complicated. Examples of past simulation successes include simulations of entry conditions for man-rated space flight vehicles, visualizations of distant planet topography via simulated fly-over and three-dimensional visualizations of coupled ocean and weather systems. In many of these situations, assimilation of real data into a highly sophisticated physics model is needed. Also use NASA missions and other activities to inspire and motivate the nation's students and teachers, to engage and educate the public, and to advance the scientific and technological capabilities of the nation.
Sub Topics:

S6.01 Technologies for Large-Scale Numerical Simulation

Lead Center: ARC

Participating Center(s): GSFC

NASA scientists and engineers are increasingly turning to large-scale numerical simulation on supercomputers to advance understanding of Earth and astrophysical systems, as well as to conduct high-fidelity engineering analyses (http://nasascience.nasa.gov/earth-science/water-and-energy-

cycle/research/?searchterm=large%20scale%20simulation [52]). The goal of this subtopic is to make NASA's supercomputing systems and associated resources easier to use, thereby broadening NASA's supercomputing user base and increasing user productivity. Specific objectives are to:

- Reduce the learning curve for using supercomputing resources;
- Minimize total time-to-solution (i.e., time to discovery, understanding, or prediction);
- Increase the scale and complexity of computational analysis and data assimilation;
- Accelerate advancement of system models and designs.

The approach of this subtopic is to develop intuitive, high-level tools, interfaces, and environments for users, and to infuse them into NASA supercomputing operations. Successful technology development efforts under this subtopic would be considered for follow-on funding by, and infusion into either of the NASA high-end computing (HEC) projects, including the High End Computing Capability (HECC) project at Ames and the NASA Center for Computational Sciences (NCCS) at Goddard. SBIR projects should be informed by direct interactions with one or both HEC projects. Research should be conducted to demonstrate technical feasibility during Phase 1 and show a path toward a Phase 2 prototype demonstration. Open Source software and open standards are strongly preferred.

Specific areas of interest include:

Application Development Environments

   With the increasing scale and complexity of supercomputers, users must often expend a tremendous effort to translate their physical system model or algorithm into a correct and efficient supercomputer application code. This subtopic element seeks intuitive, high-level application development environments, ideally leveraging high-level programming languages to enable rapid supercomputer application development, even for novice users. This environment should dramatically simplify application development activities such as porting, parallelization, debugging, scaling, performance analysis, and optimization.

Results V&V

   A primary barrier to effective use of supercomputing by novices, and often experts, is understanding the accuracy of their computational results. Errors in the input data, domain definition, grids, algorithms, and application code can individually or in combination produce non-physical results that a user may not detect. This subtopic element seeks tools and environments to help users with verification and validation (V&V) of simulation results. This could be accomplished by enabling comparison of results from similar applications or with known accurate results, access to results analysis tools and domain experts, or access to error estimation tools and training.

Data Analysis and Visualization

   Supercomputing computations almost invariably result in tremendous amounts of data, measuring in the gigabytes or terabytes, and with many dimensions and other complexity aspects. This subtopic element seeks user-friendly tools and environments for analysis and visualization of large-scale, complex data sets typically resulting from supercomputing computations.

Ensemble Management

   Conducting and fusing the results from an ensemble of related computations is an increasingly common use of supercomputers. However, ensemble computing and analysis introduces a new set of challenges for deriving full value from using supercomputing. This subtopic element seeks tools and environments for managing and automating ensemble supercomputing-based simulation, analysis, and discovery. Functions could include managing and automating the computations, model or design optimization, interactive computational steering, input and output data handling, data analysis, visualization, progress monitoring, and completion assurance.

Integrated Environments

   The user interface to a supercomputer is typically a command line or text window, where users may struggle to understand resources and services available, locate or develop applications, understand the job queue structure, develop scripts to submit jobs to the queue, manage input and output files, archive data, monitor resource

allocations, collaborate and share data and codes, and many other essential supercomputing tasks. This subtopic element seeks more intuitive, intelligent, and integrated interfaces to supercomputing resources. This integrated environment could include access to user training (e.g., tutorials, case studies, experts), application development tools, standard (e.g., production, commercial, and Open Source) supercomputing applications, results V&V tools, computing and storage resources, ensemble management tools, workflow management, data analysis and visualization tools, and remote collaboration.

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

S6.02 Sensor and Platform Data Processing & Control

Lead Center: ARC

Participating Center(s): GSFC, JPL

This subtopic seeks proposals for software-based advances in data collection quality and/or coverage of scientific instruments that support NASA Science Mission Directorate objectives across any of the Earth, Solar, Lunar, Space, or Planetary sciences.

Algorithmic based approaches expressed in software or reconfigurable hardware can improve measurement quality and coverage of existing scientific instrument technologies. Software or reconfigurable hardware based computing can enable design trades to reduce cost and or mass of instruments by implementing needed sensor or platform capabilities in software. Limited computing resources can require innovative approaches to specific problems or use of FPGA hardware.

Target platforms or instruments can be designed to fly on any of the broadest range of NASA platforms ranging from airborne (e.g., Aircraft, UAVs and SOFIA), small, micro, and nano-satellites that support current and anticipated NASA science mission to NASA's flagship mission platforms. The Small Spacecraft Build effort highlighted in Topic S4 (Low-cost Small Spacecraft and Technologies) of this solicitation participates in this subtopic. Offerors are encouraged to take this relationship in consideration as a possible flight opportunity when proposing work to this subtopic.

New approaches to software frameworks or APIs are discouraged. Technological advances should leverage or extend existing standards or capabilities within the respective science communities (i.e., Sensor Mark-up Language, Virtual Observatory, Earth Science Federation standards, Planetary data standards). Proposals can develop instrument specific software if demonstrated how the software can improve instrument performance (such as improving sensor calibration and correction of data in a tightly closed loop without human intervention). Other examples would show how on-board data processing enables rapid analysis or data sharing between instruments/platforms (e.g., perform level 0, level 1 or level 2 processing on-board the sensor or platform to support decision making based on data results).

Proposers are encouraged to plan on making contact with existing sensor development or prototype development teams or NASA relevant platform developers to understand the computation services available on the sensor, platform and the information flow expected between the sensor and human controller.

- Novel approaches that can leverage specialized, space qualified computing resources such as FPGAs that return order of magnitude reduction in data volume or screening capabilities are desirable.
- Improvements in measurement quality include system models of specific instruments (developed other SBIR subtopics or elsewhere) that account for more of the underlying instrument physics, improved data calibration and data correction capabilities and instrument "intelligence".
- Improved coverage can be achieved by data compression and/or data prioritization for transmission and closing the collection loop; also by the rapid assessment of data content for re-tasking the platform and sensor as the data are collected.

For data compression, aggressive metrics for compression and data volume have the following requirements:

RADAR Missions	SMAP (RADAR)	DESDynI (RADAR)	SWOT (RADAR)
OBP Input data rate (MHz)	32	400	500
Processor Throughput (GFLOPS)	7	20	90
Data Compression Ratio	80:1	10:1	90:1

Where raw data sample spacing is 0.75 m x 1.5 m (16 bits per sample), and the output data sample spacing is 10 m x 10 m (16 bits per sample).

For Hyper-spectral imaging instruments, here is an exemplar requirement on data compression and on-board feature detection.

Data Rate:	660 gigabits per orbit, 220 megabits per second
Data Compression Ratio:	> 3.0
On-board Detection Capability:	A quick look at the data for presence of cloud cover.

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

S6.03 Data Analyzing and Processing Algorithms

Lead Center: GSFC

Participating Center(s): ARC, MSFC, SSC

This subtopic seeks technical innovation and unique approaches for the processing and the analysis of data from NASA's space and Earth science missions (http://nasascience.nasa.gov/earth-science/atmospheric-composition/research/ [53]). Analysis of NASA science data is used to understand dynamic systems such as the sun, oceans, and Earth's climate as well as to look back in time to explore the origins of the universe. Complex algorithms and intensive data processing are needed to understand and make use of this data. Advances in such algorithms will support science data analysis related to current and future missions and mission concepts such as the Landsat Data Continuity Mission (LDCM) (http://science.hq.nasa.gov/missions/satellite_56.htm [54]), the NPOES Preparatory Project (NPP) (http://science.hq.nasa.gov/missions/satellite_58.htm [55]), the Orbiting Carbon Observatory (OCO) (http://science.hq.nasa.gov/missions/satellite_61.htm [56]), the Lunar Reconnaissance Orbiter (LRO), (http://nssdc.gsfc.nasa.gov/nmc/spacecraftDisplay.do?id=LUNARRO [57]), the Lunar Atmosphere and Dust Environment Explorer (LADEE) satellite (http://nssdc.gsfc.nasa.gov/planetary/ [58]), and the James Webb Space Telescope (JWST) (http://www.jwst.nasa.gov/ [39]).

Research should be conducted to demonstrate technical feasibility during Phase 1 and show a path toward a Phase 2 prototype demonstration. Innovations are sought in data processing and analysis algorithms in the

following areas:

NASA seeks tools that increase the utility of scientific research data, models, simulations, and visualizations. Of particular interest are innovative computational methods that will dramatically increase algorithm efficiency and thus performance of scientific applications such as assimilation/fusion of multiple source data, mining of large data holdings, reduction of telescope data and decision support systems for Lunar and planetary science.

Tools to improve predictive capabilities, to optimize data collection by identifying gaps in real-time, and to derive information through synthesis of data from multiple sources are also needed. The ultimate goal is to increase the value of data collected in terms of scientific discovery and application. Data analysis and processing must relate to advancement of NASA's scientific objectives.

NASA is soliciting proposals for software tools which access, fuse, process, and analyze image and vector data for the purpose of analyzing NASA's space and Earth science mission data. Tools and products might be used for broad public dissemination or for communicating within a narrower scientific community. These tools can be plug-ins or enhancements to existing software or on-line services. They also can be new stand-alone applications or web services, provided that they are compatible with most widely-used computer platforms and exchange information effectively (via standard protocols and file formats) with existing, popular applications. It is highly desirable that the project development leads to software that is infused into NASA programs and projects.

   To promote interoperability, tools shall use industry standard protocols, formats, and APIs, including compliance with the ISO, FDGC, and OGC standards as appropriate.

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

S6.04 Data Management - Storage, Mining and Visualization

Lead Center: GSFC

Participating Center(s): JPL, LaRC

This subtopic focuses on supporting science analysis through innovative approaches for managing and visualizing collections of science data which are extremely large, complicated, and are highly distributed in a networked environment that encompasses large geographic areas. There are specific areas for which proposals are being sought:

Distributed Scientific Collaboration

- Social networking tools that enable high bandwidth scientific collaboration among scientists distributed worldwide in a large number of different organization. These tools should allow scientists to share data and computational resources, allow collaborative visualization of data, promote the development of online communities for sharing thoughts and ideas, and address issues of data and system security.
- Novel software tools for data viewing, real-time data browse that will enable users to 'fly' through the data space to locate specific areas of interest, and general purpose rendering of multivariate geospatial scientific data sets that use geo-rectification, data overlays, data reduction, and data encoding across widely differing data types and formats.
- Novel 3D hardware virtual reality environments for scientific data visualization that make use of 3D presentation techniques that minimize or eliminate the need for special user devices like goggles or helmets.

Distributed Data Management and Access

- Metadata catalog environments to locate very large and diverse science data sets that are distributed over large geographic areas.
- Dynamically configurable high speed access to data distributed and shared over wide area high speed network environments.
- Object based storage systems, file systems, and data management systems that promote the long term preservation of data in a distributed online (i.e. disk based) storage environment, and provide for recovery from system and user errors.

Research should be conducted to demonstrate technical feasibility during Phase 1 and show a path toward a Phase 2 hardware/software demonstration, and when possible, deliver a demonstration unit for functional and environmental testing at the completion of the Phase 2 contract.

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

S6.05 Software as a Service to Large Scale Modeling

Lead Center: GSFC

Participating Center(s): ARC

Currently there are notable obstacles in making NASA's Earth and space science research models useful to new investigators. Much of the software, upwards of hundreds of thousands of lines of code per model, has evolved gradually over the past three decades. At their inceptions the individual numerical models were intricate elements of independent research projects, intended to be mostly internal products rather than tools contributing to a larger, collaborative effort in Earth and space sciences. Hence today when investigators from outside the developers' organizations choose to begin a collaboration, or merely want to use the model for their own benefit, they are often required to adhere to the unfamiliar development environment of the host institution. This environment typically includes the regulation and management of the software repository, the data management system, and the high-end computing platforms. Problems that arise from this type of a work arrangement include:

- IT security policies that restrict certain individuals from obtaining access to Government facilities (especially with providing foreign national graduate students access to the institutional high-end computers that host a particular model);
- Knowledge of running a model residing "in the heads" of support programmers, often too busy to assist outsiders;
- Interface components residing in individuals' directories unknown to others who might take advantage of them;
- User administration practices (userids, passwords, filesystem/data management, other IT security rules) that are specific to one agency's computing center;
- A lack of front-end tools available to other model developers to set up and run collaborative experiments.

The Agency seeks a computational "service layer" to enhance NASA's scientific numerical modeling efforts. The goal is to improve the accessibility of the models to universities and other Government institutions for research and operations. Proposals are sought that develop methods for hosting NASA's Earth and space science models under a "Software As A Service (SaaS)" paradigm. Proposal are also sought which couple model components and ancillary programs under a service-oriented architecture. A feasibility study should be conducted during Phase 1 that will lead to a Phase 2 prototype that makes use of a NASA Earth or space science numerical model. Under such a scenario the back-end supercomputing environment should be segregated from the user's work environment while providing an interface to specific, secure services that will allow (1) execution of the model as a "black box" and (2) the ability to edit model elements, upload, recompile, and execute.

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

Lidar System Components Topic S1.01

Accurate measurements of atmospheric parameters with high spatial resolution from ground, airborne, and space-based platforms require advances in the state-of-the-art lidar technology with emphasis on compactness, efficiency, reliability, lifetime, and high performance. Innovative lidar component technologies that directly address the measurements of the atmosphere and surface topography of the Earth, Mars, the Moon, and other planetary bodies will be considered under this subtopic. Innovative technologies that can expand current measurement capabilities to spaceborne or Unmanned Aerial Vehicle (UAV) platforms are particularly desirable. Development of components that can be used in planned missions or current technology program is highly encouraged. Examples of planned missions and technology programs are: Ice, Cloud and land Elevation Satellite (ICESat, http://icesat.gsfc.nasa.gov [6]), Laser Interferometer Space Antenna (LISA, http://lisa.nasa.gov/index.html [7]), Doppler Wind Lidar, Lidar for Surface Topography (LIST), and Earth and planetary atmospheric composition (ASCENDS).

Research should be conducted to demonstrate technical feasibility during Phase 1 and show a path toward a Phase 2 prototype demonstration. For this Program year, we are soliciting only the specific component technologies described below.

- High speed fiber multiplexers for multimode fiber (200 micron core, 0.22 NA) operating at 1064 nm wavelength. We require an N by M multiplexer (where N is 1 or more and M is 10 to 100 or more) capable of switching at speeds on the order of 10 microseconds with low insertion loss (<2 dB). The unit must be small, lightweight, capable of long life, and low power consumption.
- Space-qualifiable high reliability frequency-stabilized CW laser source with 1 W output power. A master oscillator power amplifier (MOPA) configuration is desirable since the source must be phase-modulated.
- Development of polarization-maintaining Er and/or Yb doped optical fiber amplifiers that are optimized for suppression of stimulated Brillouin scattering (SBS). Resulting fiber amplifier must be capable of single frequency (< 1MHz linewidth), peak power of > 1 kW, and M2 beam quality < 1.3.
- Efficient and compact single frequency, near diffraction limited fiber lasers operating in near infrared (1.0 -1.7 ?m) and mid-infrared (3 - 4 ?m). Requirements include: polarization maintaining output (better than 100:1), M2 beam quality < 1.5, wavelength stability <50 pm over one hour. Both pulsed lasers with repetition rates of the order of 10 KHz and pulse energies greater than 0.5 mJ, and CW lasers in multiwatts regimes are applicable. Wavelength tunability over 10s of nanometers is desirable for certain applications.
- Efficient and compact single mode solid state or fiber lasers operating at 1.5 and 2.0 micron wavelength regimes suitable for coherent lidar applications. These lasers must meet the following general requirements: pulse energy 0.5 mJ to 50 mJ, repetition rate 10 Hz to 1 kHz, and pulse duration of approximately 200 nsec.
- Single frequency semiconductor or fiber laser generating CW power in 1.5 or 2.0 micron wavelength regions with less than 50 kHz linewidth. Frequency modulation with about 5 GHz bandwidth and wavelength tuning over several nanometers are desirable.
- Development of efficient, compact, and space qualifiable laser absorption spectrometry-related technologies for measuring atmospheric pressure and density. Components of interest include but not limited to fiber based Raman amplifier-based transmitter architecture. Remote sensing of oxygen in the 1.26-micron spectral region for measuring atmospheric pressure is of particular interest.

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

Sub Topics:
  Active Microwave Technologies Topic S1.02
NASA employs active sensors (radars) for a wide range of remote sensing applications (http://www.nap.edu/catalog/11820.html [8]). These sensors include low frequency (less than 10 MHz) sounders to G-band (160 GHz) radars for measuring precipitation and clouds and for planetary landing. We are seeking proposals for the development of innovative technologies to support future radar missions. The areas of interest for this call are listed below (with applications and/or mission concept names):

- Lightweight deployable L-band antenna structures and deployment mechanisms suitable for large aperture (reflectors or phased array of 50m^2 and larger) systems. (Solid Earth Science , http://solidearth.jpl.nasa.gov/ [9])
- Compact wide bandwidth L-band and S-band (200 MHz) array antennas for airborne real aperture and synthetic aperture radar remote sensing applications.
- Rad-hard, high-efficiency, low-cost, lightweight L- and P-band Transmit/Receive (TR) modules (~250 W peak RF output power at ~100 us pulsewidth and 20% duty cycle) with respective energy storage units to provide pulsed DC power to the power amplifier while minimizing ripple on the primary DC power source. (DESDynI, http://desdyni.jpl.nasa.gov/ [10]; SES, hydrology http://www.nasa.gov/topics/earth/features/decadal_missions.html [11])
- Low Power 10-bit, 1.5 GHz analog bandwidth ADCs and digital filtering with an emphasis on rad-tolerance and space-qualification. (Ice Topography (GLISTIN), planetary landing)
- Lightweight deployable reflectors (Ku-band and Ka-band) and active feed electronics.
- High efficiency Ka-band (34-36GHz) TR modules with output power of 5-10W. The Low Noise Amplifiers (LNAs) should have a NF less than 3dB and gain better than 30dB. Included in the TR module is a low loss phase shifter. (GPM, Clouds and precipitation, planetary landing)
- Power amplifier and associated LNA for a Ka-band (34-36GHz) radar system with a peak output power of 2KW to 10KW (duty cycle of 10%) and system bandwidth of up to 1 GHz and LNA NF of less than 1.5dB. The LNA needs to have enough isolation and power handling capability to operate in this high power transmission environment. (SWOT, GLISTIN, clouds and precipitation)
- 140-160 GHz planar frequency-scanned antenna with scan range +/- 16 degrees, beamwidth 0.5 degrees, and bandwidth 400 MHz per beam. (planetary landing, atmospheric radar)
- Dual or tri-frequency (Ku/Ka/W band), matched beam antennas with high cross-polarization isolation (>32 dB). (Cloud and precipitation)
- Innovative approaches to realizing a low-cost instrument (sub-system).

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

Sub Topics:
  Passive Microwave Technologies Topic S1.03
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 (http://www.nap.edu/catalog.php?record_id=11820 [12]) to cosmic background emission. Proposals are sought for the development of innovative technology to support future science and exploration missions employing 450 MHz to 5 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). While other concepts will be entertained, specific technology innovations of interest are listed below for missions including decadal survey missions (http://www.nap.edu/catalog/11820.html [8]) such as PATH, SCLP, and GACM and the Beyond Einstein Inflation Probe (Inflation Probe (cosmic microwave background, http://universe.nasa.gov/program/probes/inflation.html [13])

- Low power >200 Mb/s 1-bit A/D converters and cross-correlators for microwave interferometers. Earth Science Decadal survey missions which apply: PATH, SCLP.
- Automated assembly of 180 GHz direct conversion I-Q receiver modules. This technology applies to both the Beyond Einstein Inflation probe and the Decadal Survey PATH concept.
- Low DC power spectrometer (channelizer) covering >500 MHz with 125 kHz resolution for planetary radiometer missions and covering 4 GHz with 1 MHz resolution for Earth observing missions. Also RFI mitigation approaches employing channelizers for broad band radiometers. Earth Science Decadal Survey mission which applies: GACM.
- RF (GHz to THz) MEMS switches with low insertion loss (< 0.5 dB), high isolation (>18 dB), capable of switching with speeds of >100 Hz at cryogenic temperatures (below 10 K) for 10^8 or more cycles. Technology applies to Beyond Einstein Probe.
- High emissivity (>40 dB return loss) surfaces/structures for use as onboard calibration targets that will reduce the weight of aluminum core targets, while reliably improving the uniformity and knowledge of the calibration target temperature. Earth Science Decadal survey missions which apply: SCLP and PATH.
- MMIC Low Noise Amplifiers (LNA). Room temperature LNAs for 165 to 193 GHz with low 1/f noise, and a noise figure of 6.0 dB or better; and cryogenic LNAs for 180 to 270 GHz with noise temperatures of less than 150K. Earth Science Decadal Survey missions that apply: PATH and GACM.
- Low loss, low RF power waveguide SPDT diode switches and active noise sources for frequencies above 90 GHz to support calibration of SWOT and other atmospheric temperature and humidity measurements.

In addition to the technologies listed above, proposals for innovative passive microwave instruments for a wide range of remote sensing applications from measurements of the Earth's surface and atmosphere to cosmic background emission would also be welcome.

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

Sub Topics:
  Sensor and Detector Technology for Visible, IR, Far IR and Submillimeter Topic S1.04
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 for Earth science (http://www.nap.edu/catalog/11820.html [8]), planetary science (http://www.nap.edu/catalog/10432.html [14]), and astronomy & astrophysics (http://www.nap.edu/books/0309070317/html/ [15]).

The following technologies are of interest for Earth and planetary science instrument concepts such as Scanning Microwave Limb Sounder (http://mls.jpl.nasa.gov/index-cameo.php [16]) on the Global Atmospheric Chemistry Mission, Climate Absolute Radiance and Refractivity Observatory (http://science.hq.nasa.gov/earth-sun/docs/Volz4_CLARREO.pdf [17]), Methane Trace Gas Sounder, and Lunar Atmosphere Dust Environment Explorer:

- New or improved technologies leading to measurement of trace atmospheric species (e.g., CO, CH4, N_2O) from geostationary and low-Earth orbital platforms. Of particular interest are new techniques in gas filter correlation spectroscopy, Fabry-Perot spectroscopy, or improved component technologies.

- Uncooled or passively cooled detectors with specific detectivity (D*) ? 10^{10} cm $Hz^{1/2}$/W in the operating wavelength ranges 6-14 ?m and 10-100 ?m.

- Efficient, flight qualifiable, spur free, local oscillators for SIS mixers operating in low Earth orbit. Two bands: (1) tunable from 200 to 250 GHz, and (2) tunable from 610 to 650 GHz, phase-locked to or derived from an ultra-stable 5 MHz reference.
- Technologies for calibrating millimeter wave spectrometers for spaceborne missions, including low power,

flight qualifiable comb generators for gain, linearity, and sideband calibration of microwave spectrometers covering the bands from 180 to 270 GHz and from 600 to 660 GHz; flight qualifiable low noise diodes for the bands from 180 to 270 and 600 to 660 GHz; very low return loss (70 dB or better) calibration targets and techniques for quantifying and calibrating out the impact of standing waves in broadband heterodyne submillimeter spectrometers.
- Low power, stable, linear, spectrometers capable of measuring the band from 6-18 GHz with ~120 100 MHz wide channels.
- Digital spectrometers with ~4 GHz bandwidth and 10 MHz resolution. Components for these digital spectrometers including high speed digitizers, efficient spectrometer firmware, and ASIC implementations.

Detector technologies for future astrophysics mission concepts, such as the Single Aperture Far Infrared (SAFIR) Observatory (http://safir.jpl.nasa.gov/technologies.shtml [18]), the Space Infrared Telescope for Cosmology and Astrophysics (SPICA) (http://www.ir.isas.ac.jp/SPICA/ [19]), and Inflation Probe (cosmic microwave background, http://universe.nasa.gov/program/probes/inflation.html [13]).

- Innovative detector designs, readout electronics, or new sensor materials (e.g. novel dopants for extrinsic Si detectors) are of interest, as is development of a photo-definable version of parylene to aid the fabrication of thermally isolated structures of bolometers (and x-ray microcalorimeters).
- Spatial Filter Array (SFA) consisting of a monolithic array of up to 1200 coherent, polarization preserving, single mode fibers that operate over a large fraction of the spectral range from 0.4 - 1.0 microns and such that each input and output lenslet is mapped to a single fiber. Uniformity of output intensity and high throughput is desired and fiber-to-fiber placement accuracies of < 2.0 microns are required with < 1.0 microns desired. Â Applications include active and passive wavefront and amplitude control, and relevant missions include Terrestial Planet Finder (http://planetquest.jpl.nasa.gov/TPF/tpf_index.cfm [20]) and Stellar Imager (http://hires.gsfc.nasa.gov/si/ [21]).

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

Sub Topics:
   Detector Technologies for UV, X-Ray, Gamma-Ray and Cosmic-Ray Instruments Topic S1.05
This subtopic covers detector requirements for a broad range of wavelengths from UV through to gamma ray. As would be expected, requirements across the board are for greater numbers of readout pixels, lower power, faster readout rates, greater quantum efficiency, and enhanced energy resolution. Typical semiconductor devices in this energy range are based on silicon or germanium. However, proposals for other detector materials are welcomed if a compelling case is made.

The proposed efforts must be directly linked to a requirement for a NASA mission. Details of these can be found at the following URLs:

- General Information on Future NASA Missions: http://nasascience.nasa.gov/missions [22]
- Specific Mission pages:
    - ConX: http://constellation.gsfc.nasa.gov [23]
    - LBTI: http://planetquest.jpl.nasa.gov/lbti/lbti_index.cfm [24]
- Future Mars Programs: http://marsprogram.jpl.nasa.gov/missions/future/futureMissions.html [25]
- Solar Probes: http://science.hq.nasa.gov/missions/sun.html [26]

Specific technologies are listed below. Highly desirable are developments that satisfy multiple requested parameters:

- Large-format focal plane detectors for use in UV and X-ray imaging and spectrometry:
    - UV-sensitive CCD and active pixel sensors with large formats: to 6k x 6k abuttable; extended UV response below 0.2 nm;
    - X-ray-sensitive CCD and active pixel sensors: up to 4k x 4k formats, 4-side abuttable; power levels of 0.1 W / megapixel; resolutions less than 120 eV; readout rates of at least 30 Hz; extended x-ray response above 6 keV.

Very-large-area X-ray detectors for survey instruments: square-meter area capability; response from 3-30 keV; ultra-low power (10 microW/channel).

- Significant improvements in wide band gap materials, individual detectors, and detector arrays for UV and X-ray applications.
- Photon counting detectors with capability to resolve single photon arrival for use in space applications.
- Mega-to-giga-channel analogue electronic systems for very-large-area X- and gamma-ray detectors as follows: up to 108 channel capability; less than 10 microW/channel power requirement; less than 100 electron rms noise level with interconnects.
- Technology to accomplish X-ray and gamma-ray imaging spectroscopy and polarimetry at the arcsecond level in the energy range from 1 keV to 20 MeV.

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

Sub Topics:
  Particles and Field Sensors and Instrument Enabling Technologies Topic S1.06
Advanced sensors and instrument enabling technologies for the measurement of the physical properties of space plasmas and energetic charged particles, mesospheric-thermospheric neutral species, energetic neutral atoms created by charge exchange, and electric and magnetic fields in space are needed to achieve NASA's transformational science advancements in Heliophysics. The Heliophysics discipline has as its primary strategic goal the understanding of the physical coupling between the sun's outer corona, the solar wind, the trapped radiation in Earth's and other planetary magnetic fields, and to the upper atmospheres of the planets and their moons. This understanding is of national importance not only because of its intrinsic scientific worth, but also because it is the necessary first step toward developing the ability to measure and forecast the "space weather" that affects all human crewed and robotic space assets. Improvements in particles and fields sensors and associated instrument technologies will enable further scientific advancement for upcoming NASA missions such as Solar Probe (http://solarprobe.gsfc.nasa.gov/ [27]), Solar Orbiter (http://www.rssd.esa.int/index.php?project=SOLARORBITER [28]), Solar Sentinels (http://www.lws.nasa.gov/missions/sentinels/solar_sentinels_orbiter.htm [29]), GEC, Magnetospheric Constellation (http://stp.gsfc.nasa.gov/missions/mc/mc.htm [30]), IT-SP (http://www.lws.nasa.gov/missions/geospace/geospace.htm [31]) and some planetary exploration missions. Technology developments that result in expanded measurement capabilities and a reduction in size, mass, power, and cost are necessary in order for some of these missions to proceed. Of special interest are magnetometers, fast high voltage stepping power supplies for charged particle analyzers, electric field booms and other supporting sensor electronics. Specific areas of interest include:

- Low cost, low power, low current, high voltage power supplies which allow ultra-fast stepping (t < 100- ?s) over the full voltage range (0 < V < 5-15 kV).
- Self-calibrating scalar-vector magnetometer for future Earth and space science missions. Performance goals: dynamic range: +/-100,000 nT, accuracy with self-calibration: 1 nT, sensitivity: 5 pT / sqrtHz, max sensor unit size: 6 x 6 x 12 cm, max sensor mass: 0.6 kg, max electronics unit size: 8 x 13 x 5 cm, max electronics mass: 1 kg, and max power: 5 W operation, 0.5 W standby, including, but not limited to "sensors on a chip".
- Strong, lightweight, thin, compactly-stowed electric field booms possibly using composite materials that

deploy sensors to distances of 10 m or more and/or long wire boom (> 50 m) deployment systems for the deployment of very lightweight tethers or antennae on spinning spacecraft.

- Low power charge sensitive preamplifiers on a chip.
- Radiation hardened ASIC spectrum analyzer module that determines mass spectra using fast algorithm deconvolution to produce ion counts for specific ion species.

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

Sub Topics:
  Cryogenic Systems for Sensors and Detectors Topic S1.07
Cryogenic cooling systems are often enabling technologies for cutting edge science from infrared imaging and spectroscopy to x-ray calorimetry. Improvements in cryogenic technologies enable further scientific advancement at lower cost, lower risk, reduced volume, and/or reduced mass. Lifetime, reliability, and power requirements of the cryogenic systems are critical performance concerns. Of interest are cryogenic technologies for cooling detectors for scientific instruments and sensors on advanced telescopes and observatories (http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20070018750_2007018830.pdf [32]) as well as on instruments for lunar and planetary exploration such as missions to Europa, Titan, or Enceladus (http://sci.esa.int/science-e/www/object/index.cfm?fobjectid=42337 [33]). Active coolers should have long life, low vibration, low mass, low cost, and high efficiency. Specific areas of interest include:

- Essentially vibration-free cooling systems such as Pulse Tube or reverse Brayton cycle cooler technologies with cooling capability of 20 mW at 4K.
- Low temperature cooling systems, operating and rejecting heat at 150K, providing 0.3W of cooling at 35K with input power on the order of 10W.
- Distributed cooling systems using circulators for larger systems including helium circulators. The temperature range is 20-100K, with flowrates of up to 1 gram/sec and a maximum pressure drop of 50 psi.
- Heat switches for redundant cryocoolers with a temperature range of 20-100K and a capacity of 20W.
- Highly efficient magnetic and dilution cooling technologies under 1 Kelvin.
- Components for advanced magnetic coolers (adiabatic demagnetization refrigerators) including:
    - Small (few cm bore), lightweight, low current (under 10A, goal under 5A) superconducting magnets capable of producing at least 3 Tesla central field while operating at least 10 Kelvin. Higher temperature superconductor (HTS) magnets operating at significantly higher temperatures are of particular interest.
    - Lightweight (relative to standard ferromagnetic flux guides) active and/or passive magnetic shielding for 3 to 4 Tesla magnets that reduces the stray field to tens of microTesla at a distance of several cm from the outside of the shield.
    - Large (>1 cubic cm) single crystal or polycrystalline magnetocaloric materials.
    - Superconducting current leads operating between 90 Kelvin down to 10 Kelvin, capable of carrying up to 10 amperes while allowing only approximately 1 mW of heat to be conducted.
    - Compact, accurate, easy to use thermometers that operate down to 10 milliKelvin.

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

Sub Topics:
  In Situ Airborne, Surface, and Submersible Instruments for Earth Science Topic S1.08
There are new platform systems that have the potential to benefit Earth science research activities. To capitalize on these emerging capabilities, proposals are sought for the development of in situ instruments for use on radiosondes, dropsondes, tethered balloons, kites, Unmanned Aerial Vehicles (UAVs), Unmanned Surface Vehicles (USVs), or Unmanned Underwater Vehicles (UUVs). Both miniaturization of current techniques, as well as innovative new methods that lead to compact and lightweight systems are important. Details of complete

instrument systems are desired, including data acquisition, power, and platform integration. Instrument performance goals such as resolution, accuracy, and response time should be discussed, as well as maintenance and reliability considerations. An outline of potential use by NASA and a plan for commercial production and marketing should be included as well. Technology innovation areas of interest include:

- Atmospheric measurements including aerosol properties, temperature, humidity, solar radiation, clouds, liquid water, ice, precipitation, and chemical composition (carbon dioxide, methane, reactive gases and radicals, dynamical tracer species).
- Three-dimensional wind measurements near the Earth's surface, and within the troposphere and lower stratosphere.
- Oceanic and coastal measurements including inherent and apparent optical properties, temperature, salinity, chemical composition, nutrient distribution, and currents.

Instrument systems to support field studies of fundamental processes are of interest, as well as for satellite measurement calibration and validation. Applicability to NASA's Airborne Science, Ocean Biology and Biogeochemistry, and Applied Sciences programs, including support of the Integrated Ocean Observing System (IOOS), is a priority.

Sub Topics:
  In Situ Sensors and Sensor Systems for Planetary Science Topic S1.09
This subtopic solicits development of advanced instruments and instrument components that are tailored to the demands of planetary instrument deployment on a variety of space platforms (orbiters, flyby spacecraft, landers, rovers, balloon or other aerial vehicles, subsurface penetrators or impactors, etc.) accessing the wide variety of bodies in our solar system (inner and outer planets and their moons, comets, asteroids, etc.). For example missions see: http://science.hq.nasa.gov/missions/solar_system.html [34].

Specifically, this subtopic solicits instrument development that provides significant advances in the following areas:

- Reduced mass, power, volume, data rates for instruments or instrument components that could be achieved in optomechanical components (e.g., room temperature lasers, detectors, mixers, microvalves, optical components and structures, gas and liquid pumps, ion sources, light sources from UV to microwave, seismometers, etc.) or electronics (e.g., FPGA, ASIC implementations, advanced array readouts);
- Improved g-force survivability for rough landings on Mars, Moon, or comet/asteroid bodies;
- Mitigation strategies for tolerance to high-radiation environments like that around Europa;
- High temperature and/or high pressure lifetime improvement for instruments landed on Venus;
- Low temperature survivability or lifetime improvement for instruments landed on cryogenic outer planet bodies or deployed to the subsurface;
- Advanced sample handling and manipulation technologies for challenging environments and planetary protection.

Proposers are strongly encouraged to relate their proposed development to (a) future planetary exploration goals of NASA; and (b) existing flight instrument capability to provide a comparison metric for assessing proposed improvements.

Instruments for both remote sensing and in situ investigations are required for NASA's planned and potential solar system exploration missions. Instruments are required for the characterization of the atmosphere, surface, and subsurface regions of planets, satellites, and small bodies. These instruments may be deployed for remote sensing, on orbital or flyby spacecraft, or for in situ measurements, on surface landers and rovers, subsurface penetrators, and airborne platforms. In situ instruments cover spatial scales from surface reconnaissance to microscopic investigations. These instruments must be capable of withstanding operation in space and planetary environmental extremes, which include temperature, pressure, radiation, and impact stresses.

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

Sub Topics:
  Space Geodetic Observatory Components Topic S1.10
NASA is working with the international community to develop the next generation of geodetic instruments and networks to determine the terrestrial reference frame with accuracy better than one part per billion (http://science.hq.nasa.gov/strategy/roadmaps/surface.html [35]). These instruments include Global Navigation Satellite System (GNSS) receivers, Very Long Baseline Interferometry (VLBI) systems, and Next Generation Satellite Laser Ranging (SLR) stations. The development of these instruments and the needed integrating technology will require contributions from a broad variety of optical, microwave, antenna and survey engineering suppliers. These needs include but are not limited to:

- Broadband (2 - 14 GHz) feeds capable of receiving GNSS signals, Ka-band (32 - 36 GHz) feeds integrated with broadband feeds, and matching antennas that meet or exceed the slewing and duty cycle requirements of the IVS VLBI2010 specifications.
- VLBI system components including > 4 Gbps recorders, phase/cable calibrators, and frequency standards / distribution systems that meet or exceed the requirements of the IVS VLBI2010 specifications.
- Cost-effective data transmission for e-VLBI from a global network of 30 VLBI stations operating up to 8 Gbps.
- Compact, low mass, space-qualified for MEO, SLR retroreflector arrays with greater than 100 million square meter lidar cross section, with a design that assures the ability to determine the array center to the center of mass of the spacecraft to a millimeter.
- A very high quantum efficiency (>50% at 532nm), low instrument noise, multi-pixilated detector for SLR use in the automated tracking.
- Geodetic GNSS software receivers and antenna systems capable of receiving all signals from the GPS, GLONASS, Galileo and Beidou/Compass GNSS.
- Continuous, reliable co-location monitoring and control system for the relative 3-D displacement of geodetic instruments within a geodetic observatory to better than 1 mm.

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

Sub Topics:
  Lunar Science Instruments and Technology Topic S1.11
NASA lunar robotic science missions support the high-priority goals identified in the 2007 National Research Council report, The Scientific Context for Exploration of the Moon: Final Report (hwttp://ww.nap.edu/catalog.php?record_id=11954 [36]). Future missions will characterize the lunar exosphere and surface environment; field test new equipment, technologies, and approaches for performing lunar science; identify landing sites and emplace infrastructure to support robotic and human exploration; demonstrate and validate heritage systems for exploration missions; and provide operational experience in the harsh lunar environment.

Space-qualified instruments are required to perform remote and in situ lunar science investigations, to include measurements of lunar dust composition, reactivity and transport, searching for water ice, assessing the radiation environment, gathering long period measurements of the lunar exosphere, and conducting surface and subsurface geophysical measurements.

In support of these requirements, this subtopic seeks advancements in the following areas:

Geophysical Measurements

  Systems, subsystems, and components for seismometers and heat flow sensors capable of long-term continuous operation over multiple lunar day/night cycles with improved sensitivity at lower mass and reduced power consumption compared to the Apollo Lunar Surface Experiments Package (ALSEP) instruments

(http://www.hq.nasa.gov/alsj/frame.html [37]). Instrument deployment options include robotic deployment from soft landers, as well as emplacement by hard landers or penetrators. Also of interest are portable surface ground penetrating radars with antenna frequencies of 250-MHz, 500-MHz, and 1000-MHz to characterize the thickness of the lunar regolith.

In Situ Lunar Surface Measurements

Light-weight and power efficient instruments that enable elemental and/or mineralogy analysis using techniques such as high-sensitivity X-ray and UV-fluorescence spectrometers, UV/fluorescence flash lamp/camera systems, scanning electron microscopy with chemical analysis capability; time-of-flight mass spectrometry, gas chromatography and tunable diode laser (TDL) sensors for in situ isotopic and elemental analysis of evolved volatiles, calorimetry, and Laser Induced Breakdown Spectroscopy (LIBS). Instruments shall have the potential to provide isotope ratio measurements and/or hydrogen distributions to ±10 ppm locally. Instrument deployment options include robotic deployment from soft landers, as well as emplacement by hard landers or penetrators.

Lunar Atmosphere and Dust Environment Measurements

Low-mass and low-power instruments that measure the local lunar surface environment which includes but is not limited to the characterization of: the plasma environment, surface electric field, and dust concentrations and its diurnal dynamics. Instrument deployment options include robotic deployment from soft landers, as well as emplacement by hard landers or penetrators.

Research should be conducted to demonstrate technical feasibility during Phase 1 and show a path toward a Phase 2 hardware and software demonstration, and when possible, deliver a demonstration unit or software package for NASA testing at the completion of the Phase 2 contract.

Sub Topics:
   Precision Spacecraft Formations for Telescope Systems Topic S2.01
This subtopic seeks hardware and software technologies necessary to establish, maintain, and operate precision spacecraft formations to a level that enables cost effective large aperture and separated spacecraft optical telescopes and interferometers (e.g., http://constellation.gsfc.nasa.gov/ [23], http://lisa.gsfc.nasa.gov/ [38]). Also sought are technologies (analysis, algorithms, and testbeds) to enable detailed analysis, synthesis, modeling, and visualization of such distributed systems.

Formation flight can synthesize large effective telescope apertures through, multiple, collaborative, smaller telescopes in a precision formation. Large effective apertures can also be achieved by tiling curved segments to form an aperture larger than can be achieved in a single launch, for deep-space high resolution imaging of faint astrophysical sources. These formations require the capability for autonomous precision alignment and synchronized maneuvers, reconfigurations, and collision avoidance. The spacecraft also require onboard capability for optimal path planning and time optimal maneuver design and execution.

Innovations are solicited for: (a) sensor systems for inertial alignment of multiple vehicles with separations of 10,000 - 100,000 km to accuracy of 1 - 50 milli-arcseconds (b) development of nanometer to sub-nanometer metrology for measuring inter-spacecraft range and/or bearing for space telescopes and interferometers (c) control approaches to maintain line-of-sight between two vehicles in inertial space near Sun-Earth L2 to milli-arcsecond levels accuracy (d) development of combined cm-to-nanometer-level precision formation flying control of numerous spacecraft and their optics to enable large baseline, sparse aperture UV/optical and X-ray telescopes and interferometers for ultra-high angular resolution imagery. Proposals addressing staged-control experiments which combine coarse formation control with fine-level wavefront sensing based control are encouraged.

Innovations are also solicited for distributed spacecraft systems in the following areas:

- Distributed, multi-timing, high fidelity simulations;
- Formation modeling techniques;
- Precision guidance and control architectures and design methodologies;
- Centralized and decentralized formation estimation;
- Distributed sensor fusion;
- RF and optical precision metrology systems;
- Formation sensors;
- Precision microthrusters/actuators;
- Autonomous reconfigurable formation techniques;
- Optimal, synchronized, maneuver design methodologies;
- Collision avoidance mechanisms;
- Formation management and station keeping.

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

Sub Topics:
  Proximity Glare Suppression for Astronomical Coronagraphy Topic S2.02
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 and innovative advanced wavefront sensing and control for cost-effective space telescopes. 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 infrared wavelengths. The ultimate application of these instruments is to operate in space as part of a future observatory mission. Much of the scientific instrumentation used in future NASA observatories for the astrophysical sciences will require control of unwanted radiation (thermal and scattered) across a modest field of view. The performance and observing efficiency of astrophysics instruments, however, must be greatly enhanced. The instrument components are expected to offer much higher optical throughput, larger fields of view, and better detector performance. The wavelengths of primary interest extend from the visible to the thermal infrared. 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

- Advanced starlight canceling coronagraphic instrument concepts;
- Advanced aperture apodization and aperture shaping techniques;
- Pupil plane masks for interferometry;
- Advanced apodization mask or occulting spot fabrication technology controlling smooth density gradients to 10-4 with spatial resolutions ~1 μm, low dispersion, and low dependence of phase on optical density;
- Metrology for detailed evaluation of compact, deep density apodizing masks, Lyot stops, and other types of graded and binary mask elements. Development of a system to measure spatial optical density, phase in homogeneity, scattering, spectral dispersion, thermal variations, and to otherwise estimate the accuracy of masks and stops is needed;
- Interferometric starlight cancellation instruments and techniques to include aperture synthesis and single input beam combination strategies;

- Single mode fiber filtering from visible to 20 μm wavelength;
- Methods of polarization control and polarization apodization; and
- Components and methods to insure amplitude uniformity in both coronagraphs and interferometers, specifically materials, processes, and metrology to insure coating uniformity.

Wavefront Control Technologies

- Development of small stroke, high precision, deformable mirrors (DM) and associated driving electronics scalable to 10^4 or more actuators (both to further the state-of-the-art towards flight-like hardware and to explore novel concepts). Multiple DM 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;
- Development of instruments to perform broad-band sensing of wavefronts and distinguish amplitude and phase in the wavefront;
- Adaptive optics actuators, integrated mirror/actuator programmable deformable mirror;
- Reliability and qualification of actuators and structures in deformable mirrors to eliminate or mitigate single actuator failures;
- Multiplexer development for electrical connection to deformable mirrors that has ultra-low power dissipation;
- High precision wavefront error sensing and control techniques to improve and advance coronagraphic imaging performance; and
- Highly reflecting broadband coatings.

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

Sub Topics:
  Precision Deployable Optical Structures and Metrology Topic S2.03
Planned future NASA Missions in astrophysics, such as the Single Aperture Far-IR (SAFIR) telescope, James Webb Space Telescope (JWST, http://www.jwst.nasa.gov/ [39]), Terrestrial Planet Finder (TPF, http://planetquest.jpl.nasa.gov/TPF/tpf_index.cfm [20]) missions: Coronagraph, External Occulter and Interferometer, ATLAST, Life Finder, and Submillimeter Probe of the Evolution of Cosmic Structure (SPECS), and the UV Optical Imager (UVOIR) 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. The desired areal density is 1 - 10 kg/m^2. 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 L2.

This topic solicits proposals to develop enabling, cost effective component and subsystem technology for these telescopes. Research areas of particular interest include precision deployable structures and metrology (i.e., innovative active or passive deployable primary or secondary support structures); innovative concepts for packaging fully integrated (i.e., including power distribution, sensing, and control components); distributed and localized actuation systems; deployment packaging and mechanisms; active opto-mechanical control distributed on or within the structure; actuator systems for alignment of reflector panels (order of cm stroke actuators, lightweight, nanometer stability); innovative architectures, materials, packaging and deployment of large sunshields and external occulters; mechanical, inflatable, or other deployable technologies; new thermally-stable materials (CTE < 1ppm) for deployables; innovative ground testing and verification methodologies; and new approaches for achieving packagable depth in primary mirror support structures.

Also of interest are innovative metrology systems for direct measurement of the optical elements or their supporting structure; requirements for micron level absolute and subnanometer relative metrology for multiple locations on the primary mirror; measurement of the metering truss; and innovative systems which minimize complexity, mass, power and cost. The goal for this effort is to mature technologies that can be used to fabricate 20 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. A successful proposal shows a path toward a Phase 2 delivery of demonstration hardware scalable to 3 m for characterization.

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

Sub Topics:
  Optical Devices for Starlight Detection and Wavefront Analysis Topic S2.04
The planned Ares V vehicle will enable the launch of extremely large and/or extremely massive space telescopes. Potential systems include 12 to 30 meter class segmented primary mirrors for UV/optical or infrared wavelengths and 8 to 16 meter class segmented x-ray telescope mirrors. UV/optical telescopes require 1 to 3 meter class mirrors with < 5 nm rms surface figures. IR telescopes require 2 to 3 meter class mirrors with cryo-deformations < 100 nm rms. X-ray telescopes require 1 to 2 meter long grazing incidence segments with angular resolution < 5 arc-sec down to 0.1 arc-sec and surface micro-roughness < 0.5 nm rms. Additionally, missions such as EUSO and OWL need 2 to 9 meter diameter UV-transparent refractive, double-sided Fresnel or diffractive lenses.

In view of the very large total mirror or lens collecting aperture required, affordability or areal cost (cost per square meter of collecting aperture) rather than areal density is probably the single most important system characteristic of an advanced optical system. For example, both x-ray and normal incidence space mirrors currently cost $3M to $4M per square meter of optical surface area. This research effort seeks a cost reduction for precision optical components by 20X to 100X to less than $100K per square meter.

The primary purpose of this subtopic is to develop and demonstrate technologies to manufacture ultra-low-cost precision optical systems for very large x-ray, UV/optical or infrared telescopes. Potential solutions include but are not limited to direct precision machining, rapid optical fabrication, slumping or replication technologies to manufacture 1 to 2 meter (or larger) precision quality mirror or lens segments (either normal incidence for uv/optical/infrared or grazing incidence for x-ray).

An additional key enabling technology for UV/optical telescopes is a broadband (from 100 nm to 2500 nm) high-reflectivity mirror coating with extremely uniform amplitude and polarization properties which can be deposited on 1 to 3 meter class mirrors.

Successful proposals will demonstrate prototype manufacturing of a precision mirror or lens system or precision replicating mandrel in the 0.25 to 0.5 meter class with a specific scale up roadmap to 1 to 2+ meter class space qualifiable flight optics systems. Material behavior, process control, optical performance, and mounting/deploying issues should be resolved and demonstrated. The potential for scale-up will need to be addressed from a processing and infrastructure point of view.

The Phase 1 deliverable will be at least a 0.25 meter near UV, visible or x-ray precision mirror or lens or replicating mandrel, its optical performance assessment and all data on the processing and properties of its substrate materials. This effort will allow technology to advance to TRL 3-4.

The Phase 2 deliverable will be at least a 0.50 meter near UV, visible or x-ray space-qualifiable precision mirror or lens system with supporting documentation, optical performance assessment, all data on materials and processing, and thermal and mechanical stability analysis. Effort will advance technology to TRL 4-5.

The proposal must address the technical need of a recognized future NASA space science mission, science measurement objective or science sensor for a Discovery, Explorer, Beyond Einstein, Origins, GOESS, New Millennium, Landmark-Discovery, or Vision mission. Missions of interest include the following: Constellation-X (http://constellation.gsfc.nasa.gov/ [23]); Generation-X (http://www.cfa.harvard.edu/hea/genx.html [40]); Single Aperture Far-Infrared (http://safir.jpl.nasa.gov/technologies.shtml [18]); Terrestrial Planet Finder

(http://planetquest.jpl.nasa.gov/ TPF/tpf_index.cfm [41]); Orbiting Wide Angle Light Collector (http://owl.gsfc.nasa.gov/ [42]); Extreme Universe Space Observatory (http://hena.lbl.gov/EUSO/ [43]).

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

Sub Topics:
  Optics Manufacturing and Metrology for Telescope Optical Surfaces Topic S2.05
This year's subtopic focuses primarily on manufacturing and metrology of optical surfaces, especially for very small or very large and/or thin optics. Missions of interest include JDEM concepts (http://universe.nasa.gov/program/probes/jdem.html [44]), Constellation-X (http://constellation.gsfc.nasa.gov/ [23]), TPF (http://planetquest.jpl.nasa.gov/TPF/tpf_index.cfm [20]) and SAFIR (http://safir.jpl.nasa.gov/technologies.shtml [18]). Optical systems currently being researched for these missions are large area aspheres, requiring accurate figuring and polishing across six orders of magnitude in period (i.e., 1st and 2nd order errors through micro-roughness). Technologies are sought that will enhance the figure quality of optics in any range as long as the process does not introduce artifacts in other ranges (i.e., mm-period polishing should not introduce waviness errors at the 20 mm or 0.05 mm periods in the power spectral density). Also, novel metrological solutions that can measure figure errors over a large fraction of the PSD range are sought, especially techniques and instrumentation that can perform measurements while the optic is mounted to the figuring/polishing machine.

By the end of a Phase 2 program, technologies must be developed to the point where the technique or instrument can dovetail into an existing optics manufacturing facility producing optics at the R&D stage. Metrology instruments should have 10 nm or better surface height resolution and span at least 3 orders of magnitude in lateral spatial frequency.

Examples of technologies and instruments of interest include:

- Interferometric nulling optics for very shallow conical optics used in x-ray telescopes;
- Segmented systems commonly span 60 degrees in azimuth and 200 mm axial length and cone angles vary from 0.1 to 1 degree;
- Low stress metrology mounts that can hold very thin optics without introducing mounting distortion;
- Low normal force figuring/polishing systems operating in the 1 mm to 50 mm period range with minimal impact at significantly smaller and larger period ranges;
- In situ metrology systems that can measure optics and provide feedback to figuring/polishing instruments without removing the part from the spindle;
- Innovative mirror substrate materials or manufacturing methods that produce thin mirror substrates that are stiffer and/or lighter than existing materials or methods;
- Extreme aspheric and/or anamorphic optics for pupil intensity amplitude apodization (PIAA).

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

Sub Topics:
  Avionics and Electronics Topic S3.01
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 guidance, navigation, command and data handling are sought to support NASA's goals and several missions and projects under development (http://nasascience.nasa.gov/search?SearchableText=missions+under+development [45], http://www.nap.edu/catalog.php?record_id=10432 [46]).

The subtopic goals are to: (1) develop high-performance processors and memory architectures and reliable electronic systems, (2) develop an avionics architecture that is flexible, scalable, extensible, adaptable, and reusable, (3) develop precision line-of-sight sensing for large telescopes and spacecraft formations, and (4) mass and technology improvements in guidance, navigation and control for low cost small spacecraft use. The subtopic objective is to elicit novel architectural concepts and component technologies that are realistic and operate effectively and credibly in environments consistent with the future vision of the Science Mission Directorate.

Successful proposal concepts will significantly exceed the present state-of-the-art. Proposals will clearly (1) state what the product is; (2) describe how it targets the technical priorities listed below; and (3) outline the feasibility of the technical and programmatic approach. If a Phase 2 proposal is awarded, the combined Phase 1 and Phase 2 developments shall produce a prototype that is testable by NASA. The technology priorities sought are listed below.

Command and Data Handling

- Processors - General purpose (processor chips and radiation-hardened by design synthesizable IP cores) and special purpose single-chip components (DSPs) with sustainable processing performance and power efficiency (>500 MIPS at >100 MIPS/W for general purpose processing platforms, >5 GMACs at >5 GMACS/W for computationally-intensive processing platforms), and tolerance to total dose and single-event radiation effects. Concepts must include tools required to support an integrated hardware/software development flow.
- Radiation-hardened non-volatile low power memories and Ethernet physical layer components.
- Tunable, scalable, reconfigurable, adaptive fault-tolerant avionics.

Guidance, Navigation and Control

- Navigation systems (including multiple sensors and algorithms/estimators, possibly based on existing component technologies) that work collectively on multiple vehicles to enable inertial alignment of the formation of vehicles (i.e., pointing of the line-of-sight defined by fixed points on the vehicles) on the level of milli-arcseconds relative to the background star field.
- Light-weight sensors (gyroscopic or other approach) to enable milli-arcsecond class pointing measurement for individual large telescopes and low cost small spacecraft.
- Isolated pointing and tracking platforms (pointing 0.5 arcseconds, jitter to 5 milli-arcsecond), targeted to placing a scientific instrument on GEO communication satellites that can track the sun for > 3 hours/day.
- Working prototypes of GN&C actuators (e.g., reaction or momentum wheels) that advance mass and technology improvements for small spacecraft use. Such technologies may include such non-contact approaches such as magnetic or gas. Superconducting materials, driven by temperature conditioning may also be appropriate provided that the net power used to drive and condition the "frictionless" wheels is comparable to traditional approaches.

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

The Small Spacecraft Build effort highlighted in Topic S4 (Low-cost Small Spacecraft and Technologies) of the solicitation participates in this subtopic. Offerors are encouraged to take this in consideration as a possible flight opportunity when proposing work to this subtopic.

Sub Topics:
  Thermal Control Systems Topic S3.02

Future Spacecraft and instruments for NASA's Science Mission Directorate will require increasingly sophisticated thermal control technology (http://nasascience.nasa.gov/search?SearchableText=missions+under+development [45], http://www.nap.edu/catalog.php?record_id=10432 [46]). Some of these requirements include:

- Optical systems, lasers (ICESAT 2), and detectors which require tight temperature control, often to better than +/- 1°C. Some new missions such as CON-X and LISA, and upcoming Earth Science missions require thermal gradients held to even tighter micro-degree levels.
- Exploration science missions to the Moon and Mars present engineering challenges requiring systems which are more self-sufficient and reliable.
- The introduction of low-cost, small, rapidly configured spacecraft as described in Topic S4 requires the development of new thermal technologies to reduce the time and costs typically required for analysis, design, integration, and testing of the spacecraft. The Small Spacecraft Build effort highlighted in Topic S4 (Low-cost Small Spacecraft and Technologies) participates in this subtopic and offerors are encouraged to take this in consideration as a possible flight opportunity when proposing work to this subtopic.

Innovative proposals for the cross-cutting thermal control discipline are sought in the following areas:

- Methods of precise temperature measurement and control to tight temperature levels.
- High conductivity, vacuum-compatible interface materials to minimize losses across make/break interfaces.
- High conductivity materials to minimize temperature gradients and provide high efficiency light-weight radiators, including interfaces to heat pipes and fluid loops that overcomes issues with CTE mismatch.
- Advanced more efficient thermoelectric coolers capable of providing cooling at ambient and cryogenic temperatures.
- Advanced thermal control coatings or process technologies including variable emittance surfaces applicable to small spacecraft.
- Single and two-phase mechanically pumped fluid loop systems which accommodate multiple heat sources and sinks, and long life, lightweight pumps for these systems. Also includes advanced fluid system components such as accumulators, valves, pumps, flow rate sensors, etc. optimized for improved reliability, long life, and low resource needs.
- Efficient, lightweight, oil-less, high lift vapor compression systems for cooling up to 2 KW.
- Advanced thermal modeling techniques that can be easily integrated into existing codes, emphasizing inclusion of two-phase systems and mechanically pumped system models.
- Integration of standardized formats into existing codes for the representation and exchange of Thermal Network Models and Thermal Geometric Models and results.

Research should be conducted to demonstrate technical feasibility during Phase 1 and show a path toward a Phase 2 hardware and software demonstration. Phase 2 should deliver a demonstration unit or software package for NASA testing at the completion of the Phase 2 contract.

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

Sub Topics:
  Power Generation and Storage Topic S3.03

Future NASA science missions will employ Earth orbiting spacecraft, planetary spacecraft, balloons, aircraft, surface assets, and marine craft as observation platforms.

(http://nasascience.nasa.gov/search?SearchableText=missions+under+development [45], http://www.nap.edu/catalog.php?record_id=10432 [46])

Proposals are solicited to develop advanced power conversion, energy storage, and power electronics to enable or enhance the capabilities of future science missions. The requirements for the power systems for these missions are varied and include long life capability, high reliability, significantly lower mass and volume, higher mass specific power, and improved efficiency over the state of practice (SOP) components/systems. Other desired capabilities are high radiation tolerance, and ability to operate in extreme environments (high and low temperatures and over wide temperature ranges).

Advanced Photovoltaic Energy Conversion

Photovoltaic cell, blanket, and array technologies that lead to significant improvements in overall solar array performance (i.e. efficiency (>30%), mass specific power (>300W/kg), decreased stowed volume, reduced initial and recurring cost, long-term operation in high radiation environments, high power arrays, and a wide range of space environmental operating conditions):

- Photovoltaic cell and blanket technologies capable of low intensity, low-temperature (LILT) operation applicable to the Outer Planets Mission;
- Photovoltaic cell, blanket and array technologies for high intensity high-temperature operation applicable to the Solar Probe mission;
- Thermophotovoltaic technologies applicable to the Outer Planets Mission;
- Component technologies of interest include advanced solar cell designs, space-durable coatings, designs capable of high voltage operation within the space environment, and technologies that reduce fabrication/testing costs while maintaining high reliability;
- Array technologies of interest include concentrators, large reliably-deployable arrays, ultra-lightweight arrays for use with flexible, lightweight cells. Of particular interest are lightweight array technologies that are electrostatically-clean and can operate at voltages up to 1000 volts, enabling direct drive electric propulsion for deep space missions.

Stirling Power Conversion

Novel methods or approaches for radiation-tolerant, sensorless, autonomous control of the Stirling converters with very low vibration and having low mass, size, and electromagnetic interference (EMI). Other technologies of interest include:

- High-temperature, high-performance regenerators;
- High-temperature, lightweight, high-efficiency, low EMI, linear alternators;
- High-temperature heater heads (> 850°C) and joining techniques and regenerators applicable to Venus surface missions (~1200°C);
- Combined electrical power generation and cooling systems applicable to Venus surface missions (~1200°C).

Energy Storage

Future science missions will require lithium-based or other advanced rechargeable electrochemical battery systems that offer greater than 40,000 charge/discharge cycles (7 year operating life) for low-Earth-orbiting (LEO) spacecraft, 20 year life for geosynchronous (GEO) spacecraft, and as low as -80°C storage and operation temperatures for planetary missions. Energy storage technologies that enable one or more of the above requirements combined with very high specific energy and energy density are of interest.

Power Management and Distribution

Advanced electrical power technologies are required for the electrical components and systems on future platforms to address the size, mass, efficiency, capacity, durability, and reliability requirements. In addition to the above requirements, proposals must address the expected improvements in energy density, speed, efficiency, or wide-temperature operation (-125°C to 200°C) with a high number of thermal cycles. Advancements are sought in

power electronic devices, components, and packaging. Technologies of interest include:

- Power electronic components and subsystems;
- Power distribution;
- Fault protection;
- Advanced electronic packaging for thermal control and electromagnetic shielding.

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

Sub Topics:
  Propulsion Systems Topic S3.04
The Science Mission Directorate (SMD) needs spacecraft with ever-increasing propulsive performance and flexibility for ambitious missions requiring high duty cycles and years of operation. Planetary spacecraft need the ability to rendezvous with, orbit, and conduct in situ exploration of planets, satellites and other solar system bodies (http://www.nap.edu/catalog.php?record_id=10432 [46]). Platforms, satellites, and satellite constellations have high-precision propulsion requirements, usually in volume- and power-limited envelopes. This subtopic seeks innovations to meet SMD propulsion requirements, reflecting the goals of NASA's In-Space Propulsion Technology program to reduce the travel time, mass, and cost of SMD spacecraft. Propulsion areas include chemical and electric propulsion systems, propulsion technologies related to sample return missions to asteroids, comets, and other small bodies, propellantless options (such as aerocapture and solar sails), and less developed but emerging propulsion concepts such as advanced plasma thrusters and momentum exchange/electrodynamic reboost (MXER) tethers.

Specific sample return propulsion technologies include, but are not limited to, ascent vehicle propulsion, pumps for pressure-fed propulsion systems, long-term storage capable solid rocket propulsion technologies, lightweight propulsion components, Earth-return propulsion systems, Earth-EDL systems, and Earth Entry Vehicle heat shield materials.

This subtopic also seeks proposals that explore uses of technologies that will provide superior performance in attitude control and overall orbit control. The Small Spacecraft Build effort highlighted in Topic S4 (Low-cost Small Spacecraft and Technologies) of the solicitation participates in this subtopic. Offerors are encouraged to consider this possible flight opportunity when proposing work to this subtopic.

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

Sub Topics:
  Balloon Technology, Terrestrial and Planetary Topic S3.05
Innovations to advance terrestrial (http://sites.wff.nasa.gov/code820/ [47]) and planetary balloons and aerobots are being solicited. The technologies proposed shall have a clear path for infusion into the current flight systems within the next few years.

Currently, NASA is developing a superpressure terrestrial vehicle targeting 100 day duration missions in mid-latitude. This added capability will greatly enable new science investigations. The design of the current pumpkin shape vehicle utilizes light weight polyethylene film and high strength tendons made of twisted Zylon® yarn. The in-flight performance and health of the vehicle relies on accurate information on a number of environmental and design parameters. Therefore, NASA is seeking innovations in the following specific areas:

Devices or methods to accurately and continuously measure individual axial loading on an array of up to 200 separate tendons during a superpressure balloon mission. Tendons are the load carrying member in the pumpkin design. During a typical mission, loading on individual tendons should not exceed a critical design limit to insure structural integrity and survival. Tendons are typically captured at the fitting via individual pins. Loading levels on the tendons can range from ~20 N to ~8,000 N and temperature can vary from room temperature to the troposphere temperatures of -90°C or colder. The devices of interest shall be easily integrated with the tendons or fittings during balloon fabrication and shall have minimal impact on the overall mass of the balloon system. Support telemetry and instrumentation is not part of the this initiative; however, data from any sensors (devices) that are selected from this initiative must be able to be telemetered in-flight using single-channel (two-wire) interface into existing NASA balloon flight support systems.

Devices or methods to accurately and continuously measure ambient air, helium gas, and balloon film temperature. The measurements are needed to accurately model the balloon performance during a typical flight at altitudes of approximately 120,000 feet. The measurement must compensate for the effects of direct solar radiation through shielding or calculation. Minimal mass and volume are highly desired. For film measurement, 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 measurement of helium gas and balloon film temperature must be compatible with existing NASA balloon packaging, inflation and launch methods. Devices and/or methods must be able to interface with existing NASA balloon flight support systems or alternatively, a definition of a telemetry solution be provided.

Innovations in materials, structures, and systems concepts have also enabled buoyant vehicles to play an expanding role in planning NASA's future Solar System Exploration Program. Balloons and airships are expected to carry scientific payloads on Mars, Venus, and Titan in order to investigate their atmospheres in situ and their surfaces from close proximity. Their envelopes will be subject to extreme environments and must support missions with a range of durations. Proposals are sought in the following areas:

Metal Balloons for High Temperature Venus Exploration

Balloons made of metals are a potential solution to the problem of enabling long duration flight in the hot lower atmosphere of Venus. Proposals are sought for metal balloon concepts and prototypes that provide 1-5 m^3 of fully inflated volume, areal densities of 1 kg/m^2 or less, sulfuric acid compatibility at 85% concentration, and operation at 460 °C for a period of up to 1 year. (http://newfrontiers.nasa.gov/program_plan.html [48])

Cryogenic Testing of Titan Aerobots (http://www.nap.edu/catalog.php?record_id=10432 [46])

Aerobots at Titan must operate at cryogenic temperatures in the range of 85 to 95 K. There is a need for inexpensive test facilities to conduct experiments on sub-scale and full scale prototype balloons ranging in size from 1 to 15 m in their largest dimension. Proposals are sought for the development and validation of innovative, low cost test facilities that can be used to conduct light gas and Montgolfiere balloon experiments with time scales ranging from hours to weeks.

Gas Management Systems for Titan Aerobots

Hydrogen-filled aerobots at Titan must contend with the problem of gas leakage over long duration (1 year or more) flights. Proposals are sought for the development and testing of two kinds of prototype devices that can be carried on the aerobot to compensate for these gas leakage problems: one device is to produce make-up hydrogen gas from atmospheric methane; the other device is to remove atmospheric gas (mostly nitrogen) that leaks from the ballonets into the hydrogen-filled blimp. Both kinds of devices will need to operate on no more than 15 W of electrical power each while compensating for a leakage rate of at least 40 g/week of hydrogen or 500 g/week of nitrogen.

Ground-launched Mars Balloons

NASA is interested in small balloons with very light payloads (< 1 kg) that can be autonomously launched on the Martian surface from a lander or large rover. Proposals are sought for balloon designs and systems concepts to enable this. It is important that proposals directly address the difficult problem of not damaging the balloon despite proximity to landed equipment and surface rocks. Preference will be given to proposals that include proof-of-

concept experiments addressing key feasibility questions for the proposed approach.

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

Sub Topics:
  NanoSat Launch Vehicle Technologies Topic S4.01

The space transportation industry is in need of low-cost, reliable, on-demand, routine space access. Both government and private entities are pursuing various launch systems and architectures aimed at addressing this market need. Significant technical risk and cost exists in new system development and operations - reducing incentive for private capital investment in this still-nascent industry. Public and private sector goals are aligned in reducing these risks and enabling the development of launch systems capable of reliably delivering payloads to low Earth orbit. The NanoSat Launch Vehicle Technology subtopic will particularly focus on higher risk entrepreneurial projects for dedicated nano and small spacecraft launch vehicles. This subtopic is seeking proposals in the following, but not limited, areas:

- Conceptual designs of system/architectures capable of reducing the mission costs associated with small payload delivery to LEO.
- Maturation of hypersonic and small launch vehicle design and analysis tools or tool-sets aimed at increasing the state-of-the-art while reducing the required design cycle time and human interaction.
- Maturation of key technologies/processes for hypersonic and small launch vehicles including, but not limited to:
    - Thermal protection systems;
    - Airframe and subsystem structures that increase system performance and propellant mass fraction;
    - Vehicle sensor networks.
- Novel, low-cost modular adapters and release mechanisms.
- Lightweight interstage designs.

Applications of wireless networking technologies for small launch vehicles are also specifically of interest to this subtopic. This technology could be used for vehicle to ground communications (spread-spectrum and non-licensed technologies), as well as within the vehicle itself. We desire new architectures for intelligent on-board communications as well as satellite-to-satellite communication using machine-to-machine (M2M) solutions. The traditional wire harness architecture could be replaced by the wireless technology for command and control, which would reduce vehicle mass and improve reliability. Also stage-to-stage interfaces and vehicle-payload interfaces are of interest. These wireless technologies can include but are not limited to WIMAXTM and ZIGBEETM.

Non-propulsive approaches and architectures for new launch vehicles can also achieve increases in launch vehicle payload mass delivered to orbit for small spacecraft missions. Offerors should consider development, test, and operational factors to show improvements in development and operational costs, payload mass fraction, and mission assurance. Special attention should be given to improved integration between the launch vehicle and payloads to further reduce operational costs. Furthermore, non-propulsive launch vehicle technologies have a dramatic impact on launch vehicle performance and constitute a large percentage of development and operational costs.

They include, but are not limited to:

- Robust on-board Guidance, Navigation and Control (GN&C) avionics. GN&C should be modular (including modular software architectures) and make use of modern architectures, including high-performance low-weight avionics hardware, and modern software tools. Emphasis is on low-weight architecture to allow maximum payload capacity.
- Range safety solutions and operational concepts to lower costs. These may include alternative solutions to expensive explosive destruct packages, including, but not limited to propulsion-cutoff systems, autonomous flight-abort systems, etc.

Research should be conducted to demonstrate technical feasibility during Phase 1 and show a path toward a Phase 2 hardware and software demonstration, and when possible, deliver a demonstration unit or software package for NASA testing at the completion of the Phase 2 contract.

Phase 2 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 space-worthy systems.

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

Sub Topics:
   Rapid End-to-End Mission Design and Simulation Topic S4.02
This subtopic addresses the need to rapidly and efficiently analyze, design, simulate, and evaluate competing mission concepts.

The traditional mission design process involves multiple tools and trades, resulting in design data being generated and stored in various proprietary formats, making iterative trades cumbersome. Current mission design and simulation environments require dedicated personnel that execute mission simulations for mission projects, but at a significant cost to project budgets. For efficient mission design and simulation activities, particularly for small satellites and other missions with small budgets and cost margins, there is a need for user-friendly tools that will provide seamless data flow between simulation environments with little overhead.

This subtopic seeks proposals for a toolset that shall integrate legacy engineering software with user-generated design and simulation tools into a single, user-friendly environment. The toolset shall automate the flow of data between analysis, design, and simulation applications with minimal user manipulation. The data shall also be preserved through the various design phases from initial concept to execution.

Data resources to be linked include cost tracking spreadsheets, task plans, risk management databases, requirements databases, technical performance metrics and margins sheets, top level and WBS element schedules, and standard monthly status reports from WBS elements. The tool should be easily scalable for large or small projects and the number of WBS elements and features included or excluded for a given project should be user-selectable. User and group permission and access controls are required.

Research should be conducted to demonstrate technical feasibility during Phase 1 and show a path toward a Phase 2 hardware and software demonstration, and when possible, deliver a demonstration application for NASA testing at the completion of the Phase 2 contract.

Phase 2 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.

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

Sub Topics:
 Cost Modeling Topic S4.03
An integrated cost-design model is required, one that incorporates the regression analysis and statistical validity of historical parametric cost models with the flexibility and relevance of a ground-up, or grassroots, cost model. By explicitly focusing on the prime cost determinant, labor, as opposed to the spacecraft parameters, and determining the historic relationships between the tasks on the WBS and cost for a given institution/firm, as opposed to space industry in general, a cost model can be produced that is specific to the production process used by an institution. Such a cost model would predict the cost of individual tasks at sub-system and component levels within a given institution, enabling cost to be included as an endogenously determined variable in the design process.

Such an integrated cost-design model is currently embodied only as human capital in individual managers who have, through their personal experience, accumulated knowledge of cost-design relationships. When these experienced managers leave, the institution loses the understanding of the relationship between cost and design choices that the manager had built up through years of experience. Without this experience, ground-up cost models can be wildly inaccurate and as a result, only parametric cost models such as the NASA/Air Force Cost Model (NAFCOM) and the Small Satellite Cost Model (SSCM) are accepted for Technical Management and Cost (TMC) reviews. This is particularly problematic for small low-cost spacecraft where designs are rapidly evolving, management structures are more varied, and the entire purpose is to provide spacecraft at costs lower than what has historically been considered possible.

This subtopic seeks proposals to define management system requirements and develop software that would enable cost (and schedule) data at the task-level to be collected and centralized creating a base dataset for institution-based cost models and cost management research. The system would codify cost information of projects ensuring it is preserved beyond the careers of individual managers and would, over time, accumulate long time-series of task-level cost information that would enable ground-up institution-based cost models to stand on a rigorous statistical framework. This would enable the development of a generic institution-based design-cost model that can then be tailored for individual institutions and used across the industry.

Research should be conducted to demonstrate technical feasibility during Phase 1 and show a path toward a Phase 2 hardware and software demonstration, and when possible, deliver a demonstration unit or software package for NASA testing at the completion of the Phase 2 contract.

In Phase 1, research should provide examples of proven cost benefits and project successes based on the use of integrated management tools for management of multiple simultaneous distributed projects. Architectures should be proposed for implementation of an integrated multi-project management tool.

In Phase 2, a management tool set will be implemented and demonstrated as part of an actual small satellite management project. The tool will be evaluated for ease of use, effectiveness as a NASA project set-up tool, management information tool, and reporting tool. Feasibility for a single manager to effectively manage and report on multiple simultaneous projects will be assessed. Project users from the WBS elements of the satellite project will evaluate ease of use of uploading data.

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

Sub Topics:
 Reusable Flight Software Topic S4.04
There is a need to rapidly develop and deploy small satellites and easily adapt new payloads in a cost effective

manner. The cost of flight software, including algorithms and data management, is continuing to increase and multiply in complexity.

Spacecraft software applications are typically customized, however, development costs can be driven down and a plug-and-play capability can be fostered through repeated use of reusable software and functional libraries that are developed once and updated only to enhance performance or correct deficiencies.

Small satellites can be effectively designed for multiple uses of the same nominal hardware set to perform multiple missions. Interfaces between differing payloads are anticipated to be "plug-and-play", where the interface between hardware elements is transparent across the interface. This implies that and allows the software to be reusable from mission to mission. An analogy would be a reusable core executive operating system that controls central satellite functions. Each payload or special hardware element will have subservient applications, written by the element developed that provides special needs. In order to be most economical, the subservient applications should be capable of utilizing an extensive library of modules.

This subtopic calls for the definition and development of a common core executive software and library modules that can be utilized repeatedly for many small satellite missions. The software shall be portable between several types of core processors. The executive and libraries shall provide robust functionality, based on open standards that can be utilized by specialized payload and component developers. In this manner, a minimum amount of custom software, limited to basic functional control of certain hardware elements, will be required. Library functions within the reusable core executive shall be capable of performing computation intense work. The intent is to not modify the reusable core executive except as experience dictates from previous missions.

The Reusable Flight Software subtopic encourages offerors to utilize open source software and hardware solutions to be utilized for other actors, including entrepreneurial and university teams, for reusability.

Research should be conducted to demonstrate technical feasibility during Phase 1 and show a path toward a Phase 2 hardware and software demonstration, and when possible, deliver a demonstration unit or software package for NASA testing at the completion of the Phase 2 contract.

Phase 2 emphasis should be placed on developing and demonstrating the software technology under relevant test conditions. Additionally, a path should be outlined that shows how the technology could be commercialized or further developed into space-worthy systems.

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

Sub Topics:
  Planetary Entry, Descent, Ascent, Rendezvous and Landing Technology Topic S5.01
NASA seeks innovative sensor technologies to enhance success for entry, descent and landing (EDL) operations on missions to Mars. This call is not for sensor processing algorithms. Sensing technologies are desired which determine the entry point of the spacecraft in the Mars atmosphere; provide inputs to systems that control spacecraft trajectory, speed, and orientation to the surface; locate the spacecraft relative to the Martian surface; evaluate potential hazards at the landing site; and determine when the spacecraft has touched down. Appropriate sensing technologies for this topic should provide measurements of physical forces or properties that support some aspect of EDL operations. NASA also seeks to use measurements made during EDL to better characterize the Martian atmosphere, providing data for improving atmospheric modeling for future landers. Proposals are invited for innovative sensor technologies that improve the reliability of EDL operations.

Products or technologies are sought that can be made compatible with the environmental conditions of spaceflight and the rigors of landing on the Martian surface. Successful candidate sensor technologies can address this call by:

- Providing critical measurements during the entry phase (e.g., pressure and/or temperature sensors embedded into the aeroshell);
- Improving the accuracy on measurements needed for guidance decisions (e.g., surface relative velocities, altitudes, orientation, localization);
- Extending the range over which such measurements are collected (e.g., providing a method of imaging through the aeroshell, or terrain-relative navigation that does not require imaging through the aeroshell);
- Enhancing the situational awareness during landing by identifying hazards (rocks, craters, slopes), or providing indications of approach velocities and touchdown;
- Substantially reducing the amount of external processing needed to calculate the measurements; and
- Significantly reducing the impact of incorporating such sensors on the spacecraft in terms of volume, mass, placement, or cost.

For a sample return mission, rendezvous technologies for capture of an Orbiting Sample (OS) with the return spacecraft:

- Remotely actuated mechanisms for automated OS capture;
- Optical and contact sensors.

For a sample return mission, monitoring local environmental (weather) conditions on the surface just prior to Planetary Ascent Vehicle (PAV) launch, via appropriate low-mass sensors.

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

Sub Topics:
  Sample Collection, Processing, and Handling Topic S5.02
Robust systems for sample acquisition, handling and processing are critical to the next generation of robotic explorers for investigation of planetary bodies (http://books.nap.edu/openbook.php?record_id=10432&page=R1 [51]). Limited spacecraft resources (power, volume, mass, computational capabilities, and telemetry bandwidth) demand innovative, integrated sampling systems that can survive and operate in challenging environments (extremes in temperature, pressure, gravity, vibration and thermal cycling). Relevant systems could be integrated

on multiple platforms, however of primary interest are samplers that could be mounted on a mobile platform, such as a rover. For reference, current Mars-relevant rovers range in mass from 200 – 800 kg.

Sample Acquisition

Research should be conducted to develop compact, low-power, lightweight subsurface sampling systems that can obtain 1 cm diameter cores of consolidated material (e.g., rock, icy regolith) up to 10 cm below the surface. Systems should be capable of autonomously acquiring and ejecting samples reliably. Other sample types of interest are unconsolidated regolith, dust, and atmospheric gas.

Sample Manipulation (core management, sub-sampling/sorting)

Sample manipulation technologies are needed to enable handling and transfer of structured and unstructured samples from a sampling device to instruments and sample processing systems. Core and regolith samples may be variable in size and composition, so a sample manipulation system needs to be flexible enough to handle the sample variability. Core samples will be on the order of 1 cm diameter and up to 10 cm long. Soil and rock fragment samples will be of similar volumes.

System Robustness and Reliability

Consideration should be given to potential failure scenarios for integrated systems. For example, recovery and mitigation techniques for platform slip and borehole misalignment should be addressed. Significant attention should be given to the sensing and automation required for real-time control, fault diagnosis and recovery. In the case of rover-mounted subsurface sampling systems, the ability to release under load will be critical to mitigate risk of losing mobility if unexpected subsurface conditions are encountered.

Sample Integrity (encapsulation and contamination)

For a sample return mission, it is critical to find solutions for maintaining physical integrity of the sample during the surface mission (rover driving loads, diurnal temperature fluctuations) as well as the return to Earth (cruise, atmospheric entry and impact). Technologies are needed for characterizing state of sample in situ – physical integrity (e.g., cracked, crushed), sample volume, mass or temperature, as well as retention of volatiles in solid (core, regolith) samples, and retention of atmospheric gas samples.

Also of particular need are means of acquiring subsurface rock and regolith samples with minimum contamination. This contamination may include contaminants in the sampling tool itself, material from one location contaminating samples collected at another location (sample cross-contamination), or Earth-source microorganisms brought to the Martian surface prior to drilling ('clean' sampling from a 'dirty' surface). Consideration should be given to use of materials and processes compatible with 110-125°C dry heat sterilization. In situ sterilization may be explored, as well as innovative mechanical or system solutions – e.g., single-use sample "sleeves," or fully-integrated sample acquisition and encapsulation systems.

For a sample return mission, sample transfer of a payload into a Planetary Ascent Vehicle (PAV)

- Automated payload transfer mechanisms;
- Orbiting Sample (OS) sealing techniques.

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

Sub Topics:
  Surface and Subsurface Robotic Exploration Topic S5.03
Technologies are needed to enable access and sample acquisition at surface and subsurface sampling sites of

scientific interest on Mars (http://books.nap.edu/openbook.php?record_id=10432&page=R1 [51]). Mobility technology is needed to enable access to difficult-to-reach sites such as access through steep terrain. Many scientifically valuable sites are accessible only via terrain that is too steep for state-of-the-art planetary rovers to traverse. Sites include crater walls, canyons, and gullies. Tethered systems, non-wheeled systems, and marsupial systems are examples of mobility technologies that are of interest. Tether technology could enable new approaches for deployment, retrieval and mobility. Innovative marsupial systems could allow a pair of vehicles with different mobility characteristics to collaborate to enable access to challenging terrain. Single vehicle systems might utilize a 200 kg class rover and dual vehicle systems might utilize a 500-800 kg primary vehicle that provides long traverse to the vicinity of a challenging site and then deployment of a smaller 20-50 kg vehicle with steep mobility capability for access and sampling at the site.

Technologies to enable acquisition of subsurface samples are also needed. Technologies are needed to acquire core samples in the shallow subsurface to about 10cm and to enable subsurface sampling in multiple holes at least 1 - 3 meters deep through rock, regolith or ice compositions. Shallow subsurface sampling systems need to be low mass and deeper subsurface sampling solutions need to be integratable onto 500-800 kg stationary landers and mobile platforms. Consideration should be given for potential failure scenarios, such as platform slip and borehole misalignment for integrated systems, and the challenges of dry drilling into mixed media including icy mixtures of rock and regolith. Systems should ensure minimal contamination of samples from Earth-source contaminants and cross-contamination from samples at different locations or depths.

Innovative low-mass, low-power, and modular systems and subsystems are of particular interest. Technical feasibility should be demonstrated during Phase 1 and a full capability unit of at least TRL level 4-6 should be delivered in Phase 2. Specific areas of interest include the following:

- Tether play-out and retrieval systems including tension and length sensing;
- Low-mass tether cables with power and communication;
- Steep terrain adherence for vertical and horizontal mobility;
- Modular actuators with 1000:1 scale gear ratios;
- Electro-mechanical couplers to enable change out of instruments on an arm end-effector;
- Drill, core, and boring systems for subsurface sampling to 10cm or 1 to 3 meters.

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

Sub Topics:
  Technologies for Low Mass Mars Ascent Vehicles (PAV) Topic S5.04
NASA aims to design, build and test vehicles that will be launched from the surface of other planets and place a payload, Orbiting Sample (OS), into orbit (http://marsprogram.jpl.nasa.gov/missions/future/futureMissions.html [25]). We are seeking proposals for the development of innovative technologies to support future Payload Ascent Vehicles (PAVs) and associated sample operations. Technology innovations should either enhance vehicle capabilities (e.g., increased payload, launch success probability, mission success) or ease implementation in spaceborne missions (e.g., reduce size, weight, power, improve reliability, or lower cost). The areas of interest for this call are listed below.

Alternate propellants, thrusters and propulsion feed system technologies for the PAV:

- Higher performing monopropellants with specific impulse >240 secs;
- High chamber pressure thrusters > 500 psia;
- Pressurization component technologies to reduce system mass (filters, solenoid valves, latch valves, tanks, fill & drain and check valves);
- Small lightweight pump technologies to operate at >500 psi output pressure;
- Non-pyrotechnic isolation valves.

Proposals should show an understanding of one or more relevant science needs, and present a feasible plan to

fully develop a technology and infuse it into a NASA program.

Sub Topics:

Technologies for Large-Scale Numerical Simulation Topic S6.01

NASA scientists and engineers are increasingly turning to large-scale numerical simulation on supercomputers to advance understanding of Earth and astrophysical systems, as well as to conduct high-fidelity engineering analyses (http://nasascience.nasa.gov/earth-science/water-and-energy-cycle/research/?searchterm=large%20scale%20simulation [52]). The goal of this subtopic is to make NASA's supercomputing systems and associated resources easier to use, thereby broadening NASA's supercomputing user base and increasing user productivity. Specific objectives are to:

- Reduce the learning curve for using supercomputing resources;
- Minimize total time-to-solution (i.e., time to discovery, understanding, or prediction);
- Increase the scale and complexity of computational analysis and data assimilation;
- Accelerate advancement of system models and designs.

The approach of this subtopic is to develop intuitive, high-level tools, interfaces, and environments for users, and to infuse them into NASA supercomputing operations. Successful technology development efforts under this subtopic would be considered for follow-on funding by, and infusion into either of the NASA high-end computing (HEC) projects, including the High End Computing Capability (HECC) project at Ames and the NASA Center for Computational Sciences (NCCS) at Goddard. SBIR projects should be informed by direct interactions with one or both HEC projects. Research should be conducted to demonstrate technical feasibility during Phase 1 and show a path toward a Phase 2 prototype demonstration. Open Source software and open standards are strongly preferred.

Specific areas of interest include:

Application Development Environments

With the increasing scale and complexity of supercomputers, users must often expend a tremendous effort to translate their physical system model or algorithm into a correct and efficient supercomputer application code. This subtopic element seeks intuitive, high-level application development environments, ideally leveraging high-level programming languages to enable rapid supercomputer application development, even for novice users. This environment should dramatically simplify application development activities such as porting, parallelization, debugging, scaling, performance analysis, and optimization.

Results V&V

A primary barrier to effective use of supercomputing by novices, and often experts, is understanding the accuracy of their computational results. Errors in the input data, domain definition, grids, algorithms, and application code can individually or in combination produce non-physical results that a user may not detect. This subtopic element seeks tools and environments to help users with verification and validation (V&V) of simulation results. This could be accomplished by enabling comparison of results from similar applications or with known accurate results, access to results analysis tools and domain experts, or access to error estimation tools and training.

Data Analysis and Visualization

Supercomputing computations almost invariably result in tremendous amounts of data, measuring in the gigabytes or terabytes, and with many dimensions and other complexity aspects. This subtopic element seeks user-friendly tools and environments for analysis and visualization of large-scale, complex data sets typically resulting from supercomputing computations.

Ensemble Management

Conducting and fusing the results from an ensemble of related computations is an increasingly common use of supercomputers. However, ensemble computing and analysis introduces a new set of challenges for deriving full value from using supercomputing. This subtopic element seeks tools and environments for managing and automating ensemble supercomputing-based simulation, analysis, and discovery. Functions could include managing and automating the computations, model or design optimization, interactive computational steering, input and output data handling, data analysis, visualization, progress monitoring, and completion assurance.

Integrated Environments

The user interface to a supercomputer is typically a command line or text window, where users may struggle to understand resources and services available, locate or develop applications, understand the job queue structure, develop scripts to submit jobs to the queue, manage input and output files, archive data, monitor resource allocations, collaborate and share data and codes, and many other essential supercomputing tasks. This subtopic element seeks more intuitive, intelligent, and integrated interfaces to supercomputing resources. This integrated environment could include access to user training (e.g., tutorials, case studies, experts), application development tools, standard (e.g., production, commercial, and Open Source) supercomputing applications, results V&V tools, computing and storage resources, ensemble management tools, workflow management, data analysis and visualization tools, and remote collaboration.

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

Sub Topics:
  Sensor and Platform Data Processing & Control Topic S6.02
This subtopic seeks proposals for software-based advances in data collection quality and/or coverage of scientific instruments that support NASA Science Mission Directorate objectives across any of the Earth, Solar, Lunar, Space, or Planetary sciences.

Algorithmic based approaches expressed in software or reconfigurable hardware can improve measurement quality and coverage of existing scientific instrument technologies. Software or reconfigurable hardware based computing can enable design trades to reduce cost and or mass of instruments by implementing needed sensor or platform capabilities in software. Limited computing resources can require innovative approaches to specific problems or use of FPGA hardware.

Target platforms or instruments can be designed to fly on any of the broadest range of NASA platforms ranging from airborne (e.g., Aircraft, UAVs and SOFIA), small, micro, and nano-satellites that support current and anticipated NASA science mission to NASA's flagship mission platforms. The Small Spacecraft Build effort highlighted in Topic S4 (Low-cost Small Spacecraft and Technologies) of this solicitation participates in this subtopic. Offerors are encouraged to take this relationship in consideration as a possible flight opportunity when proposing work to this subtopic.

New approaches to software frameworks or APIs are discouraged. Technological advances should leverage or extend existing standards or capabilities within the respective science communities (i.e., Sensor Mark-up Language, Virtual Observatory, Earth Science Federation standards, Planetary data standards). Proposals can develop instrument specific software if demonstrated how the software can improve instrument performance (such as improving sensor calibration and correction of data in a tightly closed loop without human intervention). Other examples would show how on-board data processing enables rapid analysis or data sharing between instruments/platforms (e.g., perform level 0, level 1 or level 2 processing on-board the sensor or platform to support

decision making based on data results).

Proposers are encouraged to plan on making contact with existing sensor development or prototype development teams or NASA relevant platform developers to understand the computation services available on the sensor, platform and the information flow expected between the sensor and human controller.

- Novel approaches that can leverage specialized, space qualified computing resources such as FPGAs that return order of magnitude reduction in data volume or screening capabilities are desirable.
- Improvements in measurement quality include system models of specific instruments (developed other SBIR subtopics or elsewhere) that account for more of the underlying instrument physics, improved data calibration and data correction capabilities and instrument "intelligence".
- Improved coverage can be achieved by data compression and/or data prioritization for transmission and closing the collection loop; also by the rapid assessment of data content for re-tasking the platform and sensor as the data are collected.

For data compression, aggressive metrics for compression and data volume have the following requirements:

RADAR Missions	SMAP (RADAR)	DESDynI (RADAR)	SWOT (RADAR)
OBP Input data rate (MHz)	32	400	500
Processor Throughput (GFLOPS)	7	20	90
Data Compression Ratio	80:1	10:1	90:1

Where raw data sample spacing is 0.75 m x 1.5 m (16 bits per sample), and the output data sample spacing is 10 m x 10 m (16 bits per sample).

For Hyper-spectral imaging instruments, here is an exemplar requirement on data compression and on-board feature detection.

Data Rate:	660 gigabits per orbit, 220 megabits per second
Data Compression Ratio:	> 3.0
On-board Detection Capability:	A quick look at the data for presence of cloud cover.

Proposals should show an understanding of one or more relevant science needs, and present a feasible plan to fully develop a technology and infuse it into a NASA program.
Sub Topics:
  Data Analyzing and Processing Algorithms Topic S6.03
This subtopic seeks technical innovation and unique approaches for the processing and the analysis of data from NASA's space and Earth science missions
(http://nasascience.nasa.gov/earth-science/atmospheric-composition/research/ [53]). Analysis of NASA science data is used to understand dynamic systems such as the sun, oceans, and Earth's climate as well as to look back in time to explore the origins of the universe. Complex algorithms and intensive data processing are needed to

understand and make use of this data. Advances in such algorithms will support science data analysis related to current and future missions and mission concepts such as the Landsat Data Continuity Mission (LDCM) (http://science.hq.nasa.gov/missions/satellite_56.htm [54]), the NPOES Preparatory Project (NPP) (http://science.hq.nasa.gov/missions/satellite_58.htm [55]), the Orbiting Carbon Observatory (OCO) (http://science.hq.nasa.gov/missions/satellite_61.htm [56]), the Lunar Reconnaissance Orbiter (LRO), (http://nssdc.gsfc.nasa.gov/nmc/spacecraftDisplay.do?id=LUNARRO [57]), the Lunar Atmosphere and Dust Environment Explorer (LADEE) satellite (http://nssdc.gsfc.nasa.gov/planetary/ [58]), and the James Webb Space Telescope (JWST) (http://www.jwst.nasa.gov/ [39]).

Research should be conducted to demonstrate technical feasibility during Phase 1 and show a path toward a Phase 2 prototype demonstration. Innovations are sought in data processing and analysis algorithms in the following areas:

NASA seeks tools that increase the utility of scientific research data, models, simulations, and visualizations. Of particular interest are innovative computational methods that will dramatically increase algorithm efficiency and thus performance of scientific applications such as assimilation/fusion of multiple source data, mining of large data holdings, reduction of telescope data and decision support systems for Lunar and planetary science.

Tools to improve predictive capabilities, to optimize data collection by identifying gaps in real-time, and to derive information through synthesis of data from multiple sources are also needed. The ultimate goal is to increase the value of data collected in terms of scientific discovery and application. Data analysis and processing must relate to advancement of NASA's scientific objectives.

NASA is soliciting proposals for software tools which access, fuse, process, and analyze image and vector data for the purpose of analyzing NASA's space and Earth science mission data. Tools and products might be used for broad public dissemination or for communicating within a narrower scientific community. These tools can be plug-ins or enhancements to existing software or on-line services. They also can be new stand-alone applications or web services, provided that they are compatible with most widely-used computer platforms and exchange information effectively (via standard protocols and file formats) with existing, popular applications. It is highly desirable that the project development leads to software that is infused into NASA programs and projects.

To promote interoperability, tools shall use industry standard protocols, formats, and APIs, including compliance with the ISO, FDGC, and OGC standards as appropriate.

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

Sub Topics:
  Data Management - Storage, Mining and Visualization Topic S6.04
This subtopic focuses on supporting science analysis through innovative approaches for managing and visualizing collections of science data which are extremely large, complicated, and are highly distributed in a networked environment that encompasses large geographic areas. There are specific areas for which proposals are being sought:

Distributed Scientific Collaboration

- Social networking tools that enable high bandwidth scientific collaboration among scientists distributed worldwide in a large number of different organization. These tools should allow scientists to share data and computational resources, allow collaborative visualization of data, promote the development of online communities for sharing thoughts and ideas, and address issues of data and system security.
- Novel software tools for data viewing, real-time data browse that will enable users to 'fly' through the data space to locate specific areas of interest, and general purpose rendering of multivariate geospatial scientific data sets that use geo-rectification, data overlays, data reduction, and data encoding across widely differing

data types and formats.

- Novel 3D hardware virtual reality environments for scientific data visualization that make use of 3D presentation techniques that minimize or eliminate the need for special user devices like goggles or helmets.

Distributed Data Management and Access

- Metadata catalog environments to locate very large and diverse science data sets that are distributed over large geographic areas.
- Dynamically configurable high speed access to data distributed and shared over wide area high speed network environments.
- Object based storage systems, file systems, and data management systems that promote the long term preservation of data in a distributed online (i.e. disk based) storage environment, and provide for recovery from system and user errors.

Research should be conducted to demonstrate technical feasibility during Phase 1 and show a path toward a Phase 2 hardware/software demonstration, and when possible, deliver a demonstration unit for functional and environmental testing at the completion of the Phase 2 contract.

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

Sub Topics:
  Software as a Service to Large Scale Modeling Topic S6.05
Currently there are notable obstacles in making NASA's Earth and space science research models useful to new investigators. Much of the software, upwards of hundreds of thousands of lines of code per model, has evolved gradually over the past three decades. At their inceptions the individual numerical models were intricate elements of independent research projects, intended to be mostly internal products rather than tools contributing to a larger, collaborative effort in Earth and space sciences. Hence today when investigators from outside the developers' organizations choose to begin a collaboration, or merely want to use the model for their own benefit, they are often required to adhere to the unfamiliar development environment of the host institution. This environment typically includes the regulation and management of the software repository, the data management system, and the high-end computing platforms. Problems that arise from this type of a work arrangement include:

- IT security policies that restrict certain individuals from obtaining access to Government facilities (especially with providing foreign national graduate students access to the institutional high-end computers that host a particular model);
- Knowledge of running a model residing "in the heads" of support programmers, often too busy to assist outsiders;
- Interface components residing in individuals' directories unknown to others who might take advantage of them;
- User administration practices (userids, passwords, filesystem/data management, other IT security rules) that are specific to one agency's computing center;
- A lack of front-end tools available to other model developers to set up and run collaborative experiments.

The Agency seeks a computational "service layer" to enhance NASA's scientific numerical modeling efforts. The goal is to improve the accessibility of the models to universities and other Government institutions for research and operations. Proposals are sought that develop methods for hosting NASA's Earth and space science models under a "Software As A Service (SaaS)" paradigm. Proposal are also sought which couple model components and ancillary programs under a service-oriented architecture. A feasibility study should be conducted during Phase 1 that will lead to a Phase 2 prototype that makes use of a NASA Earth or space science numerical model. Under such a scenario the back-end supercomputing environment should be segregated from the user's work environment while providing an interface to specific, secure services that will allow (1) execution of the model as a "black box" and (2) the ability to edit model elements, upload, recompile, and execute.

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

Sub Topics: