NASA's Earth Science Enterprise (ESE) is studying how our global environment is changing. Using the unique perspective available from space and airborne platforms, NASA is observing, documenting, and assessing large-scale environmental processes with emphasis on atmospheric composition, climate, carbon cycle and ecosystems, the Earth’s surface and interior, the water and energy cycles, and weather. A major objective of the ESE instrument development programs is to implement science measurement capabilities with small 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. Consequently, the objective of the Instruments for Earth Science Measurements SBIR topic is to develop and demonstrate instrument component and subsystem technologies that reduce the risk, cost, size, and development time of Earth observing instruments, and enable new Earth observation measurements. The following subtopics are concomitant with this objective and are organized by measurement technique.

Subtopics

E1.01 Passive Optics
Lead Center: LaRC
Participating Center(s): ARC, GSFC

The following technologies are of interest to NASA in the remote sensing subtopic “passive optics." Passive optical remote sensing generally requires that deployed devices have large apertures and large throughput. NASA is interested primarily in instrument technologies suitable for aircraft or space flight platforms, and these inherently also prefer low mass, low power, fast measurement times, and a high degree of robustness to survive vibrations in flight or at launch. Wavelengths of interest range from ultraviolet through the far infrared. Development of techniques, components and instrument concepts that can be developed for use in actual deployed devices and systems within the next few years is highly encouraged.

Technologies and components that are not clearly suitable for use in high throughput remote sensing instruments are not applicable to this subtopic. Technical and scientific leads at NASA have given careful consideration to the
technology areas described below, and responses are solicited for these topics.

1) Stiff actuator technology designed to produce precisely controlled motion of large (> 1.0 cm diameter) optical elements intended for use in tunable Fabry-Perot and Fourier Transform Spectrometer (FTS) instruments. Motion ranges of particular interest include 20–60 µm, 1–2 mm, and 3–5 cm. Techniques applicable to very cold temperature ( 

2) Technology leading to significant improvements in capability of large format (> 1 inch diameter), very narrow band (-1 full-width at half-maximum), polarization insensitive, high throughput infrared (0.7–15 µm) optical filters.

3) Large format (> 1 inch diameter) high-transmission far infrared filters. Technology and techniques leading to filters operating at wave numbers between 500 and 5 cm$^{-1}$ with FWHM less than 2 cm$^{-1}$ are of immediate interest, though technology leading to very high transmission edge filters (long and short pass) is also solicited. The filters must be capable of operating in a vacuum at cryogenic temperatures.

4) High performance four-band two-dimensional (2-D) arrays (128x128 elements) in the 0.4 – 2.5 µm wavelength range with high quantum efficiencies (60%–80% or higher) in all spectral bands, low noise, and ambient temperature operation.

---

**E1.02 Lidar Remote Sensing**

**Lead Center:** LaRC  
**Participating Center(s):** GSFC

High spatial resolution, high accuracy measurements of atmospheric parameters from ground-based, airborne, and spaceborne platforms require advances in the state-of-the-art lidar technology with emphasis on compactness, reliability, efficiency, low weight, and high performance. Innovative technologies that can expand current measurement capabilities to airborne, spaceborne, or Unmanned Aerial Vehicle (UAV) platforms are particularly desirable. Development of techniques, components, and instrument concepts that can be used in actual deployed systems within the next few years is highly encouraged. Technologies and components that are not clearly suitable for effective lidar remote sensing or field deployment are not applicable to this subtopic. This subtopic considers components, subsystems, and complete instrument packages addressing the following specific measurement needs:

- Molecular species (ozone, water vapor, and carbon dioxide);  
- Cloud and aerosols with emphasis on aerosol optical properties;
- Wind profiles using direct-detection lidar, or coherent-detection (heterodyne) lidar, or both; and
- Land topography (vegetation, ice, and land use).

In addition to instrument systems, innovative component technologies that directly address the measurement needs above will be considered. Technical and scientific leads at NASA have given careful consideration to the component technologies described below, and responses are solicited for these technology areas.

1. Novel laser materials and components for high efficiency solid state lasers operating at 1 and 2 µm wavelength regions. The laser components include:
   - Rugged, compact fiber lasers and fiber amplifiers for use at 1.5 and 1 µm;
   - Low voltage (Efficient and reliable high power, quasi-CW, pump diodes operating at 792 nm and 808 nm in fiber-coupled or free-space configuration; and
   - Laser crystals for generating 2 µm radiation with high thermal conductivity and small variation of the index of refraction with temperature.

2. High damage-resistant, efficient, inorganic and birefringent nonlinear optical materials for generation of ultraviolet and mid-infrared radiation.

3. Thermally efficient conductively-cooled head for solid-state lasers with side-pumped rod configuration, and thermally and mechanically stable optical bench.

4. Frequency-agile, semiconductor lasers operating in 1 to 2 µm wavelength region with spectral linewidth less than 200 kHz over 1 ms and optical power greater than 20 mW.

5. Scanning or scanable lightweight telescopes with an optical quality better than 1/6 wave at 632 nm, mass density less than 12 kg/m², and aperture diameters from 0.5–1.0 m.

6. Laser beam steering and scanning technologies operating at 0.355, 1.06, or 2.05 µm with 5–25 cm aperture diameter for airborne and 0.5–1.0 m for spaceborne instruments, meeting the following minimum requirements:
   - 60° field of regard
   - 90% optical throughput
   - wave single pass optical quality at 632 nm

7. Shared aperture angle-multiplexed holographic or diffractive optical elements having several fields of view, each
with angular resolution of 50 µrad or better for the Nd:YAG or Nd:YLF laser harmonics, and diffraction limited resolution for the Ho:YLF fundamental wavelength. Wide, flat, focal planes with low off-axis aberrations is of importance to terrain and vegetation mapping lidar applications. Hybrid designs using both 2053 nm or 1064 nm and 355 nm simultaneously are needed for dual wavelength Doppler wind lidar applications. Materials and technologies are needed that can be scaled up to 1 m apertures and larger, and space qualified. Designs using lightweight materials, such as composites or membranes and deployable folded architectures, are also desired to decrease system size and weight.

8. High gain, low noise photon counting detectors that operate without the use of cryogens are needed. Other desirable properties are linearity over a large dynamic range, saturation count rates over 100 MHz, reasonable active area size (>200 µm), 250–2200 nm response wavelengths, and high clocking and readout rates with low read noise. High-speed (500 Msamples per second or greater) waveform digitizers are also of interest for operation with integrated pulse-finding capability suitable for continuous operation and capable of locating more than 200,000 individual pulses per second.

9. Narrow band optical filters with 75% throughput, with minimum 1 inch clear aperture.

E1.03 In Situ Sensors

Lead Center: GSFC

Participating Center(s): ARC, JPL

Proposals are sought for the development of in situ measurement systems that will enhance the scientific and commercial utility of data products from the Earth Science Enterprise program and that will enable the development of new products of interest to commercial and governmental entities around the world. Technology innovation areas of interest include:

- Autonomous Global Positioning System (GPS)-located platforms (fixed or moving) to measure and transmit to remote terminals upper ocean and lower atmosphere properties including temperature, salinity, momentum, light, precipitation, and biogeochemistry.

- Dynamic stabilization systems for small instruments mounted on moving platforms (e.g., buoys and boats) to maintain vertical and horizontal alignment. Systems capable of maintaining a specified pointing with respect to the Sun are preferred.

- Small, lightweight instruments for measuring clouds, liquid water, or ice content (mass) designed for use on radiosondes, dropsondes, aerosondes, tethered balloons, or kites.

- Wide-band microwave radiometers capable of high-speed characterization of cloud parameters, including liquid and ice phase precipitation, which can operate in harsh environmental conditions (e.g., onboard ships and aircraft).

- Autonomous GPS-located airborne sensors that remotely sense atmospheric wind profiles in the troposphere and lower stratosphere with high spatial resolution and accuracy.
• Systems for \textit{in situ} measurement of atmospheric electrical parameters including electric and magnetic fields, conductivity, and optical emissions.

• Systems to measure line- and area-averaged rain rate at the surface over lines of at least 100 m and areas of at least 100x100 m.

• Lightweight, low-power systems that integrate the functions of inertial navigation systems and GPS receivers for characterizing and/or controlling the flight path of remotely piloted vehicles.

• Low-cost, stable (to within 1\% over several months), portable radiometric calibration devices in the shortwave spectral region (0.3 to 3 \(\mu\text{m}\)) for field characterization of radiance instruments such as sun photometers and spectrometers.

• Miniaturized, low power (12V DC) instruments especially suited for small boat operations that are capable of adequately resolving, at the appropriate accuracy, the complex vertical structure (optical, hydrographic, and biogeochemical) of the coastal ocean (turbid) water column. Sensors that can be easily integrated within a digital (serial) network to measure the apparent and inherent optical properties of seawater are preferred.

**E1.04 Passive Microwave**

**Lead Center: GSFC**

Proposals are sought for the development of innovative passive microwave technology in support of Earth System Science measurements of the Earth's atmosphere and surface. These microwave radiometry technology innovations are intended for use in the frequency band from about 1 GHz to 1 THz. The key science goal is to increase our understanding of the interacting physical, chemical and biological processes that form the complex Earth system. Atmospheric measurements of interest include climate and meteorological parameters including temperature, water vapor, clouds, precipitation, and aerosols; air pollution; and chemical constituents such as ozone, \(\text{NO}_x\), and carbon monoxide. Earth surface measurements of interest include water, land, and ice surface temperatures, land surface moisture, snow coverage and water content, sea surface salinity and winds, and multispectral imaging.

Technology innovations are sought that will provide the needed concepts, components, subsystems, or complete systems that will improve these needed Earth System Science measurements. Technology innovations should address enhanced measurement capabilities such as improved spatial or temporal resolution, improved spectral resolution, or improved calibration accuracies. Technology innovations should provide reduced size, weight, power, improved reliability, and lower cost. The innovations should expand the capabilities of airborne systems (manned and unmanned), as well as next generation spaceborne systems. Highly innovative approaches that open new pathways are an important element of competitive proposals under this solicitation.

Specific technology innovation areas include:

• Imaging radiometers, receivers or receiver arrays on a chip, and flux radiometers.
- Large aperture, deployable antenna systems suitable for highly reliable space deployment with root mean square (RMS) surface accuracy approaching 1/50th wavelength. Such large apertures can be real or synthetic apertures. Of key importance is the ability for a highly compact launch configuration, followed by a highly reliable erection and resultant surface configuration.

- Focal plane array modules for large-aperture passive microwave imaging applications.

- Wideband and ultra-wideband sensors with >15dB cross-pole isolation across the bandwidth.

- Sensors with low surface currents enabling scanning up to +/-50° without grating lobes, and collimation in one direction with low side lobes for 1-D aperture synthesis.

- Bi-static GPS receiving systems for application as altimeters and scatterometers.

- Enhanced onboard data processing capabilities that enable real-time, reconfigurable computational approaches which enhance research flexibility. Such approaches should improve image reconstruction, enable high compression ratios, improve atmospheric corrections, and the geolocation and geometric correction of digital image data.

- Techniques for the detection and removal of Radio Frequency Interference (RFI) in microwave radiometers are desired. Microwave radiometer measurements can be contaminated by RFI that is within or near the reception band of the radiometer. Electronic design approaches and subsystems are desired that can be incorporated into microwave radiometers to detect and suppress RFI, thus insuring higher data quality.

- New technology calibration reference sources for microwave radiometers that provide greatly improved reference measurement accuracy. High emissivity (near-black-body) surfaces are often used as onboard calibration targets for many microwave radiometers. NASA seeks ways to significantly reduce the weight of aluminum core target designs, while reliably improving the uniformity and knowledge of the calibration target temperature. NASA seeks innovative new designs for highly stable noise-diode or other electronic devices as additional reference sources for onboard calibration. Of particular interest are variable correlated noise sources for calibrating correlation-type receivers used in interferometric and polarimetric radiometers.

- New approaches, concepts and techniques are sought for microwave radiometer system calibration over or within the 1–300 GHz frequency band, which provide end-to-end calibration to better than 0.1°, including corrections for temperature changes and other potential sources of instrumental measurement drift and error.

- Microwave and millimeter wave frequency sources are sought as an alternative to Gunn diode oscillators. Compact (3) self contained oscillators with output frequency between 40 GHz and 120 GHz, low phase noise 100 mW) are needed.

- Low noise (3) heterodyne mixers requiring low local oscillator drive power (Low power lightweight microwave radiometers are desired which are able to operate stably over long periods, with DC power consumption of less than 2 W and preferably less than 1 W, not including any mechanisms.

- Monolithic microwave integrated circuit (MMIC) low noise amplifier (LNA) for space-borne microwave radiometers, covering the frequency range of 165 to 193 GHz, having a noise figure of 6.0 dB or better (and with low 1/f noise).

NASA is developing satellite systems that will use passive and active microwave sensing at L-band and other frequencies to measure sea surface salinity, and soil moisture to a depth of ~10 cm. In support of these global research efforts, the following ancillary measurement systems are required:
Inexpensive approaches to ground sensors are desired that are capable of measuring areas at least 100,000 km$^2$, with a spatial resolution of 20 km. These ground sensors will be needed to validate those space-borne measurements. Measurement of ground-wave propagation characteristics of radio signals from commercial sources may satisfy that need. Although absolute values of soil moisture are desirable, they are not required if the technique can be calibrated frequently at suitable sites. Cost per covered area, autonomous operation, anticipated accuracy, and depth resolution of the soil moisture measurement will be considerations for selection.

Autonomous GPS-located ocean platforms are needed which can measure upper ocean and lower atmosphere properties including temperature, salinity, momentum, light, precipitation, and biology, and can communicate the resultant data and computational or configuration instructions to and from remote terminals. Similar sensor packages are desired for use onboard ships while under way. This includes the development of intelligent platforms that can change measurement strategy upon receipt of a message from a command center.

Autonomous low-cost systems are desired that can measure Earth and ocean surface and lower atmospheric parameters including soil moisture, precipitation, temperature, wind speed, sea surface salinity, surface irradiance, and humidity.

Novel approaches to beam steering for these very large aperture antenna systems are also desired: 1) lightweight, electronically steerable, dual-polarized, phased-array antennas; 2) shared aperture, multi-frequency antennas; 3) high-efficiency, high power, low-cost, lightweight, phase-stable transmit/receive modules; 4) advanced antenna array architectures including scalable, reconfigurable and autonomous antennas; 5) sparse arrays, digital beamforming techniques, time domain techniques, phase correction techniques; 6) distributed digital beamforming and onboard processing technologies; and 7) brightness temperature/scatter co-registration data processing algorithms, data reduction, and merging techniques.

Ground-based microwave radiometer instrumentation, subsystems, and techniques for validating space-borne precipitation measurements. Passive microwave instrumentation, or subsystems, capable of ground-based retrievals of precipitation. The instrumentation, or subsystems, shall operate in inclement weather conditions without the interfering affects of liquid water accumulation on the aperture or field-of-view obstructions. Capabilities for volumetric scanning of the atmosphere and autonomous operation are of great interest.

E1.05 Active Microwave

Lead Center: JPL
Participating Center(s): GSFC

Active microwave sensors have proven to be ideal instruments for many Earth science applications. Examples include global freeze and thaw monitoring and soil moisture mapping, accurate global wind retrieval and snow inundation mapping, global 3-D mapping of rainfall and cloud systems, precise topographic mapping and natural hazard monitoring, global ocean topographic mapping, and glacial ice mapping for climate change studies. For global coverage and the long-term study of Earth's eco-systems, space-based radar is of particular interest to Earth scientists. Radar instruments for Earth science measurements include Synthetic Aperture Radar (SAR), scatterometers, sounders, altimeters and atmospheric radars. The life-cycle cost of such radar missions has always been driven by the resources—power, mass, size, and data rate—required by the radar instrument, often making radar not cost competitive with other remote sensing instruments. Order-of-magnitude advancement in key sensor components will make the radar instrument more power efficient, much lighter weight, and smaller in stow volume, leading to substantial savings in overall mission life-cycle cost by requiring smaller and less expensive spacecraft buses and launch vehicles. Onboard processing techniques will reduce data rates sufficiently to enable global coverage. High performance, yet affordable, radars will provide data products of better quality and deliver them to the users more frequently and in a timelier manner, with benefits for science, as well as the civil and defense
communities. Technologies that may lead to advances in instrument design, architectures, hardware, and algorithms are the focused areas of this subtopic. In order to increase the radar remote sensing user community, this subtopic will also consider radar data applications and post-processing techniques.

The frequency and bandwidth of operation are mission driven and defined by the science objectives. For SAR applications, the frequencies of interest include UHF (100 MHz), P-band (400 MHz), L-band (1.25 GHz), X-band (10 GHz) and Ku-band (12 GHz). The required bandwidth varies from a few megahertz to 20 MHz to 300 MHz to achieve the desired resolution; the larger the bandwidth, the higher the resolution. Ocean altimeters and scatterometers typically operate at L-band (1.2 GHz), C-band (5.3 GHz) and Ku-band (12 GHz). Ka-band (35 GHz) interferometers have applications to river discharge. The atmospheric radars operate at very high frequencies (35 GHz and 94 GHz) with only modest bandwidth requirements on the order of a few megahertz.

The emphasis of this subtopic is on core technologies that will significantly reduce mission cost and increase performance and utility of future radar systems. There are specific areas in which advances are needed.

- SAR for surface deformation, topography, soil moisture measurements:
  - Very large aperture L-band antennas (20 m x 20 m) for Medium Earth Orbit (MEO) or 30m diameter for Geosynchronous SAR applications.
  - Shared aperture, multi-frequency antennas (P/L-band, L/X-band).
  - Lightweight, deployable antenna structures and deployment mechanisms.
  - Rad-hard, high-efficiency, high power, low-cost, lightweight L-band and P-band T/R modules.
  - High-power transmitters (L-band, 50-100 kW).
  - L-band and P-band MMIC single-chip T/R module.
  - Rad-hard, high-power, low-loss RF switches, filters, and phase shifters.
  - Digital true-time delay (TTD) components.
  - Thin-film membrane compatible electronics. This includes: Reliable integration of electronics with the membrane, high performance (>1.2 GHz) transistor fabrication on flex material including identifying new materials, process development, and techniques that have the potential to produce large-area passive and active flexible antenna arrays.
  - Advanced transmit and receive module architectures such as optically-fed T/R modules, signal up/down conversion within the module and novel RF and DC signal distribution techniques.
  - Advanced radar system architectures including flexible, broadband signal generation and direct digital conversion radar systems.
  - Advanced antenna array architectures including scalable, reconfigurable, and autonomous antennas; sparse arrays; and phase correction techniques.
• Distributed digital beamforming and onboard processing technologies.

• SAR data processing algorithms and data reduction techniques.

• SAR data applications and post-processing techniques.

• Low-frequency SAR for subcanopy and subsurface applications:
  - Lightweight, large aperture (30 m diameter) reflector and reflectarray antennas.
  - Large electronically scanning P-band arrays.
  - Shared aperture, dual-polarized, multiple low-frequency (VHF through P-band, 50–500 MHz) antennas with highly shaped beams.
  - Lightweight, low frequency, low loss antenna feeds (VHF through P-band, 50–500 MHz).
  - High-efficiency T/R modules and transmitters (50–500 MHz, 10 kW).
  - Lightweight deployable antenna structures and deployment mechanisms.
  - Data applications and post-processing techniques.

• Polarimetric ocean/land scatterometer:
  - Multi-frequency (L/Ku-band) lightweight, deployable reflectors.
  - Large, lightweight, electronically steerable Ku-band reflectarrays.
  - Lightweight L-band and Ku-band antenna feeds.
  - Dual-polarized antennas with high polarization isolation.
  - Lightweight, deployable antenna structures and deployment mechanisms.
  - High efficiency, high power, phase stable L-band and Ku-band transmitters.
  - Low-power, highly integrated radar components.
  - Calibration techniques, data processing algorithms and data reduction techniques.
  - Data applications and post-processing techniques.

• Wide swath ocean and surface water monitoring altimeters:
  - Shared aperture, multi-frequency (C/Ku-band) antennas.
  - Large, lightweight antenna reflectors and reflectarrays.
  - Lightweight C-band and Ku-band antenna feeds.
  - Lightweight deployable antenna structures and deployment mechanisms.
- High efficiency, high power (1–10 kW) C-band and Ku-band transmitters.
- Real-time onboard radar data processing.
- Calibration techniques, data processing algorithms and data reduction techniques.

- Ku-band & Ka-band interferometers for snow cover measurement over land (Ku-band) and wetland and river monitoring (Ka-band):
  - Large, stable, lightweight, deployable structures (10–50 m interferometric baseline).
  - Ka-band along and across-track track interferometers with a few centimeters of height accuracy.
  - Ku-band interferometric polarimetric SAR.
  - Phase-stable Ku-band and Ka-band electronically steered arrays and multibeam antennas.
  - Lightweight deployable reflectors (Ku-band and Ka-band).
  - Shared aperture technologies (L/Ku-band).
  - Phase-stable Ku-band and Ka-band receive electronics.
  - High-efficiency, rad-hard Ku-band and Ka-band T/R modules or >10 kW transmitters.
  - Ku-band and Ka-band antenna feeds.
  - Calibration and metrology for accurate baseline knowledge.
  - Real-time onboard radar data processing.
  - Data applications and post-processing techniques.

- Atmospheric radar:
  - Low sidelobe, electronically steerable millimeter wave phased-array antennas and feed networks.
  - Low sidelobe, multi-frequency, multi-beam, shared aperture millimeter wave antennas (Ka-band and W-band).
  - Large (~300 wavelength), lightweight, low sidelobe, millimeter wave (Ka-band and W-band) antenna reflectors and reflectarrays.
  - Lightweight deployable antenna structures and deployment mechanisms.
  - High power (10 kW) Ka-band and W-band transmitters.
  - High-power (>1 kW, duty cycle >5%), wide bandwidth (>10%) Ka-band amplifiers.
  - High-efficiency, low-cost, lightweight Ka-band and W-band transmit/receive modules.
  - Advanced transmit/receive module concepts such as optically-fed T/R modules.
  - Onboard (real-time) pulse compression and image processing hardware and/or software.
Advanced data processing techniques for real-time rain cell tracking, and rapid 3-D rain mapping.

Lightweight, low-cost, Ku/Ka band radar system for ground-based rain measurements.

High power, low sidelobe (better than -30 dB) scanning phase array flat plate antenna (X, Ku, Ka, or W-band) for high altitude operation (65,000 feet).

E1.06 Passive Infrared - Sub Millimeter

Lead Center: JPL

Many NASA future Earth science remote sensing programs and missions require microwave to submillimeter wavelength antennas, transmitters, and receivers operating in the 1-cm to 100-µm wavelength range (or a frequency range of 30 GHz to 3 THz). General requirements for these instruments include large-aperture (possibly deployable) antenna systems with RMS surface accuracy of 100 µm.

For these systems, advancement is needed in primarily three areas: (1) the development of frequency-stabilized, low phase noise, tunable, fundamental local oscillator sources covering frequencies between 160 GHz and 3 THz; (2) the development of submillimeter-wave mixers in the 300–3000 GHz spectral region with improved sensitivity, stability, and IF bandwidth capability; (3) the development of higher-frequency and higher-output-power MMIC circuits.

Specific innovations or demonstrations are required in the following areas:

- Heterodyne receiver system integration at the circuit and/or chip level is needed to extend MMIC capability into the submillimeter regime. MMIC amplifier development for both power amplifiers and low noise amplifiers at frequencies up to several hundred GHz is solicited. Integration of a local oscillator multiplier chain, mixer, and intermediate frequency amplifier is one example. There is also a specific need to demonstrate array radiometer systems using MMIC radiometers from 60 GHz, to approximately 500 GHz.

- Solid-state, phase-lockable local-oscillator sources with flight-qualifiable design approaches are needed with >10 mW output power at 200 GHz and >100 µW at 1 THz; source line widths should be

- Stable local-oscillator sources are needed for heterodyne receiver system laboratory testing and development.

- Multi-channel spectrometers that analyze intermediate frequency signal bandwidths as large as 10 GHz with a frequency resolution of

- Compact and reliable millimeter and submillimeter imaging instrumentation that produces images simultaneously in multiple spectral bands.

- Schottky mixers with high sensitivity at T = 100 K and above.

- Low noise superconducting HEB mixers and SIS mixers.

- Receivers using planar diode or alternative reliable local oscillator technologies in the 300–3000 GHz spectrum.
• Lightweight and compact radiometer calibration references covering 100–800 GHz frequency range.

• Lightweight, field portable, compact radiometer calibration references covering frequencies up to 200 GHz. The reference must be temperature stable to within 1 K with a minimum of three temperature settings between 250 and 350 K.

• Low cost special purpose ground-based receivers to detect signals radiated from active satellites that are in orbit, for estimating rain rate, water vapor, and cloud liquid water.

• Calibrated radiometer systems that can achieve accuracy and stability of 0.1 K.

• Astrophysics receiver-detector technology proposals are also solicited, specifically under topic S2.01, Sensors and Detectors for Astrophysics.

---

**E1.07 Thermal Control for Instruments**

*Lead Center: GSFC*

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

Future instruments and platforms for NASA’s Earth Science Enterprises will require increasingly sophisticated thermal control technology.

1. Instrument optical alignment needs, lasers, and detectors require tight temperature control, often to better than +/- 1°C.

2. Heat flux levels from lasers and other high power devices are increasing, with some projected to go as high as 100 W/cm².

3. Cryogenic applications are becoming more common. Large, distributed structures, such as mirrors and antennae, will require creative techniques to integrate thermal control functions and minimize weight.

4. The push for miniaturization also drives the need for new thermal technologies towards the micro-electromechanical system (MEMS) level.

5. The drive towards ‘off-the-shelf’ commercial spacecraft, and reconfigurable spacecraft presents engineering challenges for instruments, which must become more self-sufficient.

Innovative proposals for thermal control technologies are sought in the following areas:

• Miniaturized heat transport devices, especially those suitable for cooling small sensors, devices, and electronics.

• Highly reliable, miniaturized Loop Heat Pipes and Capillary Pumped Loops that allow multiple heat load sources and multiple sinks.
- Advanced thermoelectric coolers capable of providing cooling at ambient and cryogenic temperatures.
- Inexpensive passive radiative coolers for low Earth orbit.
- Technologies for cooling very high flux (>100 W/cm²) heat sources, including spray and jet impingement cooling.
- Advanced thermal control coatings, such as variable emittance surfaces and coatings with a high emissivity at ambient and cryogenic temperatures.
- High conductivity materials to:
  - Minimize temperature gradients, especially for optical benches and structures,
  - Provide jitter isolation links between cryocoolers and sensors, and
  - Provide high efficiency light-weight radiators.
- Advanced analytical techniques for thermal modeling, focusing on techniques that can be easily integrated into existing codes.
- Thermal control systems that actively maintain optical alignment for very large structures at both ambient and cryogenic temperatures.
- Single and two-phase pumped fluid loop systems, which accommodate multiple heat sources and sinks.
- Long life, lightweight pumps for single and two-phase fluid loop systems.
- Efficient, lightweight vapor compression systems for cooling up to 2 kW.