



NASA SBIR 2020 Phase I Solicitation

S1.09 Cryogenic Systems for Sensors and Detectors

Lead Center: GSFC

Participating Center(s): JPL

Technology Area: TA8 Science Instruments, Observatories & Sensor Systems

Scope Title

Low temperature/high efficiency cryocoolers

Scope Description

NASA seeks improvements to multistage low temperature spaceflight cryocoolers. Coolers are sought with the lowest temperature stage typically in the range of 4 to 10 K, with cooling power at the coldest stage larger than currently available, and high efficiency. The desired cooling power is application specific, but two examples are 0.3 Watts at 10 K and 0.2 Watts at 4 K. Devices that produce extremely low vibration, particularly at frequencies below a few hundred Hz, are of special interest. System or component level improvements that improve efficiency and reduce complexity and cost are desirable.

Expected TRL or TRL range at completion of the project: 2 to 5

Desired Deliverables of Phase II:

Prototype Hardware

Desired Deliverables Description

Functioning hardware ready for functional and possibly environmental testing.

State of the Art and Critical Gaps

Current spaceflight cryocoolers for this temperature range include linear piston driven Stirling cycle or pulse tube cryocoolers with Joule-Thompson low temperature stages. One such state-of-the-art cryocooler provides 0.09 W of cooling at 6 K. For large future space observatories, large cooling power and much greater efficiency will be needed. For cryogenic instruments or detectors on instruments with tight point requirements, orders of magnitude improvement in the levels of exported vibration will be required.

Some of these requirements are laid out in the "Advanced cryocoolers" Technology gap in the latest (2017) Cosmic Origins Program Annual Technology Report.

Relevance / Science Traceability

Science traceability: Goal 1 and Objective 1.6 of NASA's Strategic Plan:

- Goal 1: Expand the frontiers of knowledge, capability, and opportunity in space
 - Objective 1.6: Discover how the universe works, explore how it began and evolved, and search for life on planets around other stars.

Low temperature cryocoolers are listed as a "Technology Gap" in the latest (2017) Cosmic Origins Program Annual Technology Report.

Future missions that would benefit from this technology include two of the large missions under study for the 2020 Astrophysics Decadal Survey:

- Origins Space Telescope
- Lynx microcalorimeter instrument

References

For more information on the Origins Space Telescope, see:

<https://asd.gsfc.nasa.gov/firs/>

Scope Title

Actuators and other cryogenic devices

Scope Description

NASA seeks devices for cryogenic instruments, including:

- Small, precise motors and actuators, preferably with superconducting windings, that operate with extremely low power dissipation. Devices using standard NbTi conductors, as well as devices using higher temperature superconductors that can operate above 5 K, are of interest.
- Cryogenic heat pipes for heat transport within instruments. Heat pipes using hydrogen, neon, oxygen, argon, and methane are of interest. Length should be at least 0.3 m.

Expected TRL or TRL range at completion of the project: 3 to 4

Desired Deliverables of Phase II:

Prototype Hardware

Desired Deliverables Description

Working prototypes ready for testing in the relevant environments are desired.

State of the Art and Critical Gaps

Motors and actuators: Instruments often have motors and actuators, typically for optical elements. In current cryogenic instruments, these devices often dissipate relatively large powers and are a significant design drivers.

Cryogenic heat pipes: Currently, heat transport in cryogenic instruments are handled with solid thermal straps. These do not scale well for larger heat loads.

Relevance / Science Traceability

Science traceability:

NASA Strategic plan 2018, Objective 1.1: Understand The Sun, Earth, Solar System, And Universe

Almost all instruments have motors and actuators for changing filters, adjusting focus, scanning, and other functions. On low temperature instruments, for example on mid- to far-IR observatories, dissipation in actuators can be a significant design problem.

References

For more information on earlier low temperature heat pipes, see

- Brennen, et al. AIAA paper 93-2735, <https://doi.org/10.2514/6.1993-2735>
- Prager, R.C., AIAA paper 80-1484, <https://doi.org/10.2514/6.1980-1484>
- Alario, J. and Kosson, R. AIAA paper 80-0212, <https://doi.org/10.2514/6.1980-212>

Scope Title

Ultra-Lightweight Dewars

Scope Description

NASA seeks extremely lightweight thermal isolation systems for scientific instruments. An important example is a large cylindrical, open top dewar to enable large, cold balloon telescopes. In one scenario, such a dewar would be launched warm, and so would not need to function at ambient pressure, but at altitude, under ~4 millibar external pressure, it would need to contain cold helium vapor. The ability to rapidly pump and hold a vacuum at altitude is necessary. An alternative concept is that the dewar would be launched at operating temperature, with some or all of the needed liquid helium. In both cases, heat flux through the walls should be less than 0.5 Watts per square meter, and the internal surfaces must be leak tight against superfluid helium. Initial demonstration units of greater than 1 meter diameter and height are desired, but the technology must be scalable to an inner diameter of 3-4 meters with a mass that is a small fraction of the net lift capability of a scientific balloon (~2000 kg).

Expected TRL or TRL range at completion of the project: 3 to 4

Desired Deliverables of Phase II:

Prototype Hardware

Desired Deliverables Description

A working prototype of the scale described is desired.

State of the Art and Critical Gaps

Currently available liquid helium dewars have heavy vacuum shells that allow them to be operated in ambient pressure. Such dewars have been used for balloon-based astronomy, as in the Absolute Radiometer for Cosmology, Astrophysics, and Diffuse Emission (ARCADE) experiment. However, the current dewars are already near the limit of balloon lift capacity, and cannot be scaled up to the required size for future astrophysics measurements.

Relevance / Science Traceability

Science traceability: NASA Strategic plan 2018, Objective 1.1: Understand the Sun, Earth, Solar System, and Universe.

The potential for ground-based infrared astronomy is extremely limited. Even in airborne observatories, such as SOFIA, observations are limited by the brightness of the atmosphere and the warm telescope itself. However, high altitude scientific balloons are above enough of the atmosphere that, with a telescope large enough and cold enough, background-limited observations are possible. The ARCADE project demonstrated that at high altitudes, it is possible to cool instruments in helium vapor. Development of ultra-lightweight dewars that could be scaled up to large size, yet still be liftable by a balloon would enable ground-breaking observational capability.

References

For a description of a state-of-the art balloon cryostat, see
Singal, et al. "The ARCADE 2 instrument," The Astrophysical Journal, 730:138 (12pp), 2011 April 1

Scope Title

Miniaturized/Efficient Cryocooler Systems

Scope Description

NASA seeks miniature, highly efficient cryocoolers for instruments on earth and planetary missions. A range of cooling capabilities sought. Two examples include 0.2 Watt at 30 K with heat rejection at 300 K, and 0.3 W at 35K with heat reject of 150 K. For both examples, an input power of ≤ 5 Watt and a total mass of ≤ 400 grams is desired. The ability to fit within the volume and power limitations of a SMALLSAT platform would be highly advantageous. Components, such as low-cost cryocooler electronics that are sufficiently rad hard for lunar or planetary missions, are also sought.

Expected TRL or TRL range at completion of the project: 2 to 4

Desired Deliverables of Phase II:

Prototype Hardware

Desired Deliverables Description

Desired deliverables include miniature coolers and components, such as electronics, that are ready for functional and environmental testing.

State of the Art and Critical Gaps

Present state of the art capabilities provide 0.1 W of cooling capacity with heat rejection at 300 K at approximately 5 W input power with a system mass of 400 grams.

Cryocoolers enable the use of highly sensitive detectors, but current coolers cannot operate within the tight power constraints of outer planetary missions. Cryocooler power could be greatly reduced by lowering the heat rejection temperature, but presently there are no spaceflight systems that can operate with a heat rejection temperature significantly below ambient.

Relevance / Science Traceability

Science traceability: NASA Strategic plan 2018, Objective 1.1: Understand the Sun, Earth, Solar System, and Universe.

NASA is moving toward the use of small, low cost satellites to achieve many of its Earth science, and some of its planetary science goals. The development of cryocoolers that fit within the size and power constraints of these platforms will greatly expand their capability, for example, by enabling the use of infrared detectors.

In planetary science, progress on cryogenic coolers will enable the use of far- to mid-infrared sensors with orders of magnitude improvement in sensitivity for outer planetary missions. These will allow thermal mapping of outer planets and their moons.

References

An example of cubesat mission using cryocoolers is given at: <https://www.jpl.nasa.gov/cubesat/missions/ciras.php>

Scope Title

Sub-Kelvin Cooling Systems

Scope Description

Future NASA missions will require requiring sub-Kelvin coolers for extremely low temperature detectors. Systems are sought that will provide continuous cooling with high cooling power (> 5 microWatts at 50 mK), low operating temperature (< 35 mK), and higher heat rejection temperature (preferably > 10 K), while maintaining high thermodynamic efficiency and low system mass.

Improvements in components for adiabatic demagnetization refrigerators are also sought. Specific components include:

- 1) Compact, lightweight, low current superconducting magnets capable of producing a field of at least 4 Tesla while operating at a temperature of at least 10 K, and preferably above 15 K. Desirable properties include:
 - A high engineering current density (including insulation and coil packing density), preferably > 300 Amp/mm².
 - A field/current ratio of > 0.33 Tesla/Amp, and preferably > 0.66 Tesla/Amp.
 - Low hysteresis heating.
- 2) Lightweight Active/Passive magnetic shielding (for use with 4 Tesla magnets) with low hysteresis and eddy current losses, and low remanence. Also needed are lightweight, highly effective outer shields that reduce the field outside an entire multi-stage device to < 5 microTesla. Outer shields must operate at 4 - 10 K, and must have penetrations for low temperature, non-contacting heat straps.
- 3) Heat switches with on/off conductance ratio $> 30,000$ and actuation time of < 10 s. Materials are also sought for gas gap heat switch shells: these are tubes with extremely low thermal conductance below 1 K; they must be impermeable to helium gas, have high strength, including stability against buckling, and have an inner diameter > 20 mm.
- 4) High cooling power density magnetocaloric materials, especially single crystals with volume > 20 cc. Examples of desired single crystals include GdF₃, GdLiF₄, and Gd elpasolite.
- 5) 10 mK- 300 mK high resolution thermometry.
- 6) Suspensions with the strength and stiffness of Kevlar, but lower thermal conductance from 4 K to 0.050 K.

References

For a description of the state-of-the-art subKelvin cooler in the Hitomi mission, see: Shirron, et al. "Thermodynamic performance of the 3-stage ADR for the Astro-H Soft-X-ray Spectrometer instrument," *Cryogenics* 74 (2016) 24-30, and references therein.

For articles describing magnetic subKelvin coolers and their components, see the July 2014 special issue of *Cryogenics*: *Cryogenics* 62 (2014) 129-220.

NASA has plans to purchase services for delivery of payloads to the Moon through the Commercial Lunar Payload Services (CLPS) contract. Under this subtopic, proposals may include efforts to develop payloads for flight demonstration of relevant technologies in the lunar environment. The CLPS payload accommodations will vary depending on the particular service provider and mission characteristics. Additional information on the CLPS

program and providers can be found at this link: <https://www.nasa.gov/content/commercial-lunar-payload-services>. CLPS missions will typically carry multiple payloads for multiple customers. Smaller, simpler, and more self-sufficient payloads are more easily accommodated and would be more likely to be considered for a NASA-sponsored flight opportunity. Commercial payload delivery services may begin as early as 2020 and flight opportunities are expected to continue well into the future. In future years it is expected that larger and more complex payloads will be accommodated. Selection for award under this solicitation will not guarantee selection for a lunar flight opportunity.

Expected TRL or TRL range at completion of the project: 2 to 4

Desired Deliverables of Phase II:

Prototype Hardware

Desired Deliverables Description

For components, functioning hardware that is directly usable in NASA systems is desired.

State of the Art and Critical Gaps

The adiabatic demagnetization refrigerator in the Soft X-ray Spectrometer instrument on the Hitomi mission represents the state of the art in spaceflight sub-Kelvin cooling systems. The system is a 3 stage, dual-mode device. In the more challenging mode, it provides 650 μW of cooling at 1.625 K, while simultaneously absorbing 0.35 μW from a small detector array at 0.050 K. It rejects heat at 4.5 K. In this mode, the detector is held at temperature for 15.1 hour periods, with a 95% duty cycle. Future missions with much larger pixel count will require much higher cooling power at 0.050 K or lower, higher cooling power at intermediate stages, and 100% duty cycle. Heat rejection at a higher temperature is also needed to enable the use of a wider range of more efficient cryocoolers.

Relevance / Science Traceability

Science traceability: Science traceability:

NASA Strategic plan 2018, Objective 1.1: Understand The Sun, Earth, Solar System, And Universe.

SubKelvin coolers are listed as a "Technology Gap" in the latest (2017) Cosmic Origins Program Annual Technology Report.

Future missions that would benefit from this technology include two of the large missions under study for the 2020 Astrophysics Decadal Survey:

- Origins Space Telescope
- Lynx (microcalorimeter instrument)

Also: Probe of Inflation and Cosmic Origins