NASA SBIR 2019 Phase I Solicitation

S1.09 Cryogenic Systems for Sensors and Detectors

Lead Center: GSFC

Participating Center(s): JPL

Technology Area: TA15 Aeronautics

Cryogenic systems provide the necessary environment for low temperature detectors and sensors, as well as for telescopes and instrument optics on infrared observatories. As such, technological improvements to cryogenic systems further advance the mission goals of NASA through enabling performance (and ultimately science gathering) capabilities of flight detectors and sensors. There are five areas in which NASA is seeking to expand state of the art capabilities:

Low Temperature/High Efficiency Cryocoolers

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. In applications where the device is coupled to an advanced magnetic cooler, it needs to tolerate large swings in heat load on a time scale of the order of minutes to tens of minutes. 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.

Coolers in this class are of interest for space telescopes and instruments for infrared astronomy, as well as for instruments using low temperature detectors, particularly those using advanced sub-Kelvin detectors. Examples of future missions that require this technology include two of the large missions under study for the 2020 Astrophysics Decadal Survey:

- Origins Space Telescope.
- LYNX (microcalorimeter instrument).

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

The expected Technology Readiness Level (TRL)Â range at completion of the project is 2-5.

Miniaturized/Efficient Cryocooler Systems

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 rejection of 150 K. For both examples, an input power of â‰¤ 5 Watt and a total mass of â‰¤ 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.

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.

The expected Technology Readiness Level (TRL)Â range at completion of the project is 2-4.

Sub-Kelvin Cooling Systems

Future NASA missions require sub-Kelvin coolers for extremely low temperature detectors. Systems are sought that will provide continuous cooling with high cooling power (> 5microWatts 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:

- Compact, lightweight, low current superconducting magnets capable of producing a field of at least 4 Tesla while operating at a temperature of at least 10 K, and preferably above 15 K. Desirable properties include:

- A high engineering current density, preferably > 300 Amp/mm
- A field/current ratio of > 0.5 Tesla/Amp, and preferably > 0.8 Tesla/Amp
- Low hysteresis heating
- Mass < 2.5 kg
    - Â· Suspensions with the strength and stiffness of Kevlar, but lower thermal conductance from 4 K to 0.050 K

- Lightweight Active/Passive magnetic shielding (for use with 4 Tesla magnets) with low hysteresis and eddy current losses, and low remanence
- Heat switches for operation at < 10 K with on/off conductance ratio > 30,000, actuation time of < 10 s, and an off conductance of < 50 microWatt/K. Materials are also sought for gas-gap heat switch shells: these are tubes with extremely low thermal conductance below 1 K; they must be impermeable to helium gas, have high strength, including stability against buckling, and have an inner diameter > 20 mm
- High cooling power density magnetocaloric materials, especially single crystals with volume > 20 cc. Examples of desired single crystals include GdF3, GdLiF4, and Gd elpasolite
- 10 mK- 300 mK high-resolution thermometry

Advanced superconducting detectors, such as Transition Edge Sensors (TESs) and Microwave Kinetic Inductance Detectors (MKIDs), operate at extremely low temperatures. Large arrays of such detectors will require advanced subKelvin coolers with large cooling power. These detectors offer orders of magnitude improvement in sensitivity, and thus are slated for a number of future astrophysics missions. Examples of future missions that advanced subKelvin coolers include two of the large missions under study for the 2020 Astrophysics Decadal Survey: Origins Space Telescope and LYNX (microcalorimeter instrument). Other future missions include Probe of Inflation and Cosmic Origins. SubKelvin coolers are listed as a "Technology Gap" in the latest (2017) Cosmic Origins Program Annual Technology Report.

The expected Technology Readiness Level (TRL)Â range at completion of the project is 2-4.

Rad-hard Cryogenic Accelerometers

NASA seeks accelerometers that can operate at 150 K, withstand a 0.01 Tesla magnetic field and are radiation hard to 2-5 megarads.

Cryocoolers are needed for for the operation of high sensitivity infrared detectors that are planned for missions to the outer planets and their moons. Most cryocooler components are easily made rad-hard. However, accelerometers, which are required for vibration cancellation, are currently not available that can operate in extreme conditions, especially in the high radiation environments around Jupiter's moons.

The expected Technology Readiness Level (TRL)Â range at completion of the project is 3-4.

Ultra-lightweight Dewars

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. 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. In operation, heat flux through the walls should be less than 0.5 Watts per square meter. The ability to rapidly pump and hold a vacuum at altitude is necessary. Initial demonstration units of greater than 1 meter diameter and height are desired, but the technology must be scalable to 3 â€“ 4 meters with a mass that is a small fraction of the net lift capability of a scientific balloon (~2000 kg).

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.

The expected Technology Readiness Level (TRL)Â range at completion of the project is 3-4.

References:

Low temperature/high efficiency cryocoolers

- For more information on the Origins Space Telescope, see https://asd.gsfc.nasa.gov/firs/

Miniaturized/Efficient Cryocooler Systems

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

Sub-Kelvin cooling systems

- For a description of the state-of-the-art sub-Kelvin cooler in the Hitomi mission, see:Â Shirron, et al. "Thermodynamic performance of the 3-stage ADR for the Astro-H Soft-X-ray Spectrometer instrument," Cryogenics 74 (2016) 24â€“30, and references therein.
- For articles describing magnetic sub-Kelvin coolers and their components, see the July 2014 special issue of Cryogenics: Cryogenics 62 (2014) 129â€“220.

Rad-hard cryogenic accelerometers

- I.M. McKinley, M.A. Mok, D.L. Johnson, and J.I. Rodriguez, 2018. Characterization Testing of Lockheed Martin Micro1-2 Cryocoolers Optimized for 220 K Environment, International Cryocooler Conference, Burlington, VT, USA. June 18-21, 2018. Cryocoolers 20.
- M.A. Mok, I.M. McKinley, and J.I. Rodriguez, 2018. Low Temperature Characterization of Mechanical Isolators for Cryocoolers, International Cryocooler Conference, Burlington, VT, USA. June 18-21, 2018. Cryocoolers 20.
- D. Glaister, E. Marquardt and R. Taylor, "Ball Low Vibration Cryocooler Assemblies," preesented at the ICC20, June 2018, Burlington, VT.Â

- http://iopscience.iop.org/article/10.1088/1757-899X/278/1/012005

Ultra-lightweight dewars

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