Title of Investigation:

Cooling Large Telescopes and Instruments to 4K Using Adiabatic Demagnetiz Refrigerators

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External Collaborators:

None

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FY 2003

Aggregate Amount of Funding Authorized in FY 2003 and Earlier Years:

$70,000

FY 2004 Authorized Funding:

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$70,000

Status of Investigation at End of FY 2004:

To be continued in FY 2005, with funds remaining from FY 2004

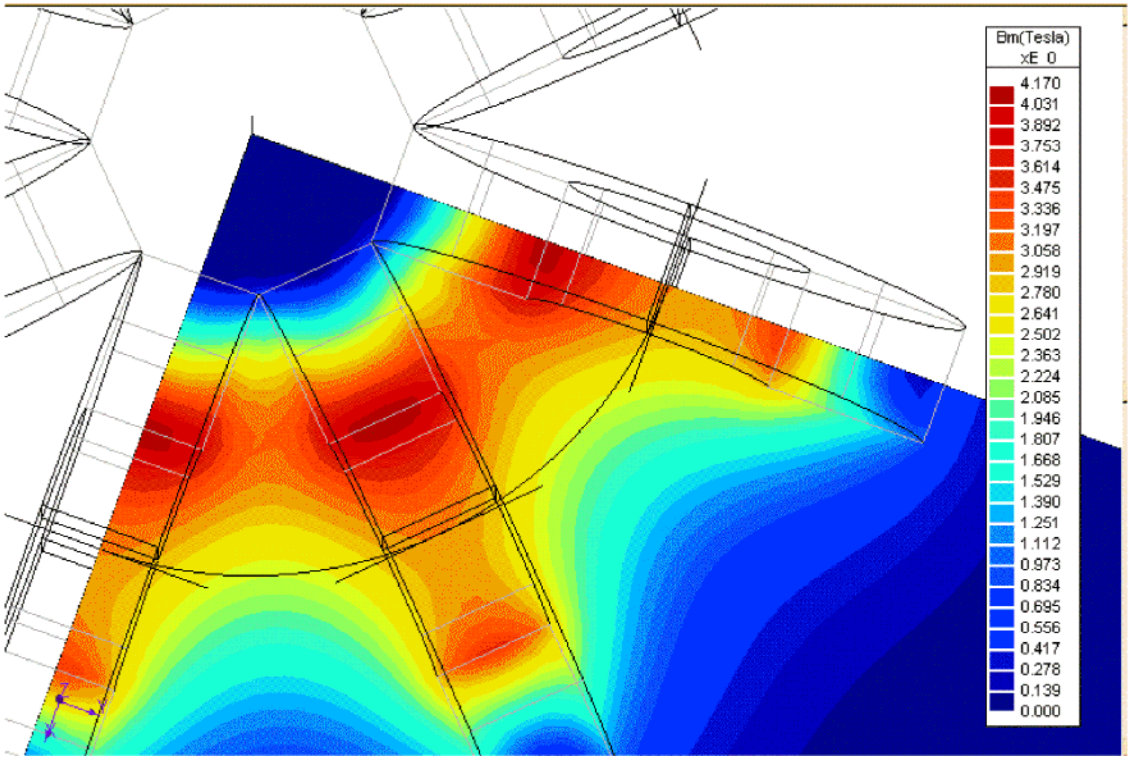
Expected Completion Date:

June 2005

Purpose of Investigation:

Future large infrared space telescopes, such as the Single Aperture Far InfraRed Observatory (SAFIR), will require that their telescopes and instruments be cooled to 4 Kelvin (K) so that they can detect submillimeter wavelengths. Such a cooling device needs to last for many years and provide greater cooling power than that flown today, making it impractical to use the most basic cooling device — a stored helium dewar. We have designed and are building an adiabatic demagnetization refrigerator (ADR) to provide this cooling. It is compact, energy efficient, and has no moving parts.

Figure 1. Toroidal coil field map



Accomplishments to Date:

During the past year, we have accomplished several of our original goals. First a quick background of the instrument: We are building an ADR to cool relatively large power loads (10-100 mW) at 4 K and to reject that heat to an external crycooler operating at 10 K. The ADR magnet consists of eight short coils wired in series and arranged in a toroid to shield its magnetic field (Figure 1). This arrangement will save the mass that would have been used for passive or active shields in an ordinary solenoid. The mass saved is about 30% of the mass or about 1.5kg in our small version, and higher percentages in higher-cooling power, larger versions. The toroid has a 130-mm outer diameter and will produce an approximately 3 Tesla (T) average field (Figure 2). In the initial demonstration model, the toroid coils are wound with ordinary NbTi superconducting wire and operated at 4 K. A second version will use Nb3Sn wire to provide complete 10 K operation. As a refrigerant for this temperature range, we will use either GdLiF4 or GdF3 crystals, pending tests of the crystals' cooling capacities per field and thermal conductance. Preliminary indications are that these materials are superior to previously used material, gadolinium gallium garnet (GGG). We will use gas-gap heat switches to alternately connect the toroid to the cold load and the warm heat sink. A small continuous stage will maintain the cold end at 4 K, while the main toroid is recycled.

We have fabricated the eight segments' coil forms and have successfully wound each with 14,500 turns of NbTi superconductor (Figure 4). These coils are about to be tested individually and as an assembly at 4.2 K. We have started fabricating the GGG cooling segments, completing two of the eight required. We have fabricated several of critical parts for the heat switches. In addition, we have tested a fluxgate magnetometer system, verifying that its sensitivity is 20 nanoTesla (0.2 milligauss). Through a Phase II Small Business Innovative Research (SBIR) contract, we have made significant progress toward achieving small-diameter, high-current-density Nb3Sn wire. Under a separate contract, the contractor agreed to wind a new set of coil segments capable of operating at up to 11 K.

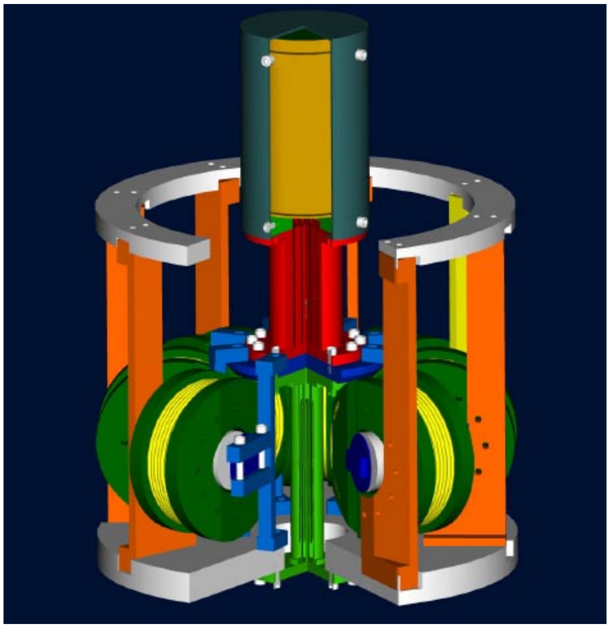


Figure 2. Cut-away drawing of the assembled toroidal ADR. The green spools are the eight coil segments arranged in a toroid. The blue are thermal links to the gray GGG refrigerant segments within the coils. The center green and red structures are the passive gas-gap heat switches and the top structure is a separate stage that maintains a constant temperature at the cold end of the ADR. For scale, the outer diameter is 130 mm.

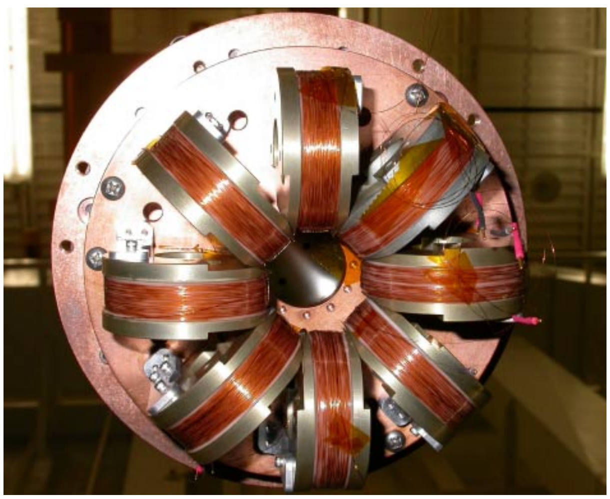


Figure 3. Photo of 8 eight segments of toroidal magnet assembled for test.

A paper entitled, "Continuous Cooling from 10 K to 4 K Using a Toroidal ADR," has been published in Cryogenics. 44 (2004) pp. 559-564. Two papers on the performance testing of this system and future extensions to higher temperatures are anticipated for inclusion in two conferences: the 2005 Space Cryogenics Workshop and the 2005 Cryogenic Engineering Conference, and their conference proceedings.

Planned Future Work:

During the next several months, we will assemble the complete system of magnets, GGG, suspension system and heat switch, and test this in an existing dewar already configured to simulate a 10 K interface. We will then measure the thermal performance of the toroidal ADR. In particular, we will measure the efficiency at various cold end temperatures and heat inputs (power absorbed at 4 K divided by the power rejected at 10 K), and the cool-down rate from 10 K. We also will measure the fringing field in this system configuration. We will use the second toroid wound with Nb_3Sn wire and the same GGG cooling segments to do a true 10 K-to-4 K demonstration.

We also have looked into the possibility of extending this technology to even higher temperatures using a multi-stage system. Our notional configuration is shown in Figure 4. Simulations look promising for obtaining a heat rejection temperature of more than 30 K (Figure 5). Several promising refrigerant materials are available for this temperature range. Such a system would ideally use high-temperature superconducting coils. We have begun exploring the feasibility of making these coils using small-diameter, high-current-density, high-temperature superconducting wire.

Summary:

We have shown through calculation and some material characterization tests that it is feasible to cool using an ADR, with no moving parts, to cycle between 4 and 10 K. Currently, we are building such an ADR to provide between 10 and 100 mW of cooling. It is envisioned that a space-qualified version of this system will provide the low-temperature stage on a cryocooled large space telescope or a far-infrared interferometer, like the Single Aperture Far InfraRed telescope (SAFIR), the SPace InfraRed Interferometric Telescope (SPIRIT), or the Submillimeter Probe of the Evolution and Cosmic Structure of the Universe (SPECS). We will succeed if we can show continuous cooling

of 10 mW or greater at 4 K, rejecting heat to a 10 K reservoir. Making superconducting magnets to produce 3T at 10 K with high field-to-current ratios represents the greatest risk. To reduce this risk, the ADR also can be run in a bootstrap manner by initially cooling the magnets to 4 K, then maintaining their temperature from the main cooling stage. In this way, already-proven superconducting technology could be used.

Figures 4 and 5. Concept of an 8-stage, two-toroid ADR to cool from 30 K to 4 K (top), and simulation of the start up and running of this ADR (bottom)