Development of a Large Volume 4 Kelvin Closed-Cycle Cryostat

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Introduction

The next generation of far-infrared space observatories will feature actively cooled telescopes enabling vastly more sensitive detectors and thus spectrometers. The instrument concept that is widely considered by ESA, JAXA, and NASA to be the leading candidate for future missions is the Post-Dispersed Polarizing Fourier Transform Spectrometer (PDPFTS). Among its benefits is the ability to exploit the sensitivity of state-of-the-art detectors. While the principles underlying the operation of the PDPFTS are well understood, to date, a fully cryogenic integrated system has not been realized in the laboratory.

In order to validate and test such an instrument concept in a laboratory setting, a ground-based cryogenic test facility with a large working volume is required. Blue Sky Spectroscopy Inc. has been tasked with the development and assembly of a cryogenic test facility. This test facility, the Large Facility Cryostat (LFC), features the requisite large volume cooled to 4 K and hosts an ultra-sensitive bolometer detector cooled to 0.3 K. The test facility will be delivered to the Astronomical Instrumentation Group (AIG) at the University of Lethbridge which will enable the integration and testing of a fully-cryogenic PDPFTS system, as well as future instrument concepts proposed to be flown on actively cooled telescopes.

Development of the Large Facility Cryostat has been completed and assembly is underway before final delivery to the AIG. This poster outlines the design and modeling of the LFC as well as the progress that has been made towards assembling the cryogenic test facility.

Design

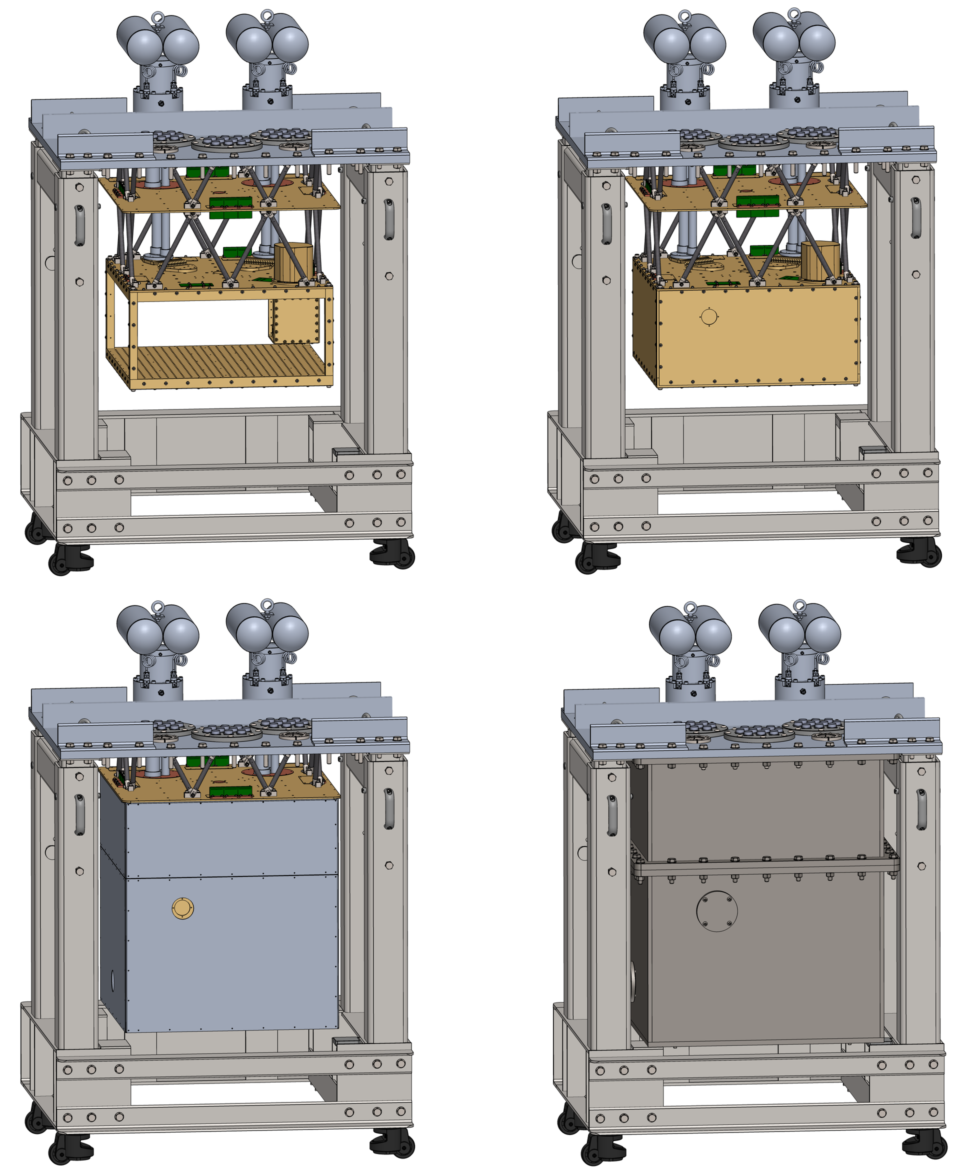

Figure 1: Overview of the Large Facility Cryostat. Two Cryomech PT415 pulse tube cryocoolers provide cooling capacity while carbon fiber reinforced polymer struts and concentric layers of radiation shielding reduce parasitic heat transfer. Top Left: Fully open. Top Right: 4 K radiation shielding. Bottom Left: 45 K radiation shielding. Bottom Right: Outer vacuum chamber.

The Large Facility Cryostat builds upon the work of Veenendaal [1] and the Test Facility Cryostat. The LFC features a 650 x 650 x 250 mm [25.6 x 25.6 x 9.8 in] 4 K volume that is re-configurable up to 650 x 650 x 400 mm [25.6 x 25.6 x 15.7 in]. Beyond volume, the LFC's design makes improvements to the hoist and outer frame, the rigidity of bolted struts, and an increased number of electrical connections. Figure 1 shows an overview of the LFC with the various layers of radiation shielding and outer vacuum chamber.

Finite Element Analysis

ANSYS® Mechanical™ was used to perform finite element analysis (FEA) on the cryostat's vacuum chamber to determine the von-Mises stresses caused by a 1 atm pressure differential and to ensure that the yield strength of the chamber walls would not be exceeded. Figure 2 shows the equivalent von-Mises stresses on the OVC while under vacuum.

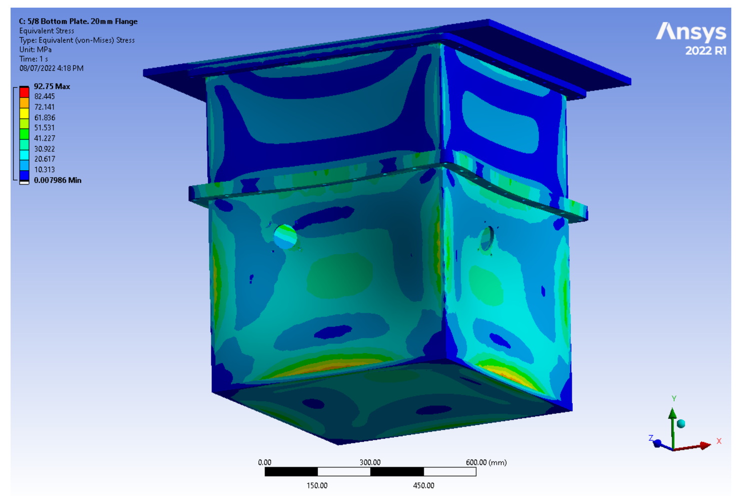

Figure 2: Finite element analysis showing the equivalent von-Mises stresses on the vacuum chamber walls due to a 1 atm pressure differential.

Finite element analysis was also used to optimize the cryostat's vibration modes and deformation of the breadboards with expected weight loading and cooling. Results from initial FEA drove the design of the breadboards towards a torsion box configuration to increase the stiffness and minimize thermal mass.

Thermal Modeling

In order to characterize and estimate the Large Facility Cryostat's cooldown time, an electrical analog thermal model of the LFC was created using a Simulation Program with Integrated Circuit Emphasis (SPICE) and building off the foundation of Li et al. [2]. A SPICE model of the LFC allowed for time-dependent heat transfer simulations. The target cooldown time for the LFC was less than 24 hours. Figure 3 shows the cooldown time results of a transient analysis.

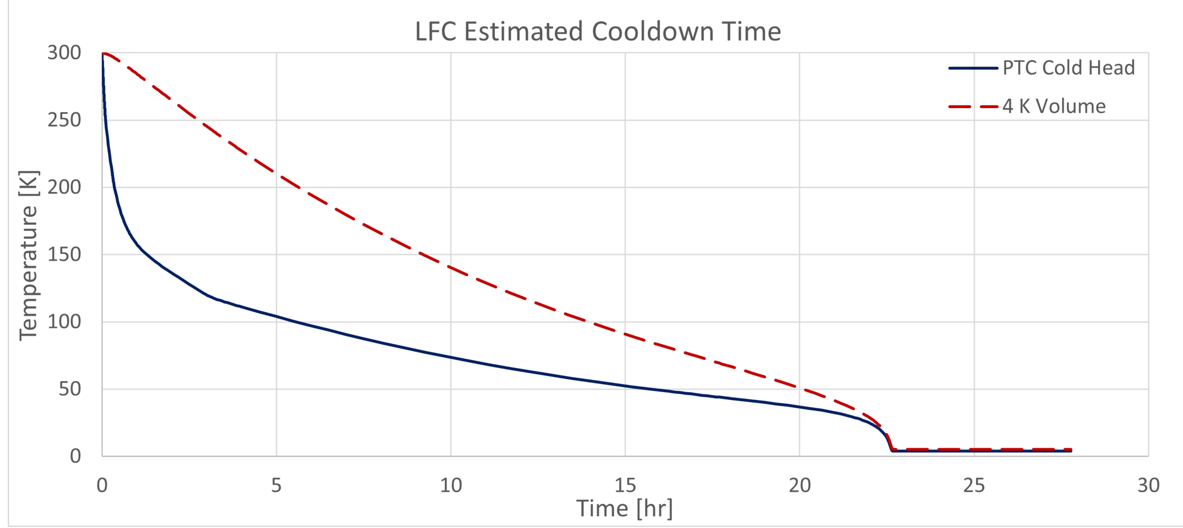

Figure 3: Time-dependent heat transfer simulation showing estimated cooldown time of the 4 K volume within the LFC. Blue: Pulse tube cryocooler cold head temperature. Red: 4 K volume temperature.

Assembly

With the design of the Large Facility Cryostat completed, parts of the cryogenic test facility have been fabricated and assembly is underway. Figure 4 shows the test fit of the vacuum chamber on the supporting framework. Figure 5 shows one of the 4 K breadboard torsion boxes. Figure 6 shows carbon fiber reinforced polymer (CFRP) struts which provide the internal structure of the cryostat. Figure 7 shows one of the Cryomech PT415 pulse tube cryocoolers which will be used to cool the cryostat to 4 Kelvin.

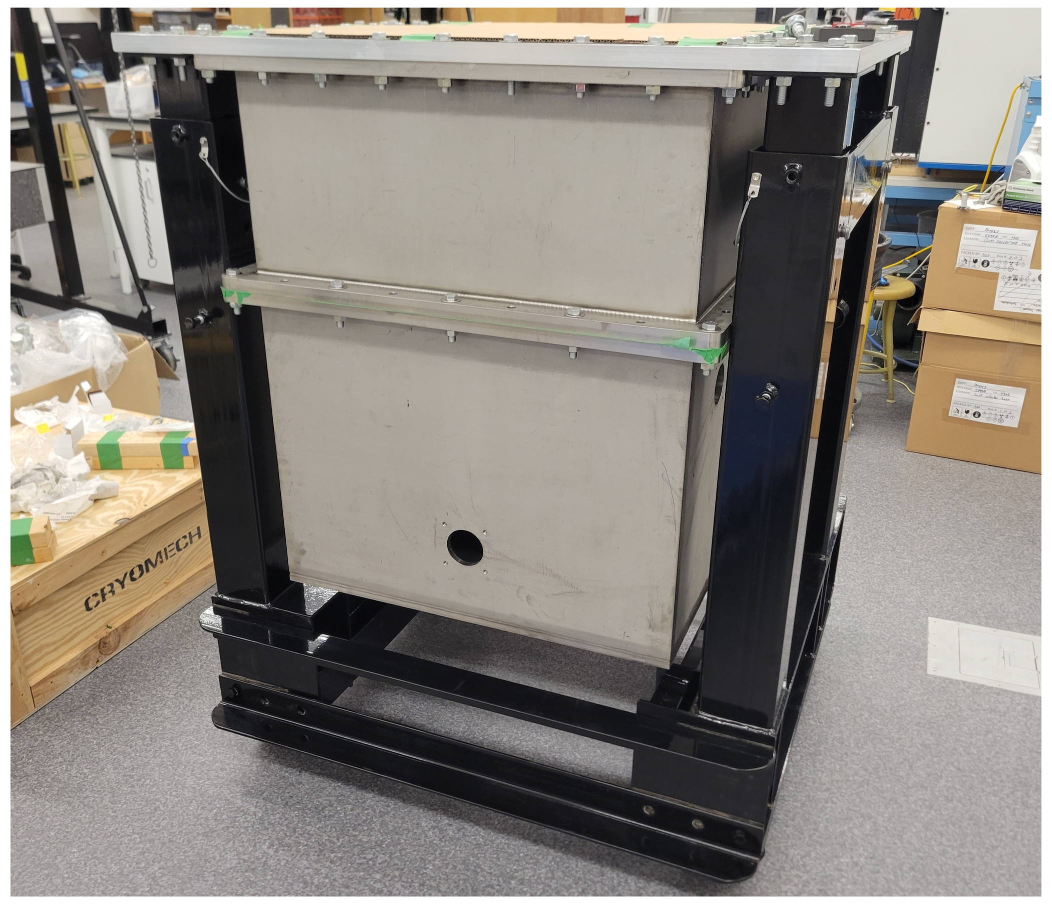

Figure 4: LFC vacuum chamber installed on supporting framework.

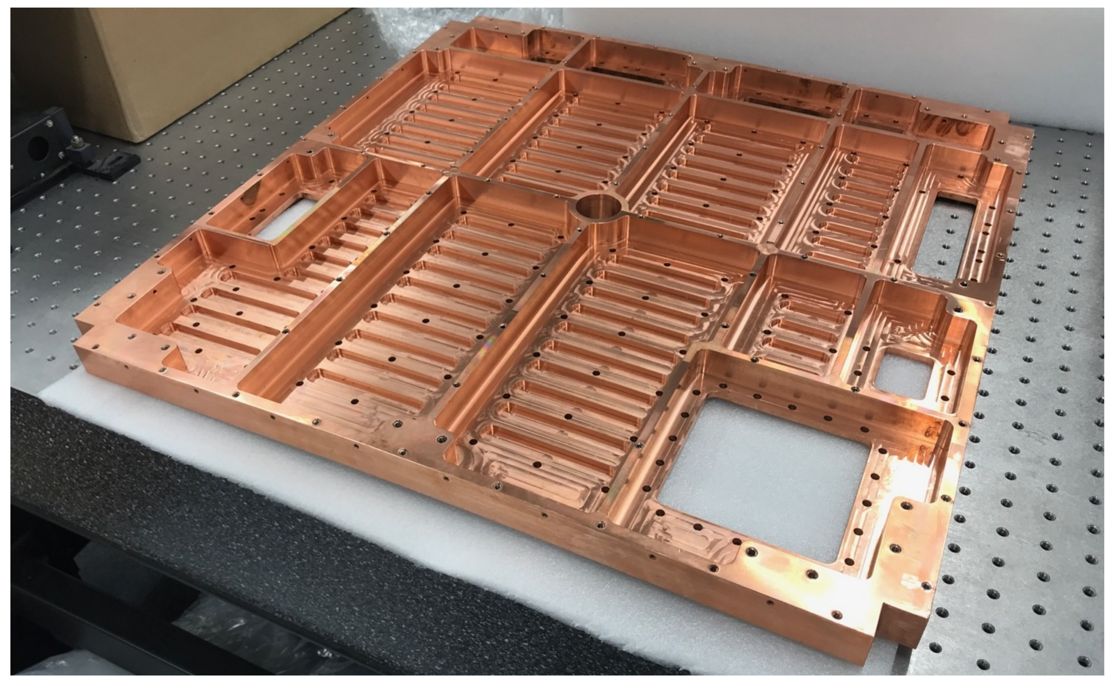

Figure 5: 4 K breadboard prior to gold plating. This breadboard is machined as a torsion box from a piece of billet copper and will be bolted to an upper skin (not shown) to increase rigidity.

Figure 6: Assembled CFRP struts. Top: CFPR strut separating 45 K and 4 K stages of the cryostat. Bottom: CFRP strut separating room temperature vacuum chamber and 45 K stage of the cryostat.

Figure 7: Cryomech PT415 pulse tube cryocooler. The Large Facility Cryostat is cooled by a pair of PT415 cryocoolers, each providing a cooling capacity of 1.5W @ 4.2K W/ 40W @ 45K [3].

Conclusions

The Large Facility Cryostat developed by Blue Sky Spectroscopy Inc. will allow a PDPFTS system to be fully integrated at cryogenic temperatures. The design of the cryogenic test facility has been completed and progress is being made towards finishing the assembly of the cryostat. Future work towards completion of the LFC involves gold plating all copper components within the cryostat to prevent oxidation and improve thermal contact at mating surfaces, installing the pulse tube cryocoolers, fabricating thermal braids to couple the cryocoolers to the cryostat, and fabricating the wiring harness.

References

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[2] Li et al., Heat Transfer Simulation Using PSPICE, 2003.

[3] Cryomech, PT415 CRYOCOOLERS.

https://www.cryomech.com/products/pt415/

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