The Terahertz Intensity Mapper: Design, Modeling, and Characterization of the Cryogenic Receiver

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***Abstract*— The Terahertz Intensity Mapper (TIM) [1,2], a balloon-borne telescope funded by NASA, is set to measure [CII] emission from star forming galaxies over a vast cosmic volume. We will present an overview of TIM's cryogenic receiver design, its thermal modeling, and the ongoing characterization efforts in preparation for the Antarctic flight scheduled for 2026.**

Keywords*— *Cryogenic Receiver, Balloon, Far-Infrared, Intensity Mapping, Kinetic Inductance Detector, Spectrometer, Terahertz

I. Design

TIM's cryogenic receiver is based on the proven design of the BLAST-TNG's receiver [3]. To accommodate our two grating spectrometers, we've expanded the cold plate and increased the capacity of the liquid helium tank to 270 liters. The receiver features three distinct cryogenic stages (see Fig. 1): a 4 K inner stage that houses the liquid helium tank and two concentric vapor-cooled shields (VCSs), VCS1 and VCS2, constructed from Aluminum 1100. These shields minimize thermal loading and provide heat sinking for various IR filters, cables, and plumbing. Each of the two VCSs is cooled by a multi-channel copper heat exchanger [4], featuring 66 parallel 3.2 mm channels. This highly efficient, low-impedance design allows the venting of cold helium gas through them even during high flow occasions like initial filling, effectively minimizing liquid helium consumption and reducing system cooldown time. The instrument space is positioned below the helium tank, with the bottom of the 4 K tank acting as a direct heat sink for the cold optics and the helium sorption refrigerator. This closed-cycle, 3-stage 3He/4He sorption refrigerator, developed by Chase Research Cryogenic, is designed to achieve a base temperature of 250 mK for our Microwave Kinetic Inductance Detectors (MKIDs) to ensure photon noise-limited performance. The cryostat assembly weighs approximately 430 kg, excluding liquid helium, cold optics, and cables.

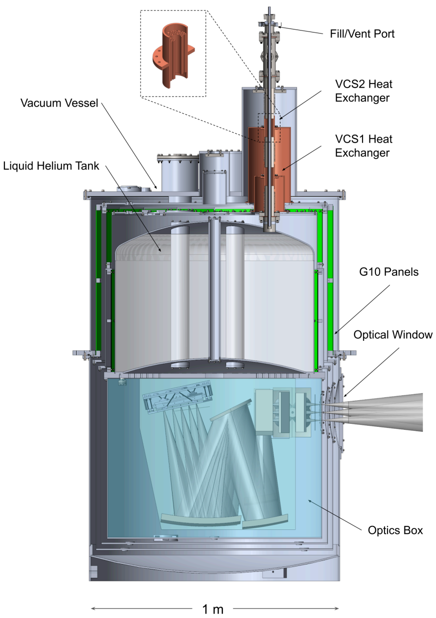

Fig. 1. Design of the TIM cryogenic receiver, highlighting the cryogenic stages and the instrument space, with a close-up view of the heat exchanger.

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II. Modeling and Characterization:

Our team has developed a Python-based cryogenic thermal model to simulate the loading and optimize the operations of the cryostat. This model accounts for various thermal transfer modes and iteratively solves for both stable state and transient responses. The equilibrium temperatures of the two VCSs are estimated to be at 60 K and 160 K, respectively. Our model predicts a thermal loading of 400 mW at the 4 K stage, with a ground-based hold time of 20 days, extending to 30 days under flight conditions.

Since its delivery to the University of Illinois in July 2024, we have assembled the cryostat and successfully cooled it to 4.2 K. The observed loading and equilibrium temperatures closely match our predictions from the model. Early tests also indicate a heat exchange efficiency exceeding 90% for both exchangers. Integration of the refrigerator and cold optics is on track for completion by summer 2024.

References

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