Design and Construction of a 100 milliKelvin Cryostat for Testing Cosmic Microwave Background Detectors

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Abstract

We investigated possible designs for a cryostat requiring a final stage that reaches 100 mK and can support a wafer, lenslet and readout assembly in order to test detectors. Achieving extreme cold temperatures requires proper design and construction of the cryostat. We successfully designed and built a four stage cryostat that achieves vacuum. Experimentally we proved that we can cool down the first two stages. Mathematically we proved that we can reach the base temperature of 100mK for the final stage.

Design

Cryostats must use multiple stage designs in order to reach sub-Kelvin temperatures. Each successive stage is slightly smaller and fits within the previous stage. Our system consists of four stages: 50K, 4K, 1K, 100mK. Our design had three major focuses: thermal isolation, radiative shielding and thermal capacity.

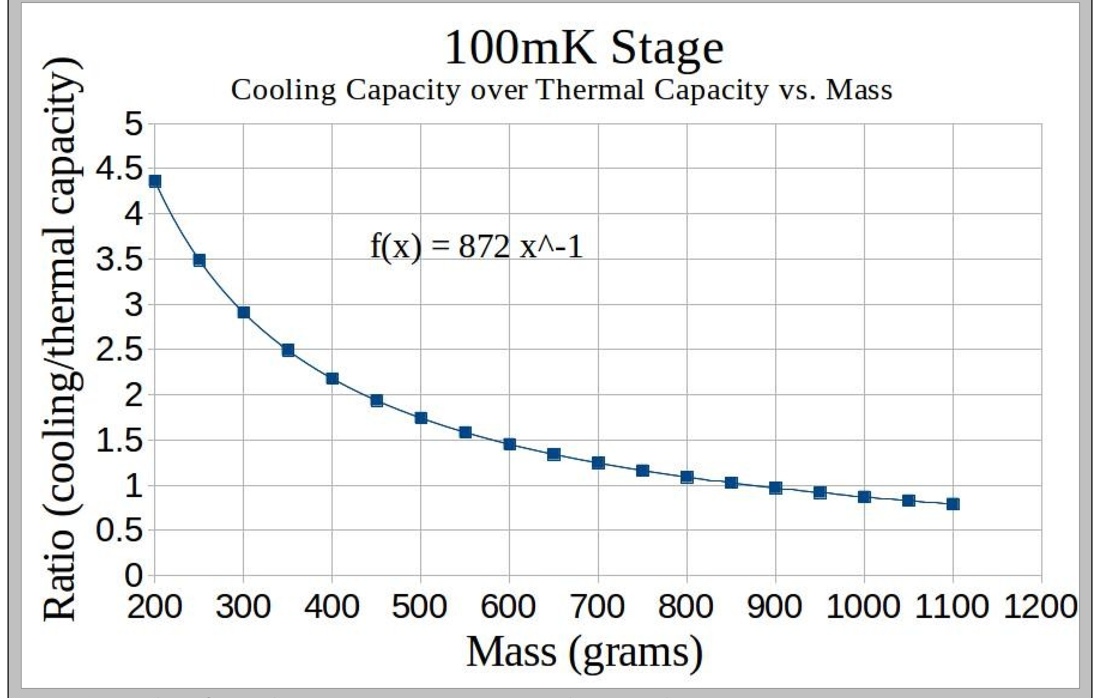
- **Thermal Isolation:** To reach cold temperature, each successive stage must be thermally isolated from the previous stage. 300K-50K used G10 plastic, 50K-4K used carbon fiber, 4K-1K-100mK used Kevlar string.
- **Radiative Shielding:** Radiative shielding prevents inner stages "seeing" radiation from prior stages. 50K and 4K both used shells for protection, with the 50K having extra help from 30 layers of multiple layer insulation.
- **Thermal Capacity:** Thermal capacity is the amount of energy that is required to cool down a stage. This only became an issue for 100mK stage.

100mK Stage

- The major constraint on the 100 mK stage was its thermal capacity
- Cooling capacity of 100mK cold head is 112mJ

The thermal capacity of the 100mK stage can be calculated with the heat energy transfer equation. However, we had to use the differential version of the equation because at sub-Kelvin temperatures Copper's specific heat capacity is dependent on temperature.

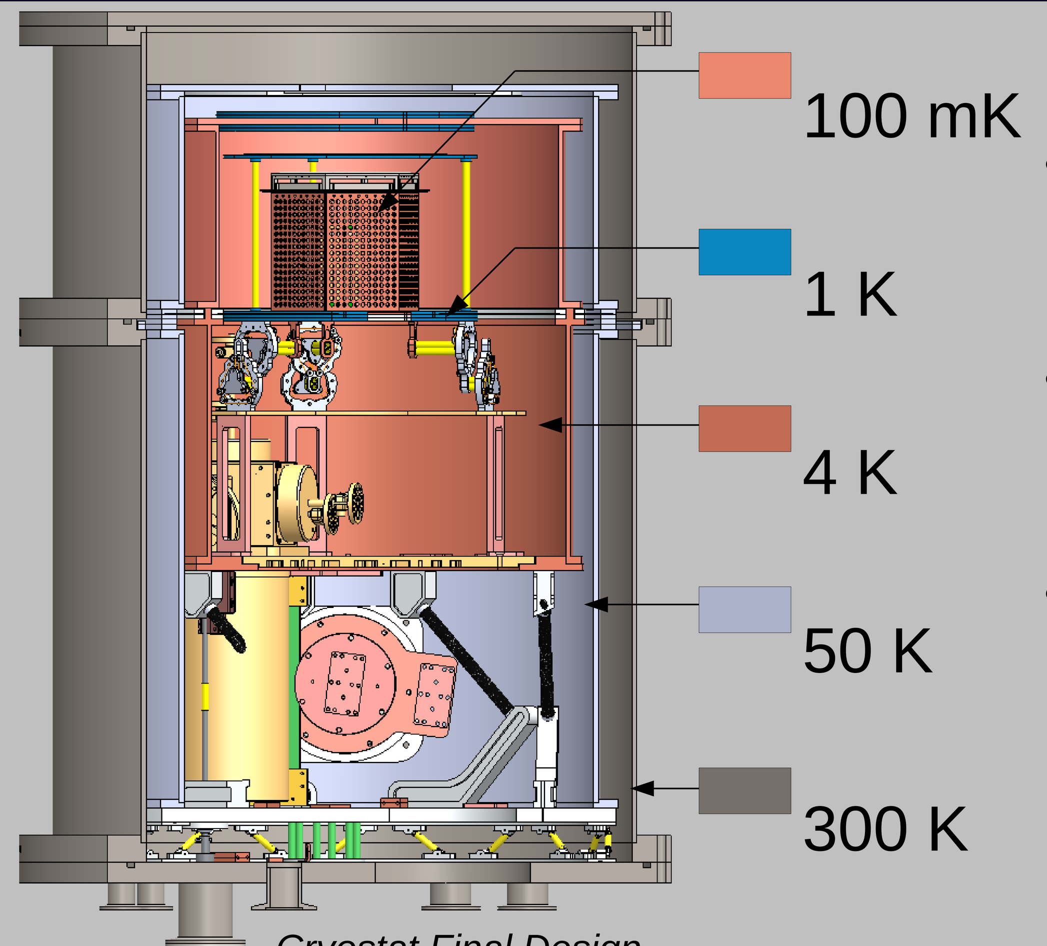
$$Q = m\int_{Ti}^{Tf} c(T)\,dT$$



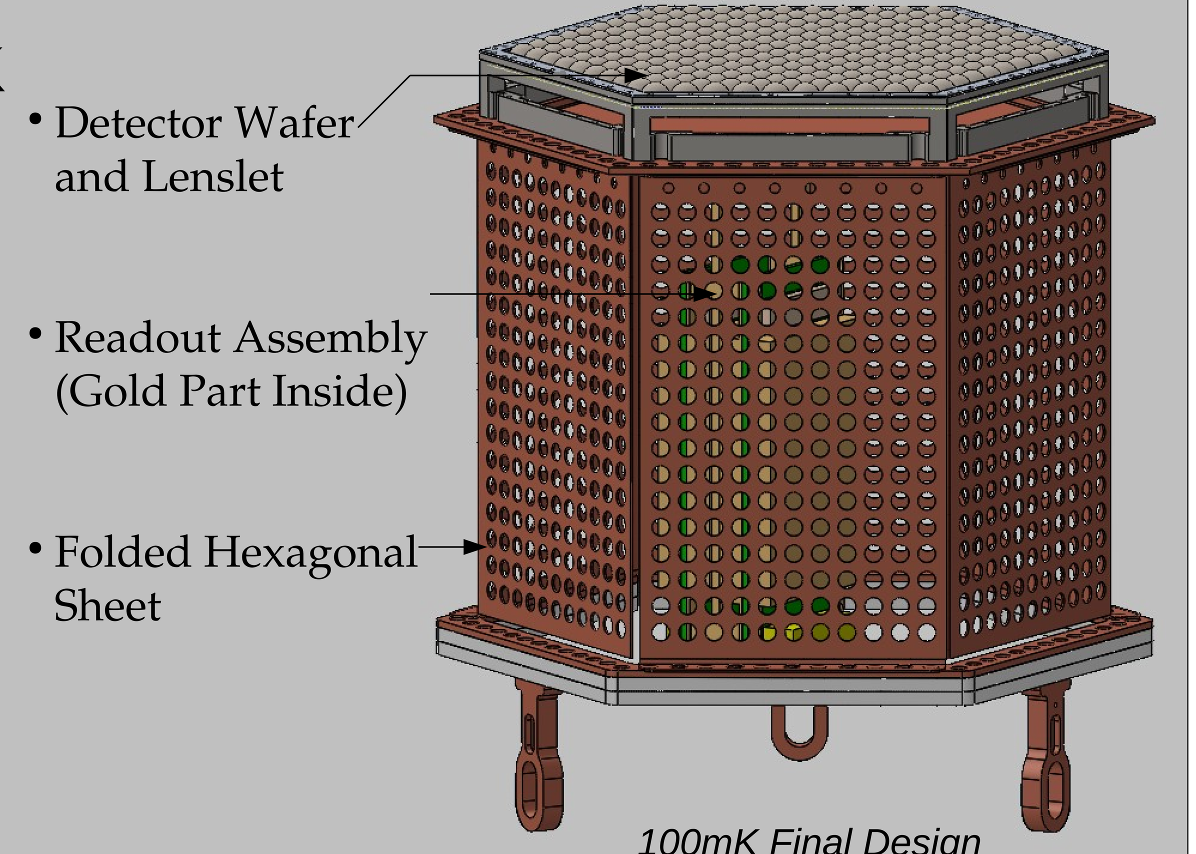
Graph of cooling capacity over thermal capacity versus mass (Copper)

- Mass of final design: 462 grams
- Ratio of cooling capacity over thermal capacity of final design: 1.89
- The hexagonal "shell" in the 100mK final design is 1/64" thick OFHC copper
- Design was to purchase "shell" as sheet and fold into shape
- Holes cut into final design decrease mass yet still enable shell to act as a Faraday cage to shield radio frequency waves

SolidWorks Models



Cryostat Final Design

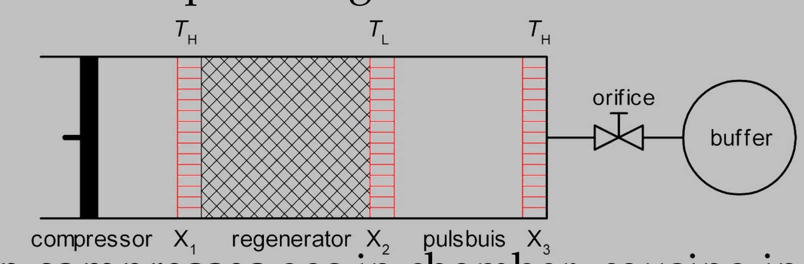


100mK Final Design
Design process described above

Refrigeration

Pulse Tube (PTR)

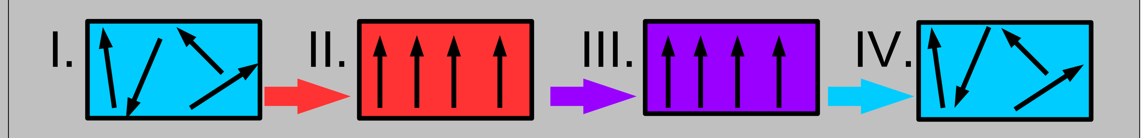
- First Stage 50K (First Stage of PTR)
- Second Stage 4K (Second Stage of PTR)
- Cycles of compressed gas



I. Piston compresses gas in chamber, causing increase in pressure and temperature of the gas
II. Gas is heat sunk to keep it at constant temperature
III. Piston retracts, gas expands to refill entire chamber and the pressure drops as well as the temperature of the gas
IV. Expanding gas passes through regenerator, and cooling gas absorbs heat from regenerators, therefore regenerators cool down
V. Repeat

Adiabatic Demagnetization (ADR)

- Third Stage 1K (First Stage of ADR)
- Fourth Stage 100mK (Second Stage of ADR)
- Cycles of magnetization

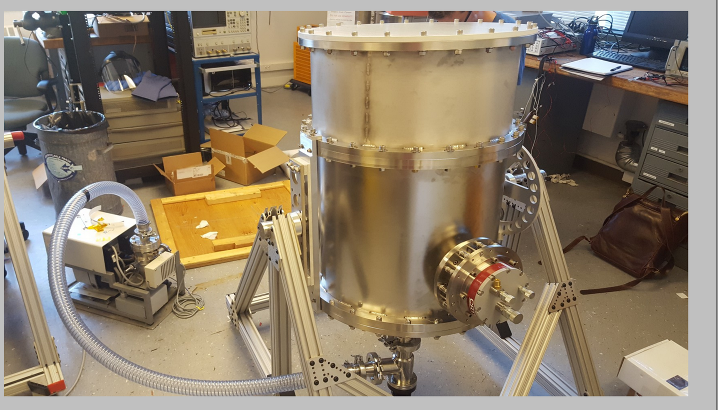


I. Magnet off, spin of pill's salt molecules randomly oriented
II.Magnet on, magnetic pills align with magnetic field, increasing internal heat of pills
III. Heat switch connected, from 4K to ADR to heat sink pill's temperature to 4K. Entropy of salt decreases as spins become ordered.
IV. Heat switch disconnected,Magnet off, spins of pill randomly change, entropy increases causing a decrease in temperature
V. Repeat

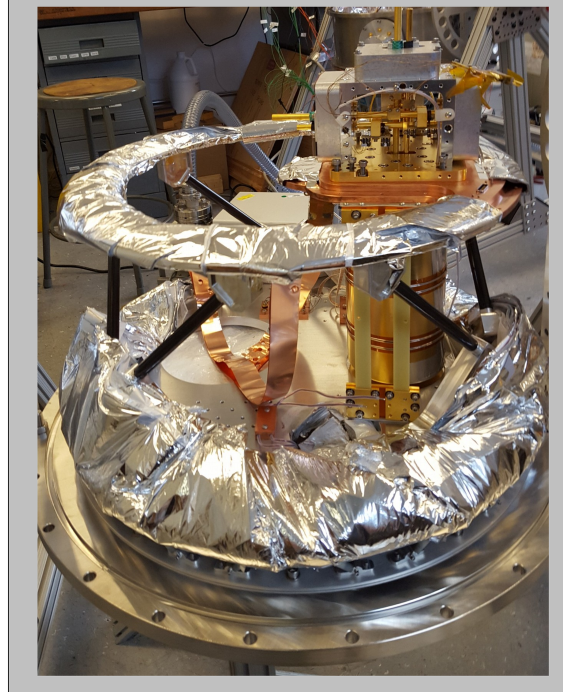
Construction and Testing

Multi layer insulation installed onto 50 K plate

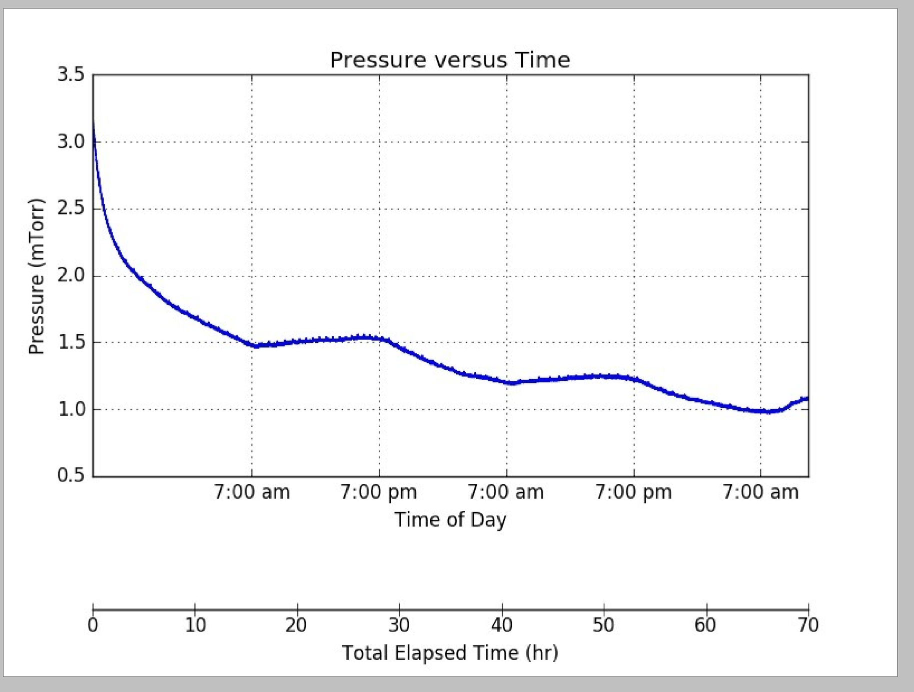
- First and second stages were assembled, including machining of various parts for the stages
- Multi layer insulation was installed onto the 50 K plate
- 300 K Plate Flanges Leak Checked
- Cryostat installed onto cart and vacuum pumped to 1mTorr
- Preliminary cool down achieved



Vacuum pump setup of cryostat on cart



Final assembly of first and second stages



Graph of pressure versus time of cryostat while on turbo vacuum pump

Leak checking 300 K plate flanges

Conclusion

- SolidWorks model completed
- All parts ordered
- Cryostat assembled completely up to second stage
- Vacuum environment inside cryostat reached
- Preliminary cool down achieved

Acknowledgments

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