Characterising Superconducting Detectors for the Cosmic Microwave Background

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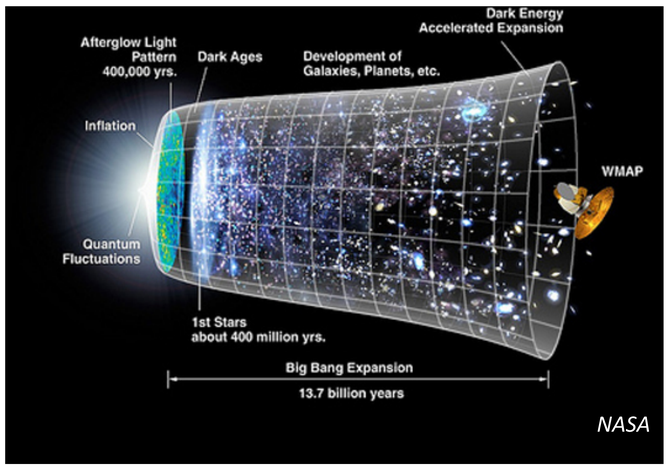
1. Motivation: Probing the Early Universe

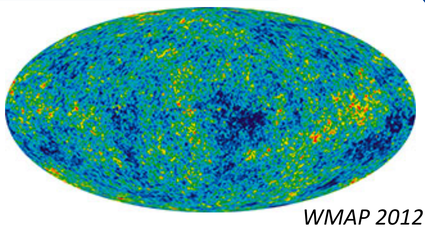
The History of the Universe



NASA

Inflation

- Inflation is thought to be a period of exponential expansion after the Big Bang
- It causes ripples in space which induce a curl-like pattern in the CMB polarization



WMAP 2012

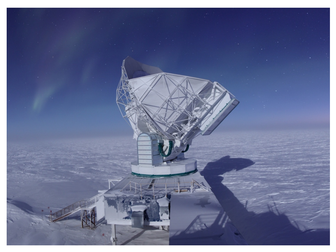
Cosmic Microwave Background (CMB)

- The CMB gives us a picture of the Universe, when it transitioned from an optically-thick ionized-plasma to neutral, which occurred ~380,000 years after the Big Bang
- It is isotropic in temperature and brightness to one part in 100,000, which suggests the Universe was causally connected earlier in its history

2. The South Pole Telescope

The **South Pole Telescope** (SPT) is a 10m mm-wavelength telescope located at the South Pole, and designed to make high sensitivity measurements of the CMB. The high altitude and dry atmosphere of the South Pole make it an ideal location.

SPT-3G will be the third generation camera for the SPT. Compared to the currently operating SPTpol camera, already one of the most sensitive CMB instruments in the world, SPT-3G will have ~10x more detectors and a ~20x larger mapping speed.



SPT : Jason Gallicchio, University of Chicago

3. Detector Design

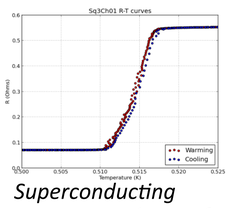
The SPT-3G focal plane consists of 10 detector arrays. Each detector array consists of 271 pixels per array with 6 detectors per pixel. Each pixel measures the linear polarization in three different frequency bands at 90, 150, and 220 GHz.

Array images: VMS,Fermilab

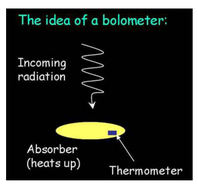
A pixel

Transition Edge Sensor (TES) Bolometers

- Incident radiation heats up absorber in bolometer and changes the resistance
- TES on bolometer operates on its superconducting transition
- Large change in electrical resistance for small temperature change: Steepness allows high sensitivity
- 6 TES detectors per pixel for each polarization and frequency



Superconducting transition Ti/Au TES[2].



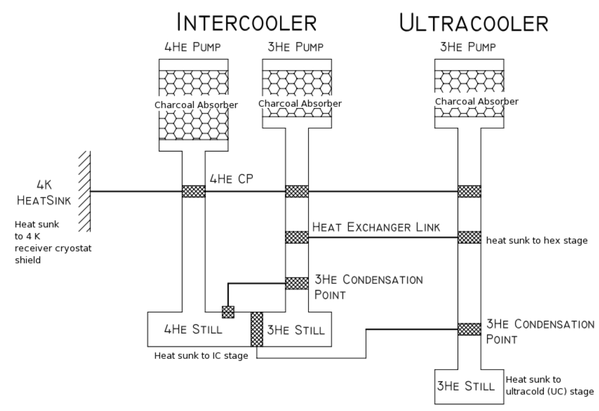
Bolometer: http://pole.uchicago.edu/public/detectors.html

References

1. Benson, B. A., et al., SPT-3G: A Next-Generation Cosmic Microwave Background Polarization Experiment on the South Pole Telescope, 2014, SPIE
2. Posada, C. M., et al., Fabrication of Large Dual-Polarized Multichroic TES Bolometer Arrays for CMB Measurements with the SPT-3G Camera, 2015
3. Bhatia, R. S., et al., A three-stage helium sorption refrigerator for cooling of infrared detectors to 280 mK, 2000, Cryogenics, 40, 685

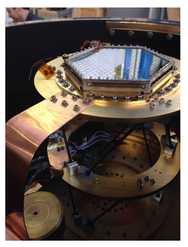
4. Cryostat

To reduce their noise, the detectors are cooled to 250 mK via a three-stage **He4-He3-He3 sorption refrigerator.**



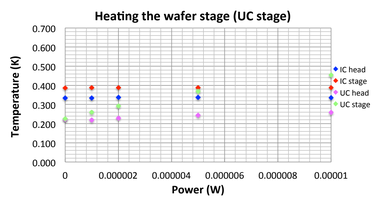
Schematic of He-10 refrigerator: Philhour, Byron 2002

Each stage consists of a separate He reservoir, where the He is condensed into a liquid and then pumped on to reach a colder temperature, with each stage thermally buffering the next.



Wafer attached to UC stage

Cryostat containing He-10 fridge and stages

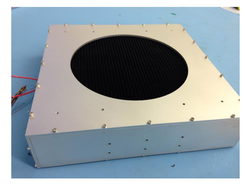


Temperature vs Power of heat loading with wafer attached to UC stage

It was important to observe how the wafer would react physically to the cold temperature. The temperature was monitored as the power of the heater was increased to characterize the thermal gradient between the detector wafer and the ultra-cold (UC) head of the He-10 fridge.

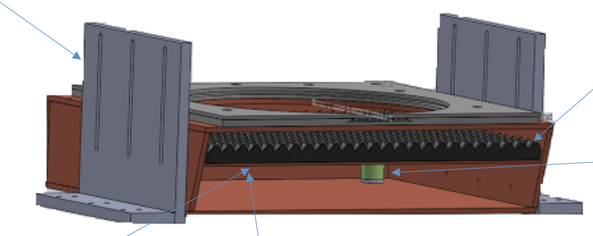
5. Blackbody Cold Load

A **blackbody source** was constructed using a design and will be installed below the wafer inside the cryostat. The source will be used to characterize the efficiency of the detectors to absorb mm-wavelength radiation.



Constructed Blackbody Source

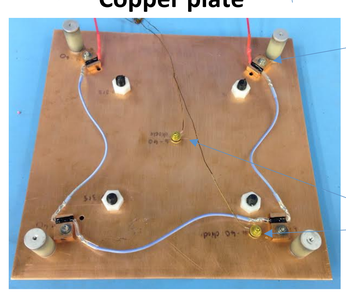
Support legs attached to 4K stage of cryostat, to hold the blackbody source half an inch below the detectors.



Pyramidal **black polypropylene** acts as a blackbody source at mm-wavelength wavelengths, to approximate the CMB.

G10 legs to insulate copper plate from aluminum box and for stability.

Copper plate



4 x 1.4kOhm **resistors** attached and evenly spaced in copper blocks. Uniformly heats black polypropylene.

Diodes also attached to copper plate to allow temperature measurement.

The resistors were chosen to give a maximum power output of ~ 70mW . This was in order to generate radiation from the black polypropylene such that it reaches the wafer at ~25K. This corresponds to the temperature of the CMB as seen by SPT due to atmospheric and telescope optics increasing the loading from 2.7K.

6. Ongoing and future work

- Basic temperature measurements of blackbody within cryostat .
- Testing of detectors inside cryostat using blackbody source.
- Eventual deployment of detector array to the South Pole.

August 2015

Fermilab

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