SPT-SLIM Calibrator Box

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Introduction

SPT: The South Pole Telescope (SPT) is a 10-meter, sub-mm-quality telescope that conducts surveys at mm wavelengths to study the cosmic microwave background (CMB) [1].

SPT-SLIM: A new instrument for the SPT project that uses Line Intensity Mapping (LIM) techniques and Kinetic Inductance Detectors (KIDs) for the purpose of surveying large-scale structure (LSS) at high redshift [2]. KIDs are a new type of highly multiplexed superconducting detector used by SPT-SLIM [2].

Figure 1: Image of the South Pole Telescope [1].

LIM: Line intensity mapping (LIM) is an observational technique in which an atomic or molecular line is observed spectroscopically across a range of redshifts, tracing the large-scale structure in the universe [3].

LIM is a tool that can tell us more about the structural growth of the universe as a result of the measurement of distributions of matter at large scales, as well as the history of cosmic star formation [3].

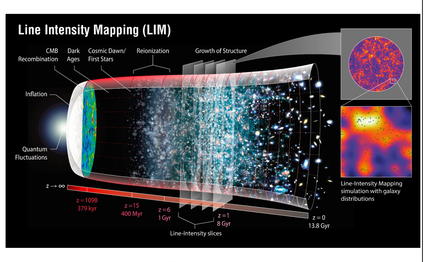


Figure 2: Example of accumulated line intensity mapping data [3].

Project Goals:

This project aims to design and construct an infrared calibration source that is able to be easily interfaced on the telescope mirror. Functionally, the calibrator box aims to chop between 1000K and 300K blackbody sources to provide a baseline conversion from time-ordered data to units of blackbody temperature.

Calibrator Background

Role of the Calibrator:

- The calibrator will be operational regularly, opening the shutter and illuminating the shutter for approx. 1 minute every hour, in order to convert the time ordered-data that is measured by the detectors into units of blackbody temperature [4].
- The reasoning behind regularly running the calibrator is because the conversion to blackbody temperature units depends on the optical power incident on the detectors, which varies with varying temperatures and elevation [4].

How the Calibrator Operates:

- First, the detectors scan over the HII regions, RCW38 or MAT5a, while shutter is open [4].
  - These regions have a well understood reference flux from previous observations by CMB surveys.
- Next, the source flux is compared to the reference flux to attain the calibration for the various detectors in the units of CMB temperature [4].
- Since during observation the optical power on the incident on the detector may vary, the detectors responsivity may also vary. To correct for this the calibrator has two thermal sources, 1000K and 300K. These sources are chopped between and sent to the detectors through a light pipe. The response to this source is then measuring at various points of the surveying process.

$$Calibration\ Factor = \frac{R_i(SurveyField)}{R_i(HII)} \times \frac{\int M(HII)d\Omega}{\int M(refHII)d\Omega} \quad [4]$$

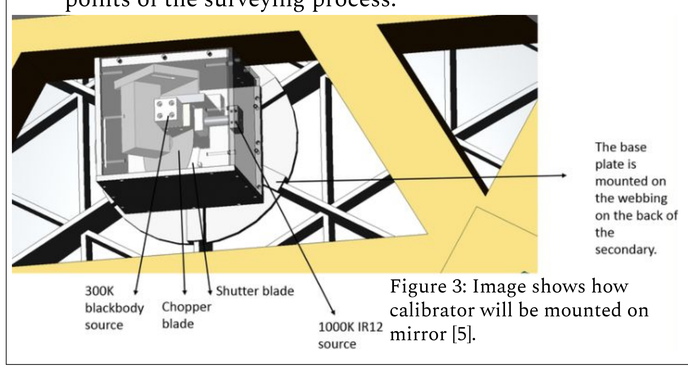


Figure 3: Image shows how calibrator will be mounted on mirror [5].

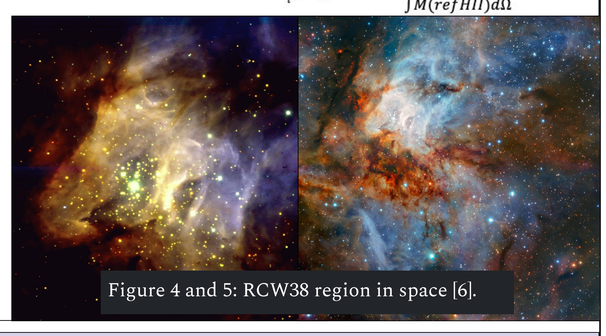


Figure 4 and 5: RCW38 region in space [6].

Design

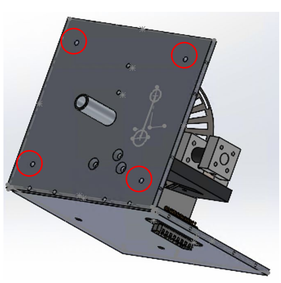
Design Components and Functions:

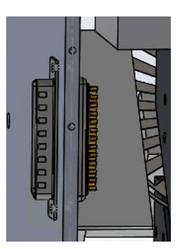
- The IR-12k temperature source provides the 1000K source that is chopped with the 300K source using the C-995 chopper wheel. This chopped signal is sent through to the detectors when the SH-10-5V shutter is open and the detectors are ready for calibration.

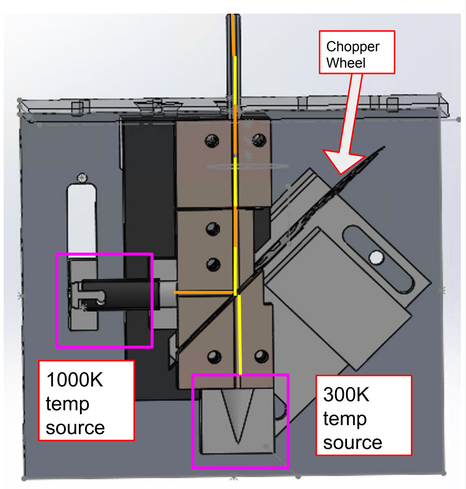
IR-12k Temperature Source | Shutter: SH-10-5V | Chopper Wheel: C-995-Close Head Assembly

Design Goals:

- Reduce weight of calibrator box
  - This was mainly done by the reduction of the wall thickness from the previous model used in SPT-3g. Wall thickness was decreases to 0.19in.
- Include interface to mirror as well as electrical interfaces.
  - Mirror interface was implemented by including 4 threaded holes on the front of the calibrator so an intermediate plate can be created to mount the calibrator to the mirror as specifications may change.
  - Electrical interface was made purposefully adaptable based on the unknown connector at the South Pole.







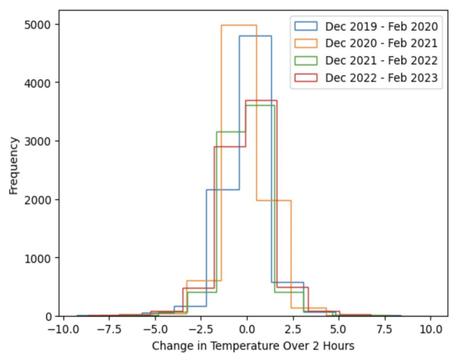
- Design calibrator to chop between two temperature sources.

Temperature Dependencies

- Because of frigid temperatures at the South Pole, an analysis of the weather temperature fluctuations and operating temperatures of the electronics was done.
  - Results would indicate whether there is a need for additional environmental isolation for the box.

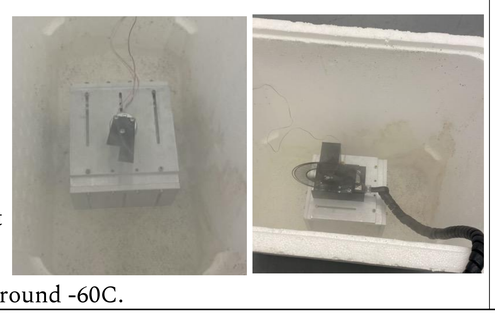
Temperature fluctuations:

- Thermal fluctuations were looked into in order to determine the stability of the calibration source.
- Temperature fluctuations over 2 hour periods were analyzed for 4 years worth of consecutive austral summers.
- 2 hour period was determined by frequency in SPT-3g
  - Results indicate that 95% of fluctuations in temperature were 5C or less indicating additional thermal insulation is not needed.
  - Worst case scenario is a 2.5% change in the 300k source, not enough to effectively hinder results.



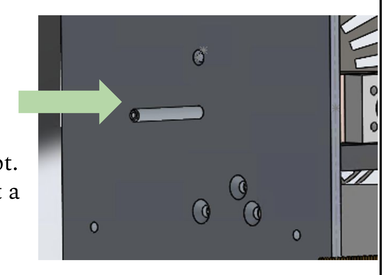
Operating Temperatures:

- A test was done to determine if the electronics used in the calibrator box are able to perform at below freezing temperatures.
  - Liquid nitrogen was used to cool the electronics.
  - Results show that the electronics performed normally at 200K or ~ -70C which is lower than the lowest temp. at the SP during SPT-SLIM operational months which is around -60C.



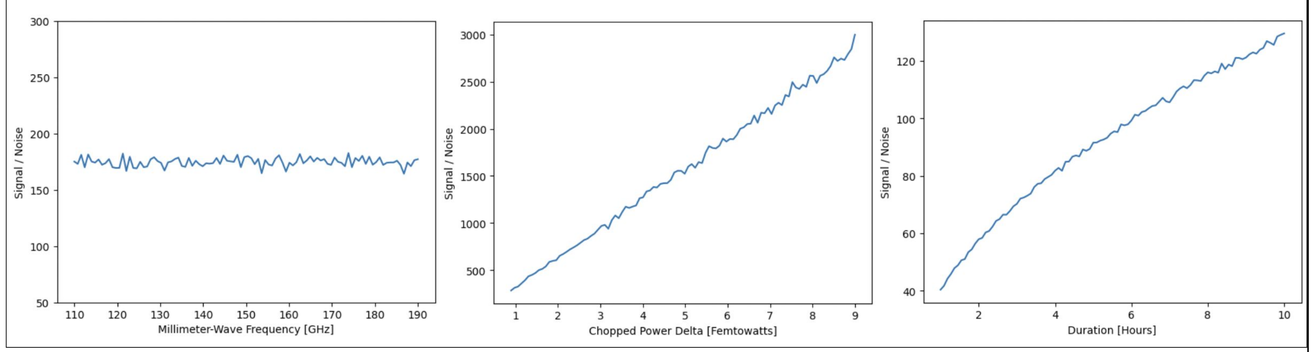
Light Pipe and S/N

- The light pipe is a tunnel that the chopped light source from the calibrator travels through on its way to the detectors.
  - Adjusting the diameter of this tunnel affects the power incident on the opening and therefore the signal to noise ratio.
- Planck's blackbody equation was used to compute this quantity using python script.
  - The reduction of the diameter of the light pipe was necessary in order to target a S/N ratio of 100-1000.

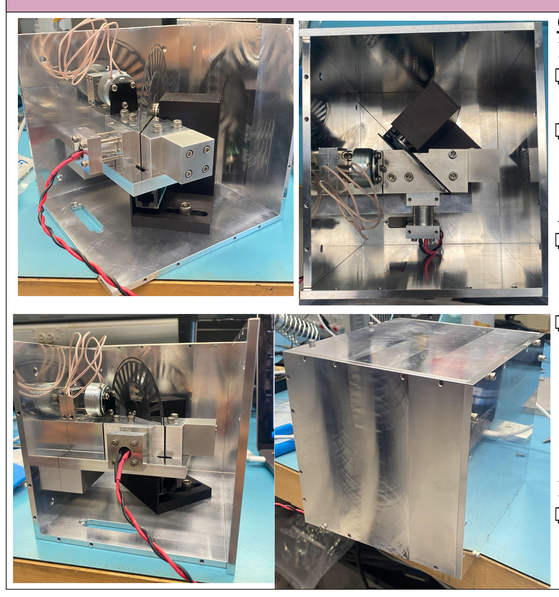


$$P^x = \int_{\nu}^{\nu+\Delta\nu} \frac{h\nu}{exp(\frac{h\nu}{k_B T})-1} d\nu$$

- Because the S/N ratio is multi-faceted, looking at its dependencies on frequency, chopped power value, and duration of calibration was of interest. This also served as a sanity check on my code since the shape of the plots can be predicted fairly simply.



Final Product and Conclusions



Overview:

Background:

- SPT-SLIM is a rendition of the SPT project that aims to use LIM techniques to survey high-redshift areas of the galaxy.
- A calibrator is needed to serve as a conversion tool to turn the measured data in terms of CMB temperature units, as well as adjusting the detector responsivity as we move to different elevations.

Analysis:

- With the help of Planck's blackbody equation, an analysis was done to determine the diameter of the light pipe the chopped signal travels through and the corresponding signal to noise ratio.
- Because of the frigid temperatures at the South Pole, an analysis was done to determine the temperature fluctuation as well as the low operating temperature limits of the electronics.
  - It was determined that rapid and large changes in temperature were not of concern and that the electronics performed well under extreme conditions.

Fabrication:

- As seen on the left, calibrator was fabricated and constructed. Testing and data collection will be done in the remaining weeks of internship.

Citations

[1] B. Benson, et al. *The Department of Astronomy and Astrophysics: South Pole Telescope* URL: https://astro.uchicago.edu/research/spt.php (Accessed: 20 July 2023).

[2] K. S. Karkare, A. J. Anderson, P. S. Barry, B. A. Benson, J. E. Carlstrom, T. Cecil, et al. SPT-SLIM: A Line Intensity Mapping Pathfinder for the South Pole Telescope. Journal of Low Temperature Physics, March 2022. URL: https://doi.org/10.1007/ s10909-022-02702-2, doi:10.1007/s10909-022-02702-2.

[3] Oxholm, T. M. (2022, April 1). *A beginner's Guide to Line Intensity Mapping Power Spectra*. arXiv.org. https://arxiv.org/abs/2204.00685#:~:text=Line%20intensity%20mapping%20(LIM)%20is,dark%20matter%20throughout%20the%20universe.

[4] Sobrin, J. A., Anderson, A. J., Bender, A. N., Benson, B. et al. (2022, February 25). *The design and integrated performance of SPT-3G*. arXiv.org. https://arxiv.org/abs/2106.11202

[5] Benson et al., SPT-3G: A Next-Generation Cosmic Microwave Background Polarization Experiment on the South Pole Telescope, Arxiv 1407.2973

[6] RCW38. (2018, July 11). *Celestial art*. www.eso.org. https://www.eso.org/public/images/eso1823a/

Acknowledgements

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