Optimizing the observing bandwidths for the CLASS HF detectors

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Imprints of Inflation on the Cosmic Microwave Background

- Small fluctuations in the early moments of the universe become anisotropies in temperature of the CMB, 2.7260 ± 0.0013 K
Imprints of Inflation on the Cosmic Microwave Background

- Process of inflation yields large gravitational waves

E - Modes

B - Modes
Imprints of Inflation on the Cosmic Microwave Background

- Process of inflation yields large gravitational waves
- GW’s uniquely cause B-mode polarization
Imprints of Inflation on the Cosmic Microwave Background

- Process of inflation yields large gravitational waves
- GW’s uniquely cause B-mode polarization
- Therefore, a B-mode signal in the CMB would be evidence for inflation
Detecting the CMB

- The Cosmology Large Angular Scale Surveyor (CLASS) will use very sensitive, very cold bolometers at four different frequencies in order to detect the very low-frequency microwave photons from the CMB.
Avoiding Other Sources

- Optical filters, feed horns, waveguides and on-chip filters remove frequencies beyond the desired signal.
- Location in the Atacama desert will decrease microwave signal from the atmosphere.
- The Variable Polarization Modulator distinguishes the polarization of the photons.
The atmosphere behaves like a black body - absorbing and emitting - at about 270 K
The Atmospheric Signal

- It doesn’t absorb and emit on all frequencies, but where it absorbs, it emits; where it doesn’t absorb, it doesn’t emit.

Data from Refs. [1] and [2]
The Atmospheric Signal

Data from Refs. [1] and [2]

- The waveguides only permit transmission of photons at certain wavelengths
To determine the optimal bandwidth for on-chip filter placement:

- Maximize power from the CMB
- Minimize noise from the signal
- Use a model based on variable atmospheric transmission
Planck’s law (intensity per frequency)

\[ B_\nu(T) = \frac{2\hbar \nu^2}{c^2} \frac{1}{e^{\frac{\hbar \nu}{k_B T}} - 1} \]  \hspace{1cm} (1)

Power per frequency, Approximating \( A\Omega = \chi^2 \) (Ref. [3])

\[ p(\nu) = A\Omega B_\nu(T) = \alpha \epsilon f \frac{2\hbar \nu}{e^{\frac{\hbar \nu}{k_B T}} - 1} \]  \hspace{1cm} (2)
Variance per frequency

\[ \sigma^2 = \langle n^2 \rangle - \langle n \rangle^2 \]  

(3)

Derived for radio-frequency bolometers in Ref. [4]:

\[ N E P^2 = \frac{4h^2 \nu^2 (\alpha \epsilon f)}{\frac{h \nu}{e^{\frac{kBT}{T}} - 1}} \left( 1 + \frac{\alpha \epsilon f}{\frac{h \nu}{e^{\frac{kBT}{T}} - 1}} \right) \]  

(4)
Since the water in the atmosphere is variable and influences atmospheric transmissivity, I weighted the power and noise by the PWV on a Rayleigh distribution.

\[ D = \frac{x}{\sigma^2} e^{-\frac{x^2}{2\sigma^2}} \]  

(5)

Given the percent of time the Atacama is below a set of PWVs, I performed a \( \chi^2 \) test to evaluate \( \sigma = 1.056251 \).
Optimization map

Normalized Ratio of CMB Power to Sum Noise for varying bandwidths, weighted by PWV

Bandwidth End Point (GHz)

Bandwidth Start Point (GHz)
The maxima represent the bandwidths with the highest CMB signal and the lowest noise and yield the following results.

<table>
<thead>
<tr>
<th>Band</th>
<th>Recommended Band</th>
<th>Total Power</th>
<th>Total NEP</th>
</tr>
</thead>
<tbody>
<tr>
<td>90 GHz</td>
<td>75.2 to 108.8 GHz</td>
<td>4.9781 pW</td>
<td>3.4497 \cdot 10^{-5} \text{ pW/\sqrt{Hz}}</td>
</tr>
<tr>
<td>150 GHz</td>
<td>125.5 to 164.7 GHz</td>
<td>7.0871 pW</td>
<td>5.0195 \cdot 10^{-5} \text{ pW/\sqrt{Hz}}</td>
</tr>
<tr>
<td>220 GHz</td>
<td>187.1 to 239.0 GHz</td>
<td>13.6861 pW</td>
<td>8.9116 \cdot 10^{-5} \text{ pW/\sqrt{Hz}}</td>
</tr>
</tbody>
</table>
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References

1. ALMA Collaboration, Atmosphere model based on Juan Pardo’s ATM model for the altitude of the Atacama Desert, almascience.eso.org/about-alma/weather/atmosphere-model

2. K. U-Yen, High Frequency Structure Simulations for the CLASS waveguides.

