CMB-S4

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for the CMB-S4 Collaboration
Project Status

- Joint DOE/NSF oversight group in place
- Received DOE CD-0 in July 2019
- Responded to Astro 2020 decadal survey
- Working towards baseline design to support NSF preliminary design and DOE CD-1 reviews (2021)
- Current schedule targets survey operations starting in 2027!

Science Goals (driving design)

- gravitational waves from early universe $\sigma(r)=5\times10^{-4}$
- light relics $\sigma(N_{\text{eff}})=0.03$
- high-z galaxy clusters 100s of clusters $z>2$
- time-variable mm-wave sky <2 days

Science Goals

- Measure $N_{\text{eff}}$, $H_0$ test $\Lambda$CDM
- Map integrated matter density
- Constrain inflation
- Astrophysics ++

Experimental Strategy

**Ultra-deep survey:**
Observe ~3% of the sky with 150,000 detectors in SATs & a de-lensing LAT with 120,000 detectors.

**Deep-wide survey:**
Two LATs observing ~60% of the sky with 240,000 detectors.
**Frequency Coverage**

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Observe ~3% of the sky with 150,000 detectors in SATs & a de-lensing LAT with 120,000 detectors.

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Observing Sites

Ultra-deep survey: observe ~3% of the sky with 150,000 detectors in SATs & a de-lensing LAT with 120,000 detectors.

Deep-wide survey: Two LATs observing ~60% of the sky with 240,000 detectors.

7 years of observing at two sites.
slow evolution in details continues, but this is still very close to the current reference design
Reference Design: Map depths

- 3% of the sky from south pole

\[
\begin{array}{|c|c|c|c|c|c|c|c|c|}
\hline
\text{Frequency} & 20 & 30 & 40 & 85 & 95 & 145 & 155 & 220 & 270 \\
\hline
\text{Angular resolution (arcmin)} & 11.0 & 72.8 & 72.8 & 25.5 & 25.5 & 22.7 & 22.7 & 13.0 & 13.0 \\
\text{Total survey weight / } 10^6 \text{ (} \mu K^{-2} \text{)} & 0.12 & 0.69 & 0.43 & 11.0 & 14.1 & 5.7 & 4.8 & 0.71 & 0.24 \\
\text{Q/U rms (} \mu K\text{-arcmin)} & 8.4 & 3.5 & 4.5 & 0.88 & 0.78 & 1.2 & 1.3 & 3.5 & 6.0 \\
\hline
\end{array}
\]

- ~70% of the sky from Chile

\[
\begin{array}{|c|c|c|c|c|c|c|}
\hline
\text{Frequency (GHz)} & 20 & 30 & 40 & 95 & 145 & 225 & 270 \\
\hline
\text{Angular resolution (arcmin)} & 11.0 & 7.3 & 5.5 & 2.3 & 1.5 & 1.0 & 0.8 \\
\text{White noise level (} \mu K\text{-arcmin)} & 8.4 & 5.0 & 4.5 & 0.68 & 0.96 & 5.7 & 9.8 \\
\hline
\end{array}
\]

\[
\begin{array}{|c|c|c|c|c|c|c|}
\hline
\text{Frequency (GHz)} & 30 & 40 & 95 & 145 & 220 & 270 \\
\hline
\text{Angular resolution (arcmin)} & 7.4 & 5.1 & 2.2 & 1.4 & 1.0 & 0.9 \\
\text{Total survey weight (} TT \text{)/} 10^6 \text{ [} \mu K^2 \text{]} & 0.22 & 0.68 & 26.3 & 26.3 & 2.2 & 0.38 \\
\text{White noise level for } TT \text{ (} \mu K\text{-arcmin)} & 21.8 & 12.4 & 2.0 & 2.0 & 6.9 & 16.7 \\
\text{White noise level } E/B \text{ (} \mu K\text{-arcmin)} & 30.8 & 17.6 & 2.9 & 2.8 & 9.8 & 23.6 \\
\hline
\end{array}
\]

https://arxiv.org/abs/1907.04473
Reference Design: Point source sensitivity

<table>
<thead>
<tr>
<th>CMB-S4 Survey</th>
<th>30 GHz</th>
<th>40 GHz</th>
<th>95 GHz</th>
<th>145 GHz</th>
<th>220 GHz</th>
<th>270 GHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full depth (wide)</td>
<td>0.8</td>
<td>0.6</td>
<td>0.2</td>
<td>0.2</td>
<td>0.6</td>
<td>1.1</td>
</tr>
<tr>
<td>1 week (wide)</td>
<td>15</td>
<td>11</td>
<td>3</td>
<td>4</td>
<td>11</td>
<td>21</td>
</tr>
<tr>
<td>Full depth (ultra-deep)</td>
<td>0.1</td>
<td>0.1</td>
<td>0.04</td>
<td>0.07</td>
<td>0.4</td>
<td>0.5</td>
</tr>
<tr>
<td>1 week (ultra-deep)</td>
<td>2</td>
<td>3</td>
<td>0.8</td>
<td>1</td>
<td>7</td>
<td>9</td>
</tr>
</tbody>
</table>

[just noise, not including confusion]

https://arxiv.org/abs/1907.04473
Survey products
extragalactic foregrounds make T map less sensitive than you might think

pol maps expected to be largely unaffected by extragalactic sources, but Galaxy....

Alvarez et al; 2006.06594
Survey products: CMB/kSZ

extragalactic foregrounds make T map less sensitive than you might think

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from Srini Ragunathan
Survey products

- Planck fidelity
- Simulated sky
- CMB-S4 fidelity

- Lensing
- Compton-y
Survey products: Lensing

from CMB-S4 science book: astro-ph/160517

fig by Alex van Engelen
Survey products: Lensing

iterated E/B noise; by Chunyu Lu
Survey products

Planck fidelity

Simulated sky

CMB-S4 fidelity

Lensing

Compton-y

CMB-S4
Survey products: Compton $y$

Thermal SZ map expected to be sample variance limited on intermediate scales

https://arxiv.org/abs/1907.04473  (Colin Hill)
Survey products: Compton $y$

Thermal SZ map expected to be sample variance limited on intermediate scales

from Srini Ragunathan
Large Scale Structure with CMB-S4

- neutrino masses
  - CMB lensing, cluster counts $\sigma(M_\nu)\sim 20$ meV in each
- kSZ statistics (power spectrum, trispectrum)
  - optical depth measurement? Alvarez et al 2006.06594 $\sigma(\tau)=0.003$
- tSZ statistics
- galaxy cluster catalog
  - 70K clusters

- “galaxy” {number density, shear} + CMB lensing
- “galaxy” {number density, shear} + y
- “galaxy” {number density, shear?} + kSZ

- electron density fluctuations (patchy $\tau$), polarized SZ
We want to communicate to the extended community how CMB-S4 measurements can be used to advance these science topics in unique and complementary ways, and to work with them on exploring powerful joint analysis of CMB and other probes