Thermal Stability in Precision Cosmology Experiments: The Planck LFI Case

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Planck/LFI

- Produce full sky CMB maps with an angular resolution, at 70 GHz, of about 13 arcmin and a sensitivity per pixel, of few µK.
- Cryogenically cooled low noise detectors
- Accurate control of systematic effects at µK level
Systematic effects

- Beam distortions
- Straylight
- Thermal effects
- Intrinsic instrumental effects
- Pointing
Systematic effects

- Thermal effects
Thermal environment

- 50 K telescope environment
- V-grooves at different temperatures
- 300 K stage
Thermal environment

4 K HFI focal plane
0.1 K HFI bolometers

20 K LFI focal plane

LFI waveguides from 20 K to 300 K
Requirements on max systematics from thermal effects

- The global contribution from spin-synchronous thermal fluctuations in each pixel will be less than ± 0.8 µK
- The global contribution from other periodic thermal fluctuations in each pixel will be less than ± 1.1 µK
Sensitivity of LFI radiometers to thermal fluctuations

\[ p(t) = a k \beta G_{FE} G_{BE} G_{DC} \left( \tilde{T}_s + T_{n1} + \frac{T_{n2}}{G_{FE}} - r \left( \tilde{T}_{4K} + T_{n1} + \frac{T_{n2}}{G_{FE}} \right) \right) \]
Fluctuations propagation

Mechanical damping

Transfer function:

\[ \frac{\partial p}{\partial T_s} \delta T_s = \frac{\partial p}{\partial T_i} \delta T_i \]

Maps
Fluctuation sources: sorption cooler

Single bed cycle: 667 sec
Full cycle: 4000 sec

Temperature (K)

Time (sec)
Fluctuations propagation

- Sorption cooler

Front end

Thermo-mechanical damping
Low pass filter
Fluctuations propagation
Transfer function for front-end temperature fluctuations

\[ T_f = L_{\text{feed-OMT}} \left\{ 1 - \frac{1}{L_{\text{feed-OMT}}} \right\} \left[ r \left( 1 - \frac{1}{L_{4K}} \right) + \left[ \tilde{T}_s + T_n - r(\tilde{T}_{4K} + T_n) \right] \ln(10) \frac{\partial G_{\text{dB}}}{\partial T_{\text{phys}}} + (1 - r) \frac{\partial T_n}{\partial T_{\text{phys}}} \right] \]

Term arising from temperature fluctuations at Feed - OMT level

Term arising from temperature fluctuations at reference horn level

Dependence of gain on physical temperature

Dependence of noise temperature on physical temperature

Values of \( T_f \) for \( \partial G/\partial T_{\text{phys}} \approx 0.05 \text{ dB/K} \) and \( \partial T_n/\partial T_{\text{phys}} \approx 0.8 \text{ K/K} \)

<table>
<thead>
<tr>
<th>Frequency (GHz)</th>
<th>30 GHz</th>
<th>44 GHz</th>
<th>70 GHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>( T_f )</td>
<td>0.17</td>
<td>0.13</td>
<td>0.08</td>
</tr>
</tbody>
</table>

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Data Analysis

- Map Production

- Destriping

Too high level: 5.3 to 8.1 $\mu$K in the maps!
Hardware solution: active T control

- Mechanical constraint
- Low power (about 100mW)
- Limited thermal break
Hardware solution: active T control
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Hardware solution: active T control

<table>
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<th>Frequency (GHz)</th>
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<th>44</th>
<th>70</th>
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<tbody>
<tr>
<td>$\delta T$ p-p ($\mu$K)</td>
<td>11.1</td>
<td>10.4</td>
<td>14.6</td>
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<tr>
<td>Before destriping</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\delta T$ p-p ($\mu$K)</td>
<td>0.65</td>
<td>0.65</td>
<td>1.00</td>
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<tr>
<td>After destriping</td>
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<td></td>
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</tr>
</tbody>
</table>

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• Sorption cooler

4K Reference Load

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Summary and Conclusions

- Relevant thermal effects identification
- Propagate effects to detectors
- Evaluation of the effects upon measurement
- Reduce the effects if needed