CIB: The Study of Systematic Errors

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Outline

• DIRBE - mean CIB intensity & systematic uncertainty

• IRAC - CIB fluctuations & a zodiacal light test

• DIRBE - Revisiting the zodiacal light & unexpected discoveries
**COBE / DIRBE**

- Absolute zero point sky brightness measurements
- 1.25, 2.2, 3.5, 4.9, 12, 25, 60, 100, 140, 240 µm
- 0.7° beam (squarish shape and squarish profile)
- $64^\circ < \varepsilon < 124^\circ$ scanning
- >9 months of cryogenic observing.
DIRBE CIB Detection

Criteria for success

• After subtraction of all foregrounds…

  1. $\nu I_\nu > 0$ (a positive signal)

  2. $\nu I_\nu(\alpha_1,\delta_1) = \nu I_\nu(\alpha_2,\delta_2)$ (an isotropic signal)
DIRBE Residual

# Systematic Error Budget


<table>
<thead>
<tr>
<th>Wavelength (µm)</th>
<th>Detector Offset Uncertainty (nW m⁻² sr⁻¹)</th>
<th>Detector Gain Uncertainty (nW m⁻² sr⁻¹)</th>
<th>Zodiacal Light Uncertainty (nW m⁻² sr⁻¹)</th>
<th>Bright Source Blanking Uncertainty (nW m⁻² sr⁻¹)</th>
<th>Faint Source Model Uncertainty (nW m⁻² sr⁻¹)</th>
<th>$I_0(100$ μm) from H I Uncertainty (nW m⁻² sr⁻¹)</th>
<th>$R(λ)$ Uncertainty (nW m⁻² sr⁻¹)</th>
<th>Total Systematic Uncertainty (nW m⁻² sr⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.25 ...........</td>
<td>0.05</td>
<td>0.031</td>
<td>15</td>
<td>2.3</td>
<td>15</td>
<td>...</td>
<td>...</td>
<td>21</td>
</tr>
<tr>
<td>2.2 .............</td>
<td>0.028</td>
<td>0.031</td>
<td>6</td>
<td>0.6</td>
<td>10</td>
<td>...</td>
<td>...</td>
<td>12</td>
</tr>
<tr>
<td>3.5 .............</td>
<td>0.015</td>
<td>0.031</td>
<td>2</td>
<td>0.2</td>
<td>6</td>
<td>0.4</td>
<td>0.2</td>
<td>6</td>
</tr>
<tr>
<td>4.9 .............</td>
<td>0.010</td>
<td>0.030</td>
<td>6</td>
<td>0.02</td>
<td>5</td>
<td>0.5</td>
<td>0.3</td>
<td>8</td>
</tr>
<tr>
<td>12 ................</td>
<td>0.015</td>
<td>0.051</td>
<td>138</td>
<td>Small</td>
<td>Small</td>
<td>3.0</td>
<td>3.8</td>
<td>138</td>
</tr>
<tr>
<td>25 .............</td>
<td>0.010</td>
<td>0.151</td>
<td>156</td>
<td>Small</td>
<td>Small</td>
<td>1.5</td>
<td>1.2</td>
<td>156</td>
</tr>
<tr>
<td>60 ................</td>
<td>1.34</td>
<td>0.104</td>
<td>27</td>
<td>...</td>
<td>...</td>
<td>2.2</td>
<td>1.3</td>
<td>27</td>
</tr>
<tr>
<td>100 .............</td>
<td>0.81</td>
<td>0.135</td>
<td>6</td>
<td>...</td>
<td>...</td>
<td>5.0</td>
<td>5.3</td>
<td>9</td>
</tr>
<tr>
<td>140 .............</td>
<td>5</td>
<td>0.106</td>
<td>2.3</td>
<td>...</td>
<td>...</td>
<td>9.5</td>
<td>4.8</td>
<td>12</td>
</tr>
<tr>
<td>240 .............</td>
<td>2</td>
<td>0.116</td>
<td>0.5</td>
<td>...</td>
<td>...</td>
<td>4.2</td>
<td>2.3</td>
<td>5</td>
</tr>
</tbody>
</table>
Isotropy

1.25 μm Residual

2.2 μm Residual

3.5 μm Residual

4.9 μm Residual

Isotropy


HQA = 8780 deg$^2$; HQB = 854 deg$^2$
CIB Fluctuations

• Measurement of the small angular scale structure of the background. (Angular power spectra or correlation functions.)

• Does not require absolute zero point calibration.

• Does not require accurate models of mean foreground intensities.

• Does require knowledge of the structure in the foreground components.
CIB Fluctuations

• **2MASS** 1.2, 1.6, 2.2 µm (J, H, Ks)

• **Spitzer / IRAC**
  
  • angular resolution $\sim 2''$
  
  • wavelengths = 3.6, 4.5, 5.8, 8 µm
  
  • sensitivity = 1, 1.3, 3.9, 3.5 nW m\(^{-2}\) sr\(^{-1}\) in 3600 s
  
  • Kashlinsky et al. (2005, etc. etc.)
Table 2
Background Analysis Checks

<table>
<thead>
<tr>
<th>Issue</th>
<th>Test</th>
<th>Result</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Excess power on preferred axes?</td>
<td>Compare power spectra before and after blanking axes</td>
<td>Ignoring power on the FFT axes can mitigate artifacts</td>
<td>Figure 2, Section 3.2</td>
</tr>
<tr>
<td>2. Self-calibration effectiveness?</td>
<td>Compare different channels</td>
<td>Self-calibration does remove some artificial patterns</td>
<td>Figures 3–6, Section 4.1</td>
</tr>
<tr>
<td>3. Optimal depth for resolved source models?</td>
<td>Check residual skewness and correlation with model</td>
<td>Zero skewness is most robust and simplest criterion</td>
<td>Figures 7–13, Section 4.2</td>
</tr>
<tr>
<td>4. Correct PRF for resolved source models?</td>
<td>Test with modified PRFs</td>
<td>PRF at 4.5 μm may be slightly too sharp, but not a problem</td>
<td>Figure 14, Section 4.2</td>
</tr>
<tr>
<td>5. Sensitivity to clipping fraction?</td>
<td>Alter clipping masks and add random clipping</td>
<td>Little sensitivity to variation of masked area</td>
<td>Figures 17–20, Section 4.2</td>
</tr>
<tr>
<td>6. Results related to dither pattern?</td>
<td>Calculate power spectrum of dither pattern</td>
<td>Very unlike power spectrum of residual intensity</td>
<td>Figure 22, Section 4.3</td>
</tr>
<tr>
<td>7. Results related to dither pattern + calibration?</td>
<td>Calculate power spectrum of dithered detector offset</td>
<td>Calibration errors would yield distinct large-scale power</td>
<td>Figure 23, Section 4.3</td>
</tr>
<tr>
<td>8. Results related to foreground sources and mask?</td>
<td>Calculate power spectrum of foreground sources, mask, “halo” image</td>
<td>Test power is too flat, or too weak to produce observed large-scale power</td>
<td>Figures 24–29, Section 4.3</td>
</tr>
<tr>
<td>9. Similar results in different fields?</td>
<td>Compare parameterized fits to different power spectra</td>
<td>Large-scale power has similar shape in different fields, but scales with shot noise (depth)</td>
<td>Figures 30–35, Section 5 Tables 3–5</td>
</tr>
<tr>
<td>10. Similar structure at different wavelengths?</td>
<td>Calculate cross-correlation coefficients and colors</td>
<td>Significant correlation and constant color indicate celestial origin at 3.6 and 4.5 μm</td>
<td>KAMM1</td>
</tr>
<tr>
<td>11. Possible zodiacal light structures?</td>
<td>Constrain by re-observation at different epochs</td>
<td>Indicates that fluctuations in zodiacal light are smaller than those in the observed background</td>
<td>KAMM1</td>
</tr>
<tr>
<td>12. Possible ISM (cirrus) structures?</td>
<td>Constrain by observations of regions at various H I column density</td>
<td>ISM could dominate large-scale fluctuations at 8 μm, but should be unimportant at shorter λ</td>
<td>KAMM1</td>
</tr>
</tbody>
</table>
A Specific Zodiacal Light Test

• Watch the same low ecliptic latitude patch from high to low elongation. (COSMOS field)

• Do the CIB fluctuations change in any way associated with the zodiacal light intensity?
4.5 µm Field (All Epochs)

(Log scale)
Self-Calibration

Detector Offsets

Scaled at ~ ±15 nW m⁻² sr⁻¹

Self calibration adjusts for
(a) fixed pattern effects in the detector calibration
(b) time dependent variation over the field of view.
Expected Zodi Trend (t)

\[ \sim 85^\circ < \epsilon < \sim 120^\circ \]
Expected Zodi Trend (#)
Self-Calibration
Time-dependent Offsets
Self-Calibration

Time-dependent Offsets

- first frame effect
- ZL(t)
- spatial gradient
- transient effect

$\sigma \sim 0.3 \text{ nW m}^{-2} \text{ sr}^{-1}$

3.6 $\mu$m
Self-Calibration
Time-dependent Offsets

- ZL(t) - first frame effect
- spatial gradient
- transient effect

σ ~ 0.2 nW m⁻² sr⁻¹

4.5 µm
Power Spectra

3.6 μm Epoch 1 flat noise

white noise
shot noise (sources)
power law
White Noise Component

3.6 µm

4.5 µm

Trend with ZL suggests that photon shot noise is a significant part of the white noise component
Power Law Component

3.6 \mu m

No trend with ZL

4.5 \mu m

Trend with ZL?
Work in Progress!

• Final results may change.
• Still some aspects that don’t quite fit.
• Observations probably should have been deeper.
Re-visiting DIRBE Data

Wondered if the dust trail of the disintegrating Kreutz family comets was visible — if looking at the right time and direction.

1. Made daily (not weekly) sky maps to isolate the correct time.

2. Subtracted zodiacal light model, and constant background at each pixel.

3. Examined the results as animations.
The COBE Sky Cube
1.25, 12, 100 μm
12µm Daily Sky Maps

[-2500, 13500] nW m\(^{-2}\) sr\(^{-1}\)
12µm Daily Residual Maps

[-125, 125] nW m\(^{-2}\) sr\(^{-1}\)
Comet Encke Dust Trail

12 µm, polar projection
DIRBE Results

• Zodiacal light dust bands and low latitude structure differ from the model as a function of time.

• Some high latitude structure does too.

• At least 6 comet trails can be detected at ≤1% of the zodiacal light brightness. (Despite the 0.7° beam!)

• One more comet (5 vs. 4), and ~100 more asteroids (~100 vs. 3) than previously recognized.

• Also…
Solar-induced Variation

4.9 µm ($\beta > 75^\circ$)

Solar Mg II index (~2% modulation)

e.g. Kelsall et al. (1998)
NIRB Implications

• Mean NIRB intensity may not be strongly affected by data that are averaged over long periods and/or large areas.

• NIRB fluctuations may or may not average out depending on when and how the data were collected.

• **Dust trails** may be a 0.5 nW m\(^{-2}\) sr\(^{-1}\) perturbation vs. “large scale” structure at \(~0.1\) nW m\(^{-2}\) sr\(^{-1}\). (extrapolation to shorter \(\lambda\) is unknown)

• **Solar-induced variation** can be a 2 nW m\(^{-2}\) sr\(^{-1}\) perturbation affecting very large areas at 1-5 \(\mu\text{m}\).