Flux Calibration of the Herschel-SPIRE Photometer

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Flux Calibration Equations

The derivative of the observed signal $S_{\text{Meas}}$ was found empirically to be the following function of voltage $V$:

$$\frac{dS_{\text{Meas}}}{dV} = K_1 + \frac{K_2}{K_3 - V}$$

The integral of this equation gives the conversion from voltage to flux density:

$$S_{\text{Meas}} = K_1 (V_{\text{Meas}} - V_0) + K_2 \log \frac{V_{\text{Meas}} - K_3}{V_0 - K_3}$$

The $V_0$ terms are zero-point voltages that (for convenience) are set to the mean values for “dark” sky.

An additional $K_{\text{MonP}}$ term is applied to convert the flux densities to monochromatic values for sources where $\nu S_{\nu}$ is constant.
Flux Calibration Steps

The $K$ parameters are derived for each functional bolometer in each array. Separate terms are used for the nominal and bright source voltage bias modes.

The $K_3$ terms and the unscaled $K_1$ and $K_2$ terms are derived by performing staring observations of backgrounds with varying brightnesses while PCal (an internal calibration source) is flashed.

The $K_1$ and $K_2$ terms are then scaled using fine scan observations of Neptune in which each bolometer passes over Neptune in a series of zigzag patterns.
**PCal Flash Observations**

The background signals in the PCal flash observations need to vary over the full range of expected surface brightnesses, but the exact signals from the backgrounds themselves do not need to be known.

For nominal bias mode, PCal flash observations are made in Sgr A* region.

For bright source mode, PCal flash observations are made in Sgr B2 region.

Additional calibration observations of dark fields and other sources are used to define the derivative of the curve at low surface brightnesses.
Neptune Fine Scan Observations

The fine scan observations are set up so that, in each observation, each bolometer scans over Neptune in a zigzag pattern. Scan legs are separated by 1".

A total of four observations are performed in each bias mode, with two of the observations scanning in a direction perpendicular to the other two observations.

The signals in the timeline data for each bolometer from each observation are then fitted with Gaussian functions to find the peak signal from Neptune and the background signal.
PSWE2 (nominal)
Calibration Uncertainties for Individual Bolometers

The calibration for the individual bolometers have three sources of uncertainty:

- Uncertainty from the fits to the PCal flash data
- Uncertainties from determining the scaling terms from the fine scan data
- Uncertainties from the model flux densities of Neptune (4%)
Fraction Uncertainty in $S$

$S$ (Jy/beam)

PSWE2 (nominal)
## Uncertainties for Individual Bolometers from Fitting PCal Flash Data

<table>
<thead>
<tr>
<th>Array</th>
<th>Median Fractional Uncertainty</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Nominal Mode</td>
<td>Bright Source Mode</td>
</tr>
<tr>
<td>250 µm</td>
<td>0.00021</td>
<td>0.0061</td>
<td></td>
</tr>
<tr>
<td>350 µm</td>
<td>0.00022</td>
<td>0.0051</td>
<td></td>
</tr>
<tr>
<td>500 µm</td>
<td>0.00016</td>
<td>0.0020</td>
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</tbody>
</table>
## Uncertainties for Individual Bolometers from Scaling Terms

<table>
<thead>
<tr>
<th>Array</th>
<th>Fractional Uncertainty</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Nominal Mode</td>
<td></td>
<td>Bright Source Mode</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Median</td>
<td>Max</td>
<td>Median</td>
</tr>
<tr>
<td>250 µm</td>
<td></td>
<td>0.0059</td>
<td>0.047</td>
<td>0.0032</td>
</tr>
<tr>
<td>350 µm</td>
<td></td>
<td>0.0042</td>
<td>0.045</td>
<td>0.0023</td>
</tr>
<tr>
<td>500 µm</td>
<td></td>
<td>0.0052</td>
<td>0.012</td>
<td>0.0038</td>
</tr>
</tbody>
</table>
Tests of the Flux Calibration

We tested the new flux calibration terms on typical SPIRE observations of three sources:

- Neptune
- Uranus
- Gamma Dra

Photometry is done in the timeline data.
The diagrams show the ratio of measured vs. model $f_x$ for Neptune at three different nominal sizes: 250μm, 350μm, and 500μm. The x-axis represents the operation day, ranging from 250 to 1250. The y-axis represents the ratio of $f_x$ (measured) to $f_x$ (model), with values ranging from 0.98 to 1.02. The data points for each nominal size are plotted over a range of operation days, showing the variation in the ratio over time.
## Results of Photometry Tests

<table>
<thead>
<tr>
<th>Array</th>
<th>Neptune Measured /Model Ratio (nominal)</th>
<th>Neptune Measured /Model Ratio (bright)</th>
<th>Uranus Measured /Model Ratio (bright)</th>
<th>Gamma Dra Flux Densities (nominal; mJy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>250 µm</td>
<td>0.993±0.005</td>
<td>0.997±0.005</td>
<td>0.982±0.006</td>
<td>266±3</td>
</tr>
<tr>
<td>350 µm</td>
<td>0.993±0.008</td>
<td>0.996±0.007</td>
<td>0.973±0.010</td>
<td>142±4</td>
</tr>
<tr>
<td>500 µm</td>
<td>0.997±0.004</td>
<td>0.998±0.003</td>
<td>0.971±0.004</td>
<td>73±4</td>
</tr>
</tbody>
</table>
Conclusions (PRELIMINARY)

- Sources of instrumental uncertainty for flux calibration of individual bolometers is \( \sim 0.5\% \), although some bolometers have uncertainties of 1-5%.

- Instrumental sources of uncertainty in flux calibration for entire arrays is 1.5% for most sources (sources fainter than Neptune).

- Uncertainties in flux calibration probably dominated by uncertainties in model flux densities of Neptune (4%).