Astrometric Accuracy Achievable with SPIRE Peak-up Mode

PREPARED BY: Matt Griffin

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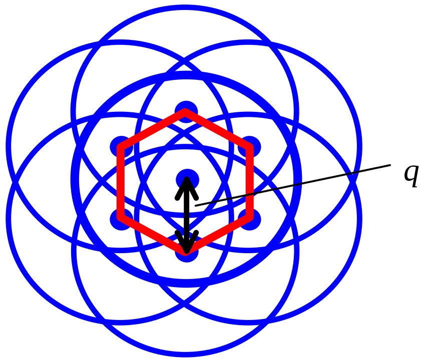
1. Peak-up mode

SPIRE can only measure the positional offset between an object on the sky and the boresight of the SPIRE instrument, defined to be the centre of the beam pattern of a particular chosen detector in the PSW (250-µm) array. (PSW detectors have the smallest beam FWHM, ~18").

In peak-up mode the SPIRE BSM is used to do a 7-point hexagonal jiggle map with spacing q arcsec., as shown here.

A suitable value for q is ~ 6": this spacing is 1/3 of the beam at 250 µm (so consistent with full sampling), and is almost twice the APE. From the 7-point map, the total flux density and position of the source can be computed, with uncertainties that depend on the S/N.



Assuming that the focal plane geometry has been established at a basic level and the source is within the beam with the nominal pointing, the offsets of the source in spacecraft coordinates (Δq_Y and Δq_Z) with respect to the SPIRE boresight can be computed using the recorded data.

As a nominal case, we take the BSM chop frequency to be f_{chop} = 2 Hz and allow 20 chop cycles per position. We then have 10 seconds per jiggle position and about 70 seconds for the 7-point.

For more details see *Operating Modes for the SPIRE Instrument* (SPIRE-RAL-DOC-000320).

2. Use of peak-up mode for pointing calibration

For pointing calibration observations, a bright point-like source of accurately known position must be used. For a good S/N, s, say > 50, on the centre with a total observation time on the order of 1 minute, the source must be brighter than about 1 Jy. Suitable objects for this purpose are:

- Neptune and asteroids (the brighter 10 or so) - all in the ecliptic plane. They would have to be tracked accurately during the observation. The other planets will not be suitable as they will cause some non-linearity in the detector response that could distort the measurements.
- Bright quasars and galaxies: Probably quite a few (several 10s or more) isotropically distributed over the sky. Some work will be needed on existing catalogues and the literature to compile a suitable list.
- Compact HII regions: Mainly near the galactic plane; not favoured because they may be extended and asymmetrical, and the positions may not be known to sufficient accuracy.

3. Uncertainties in the measurement

There are three main contributions to the overall measurement error.

3.1 Statistical uncertainty

Statistical errors in the measured data introduce a random error in the fitted position. Figure 1 shows the SPIRE 250-µm beam profile (assumed Gaussian with 18" FWHM). The lower plot is an expanded version showing the profile near the centre of the beam. Note that the signal changes only by about 1% for an offset angle of about 1" and only 0.2% for an offset of 0.5". To be sensitive to the latter at the 3-σ level would require an instantaneous S/N of > 1500, and stability of the whole system at a level better than this over the period of the measurement. We regard that as unlikely to be achieved in practice, and assume here that with good enough S/N we can measure the offset to a statistical accuracy of δq_{stat} = 1" (about 1/20th of a beam) with respect to the source position.

3.2 Uncertainty due to pointing instability during the measurement

The Herschel RPE system requirement is 0.3" over 1 minute duration, comparable to a typical measurement time. The effect that this will have on the measurement depends on whether it is a random fluctuation or a drift over the course of the measurement. Presumably, the latter is more likely, so that the source moves by up to 0.3" during the measurement. The effect would need to be simulated to determine the magnitude of the error introduced, but to first order the result will be that the fit to the data will correspond to the average position of the source during the period. Therefore, and additional error of δq_{RPE} = 0.15" should be included for this effect. This is a small contribution in relation to the statistical error.

3.3 Uncertainty in the source position

Peak-up measures the pointing direction only in relation to the source position on the sky. In converting to an absolute pointing error, any uncertainty in the source coordinates, δq_{pos} must be added in quadrature.

3.4 Overall uncertainty

Assuming that the individual contributions are uncorrelated, the overall uncertainty is

$$\delta\theta_{tot} = \left[\delta\theta_{\mathrm{stat}}{}^2 + \delta\theta_{\mathrm{RPE}}{}^2 + \delta\theta_{\mathrm{pos}}{}^2\right]^{1/2}$$

Some study will need to be done to characterise the typical uncertainties in the source positions, but it is expected that for SPIRE the total uncertainty will be dominated by the statistical errors.

There are no long-term errors associated with this pointing calibration. The measurement s a relative one, characterising the signals measured in a very short period of time from an astronomical source. For instance, if two measurements were made a week apart, it would make no difference to the result if the source brightness had varied over that timescale; or if the detector responsivity or system gain had varied over that timescale - all of these effects are taken out as we just use ratios of signals measured over a short period.

4. Conclusions and comments

- When used on sufficiently bright point-like sources, the SPIRE peak-up mode can determine the offset between the source position and the SPIRE boresight with a statistical accuracy of 1". This is approximately 1/20th of the smallest SPIRE beam, and is sufficient for SPIRE's pointing accuracy requirement.

- PACS has smaller beams as it operates at shorter wavelengths, and an also produce an instantaneously fully-sampled image. It is therefore more suitable instrument to verify the pointing calibration at sub-arcsecond accuracy.

Figure 1: SPIRE 250-mm beam profile