Astrometric Accuracy Achievable with SPIRE

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Contents

1. Point source observations with SPIRE

Two SPIRE photometer observing modes (Photometer Observatory Functions, or POFs) are available for observations of point sources:

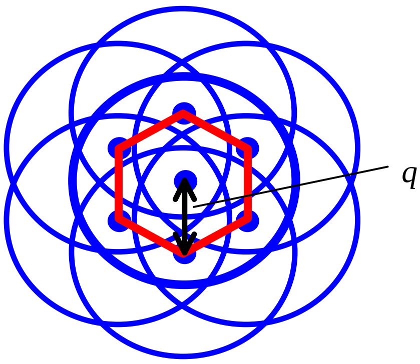
- POF 1: Chopped photometry
- POF 2: Seven-point map

Details of these and other SPIRE observing modes are given in *Operating Modes for the SPIRE Instrument* (SPIRE-RAL-DOC-000320, Issue 3.3, 24 June 2005).

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

In POF 2 mode, the SPIRE Beam Steering Mirror 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 16 chop cycles per position with one nod cycle. We then have approx. 64 seconds per jiggle position and about 150 seconds in total for the 7-point, including BSM settling time and telescope nod time.

2. Use of POF 2 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 in the absolute knowledge of 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.

3.3 Uncertainty due to pointing jitter or drift 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 $\delta q_{RPE}/2$ (= 0.15") should be included for this effect. This is a small contribution in relation to the statistical error.

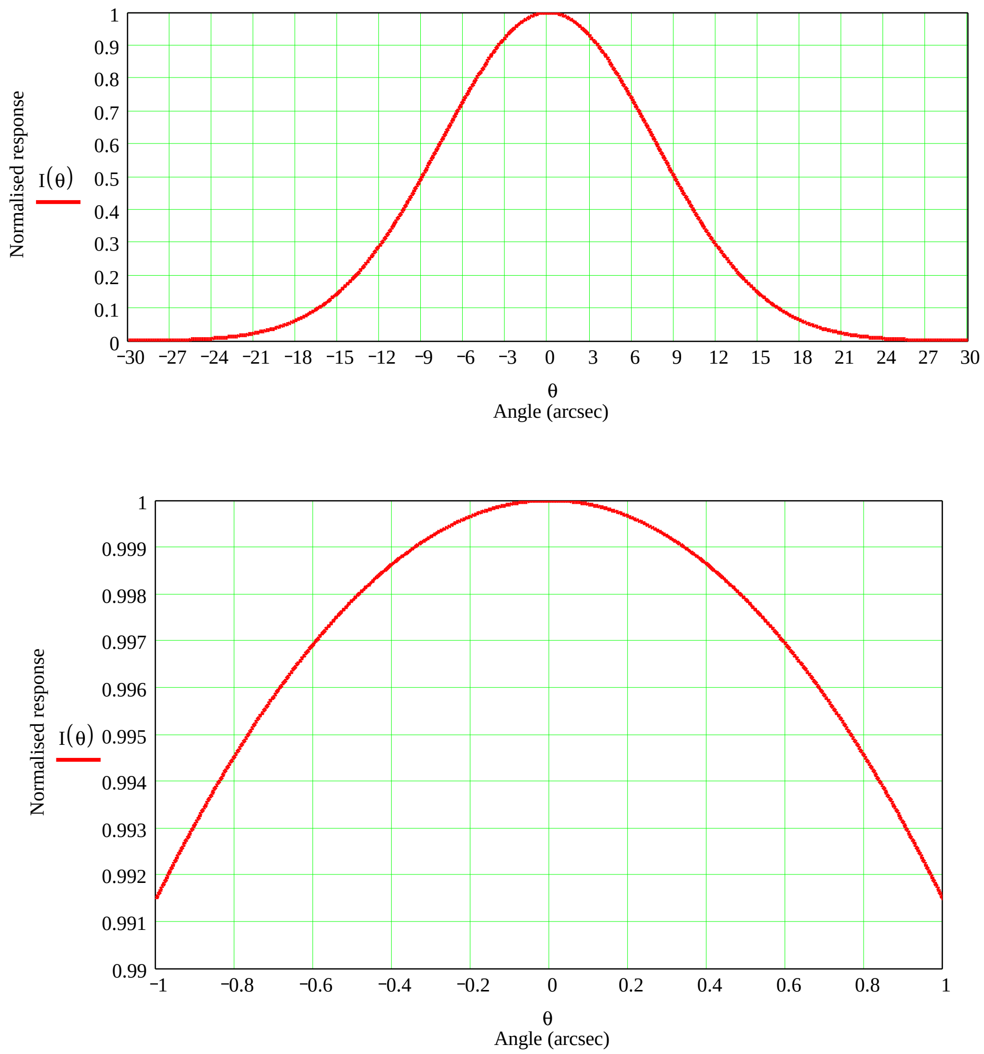
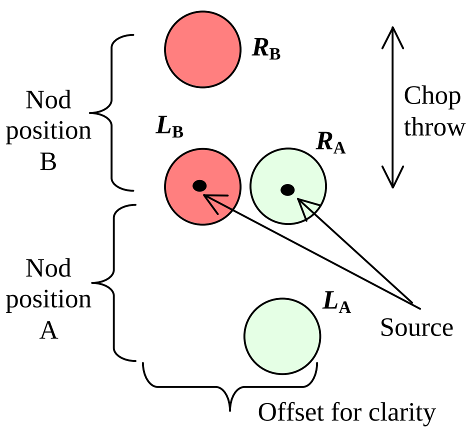


Figure 1: SPIRE 250-mm beam profile

3.4 Uncertainty due to error in the nod position

Nodding the telescope involves moving the target source is from one instrument chop position to the other chop position by re-pointing the satellite, as shown in Figure 2 It is designed to eliminate the offset signals in the two beams arising from the overall background from the telescope and the ambient environment. It is assumed here that the SRPE (defined as *the angular separation between the average actual LoS direction and a desired LoS direction which is defined relative to an initial reference direction*) applies to the position reached when the telescope is nodded by the required 126”.



Let S be the signal from the source.

Signal for Nod position A $= (R_A - L_A) = [(S + O_R) - O_L]$

Signal for Nod position B $= (R_B - L_B) = [O_R - (S + O_L)]$

Difference signal $= [(S + O_R) - O_L] - [O_R - (S + O_L)]$

$= 2S$

Figure 2: Signal estimation for a nodding observation

The signal is calculated by subtracting the amplitudes measured in the two positions, and the final flux density and position can only be fitted by assuming that the relative position of the source with respect to the beam centre is the same for the two beams (R_A and L_B): it would be extremely difficult to fit the source position independently for the two nod positions. Any additional pointing error, δq_{SRPE}, introduced during nodding will thus corrupt the measurement. Again, to first order the result will be that the fit will correspond to the average position of the source: δq_{SRPE} ~ SRPE/2. Therefore, and additional error of δq_{SRPE} should be included for this effect. This could be a large contribution in relation to the statistical error.

3.5 Overall uncertainty

Assuming that the individual contributions are uncorrelated, the overall 1-σ uncertainty is the quadrature sum of the individual 1-σ errors:

$$dq_{tot} = \left[dq_{\text{stat}}^{\;2} + \left(\frac{dq_{\text{RPE}}}{2}\right)^2 + dq_{\text{pos}}^{\;2} + \left(\frac{dq_{\text{SRPE}}}{2}\right)^2 \right]^{1/2} .$$

There are no long-term errors associated with this pointing calibration. The measurement is 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.

The accuracy to which the position can be recovered has been studied by carrying out POF 2 simulations, and the results are reported in *Recovery of Point Source Flux Density and Position from SPIRE POF 2 Observations* (SPIRE-UCF-NOT-002315). These simulations make two important assumptions:

(i) any asymmetry in the beam profile is negligible in terms of the S/N of the observations;
(ii) the telescope pointing errors during an observation are zero (i.e., RPE, SRPE = 0).

The results show that for high S/N observations (such as pointing calibrations), the highest quality measurement of position that would be practical is about 3% of the smallest (PSW) FWHM, corresponding to about 0.5”.

4. Conclusions and comments

- When used on sufficiently bright point-like sources, the SPIRE POF 2 mode can determine the offset between the source position and the SPIRE boresight with a statistical accuracy of no better than 0.5”. Achieving this will require highly symmetric beam profile and zero SRPE during the observations. In practice, we should expect some degradation with respect to this ideal performance. We therefore do not envisage being able to guarantee measurement of the boresight of SPIRE with respect to a source of known astrometric position to better than 1”. (This is sufficient for SPIRE's pointing accuracy requirement.)

- SPIRE cannot characterise the pointing to an accuracy better than about half the SRPE.

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