SPIRE

Scan Map Parameters for Rectangular Maps

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1. Introduction

This document provides a brief explanation of calculations performed to determine which mapping mode is optimal for small regions, when using the SPIRE photometer. The two modes under consideration are scan map mode without chopping (POF5) and raster scanning using tiles created by individual jiggle maps (POF3/4). The primary parameter used to differentiate between these two modes is the time it takes to integrate down to a given flux limit; the shorter the time, the better.

An algorithm is presented to enable calculation of the total observing time required to cover a rectangular map in scan map mode, of any size, including realistic assumptions about the overheads. This can then be used to compare scan map mode with jiggle map mode.

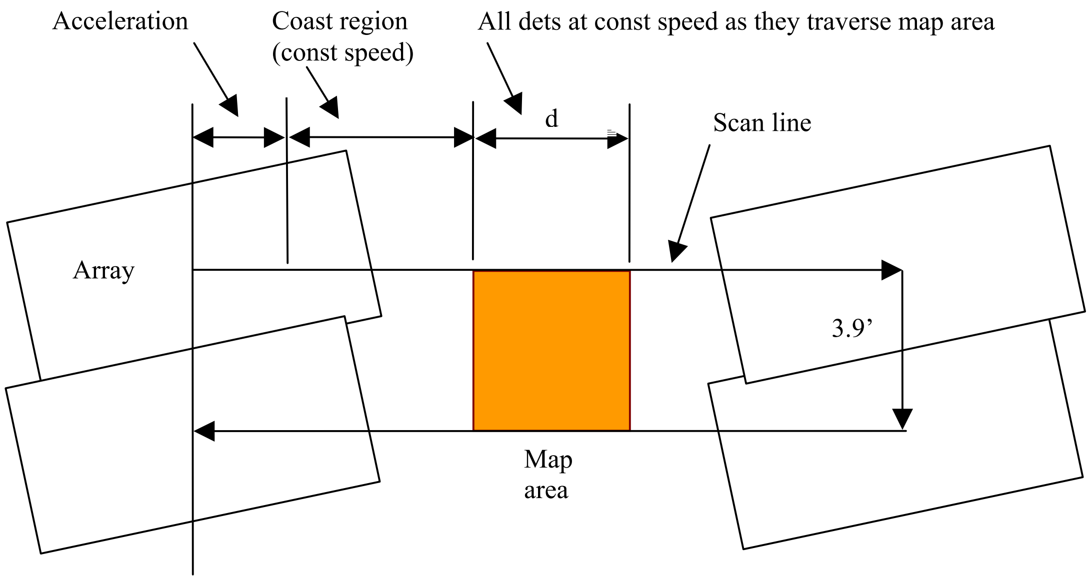
Note: this algorithm is only applicable to scan maps produced using the 'long' scan direction described in [1]. If 'diagonal' or 'short' axis scanning is used the algorithm must be modified.

2. General Algorithm for Rectangular Maps in Scan Map Mode

When performing a scan map observation the area to be mapped is built up by a series of strips, each 235" (~3.9') wide and of any length (d). This is a consequence of the scanning angle and the array overlap required to produce a uniform coverage of the final map area by all three photometer arrays (see [2]). A single strip is made up of both a forward and reverse scan. Extra strips can then be added by a subsequent pass of the array after it is moved downwards by a further 235". In this way a map of *n* strips will be made up of (*n+1*) scan lines.

The array must start some way off of the map so that it can get up to full speed before reaching the map area (2.5' for a scan speed of 30"/s). An additional buffer region ensures that the whole array is going full speed when the corner arrives at the map edge (4.5' in this case, called the coast region). This is necessary if we want to be sure that the map area contains only data obtained when the array is scanning at a uniform speed. The use of two scan lines ensures that the map area is free from the edges of the array where the tilt means fewer detectors cover the sky in the strips above and below the map area.

The following schematic shows how a single map strip can be observed in this way



If repeats of the map are required (to obtain a fainter flux limit) then the array has to return to the start of the original scan pattern and begin again after finishing one map. The following table summarises the various parameters required to calculate the total observing time for a given rectangular map.

Notes on parameters:

Parameter	Description	Nominal value
d	Length of map area	Chosen by observer (>480”)
n	Number of strips (depth of map area = n*235”)	Chosen by observer
N	Number of repeats required	Chosen by observer
v	Scan speed	30”/s
a	Acceleration of the spacecraft	$3''/s^2$
T_{acc}	Acceleration time	v/a = 10 s
T_{dec}	Deceleration time	v/a = 10 s
T_{scan}	Scan time	d/v
T_{coast}	Total coast time	540”/v = 18 s
$T_{transit}$	Transit time	2*sqrt(235”/a) = 17.7 s
R	Repeat overhead	180 s

Total observing time (T) is built up from acceleration time, coasting time (for both halves), scan time, deceleration time, transit time between scan lines and repeat overhead.

Numerically these combine in the following way:

$$T = N \cdot \left[(n+1) \cdot \left(T_{acc} + T_{coast} + T_{scan} + T_{dec}\right) + n \cdot T_{transit} + R\right]$$

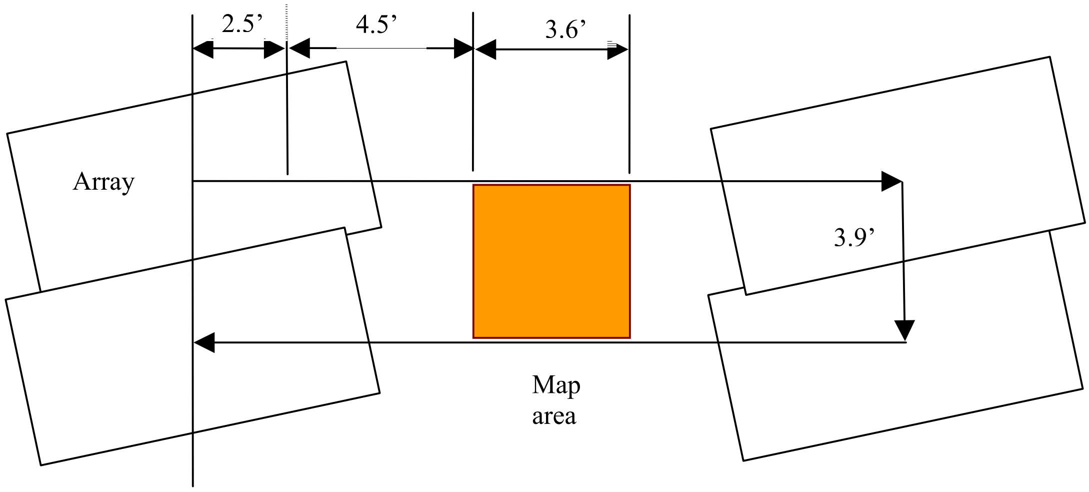
The map repeat overhead is assumed to be 180 s, i.e. the slew tax for an observation. For now I shall assume a worst case scenario in which the slew tax is charged for every repeat but it is possible that more than one map repeat could be included in a single observation.

3. Comparison of Scan vs. Jiggle mapping

The basic unit, against which scan map observations are compared, is the point source sensitivity achieved by a single jiggle map using 4 chop cycles. The Operating Modes document [3] (p28/47) gives the total integration time for an observation of this type as 256 s (and a total *observation* time of 336 s plus 180 s slew tax). The Sensitivity Model [4] gives the basic point source detection limit (no overheads) as 137.6 mJy (ΔS_1σ_1s) for the PSW array (the exact array doesn’t really matter as we are comparing like with like here). Therefore, the point source detection limit for this map would be **ΔS_1σ = 8.6 mJy**.

3.1 Method for a single jiggle map

The assumption at this stage is that a single jiggle map has an area of 3.6’x3.6’. The actual map will be slightly larger than this (more like 4’) but this assumption allows for trimming of bad signal-to-noise areas around the edge, and compensates for overlaps of tiled maps for larger areas. To map an equivalent area using scan map mode we must perform a scan something like that shown in the following schematic; essentially this is a single strip with a scan length of 3.6’. Note how the actual map area scanned is slightly larger the jiggle map because the separation between subsequent scan lines is 3.9’ rather than 3.6’.



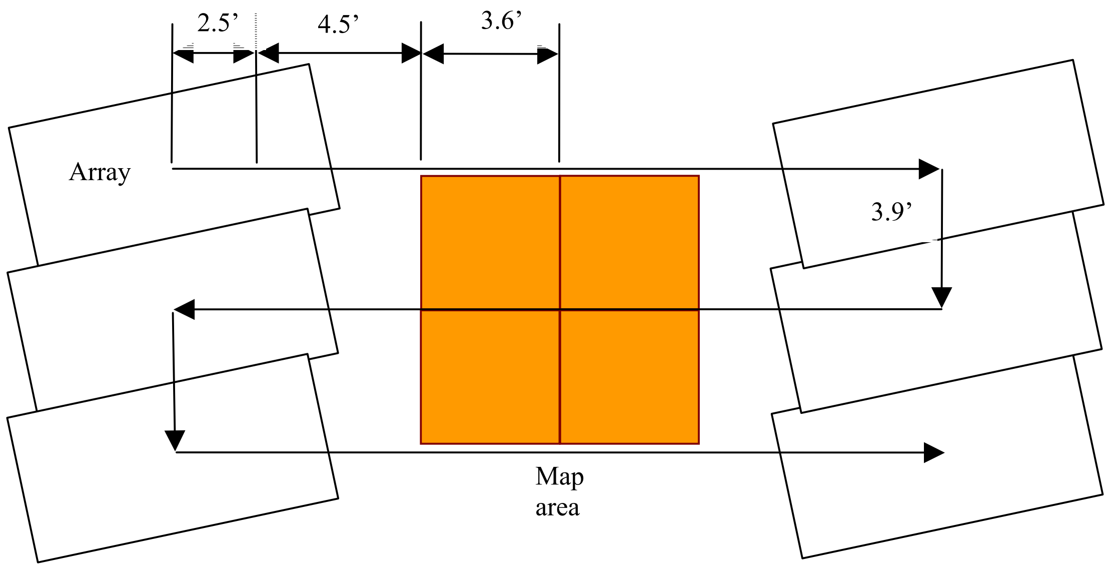
This does of course mean that there is a great deal of extra data covered in the scan map but its quality cannot be assured (see below).

Assuming a nominal scan speed of 30”/s the effective integration time at any point in the map area (see [5]) is 16.83 s for the PSW array in a single observation. Using the sensitivity model, the point source detection limit for scan mapping is 87.6 mJy (ΔS_1σ_1s) giving **ΔS_1σ = 21.4 mJy**. To achieve a similar sensitivity as the 4 chop cycle jiggle map requires 6 repeats of this scan pattern (giving an ultimate sensitivity of **ΔS_1σ = 8.74 mJy**).

Using the algorithm above, the total time to integrate down to the same sensitivity as the jiggle map is **1729 s**. Compared to the time for the jiggle map of **336+180 = 516 s** this is clearly much worse. Therefore the jiggle map should be used in this situation.

3.2 Method for a 2x2 jiggle mosaic

Moving to larger maps, if we were to mosaic 4 jiggle maps together into a 2x2 square then clearly it would take 4 x 516 = **2064 s**. For a scan map we would need to modify the above scheme a little.



This time n=2 and d=432”. Total time for scan map = **2236 s**

The two modes are now comparable. The jiggle map is slightly quicker but the scan map provides additional data that may be useful.

3.3 Method for a 3x3 jiggle mosaic

For a 3x3 mosaic n=3 and d=648". The total observation time for 9 jiggle maps is then 9 x 516 = **4644 s**.

For the scan map it is now **2829 s**.

Now scan map mode takes less time than a jiggle map and so scanning is the recommended mode for maps of this size. For any map larger than this it will also be more efficient to use scan map mode rather than jiggle map mode.

4. Summary for a variety of geometries

It is possible that an observer will not want a square patch of sky observed, for example they may want a mosaic of 2x3 jiggle maps, or they may want to scan at a different speed.

For a speed of 10"/s 2 repeats are needed (giving a sensitivity of $\Delta S\_1\sigma = 8.74$ mJy) and for 60"/s 13 repeats are needed (giving a sensitivity of $\Delta S\_1\sigma = 8.38$ mJy).

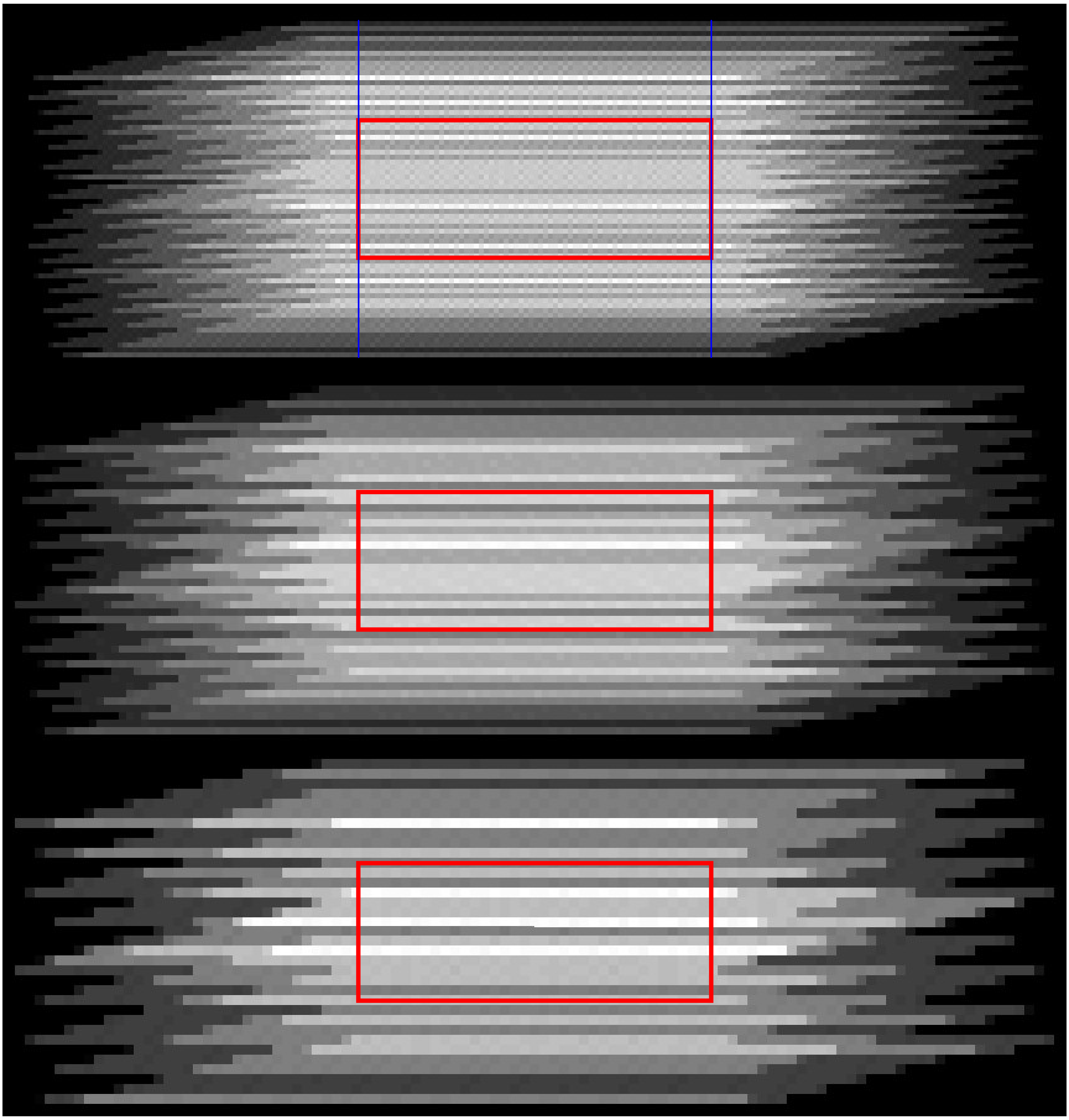
This table summarises a few possibilities. The most efficient method is highlighted in **bold**.

Jiggle Mosaic Geometry (WxH)	Scan speed ("/s)	Total Jiggle Time	Total Scan Time
1x1	10	**516**	724
1x1	30	**516**	1729
1x1	60	**516**	3938
2x2	10	2064	**1054**
2x2	30	**2064**	2236
2x2	60	**2064**	4992
3x3	10	4644	**1470**
3x3	30	4644	**2829**
3x3	60	**4644**	6140
2x1	10	1032	**810**
2x1	30	**1032**	1815
2x1	60	**1032**	4032
3x1	10	1548	**898**
3x1	30	**1548**	1902
3x1	60	**1548**	4125
3x2	10	3096	**1184**
3x2	30	3096	**2365**
3x2	60	**3096**	5133

5. Quantification of the extra data obtained in scan map mode

When performing a scan map observation the map area contains data of a uniform quality, all taken with the arrays travelling at the nominal scan speed. However, above and below this nominal map area there is more data, albeit less well sampled because of the tilt of the arrays relative to the scan direction. Additionally, some detectors are at full speed well in advance of when they actually reach the map area, and some are still going at full speed well after they have moved beyond the map area. All this data can be used when making the final maps, so effectively there is bonus data when using scan map mode. Here we quantify that bonus data.

The following images are integration time maps for the three arrays; the grey scale is linear and the red rectangle represents the map area containing data of guaranteed quality. This is an observation of a single strip of 10' length, probably the smallest map likely to be observed in scan map mode. The pixel size used to create these maps are roughly 0.5*FWHM, so PSW: 8", PMW: 12", PLW: 16". Only data obtained with the arrays moving at the full scanning speed are included in these maps. Because of this, every data point in these maps is viable, and clearly a large fraction of this good data lies outside the strict map region defined by the red rectangle.



These maps can be divided into three regions: 1) the map area inside the red rectangle; 2) the edges directly above and below the map area, within the blue vertical lines; 3) the ends, outside of the blue vertical lines. For this example the following table presents a few statistics extracted from each region.

		PSW	PMW	PLW
Map area	Total counts	76,700	49,800	24,100
	Mean	34.8	50.9	43.5
	SD	4.9	8.3	10.1
Bonus edges	Total counts	73,600	48,000	23,000
Bonus ends	Total counts	143,100	88,000	43,700

The total number of data points in each region can be summarised (approximately) by the following expressions, where d is in arc seconds and ‘strips’ = number of data strips making up the map:

Map counts = strips*251*d
Edges counts = 241*d
Ends counts = (strips+1)*137,400

The approximate area (in square arc seconds) covered by the different regions can be summarised by the following expressions:

Map area = strips*235*d
Edges area = 320*d
Ends area = (strips*235 + 320)*1080

These two sets of expressions can be combined to compare the bonus data with the map data. The first table shows how the total quantity of data compares:

Bonus Data	Total No. data points w.r.t map area
Edges	(96/strips) %
Ends	54700*(strips+1)/(strips*d) %

The approximate areas covered by the bonus regions are shown in the next table, as a percentage of the main map area:

Bonus Data	Area w.r.t map area
Edges	(136/strips) %
Ends	460*(strips*235 + 320)/(strips*d) %

The main map area contains the highest density of data with the edges and ends experiencing less integration time per unit area. Approximate mean values are shown in the final table:

Bonus Data	Mean integration time w.r.t map area
Edges	70 %
Ends	45 %

Although these values are averages the distribution of integration time is not uniform, as can be seen in the integration time maps above. Close to the main map region the integration time per pixel in the bonus data will be close to 100 % of that experienced in the map region, declining to 0 % furthest from the map region.

6. Conclusions

The nominal scanning speed will be 30"/s so in general, for maps larger than ~8'x8', scanning is more efficient then jiggling. This supports the current baseline of using scan map mode for all maps except a single 4'x4' field, which will be done using jiggle map mode.

Several other factors need to be taken into consideration if simple observing efficiency is not the primary concern. Jiggle mapping is immune to 1/f noise so this may be attractive in some cases. However, it also removes large scale structure, which could be something one wishes to avoid doing, in which case scanning is better. The additional data around the edges of a small scan map may be useful albeit of lower quality than the main map area. Pointing errors may be different for the two modes.

References

[1] *Scan Map Scanning Angles and Separation*, Tim Waskett, Bruce Sibthorpe, SPIRE-UCF-NOT-002758

[2] *Determination of optimum POF 5 – scan map parameters*, Bruce Sibthorpe, Tim Waskett, SPIRE-UCF-NOT-002755

[3] *Operating Modes for the SPIRE Instrument*, Matt Griffin, Bruce Swinyard, Ken King, Issue 3.3, 24 June 2004 (Operating Modes Document – OMD)

[4] *SPIRE Sensitivity Model*, Matt Griffin, Working Version 13th December 2004 (Sensitivity Modes Document – SMD)

[5] *SPIRE Photometer Simulator Verification – Scan Map Sensitivity*, Tim Waskett, Bruce Sibthorpe, SPIRE-UCF-NOT-002756