WALLABY Memo 22 v1.0: Sky Tiling

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Overview

In this document we look at pragmatic options for WALLABY tiling, informed by results from the ASKAP performance by D McConnell (ASKAP memo 015, 3rd Oct 2017) and work carried out by A Robotham and presented by L Staveley-Smith at various WALLABY meetings.

Noise Effective Area

In the work originally carried out by A Robotham in 2016 a simple combination of a beam and tile response functions was explored. Using predicted beam response (assumed to be Gaussian) and measured tile response (using the sensitivity profile of the MkI BETA PAFs from Aaron Chippendale), the FoV sensitivity with no offsetting was computed. The most efficient effective area was computed for different beam pitches, with a peak value around 0.9 degrees, implying an effective tile size of just over 5x5 degrees (see Figure 1). Since the exact tile size looked to be flexible around this value, different tile sizes need to be experimented with when deciding on the final tiling.

Offsetting

Given the optimal sized tile, we built a repeating pattern of the throughput with no offsetting (see Figure 3). This produces a pattern with variances notable at the scale of the beam pitch and the tile scale. The question then was what combination of tile offsets creates the most uniform response over large contiguous areas (assuming regular square tiling)? The obvious options to look at were the half pitch scale offsets (roughly 0.5 deg), and half tile scale offsets (roughly 2.5 degrees). Figure 2 gives and example of what a half beam offset would look like on the sky.

Figure 4 shows the effect of offsetting by a half beam scale, where the dynamic range (the ratio in reponse between the 84th/16th percentile of sensitivity, where nearer to 1 means more uniform) drops from 1.213 (with no offsetting) to 1.086, i.e. the field is significantly more uniform.

Figure 5 shows the effect of offsetting by a half tile scale, where the dynamic range drops from 1.213 (with no offsetting) to 1.192, i.e. the field is slightly more uniform.

Figure 6 shows the effect of offsetting by a half beam and half tile scales, where the dynamic range drops from 1.1213 (with no offsetting) to 1.031, i.e. the field is significantly more uniform. This is also a marked improvement on the beam only offsetting (which returned 1.086). The suggestion from this early work was that half beam offsetting is vital (which has been implemented in early science observations for the most part), and half tile offsetting is desirable where appropriate. The caveat here is that the tiling structure would need to be well aligned and square in nature to get the full benefit of half tile offsetting. Given the complexity of tiling a sphere with square tiles (the problem facing WALLABY) it might not be appropriate to implement both offsets in all regions of sky. For smaller area suveys (e.g. DINGO) for types of offsetting should be utilised.

WALLABY Sky Tiling

With an idea of an optimal way to treat the ASKAP tile size (somewhere near 5x5 degrees) the next question was how to most efficiently tile the WALLABY sky, which is effectively all of the sky below Dec +30 deg.

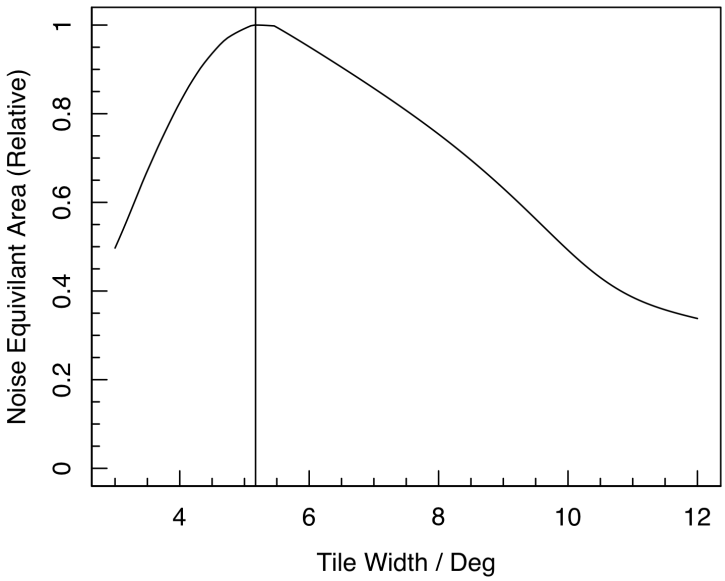

Figure 1: The optimal tile size in terms of Noise Effective Area.

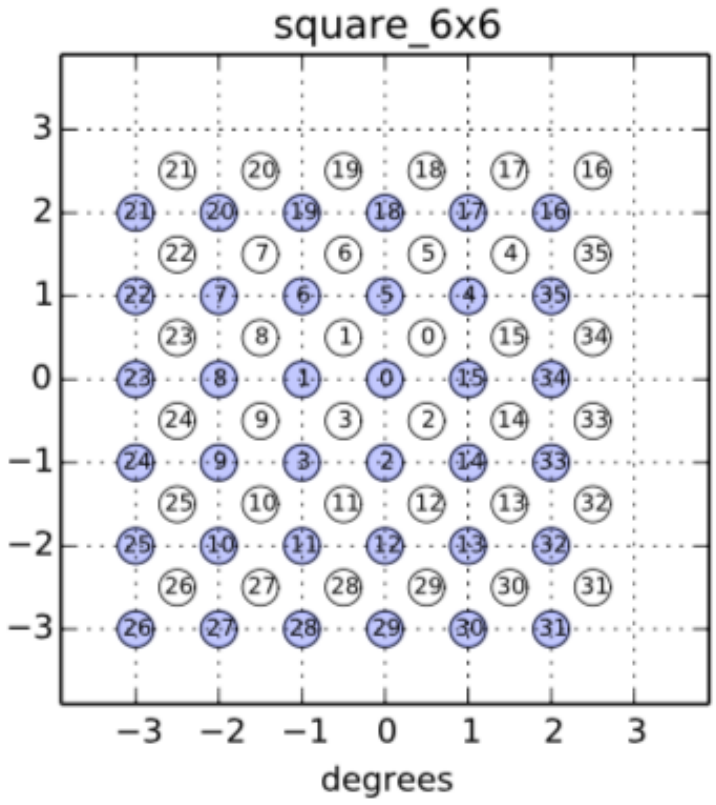

Figure 2: Example half beam offset for 6x6 beams configuration (taken from D McConnell Memo 015).

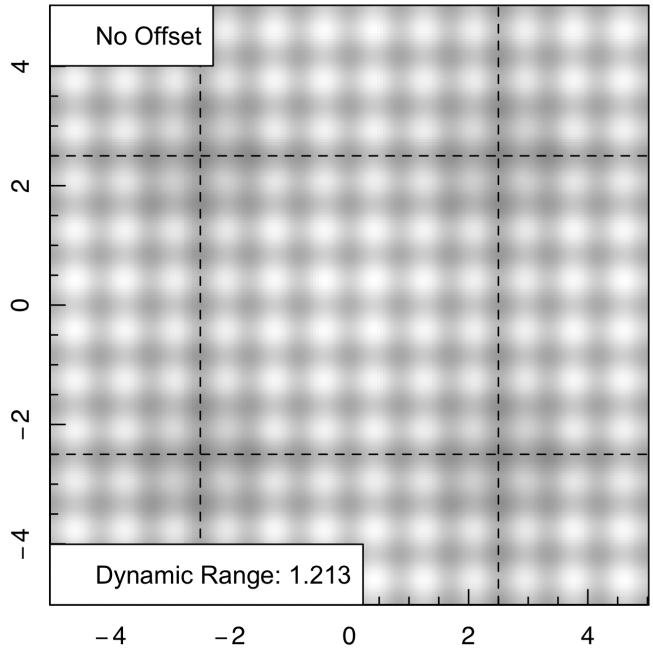

Figure 3: The raw combined beam and tile response.

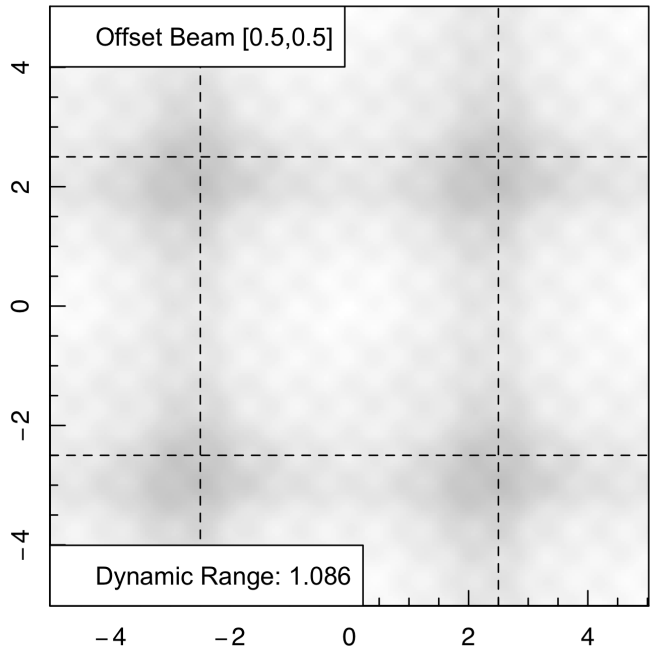

Figure 4: Half beam offset response.

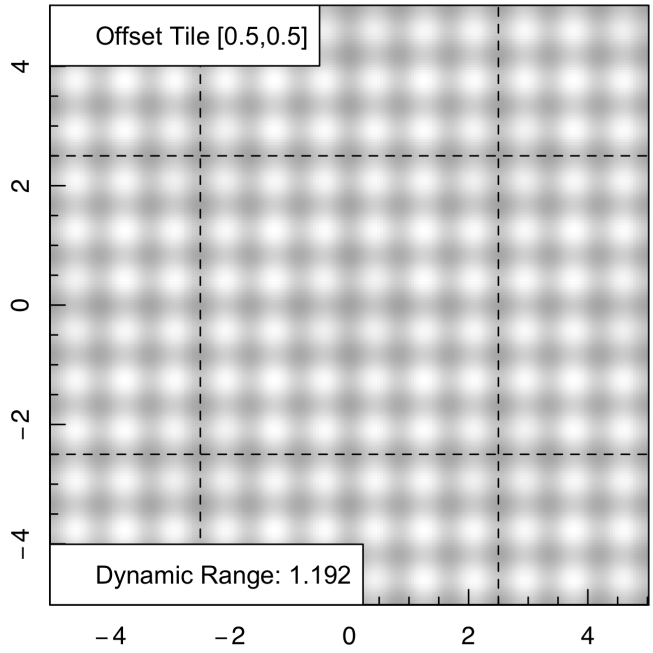

Figure 5: Half tile offset response.

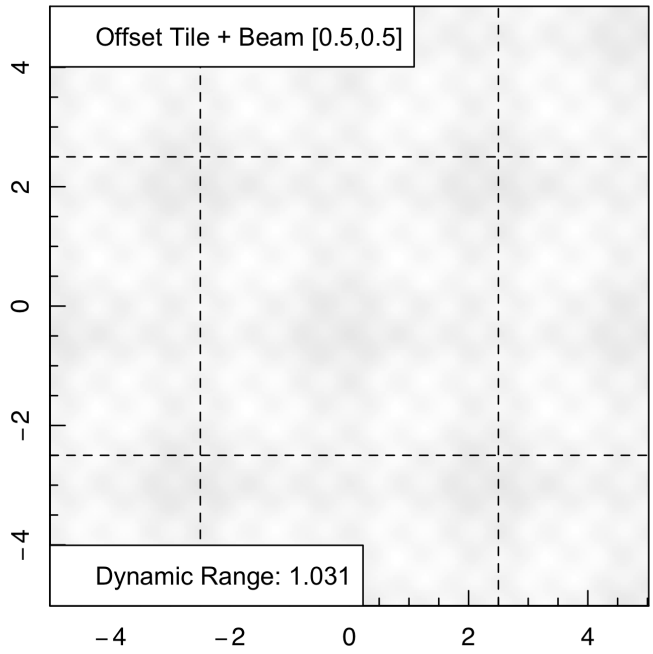

Figure 6: Half beam and half tile offset response.

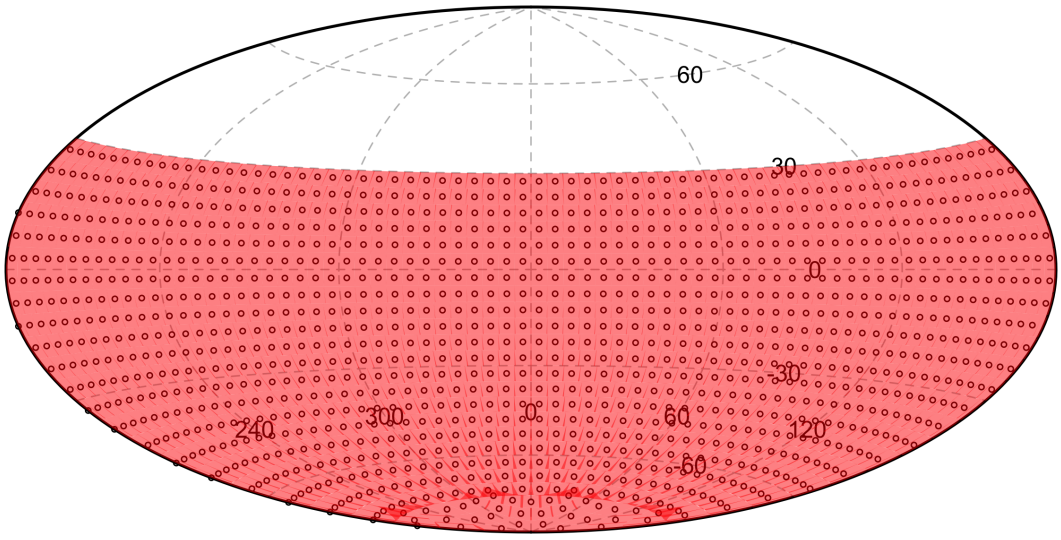

Figure 7: Spherical cap WALLABY tiling example.

Two schemes were investigated in some detail: spherical cap tiling and tennis ball tiling.

Spherical cap tiling former breaks the sky into two zones, one where the tiling is achieved by assembling rings of tiles in right ascension down to some declination, after which point the remaining spherical cap is tiled by rotating the sky 90 degrees and tiling the remaining circular region with strips of tiles (e.g. Figure 7). Tennis ball tiling is achieved by treating the full sky like the two strips that assemble a tennis ball, where each is tiled as strips, but the two strips interleave at 90 degrees with respect to each other (e.g. Figure 8).

When computing the above, the key concept is the sky tiling efficiency in terms of excess coverage, which is simply the percentage of excess sky area observed compared to the sky area tiled uniquely. I.e. if this is 0% then the sky is perfectly tiled, with no overlap between our square tiles (impossible) and if it is 10% then roughly 10% of sky has been tiled more than once due to tile overlaps (so will be deeper) and 90% has been observed once. Since we want to be efficient and uniform, excess coverage values nearer to 0% are desirable.

It was established for WALLABY that given our declination selection, spherical cap tiling is certainly going to be more efficient, so the remaining question is then what tile size and spherical cap size produce the most efficient survey. For certain tile sizes big improvements in efficiency can sometimes be gained by varying the declination at which we swap to cap tiling and by slightly adjusting the declination limit of WALLABY. Figure **??** shows the results of varying both.

In general it was found that smaller tiles are easier to tile with. For an optimal sky tiling, the key things are that the spherical cap angle (θ_{cap}) needs to be an integer multiple of the tile size (T_{dim}), and the declination limit (ϕ_{lim}) must be such that $(90 - \theta_{cap}/2 + \phi_{lim})/T_{dim}$ is also an integer. To have even better tiling it is slightly advantageous that $360/T_{dim}$ is also an integer since the equatorial RA rings disproportionately dominate the sky area.

Whilst there are slightly better hot spots given the above constraint, in general the differences are small. There might be pragmatic reasons to prefer a smaller cap size, e.g. it is easier to schedule the RA strips given the lack of field rotation required.

Specific Recommendations

In the ASKAP performance by D McConnell (Memo 015, 3rd Oct 2017) more accurate measurements were made of optimal pitch and effective tile areas (see Figures 9 and 10). WALLABY is most interested in tiling

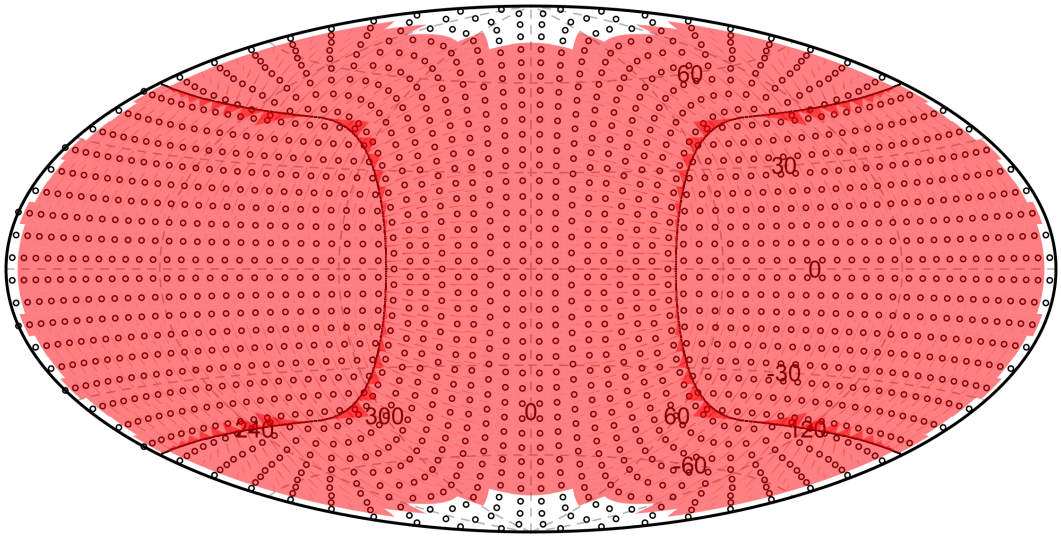

Figure 8: Tennis ball all sky tiling example.

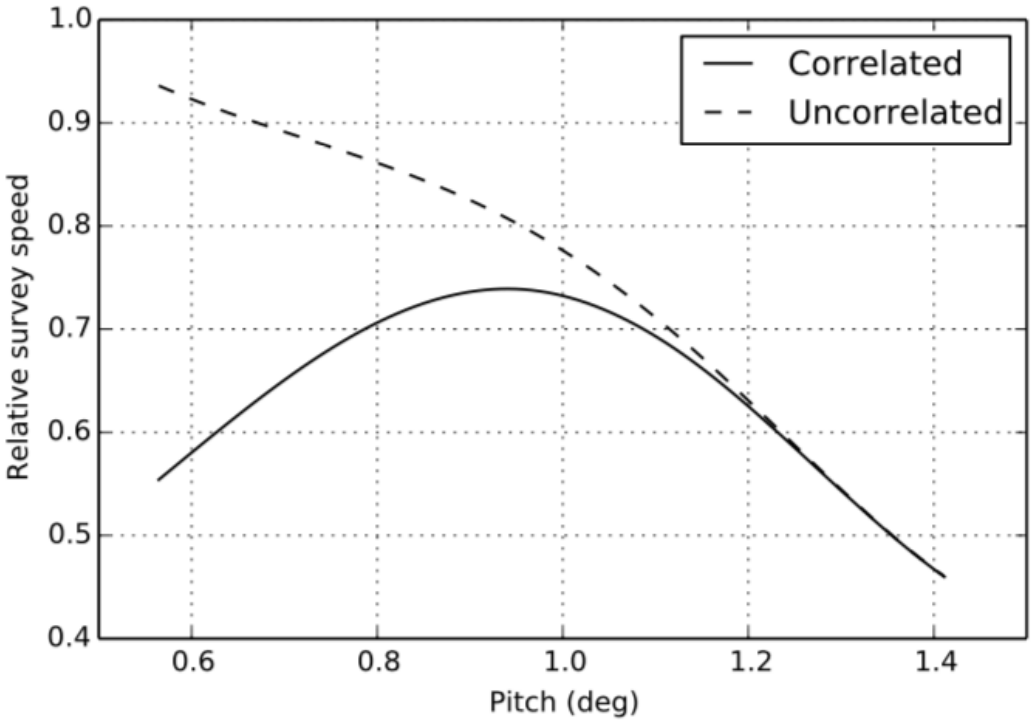

Figure 9: New ASKAP performance measurements.

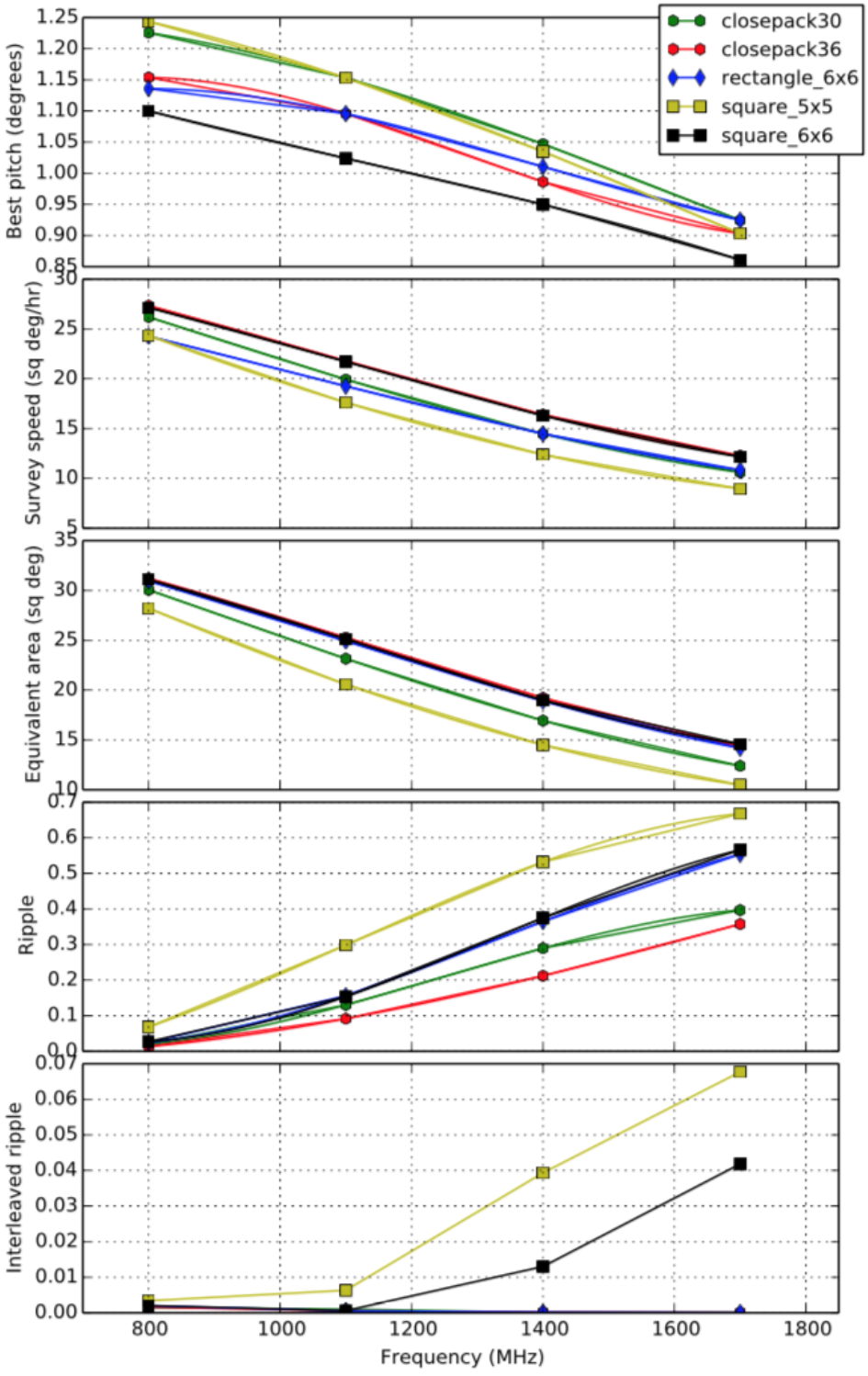

Figure 10: New ASKAP performance measurements.

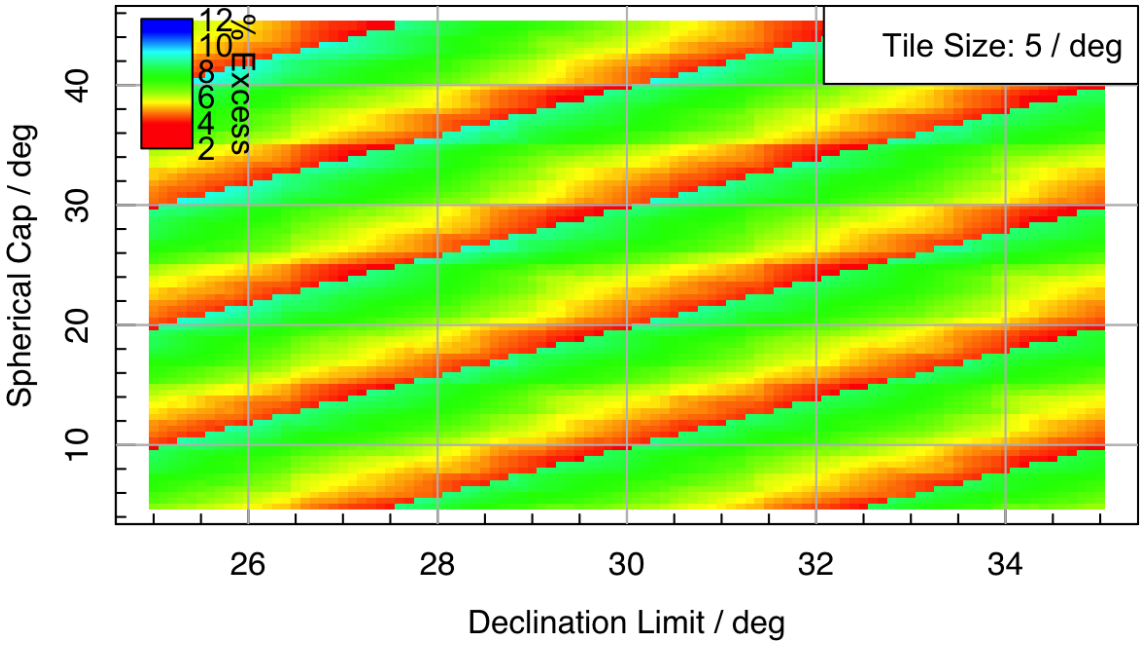

Figure 11: Example tile optimisations. Redder is better, and bluer worse.

performance at frequencies near 1360 MHz (corresponding to the predicted peak in redshift of around 0.04). In this regime a square 6x6 grid of beams tiling with a pitch of around 0.95 deg (a 5.7 degree tile) is close to optimal. To bracket the options we look at three reasonable schemes using T_{dim} = 5.0 / 5.7 and 6.0 degrees for the final part of this memo.

Optimal Tiling Grids

Figures 11–13 shows the results from experimenting with a fine grid of possible spherical cap sizes and declination limits. Given what was stated above regarding optimal solutions, it is easy to see the repeating bands of optimal solutions that combine good choices of both together given the target tile size.

There is not a huge variation in the quality of the different 'best' solutions, but ones near a cap size of about 30 degrees tend to be marginally preferable. For the final example sky tiling plots (Figures 14–16ß) we create close to optimal solutions with good spherical caps nearest to this value.

Example Tile Position Information

Tile: 5 Degrees

The starting RA and Dec for the RA strips, and all spherical cap tiles.

Table 1: Spherical cap tile positions and rotation angles (East from North in deg). The type specifies whether this represents the starting tiling of a strip (1), or the cap (2).

RA / deg	Dec / deg	Type	Ang-N2E / deg	N Strip	RA Offset / deg
2.727	27.500	1	0.000	66	5.455
2.647	22.500	1	0.000	68	5.294
2.571	17.500	1	0.000	70	5.143

RA / deg	Dec / deg	Type	Ang-N2E / deg	N Strip	RA Offset / deg
2.535	12.500	1	0.000	71	5.070
2.500	7.500	1	0.000	72	5.000
2.500	2.500	1	0.000	72	5.000
2.500	-2.500	1	0.000	72	5.000
2.500	-7.500	1	0.000	72	5.000
2.535	-12.500	1	0.000	71	5.070
2.571	-17.500	1	0.000	70	5.143
2.647	-22.500	1	0.000	68	5.294
2.727	-27.500	1	0.000	66	5.455
2.857	-32.500	1	0.000	63	5.714
3.051	-37.500	1	0.000	59	6.102
3.214	-42.500	1	0.000	56	6.429
3.529	-47.500	1	0.000	51	7.059
3.830	-52.500	1	0.000	47	7.660
4.286	-57.500	1	0.000	42	8.571
4.865	-62.500	1	0.000	37	9.730
5.806	-67.500	1	0.000	31	11.613
7.200	-72.500	1	0.000	25	14.400
35.236	-74.634	2	36.225	NA	NA
144.764	-74.634	2	53.775	NA	NA
215.236	-74.634	2	36.225	NA	NA
324.764	-74.634	2	53.775	NA	NA
57.177	-76.066	2	57.952	NA	NA
122.823	-76.066	2	32.048	NA	NA
237.177	-76.066	2	57.952	NA	NA
302.823	-76.066	2	32.048	NA	NA
19.508	-76.725	2	20.002	NA	NA
160.492	-76.725	2	69.998	NA	NA
199.508	-76.725	2	20.002	NA	NA
340.492	-76.725	2	69.998	NA	NA
78.595	-77.256	2	78.869	NA	NA
101.405	-77.256	2	11.131	NA	NA
258.595	-77.256	2	78.869	NA	NA
281.405	-77.256	2	11.131	NA	NA
0.000	-77.500	2	0.000	NA	NA
180.000	-77.500	2	0.000	NA	NA
43.058	-79.709	2	43.522	NA	NA
136.942	-79.709	2	46.478	NA	NA
223.058	-79.709	2	43.522	NA	NA
316.942	-79.709	2	46.478	NA	NA
71.505	-82.097	2	71.669	NA	NA
108.495	-82.097	2	18.331	NA	NA
251.505	-82.097	2	71.669	NA	NA
288.495	-82.097	2	18.331	NA	NA
17.337	-82.141	2	17.492	NA	NA
162.663	-82.141	2	72.508	NA	NA
197.337	-82.141	2	17.492	NA	NA
342.663	-82.141	2	72.508	NA	NA
44.973	-86.465	2	45.027	NA	NA
135.027	-86.465	2	44.973	NA	NA
224.973	-86.465	2	45.027	NA	NA
315.027	-86.465	2	44.973	NA	NA

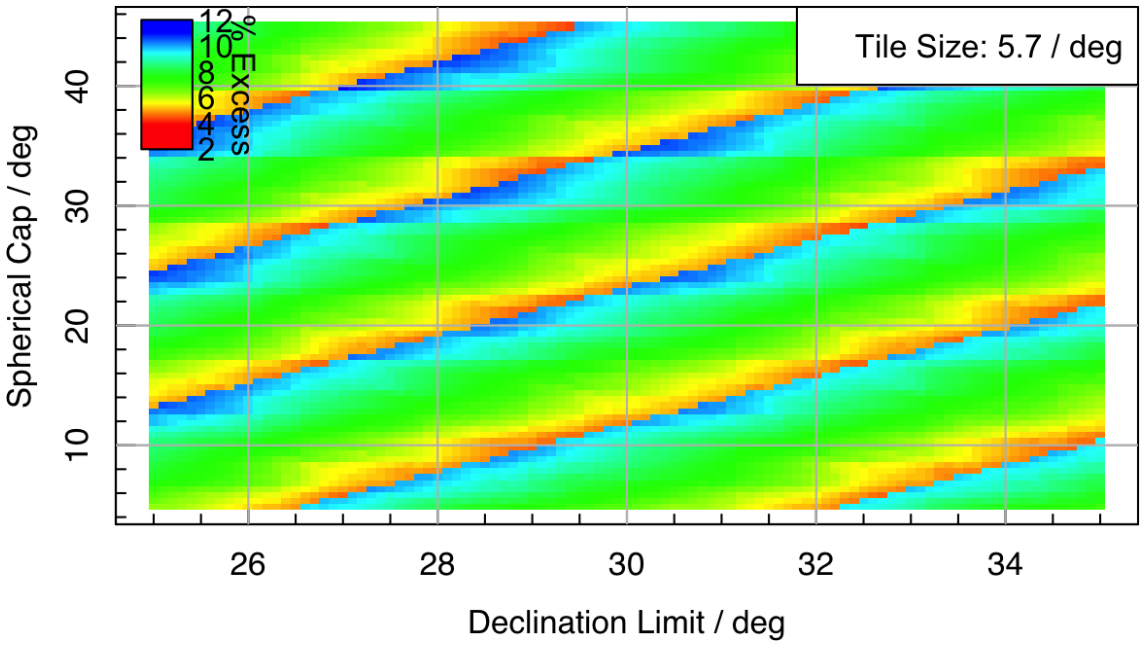

Figure 12: Example tile optimisations. Redder is better, and bluer worse.

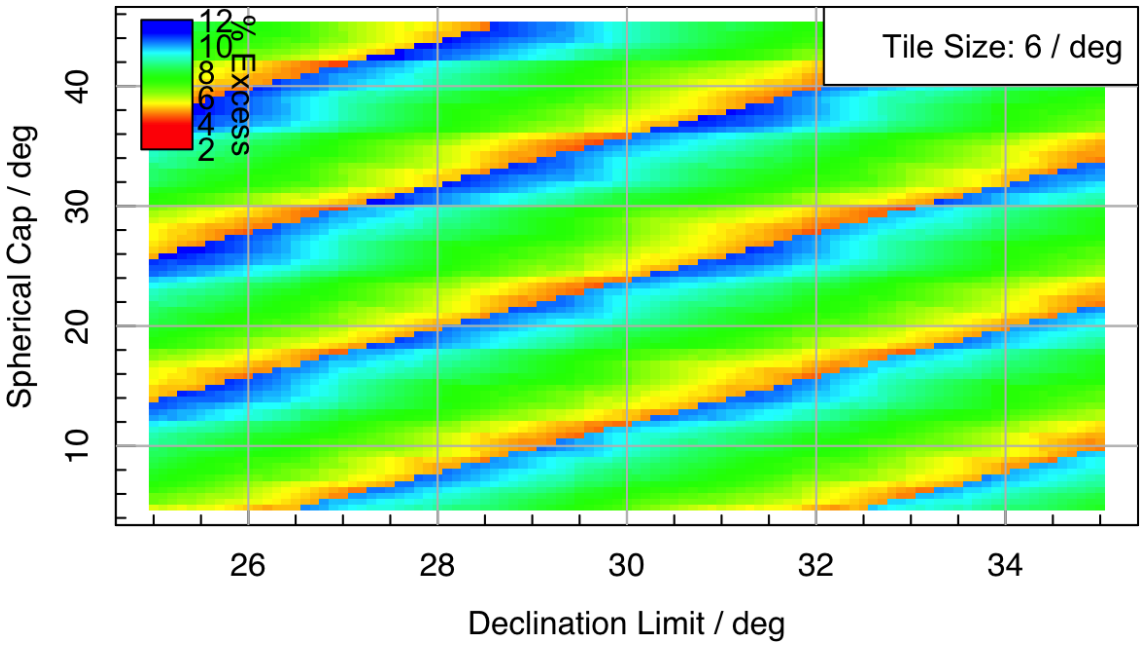

Figure 13: Example tile optimisations. Redder is better, and bluer worse.

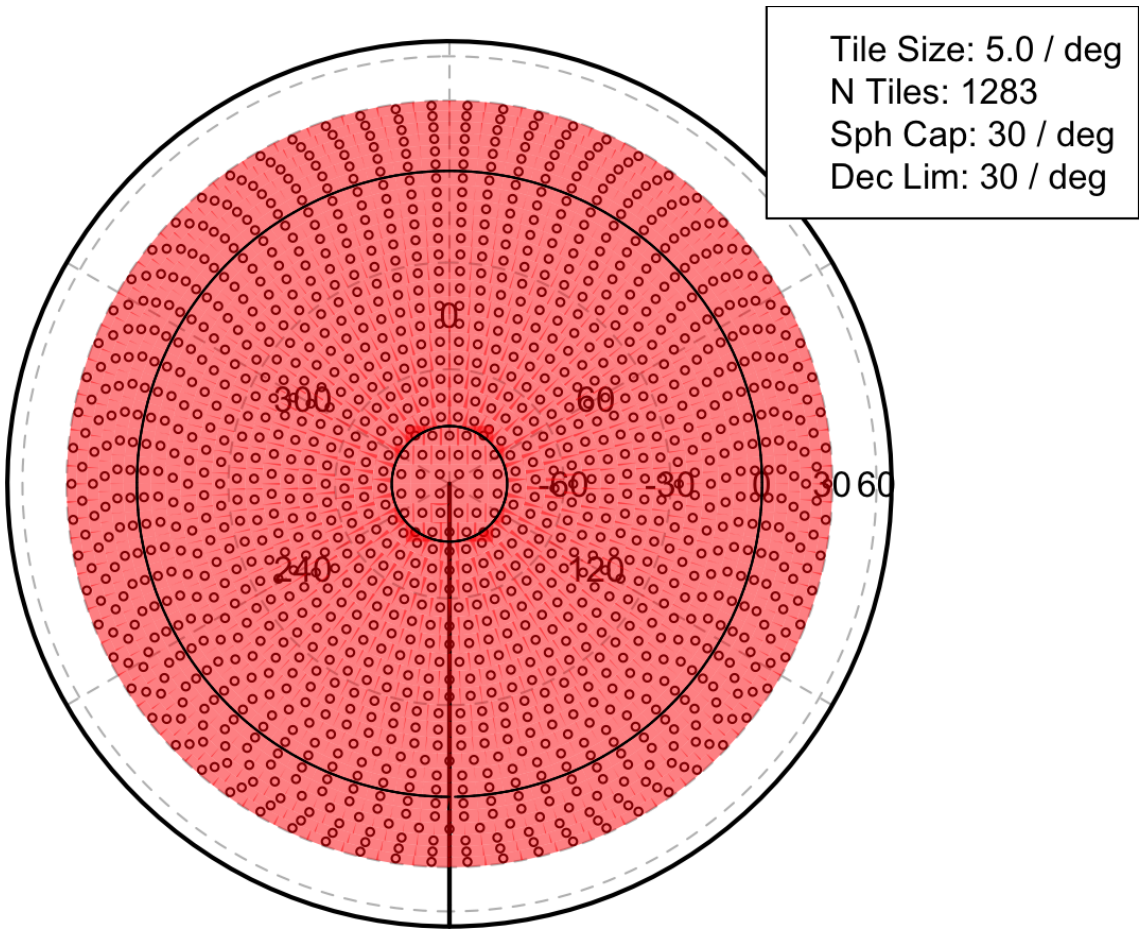

Figure 14: Example sky tiling. Principle RA and Dec limits in degrees are as labelled.

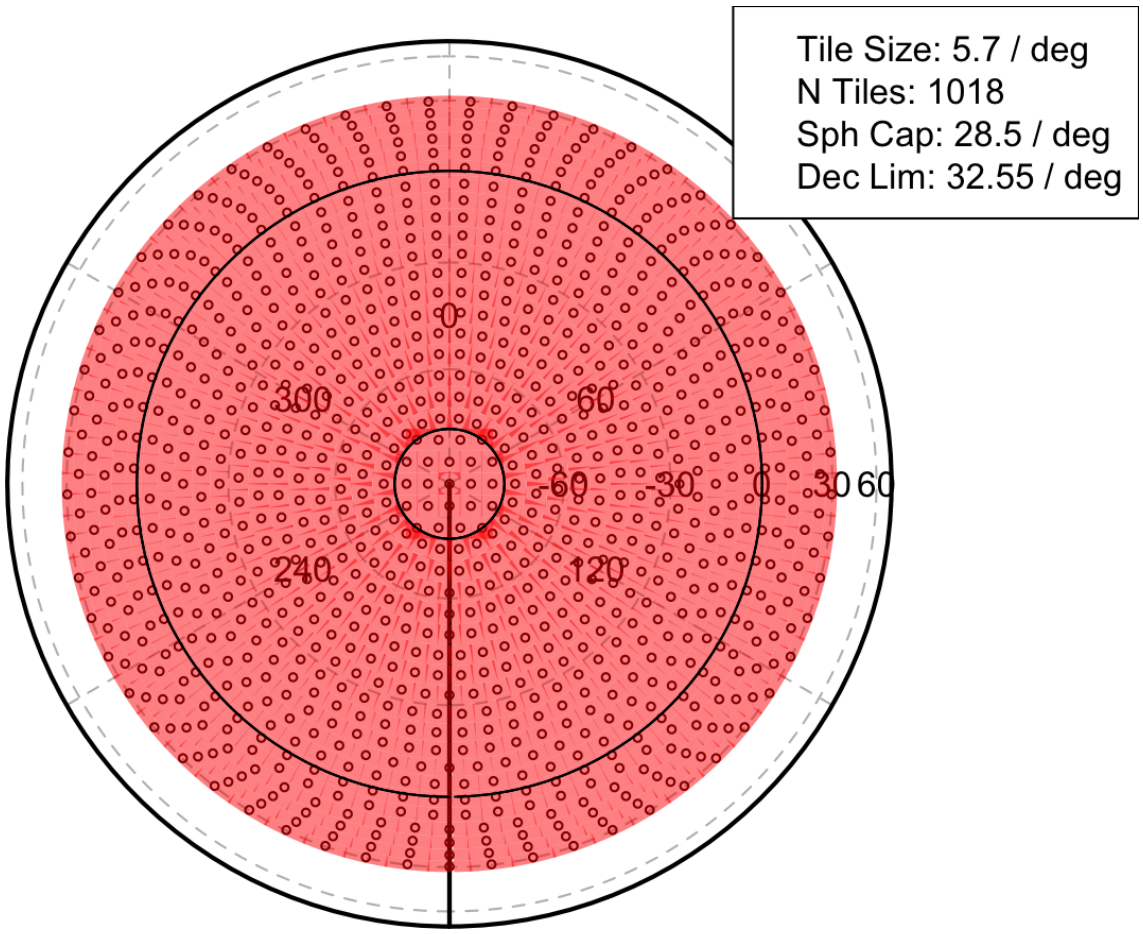

Figure 15: Example sky tiling. Principle RA and Dec limits in degrees are as labelled.

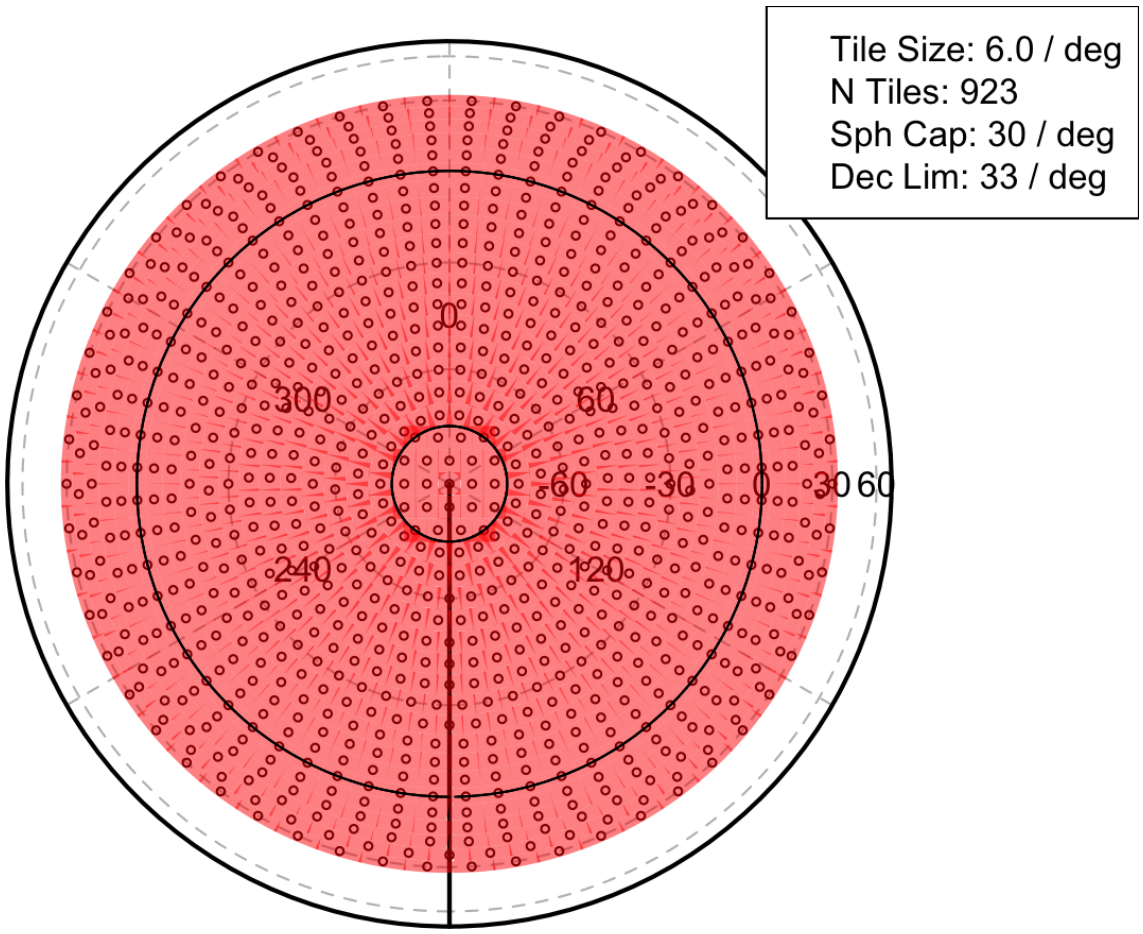

Figure 16: Example sky tiling. Principle RA and Dec limits in degrees are as labelled.

Tile: 5.7 Degrees

The starting RA and Dec for the RA strips, and all spherical cap tiles.

Table 2: Spherical cap tile positions and rotation angles (East from North in deg). The type specifies whether this represents the starting tiling of a strip (1), or the cap (2).

RA / deg	Dec / deg	Type	Ang-N2E / deg	N Strip	RA Offset / deg
3.158	29.700	1	0.000	57	6.316
3.051	24.000	1	0.000	59	6.102
2.951	18.300	1	0.000	61	5.902
2.857	12.600	1	0.000	63	5.714
2.812	6.900	1	0.000	64	5.625
2.812	1.200	1	0.000	64	5.625
2.812	-4.500	1	0.000	64	5.625
2.857	-10.200	1	0.000	63	5.714
2.903	-15.900	1	0.000	62	5.806
3.000	-21.600	1	0.000	60	6.000
3.103	-27.300	1	0.000	58	6.207
3.273	-33.000	1	0.000	55	6.545
3.462	-38.700	1	0.000	52	6.923
3.750	-44.400	1	0.000	48	7.500
4.186	-50.100	1	0.000	43	8.372
4.615	-55.800	1	0.000	39	9.231
5.455	-61.500	1	0.000	33	10.909
6.429	-67.200	1	0.000	28	12.857
8.182	-72.900	1	0.000	22	16.364
143.441	-75.755	2	52.581	NA	NA
216.559	-75.755	2	37.419	NA	NA
36.559	-75.755	2	37.419	NA	NA
323.441	-75.755	2	52.581	NA	NA
62.721	-77.484	2	63.279	NA	NA
117.279	-77.484	2	26.721	NA	NA
242.721	-77.484	2	63.279	NA	NA
297.279	-77.484	2	26.721	NA	NA
13.929	-78.250	2	14.215	NA	NA
166.071	-78.250	2	75.785	NA	NA
193.929	-78.250	2	14.215	NA	NA
346.071	-78.250	2	75.785	NA	NA
90.000	-78.839	2	0.000	NA	NA
270.000	-78.839	2	0.000	NA	NA
44.252	-82.030	2	44.530	NA	NA
135.748	-82.030	2	45.470	NA	NA
224.252	-82.030	2	44.530	NA	NA
315.748	-82.030	2	45.470	NA	NA
0.000	-84.300	2	0.000	NA	NA
180.000	-84.300	2	0.000	NA	NA
90.000	-84.420	2	0.000	NA	NA
270.000	-84.420	2	0.000	NA	NA
0.000	-90.000	2	0.000	NA	NA

Tile: 6 Degrees

The starting RA and Dec for the RA strips, and all spherical cap tiles.

Table 3: Spherical cap tile positions and rotation angles (East from North in deg). The type specifies whether this represents the starting tiling of a strip (1), or the cap (2).

RA / deg	Dec / deg	Type	Ang-N2E / deg	N Strip	RA Offset / deg
3.333	30.000	1	0.000	54	6.667
3.158	24.000	1	0.000	57	6.316
3.103	18.000	1	0.000	58	6.207
3.000	12.000	1	0.000	60	6.000
3.000	6.000	1	0.000	60	6.000
3.000	0.000	1	0.000	60	6.000
3.000	-6.000	1	0.000	60	6.000
3.000	-12.000	1	0.000	60	6.000
3.103	-18.000	1	0.000	58	6.207
3.158	-24.000	1	0.000	57	6.316
3.333	-30.000	1	0.000	54	6.667
3.529	-36.000	1	0.000	51	7.059
3.830	-42.000	1	0.000	47	7.660
4.186	-48.000	1	0.000	43	8.372
4.737	-54.000	1	0.000	38	9.474
5.455	-60.000	1	0.000	33	10.909
6.429	-66.000	1	0.000	28	12.857
8.182	-72.000	1	0.000	22	16.364
36.529	-75.005	2	37.484	NA	NA
143.471	-75.005	2	52.516	NA	NA
216.529	-75.005	2	37.484	NA	NA
323.471	-75.005	2	52.516	NA	NA
62.699	-76.827	2	63.317	NA	NA
117.301	-76.827	2	26.683	NA	NA
242.699	-76.827	2	63.317	NA	NA
297.301	-76.827	2	26.683	NA	NA
13.919	-77.631	2	14.237	NA	NA
166.081	-77.631	2	75.763	NA	NA
193.919	-77.631	2	14.237	NA	NA
346.081	-77.631	2	75.763	NA	NA
90.000	-78.251	2	0.000	NA	NA
270.000	-78.251	2	0.000	NA	NA
44.240	-81.610	2	44.548	NA	NA
135.760	-81.610	2	45.452	NA	NA
224.240	-81.610	2	44.548	NA	NA
315.760	-81.610	2	45.452	NA	NA
0.000	-84.000	2	0.000	NA	NA
180.000	-84.000	2	0.000	NA	NA
90.000	-84.125	2	0.000	NA	NA
270.000	-84.125	2	0.000	NA	NA
0.000	-90.000	2	0.000	NA	NA