Investigating Improvements to the Y+ Configuration Set

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Abstract

The previous round of Y+ configuration work primarily optimized the most extended array configuration, leaving the intermediate configurations in a bad state. Earlier work attempted to optimize each of the 9 Y+ configurations, but this resulted in a full resolution array with very poor properties. The work presented here optimizes the full resolution array and two intermediate arrays to achieve much better results, but at the expense of adding more pads. The sidelobe levels of the two intermediate resolution arrays are about half of the previous design, and the beams are within a few percent away from being circular and a few percent away from the desired resolution as determined by a geometrical series. This new design adds 10 more pads - 42 pads for the Y+ configurations rather than the 32 used last time - and 12 of the 42 pad positions are in new places that don't have transporter road designs. However, these locations all look to be fairly easily accessible.

In addition to the specifications for the three new Y+ arrays, recommendations for three related future work projects are given.

1 What the Problem Was for the Y+ Arrays

Over 20% sidelobes. Non-circular beams.

2 What Should We Optimize This Time?

Richard Hills, requested that I optimize the beam parameters for three different Y+ configurations - the full resolution array and two transitional arrays between Conway's highest resolution array and the full resolution Y+ array. As each of these three arrays moved 12 antennas out from the previous array, this gives us more degrees of freedom than moving 4 antennas does, and hopefully this will allow each subsequent configuration to correct any issues that the array is stuck with from the leftover pad positions from the smaller configurations.

Another very important consideration is pad reuse - we want to select pad positions from the already approved 32 Y+ pad positions and the additional 4 which were presented but not approved(they don't have road designs, but we know that they are accessible. However, this work will necessarily require some new pads if we are to make any improvement over the previous design. The question is: how many new pads will be required?

2.1 Array Nomenclature

Conway's configurations are numbers from 1 as the most compact to 20 as the largest. We formerly numbered the Y+ configurations as Y0 (Conway's outermost array), Y1 (our most compact Y+ array), through Y9 - the most extended Y+ array. In the full array reconfiguration plan, the Y1 through Y9 were renamed 21 - 29.

To distinguish the new Y+ configurations from the old configurations Y1 through Y9, we have named the three configurations from inside out Y-A, Y-B, and Y-C. This is somewhat unfortunate in that the naming sequence is the opposite of the VLA's, which starts with the A as the high resolution array, but I would argue that the VLA folks got it wrong.

2.2 Target Resolutions

All sidelobe levels and resolutions are for NATURAL WEIGHTING. Briggs weighting will give sidelobe levels about 60% as large, and significantly smaller beams as well, but people got confused when I presented both NATURAL and BRIGGS weighted results last time, so I will not present any BRIGGS weighted beam parameters.

We simulate observations of an object at declination = -48 degrees, as this builds in a roughly 10% N-S elongation into the optimized array configuration. We simulate +/- 2 hour tracks, partly because the low brightness sensitivity of the high resolution arrays will usually require long observations to improve the sensitivity, and partly because of the 6-pointed star pattern in the (u,v) plane made by a "Y" configuration - four hours of earth rotation synthesis results in adjacent points rotating into each other to fill in the (u,v) pattern.

Note that all simulations and beam sizes are for 300 GHz. At 300 GHz, Conway's configuration 20 gives a 4 hour track, naturally weighted resolution of 0.08153 arcsec. The old full resolution Y+ configuration gave a resolution of 0.01659 arcsec. This jump in resolution space is spanned if each of the three new configurations has a factor of 1.70 higher resolution than the previous configuration.

Array	Resolution	Y+ Pads Occupied	
Y0	0.0815	0	Conway's highest resolution array
Y-A	0.0480	12	
Y-B	0.0282	24	
Y-C	0.0166	36	Full resolution Y+

This design has 36 pads built in at the highest level, so without even doing anything we have 4 more pads than used in the previous design.

3 Optimization Path and Results

The approach used last time did not particularly emphasize the baselines required to get a good (u,v) coverage at 0.0480 arcsec resolution. So the Y3 configuration results in inner sidelobe level of 0.206 and a beam of 0.0363 x 0.0411 arcsec - ie, on average the baselines in this configuration were significantly longer than what we need.

On the other hand, if we optimize for 12 totally new pad positions plus the outer 38 Conway pad positions and seek a Y-A array with low sidelobes and a circular beam close to 0.0480 arcsec, we can get a configuration with 0.015 sidelobes and a beam within 5% of circular and within 1 percent of the desired size - ie, a high quality beam which is basically an extension of the Conway configurations. However, if we nail those pad positions down as part of the Y+ configuration, we end up having too many short spacings and we are overly constrained in our efforts to produce a high quality beam at higher resolution.

So we took a different approach and sought to first optimize the Y-B, and then it is only one step away from this configuration to the smaller Y-A array and the full resolution Y-C array.

The array configurations are included in an appendix to this document, but there is no consistent antenna numbering system yet. Pad positions are provided in shifted UTM coordinates: UTMX - 600000 m and UTMY - 7400000 m.

3.1 Y-B Array Configuration: 6 New Pad Positions

For the optimization of the Y-B array with 0.0282 arcsec target resolution, we started with the previously "sub-optimized" Y6 array, consisting of 26 Conway pads occupied and 24 Y+ pads occupied. The beam for this starting configuration had inner sidelobes of 0.1214 (not bad), but a beam shape of 0.0247 x 0.0225 arcsec - not great. In the first stage of optimization, we let all of the outer 24 antennas wander within the confines of the fairly restrictive mask. It should be noted that the mask is inhomogeneous - the inner 5x5 km zone uses Conway's mask, which does not consider roads at all. The outer part of the mask is built around pre-designed roads built up iteratively with M3 engineers. Permitting 24 new pads, we were able to get an inner sidelobe level of 0.0861 and a beam of 0.0283 x 0.0272 arcsec. The main beam shape/size is very tight - if we loosened it a bit, the algorithm would be able to do a bit better job on the sidelobe level, and the search for the optimum was not exhaustive - rather I wanted to get an idea of what sort of sidelobe levels were possible to give me a gauge of how many new pads we really need.

I iteratively "rectified" the array to the old Y+ design - if one of the new pad positions fell within about 1000 m of a previously defined pad position, I would move the pad position to the established pad and fix this pad so it would no longer participate in the optimization procedure. I left the pad positions which were farther from previously defined pad positions as slack in the system to reoptimize and make up for moving some of the pads to the non-optimal positions.

After four iterations of rectification and subsequent optimization, I got to a Y-B configuration which used 6 new pad positions and 18 previously defined pad positions. The inner sidelobes were 0.0948 - only marginally higher than the 0.0861 inner sideblobe level which we got with 24 new pad positions, and somewhat better than the 0.1214 sidelobe level in the old Y6 configuration. The beam shape was significantly better than the Y6 beam - at 0.0278 x 0.0256 we are within 6% of the desired resolution and within 8% of a circular beam.

Do we really need all 6 new pad positions? I tried scooting the new pad to the north of APEX over to a Y9 pad that had not yet been occupied (the free pad that was closest to an unused pad), and the sidelobe level went up to 0.1029. Not prohibitive.

We've already mentioned the new pad near APEX - this is close to the pipeline and we have a road right there already, so it will be no problem. There are five other new pads in a

Configuration	inner	mid	out	B_{maj} [arcsec]	B_{min} [arcsec]
Desired Y-A				0.0480	0.0480
Initial Y-A	0.2061	0.1857	0.0365	0.0411	0.0363
12 antennas free	0.0140	0.0219	0.0377	0.0524	0.0514
YY_a14 6 antennas free*	0.0391	0.0181	0.0350	0.0512	0.0494
5 antennas free	0.0831	0.0194	0.0430	0.0489	0.0464
Desired Y-B				0.0282	0.0282
Initial Y-B	0.1214	0.1212	0.0334	0.0247	0.0225
24 antennas free					
6 antennas free*	0.0951	0.0687	0.0383	0.0278	0.0257
5 antennas free	0.1029	0.0816	0.0372	0.0274	0.0255
Desired Y-C				0.0166	0.0166
Initial Y-C	0.0722	0.0691	0.0441	0.0181	0.0167
12 antennas free	0.0548	0.0529	0.0383	0.0183	0.0170
YY_c5_24.STN*	0.0535	0.0553	0.0394	0.0192	0.0168
YY_c5_26.STN*	0.0693	0.0647	0.0430	0.0180	0.0170

Table 1: Beam parameters for some different possible array configurations. The configurations with asterisks are the ones we are recommending. "Free antennas" are antennas which are moveable in order to facilitate the optimization.

cluster to the NE of the central array, between Chajnantor and Chascon. Two of these are to the north of the pipeline and three are to the south of the pipeline. Access to the northern two new pads is through what is labeled here as antenna 34 (this antenna number cannot be correlated with any other numbering system). Access to the three pads in this cluster south of the pipeline is from a road that crosses the nasty arroyo to the north, but south of the pipeline.

3.2 Y-C Array Configuration: No Additional New Pads

For the highest resolution Y+ array, or Y-C, we are aiming for a resolution of 0.0166 arcsec. We made an initial Y-C configuration from the Y-B configuration and 12 of the previously defined Y+ pads.

, evacuating the inner 12 Conway pads and occupied 12 more of the previously defined Y+ pads, and then optimized for the positions of the outer 12 antennas.

++Sidelobes: in: 0.0548 mid: 0.0529 out: 0.0383 bmaj: 0.0183 bmin: 0.017

As we did for the Y-B configuration, we rectified to the existing Y9 configuration's stations.

3.3 Y-A Array Configuration: 6 New Pad Positions

OK, we saved the hard part for last.

NOTICE: table numbers of YY_a14 don't quite match the plot for 6 free antennas. Check this!!!!

NOTICE: we lost the beam data for Y-B with 24 free antennas.

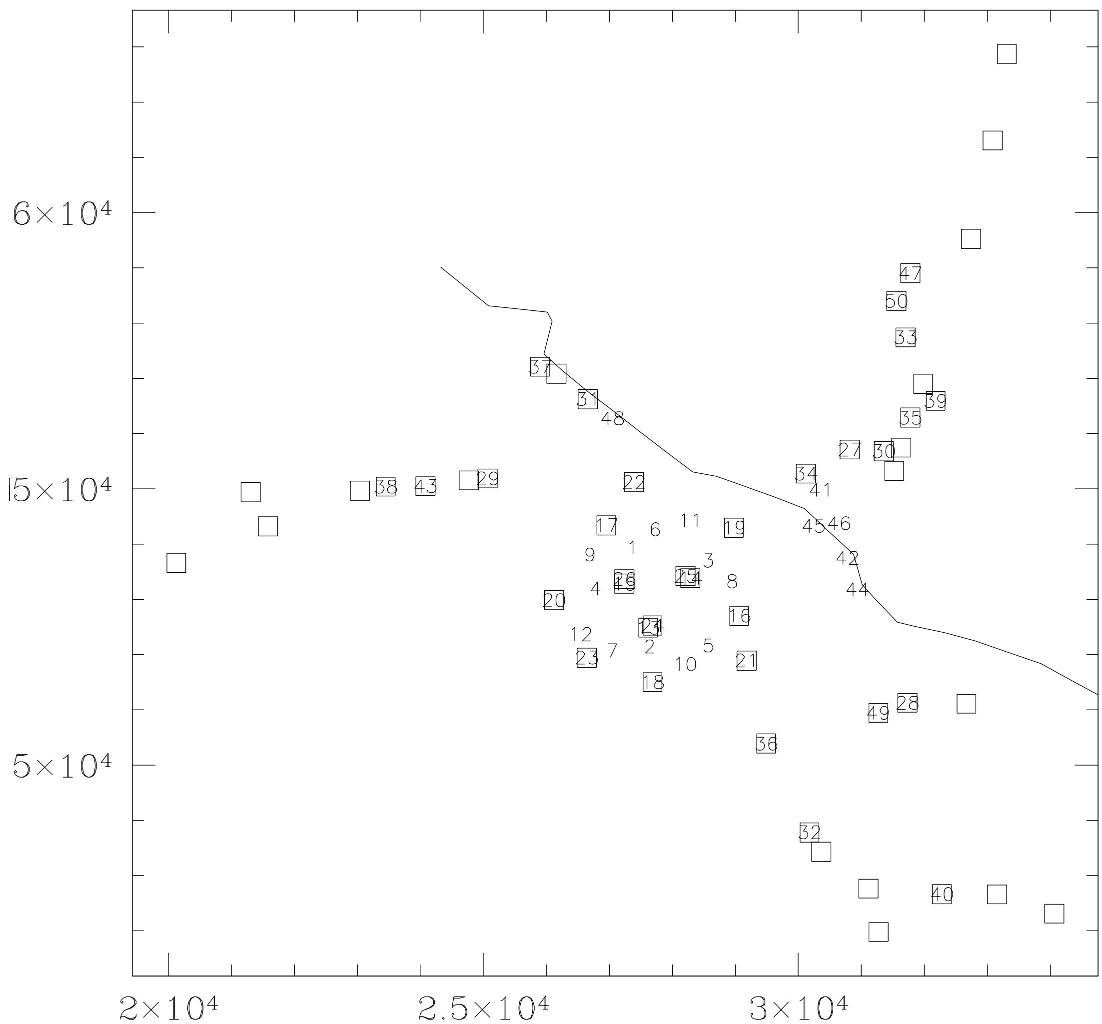

Figure 1: The pipeline slicing through the ALMA site showing the numbered antennas for the favored Y-B configuration which reuses 18 pads from the previously presented Y9 configuration (open squares), but also 6 new pads.

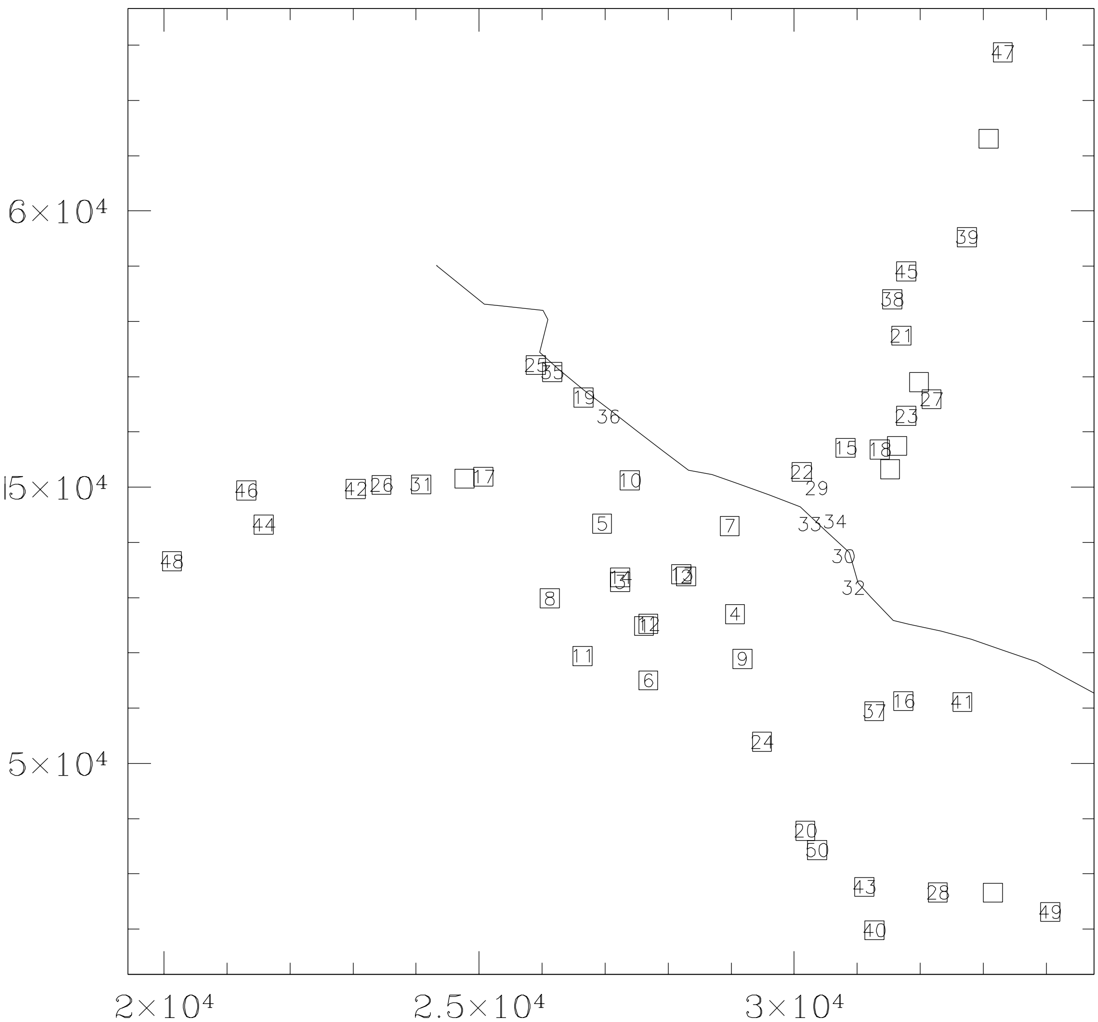

Figure 2: One possible Y-C array, YY_c5_24, with lower sidelobes.

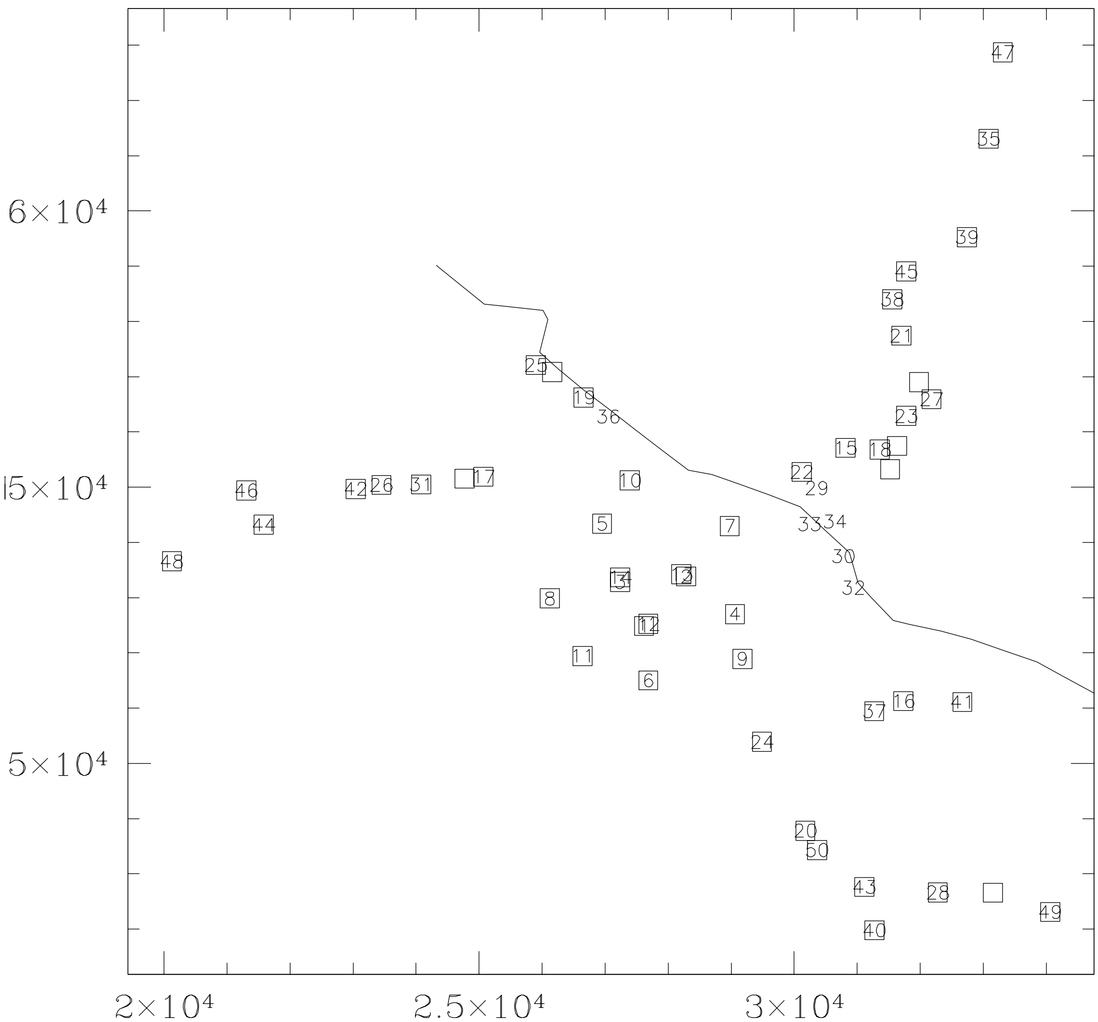

Figure 3: One possible Y-C array, YY_c5_26, with a more circular beam.

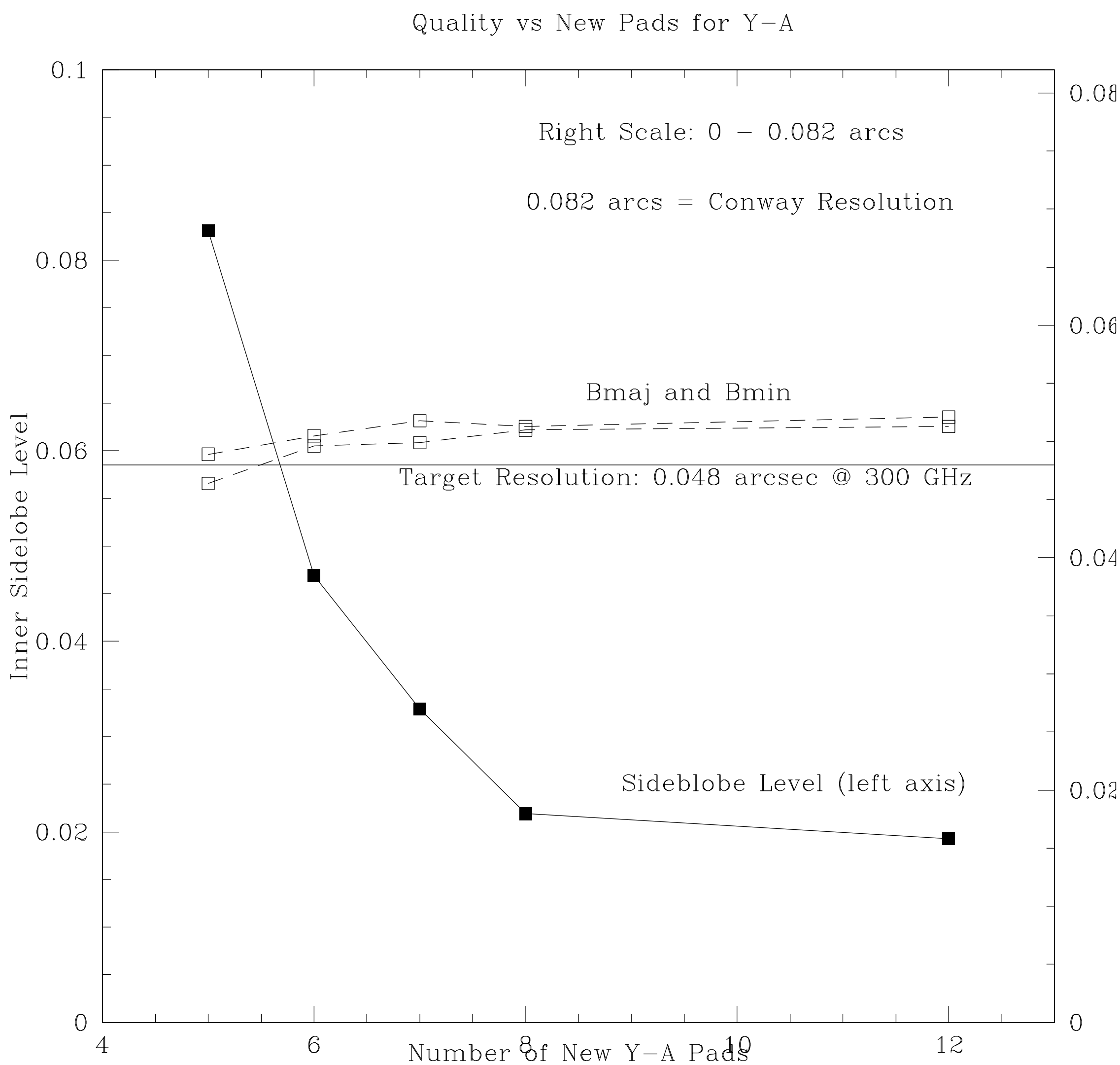

Figure 4: Measures of configuration quality as a function of the number of new pads for possible Y-A configuration. Note that I can change the relative weighting for sidelobe level and beam size/shape in the optimization. In the configurations with more freely-placed antennas, I am guessing that the algorithm could get extra low sidelobes at the expense of resolution, and an array with a more nearly correct resolution could be obtained at the expense of sidelobe level.

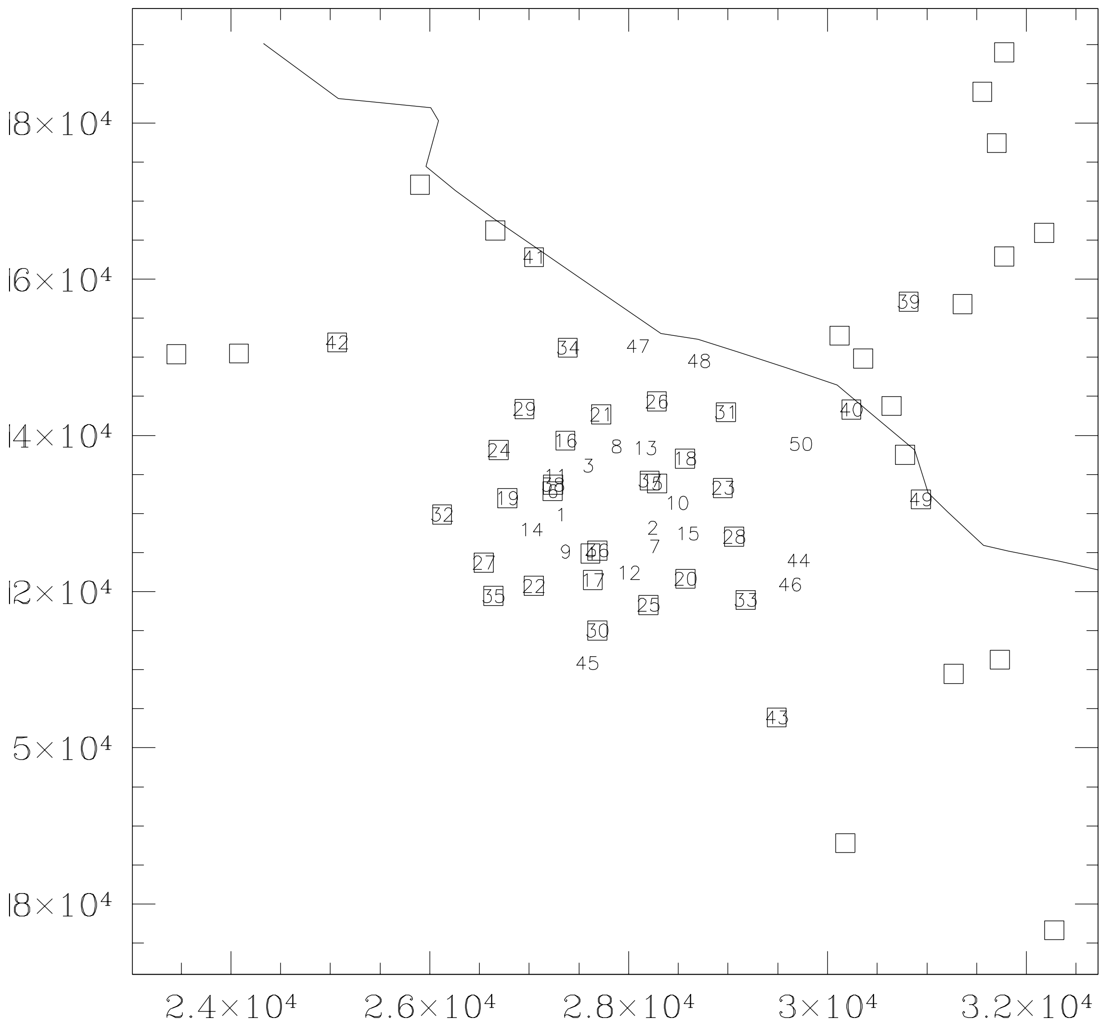

Figure 5: Recommended Y-A configuration using 6 Y-B pads and 6 new pads.

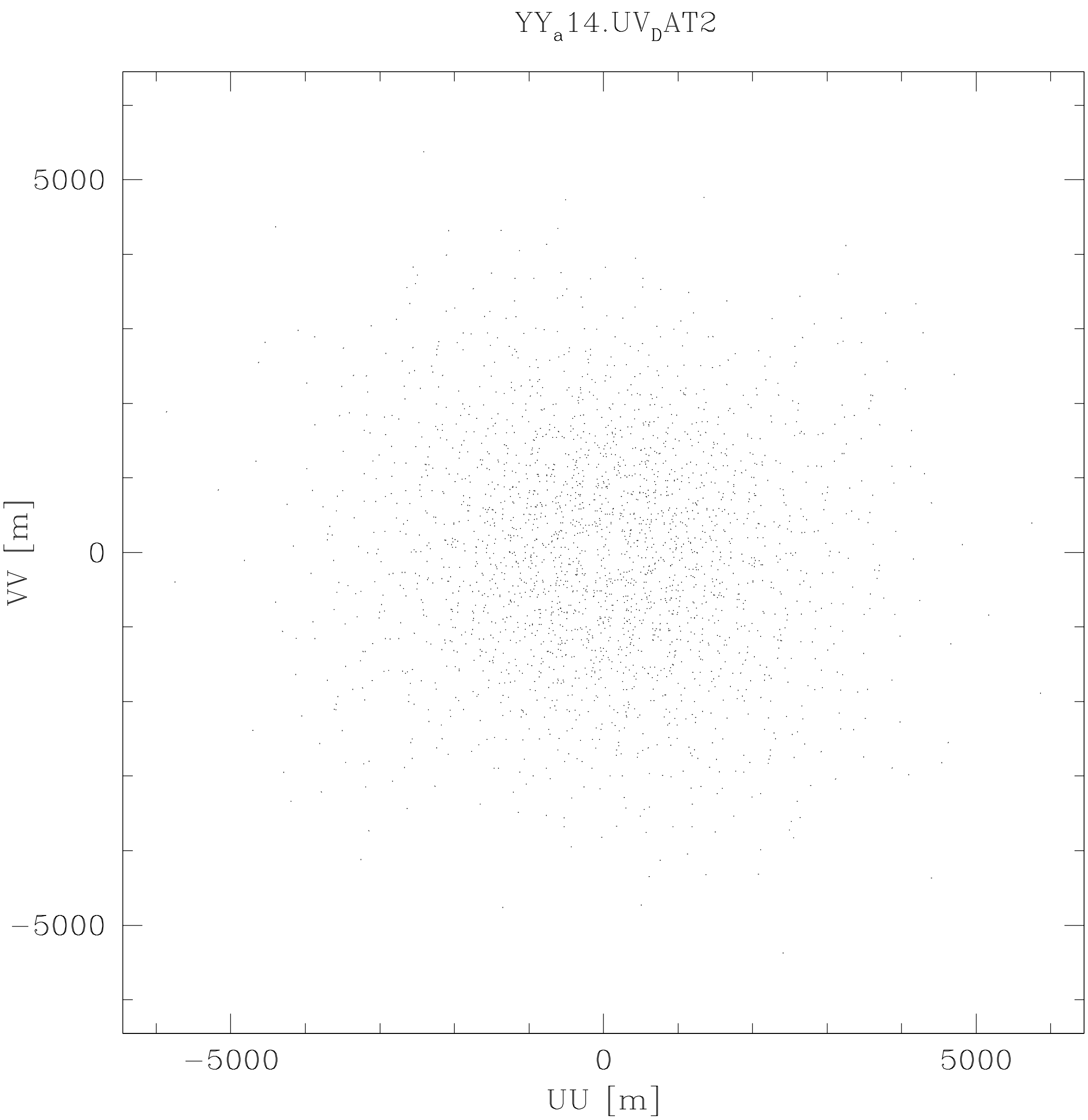

Figure 6: Snapshot coverage for configuration Y-A. ALL UV plots should be SQUARE, but the software didn't make them that way.

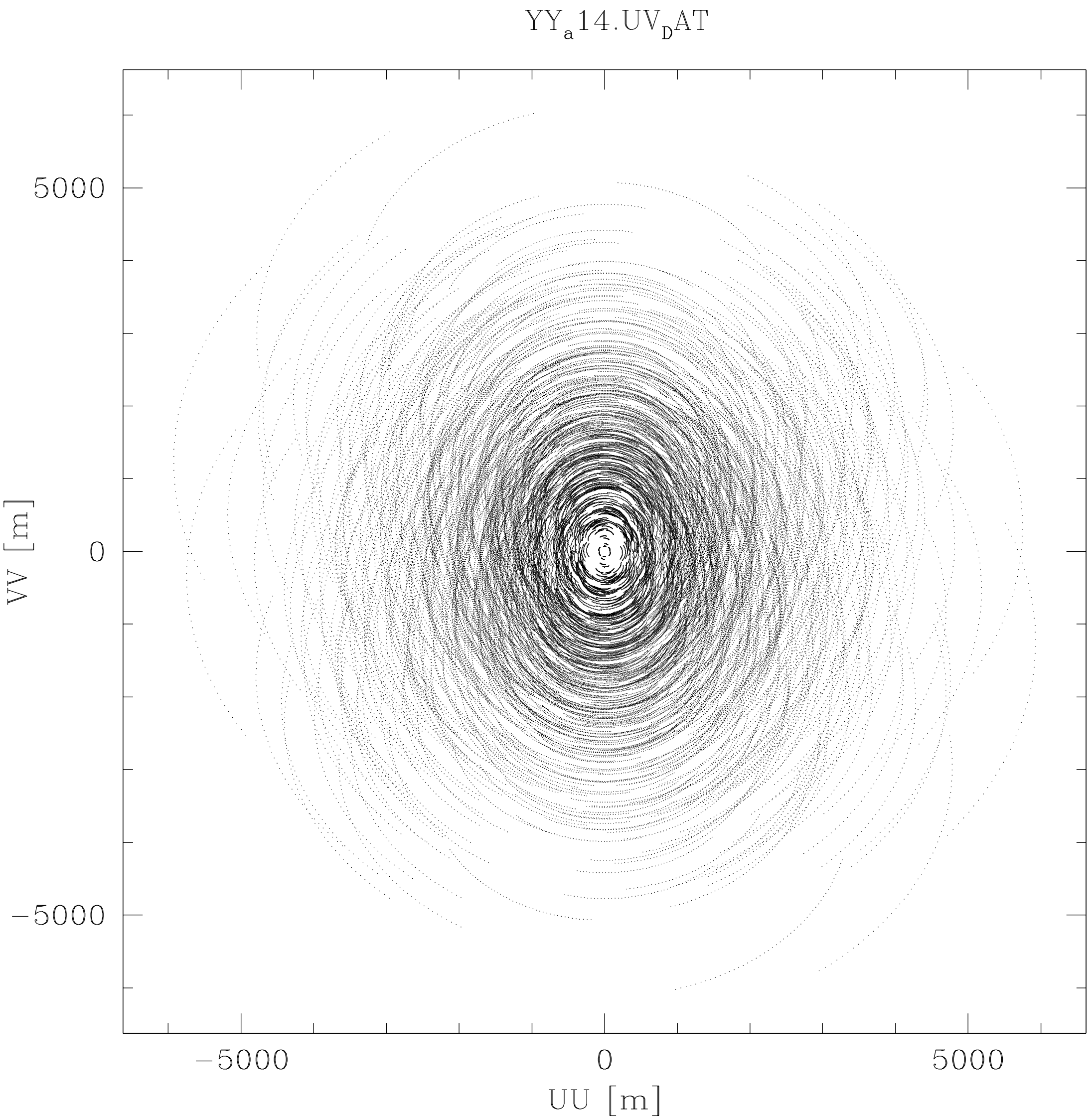

Figure 7: +/- 4 Hour coverage for configuration Y-A.

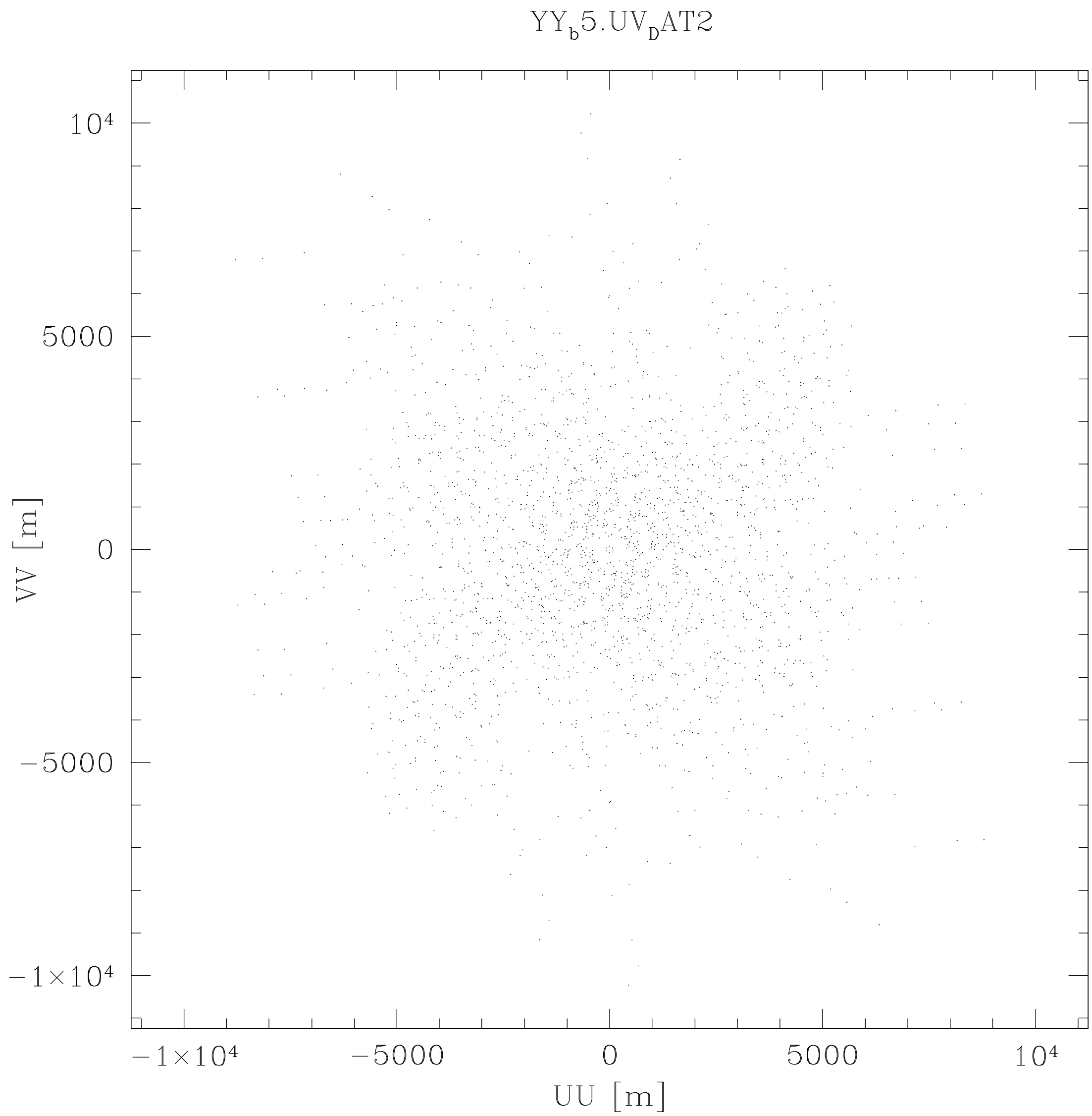

Figure 8: Snapshot coverage for configuration Y-B.

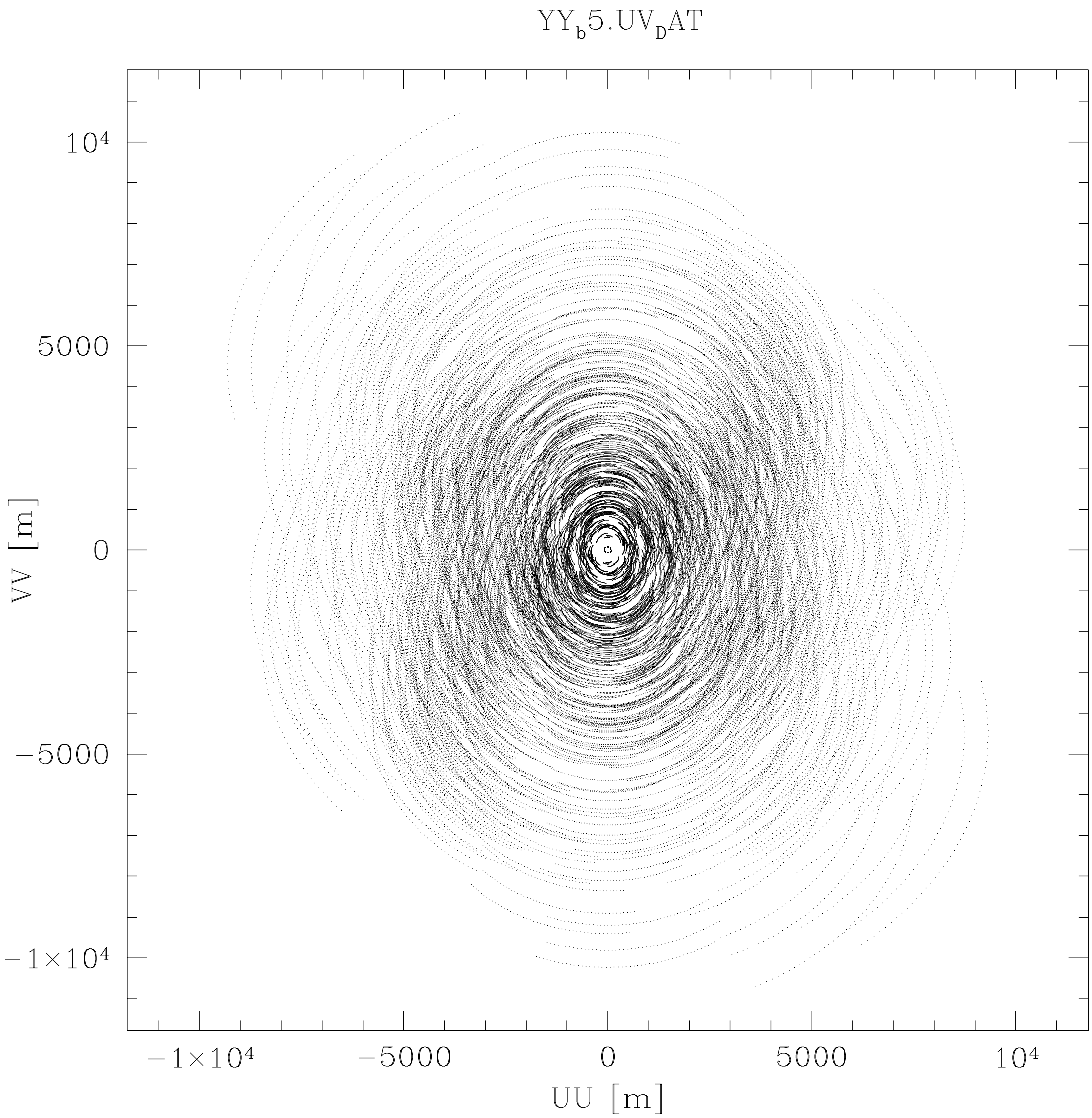

Figure 9: +/- 4 Hour coverage for configuration Y-B.

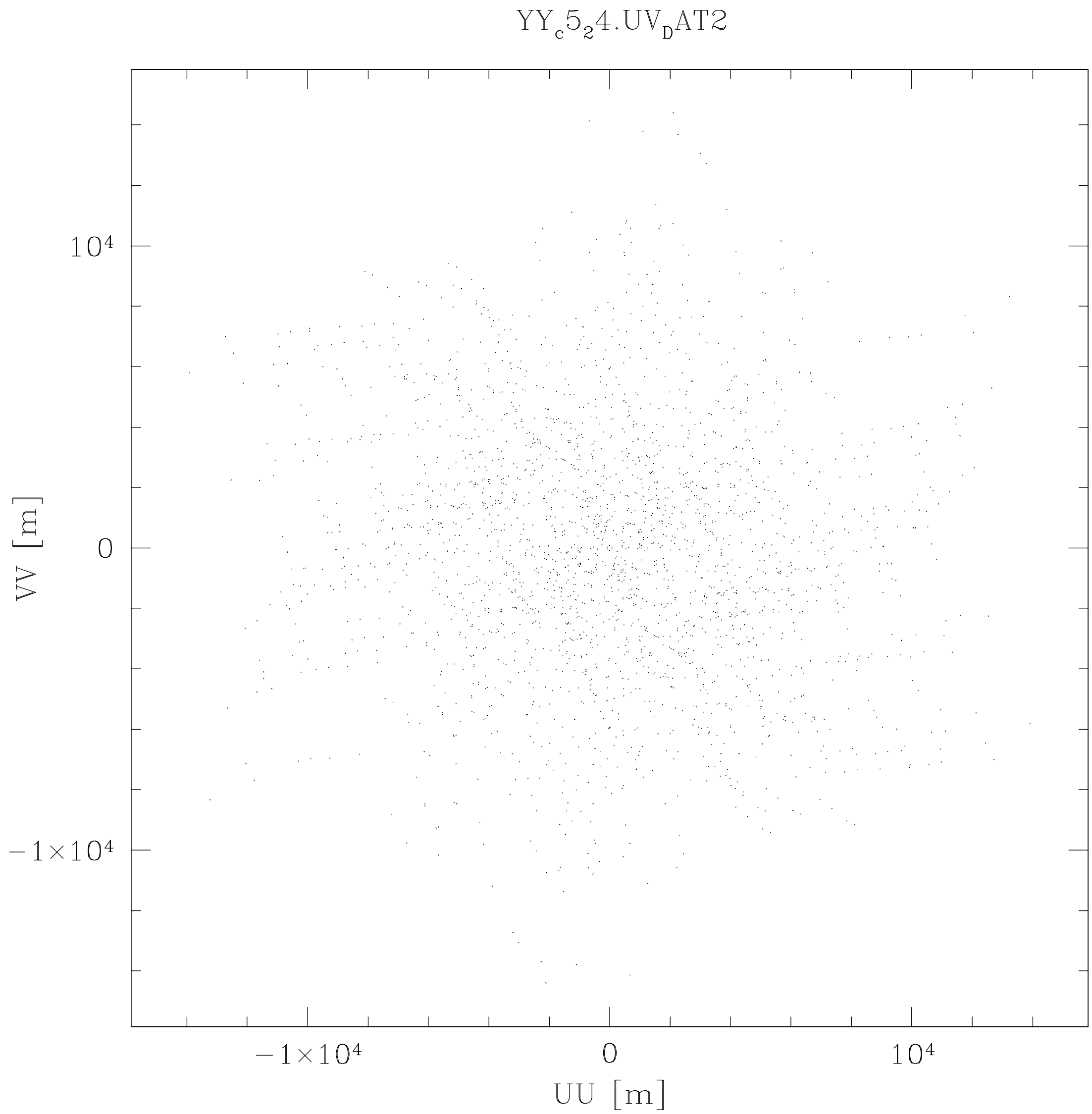

Figure 10: Snapshot coverage for configuration Y-C/24.

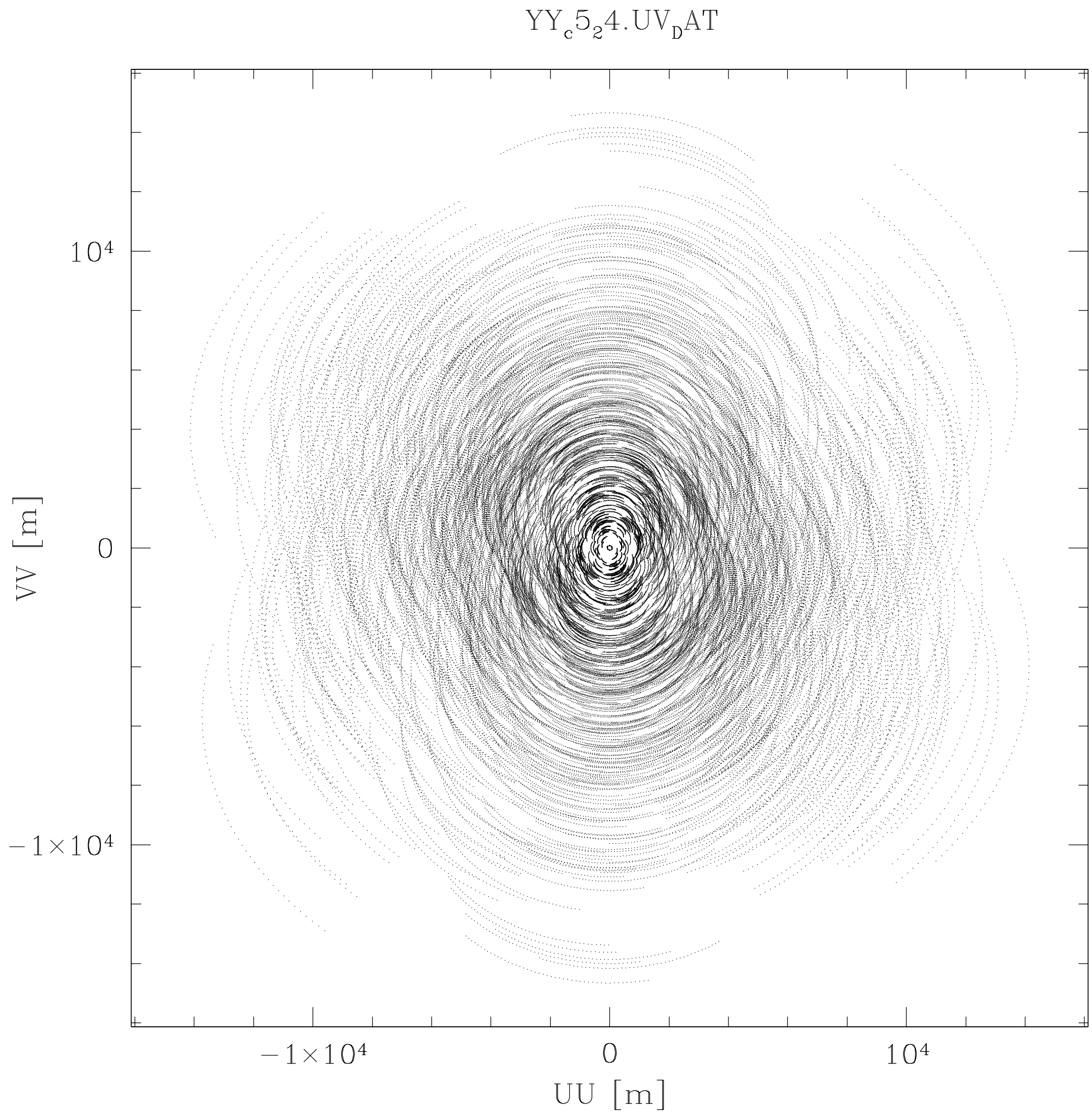

Figure 11: +/- 4 Hour coverage for configuration Y-C/24.

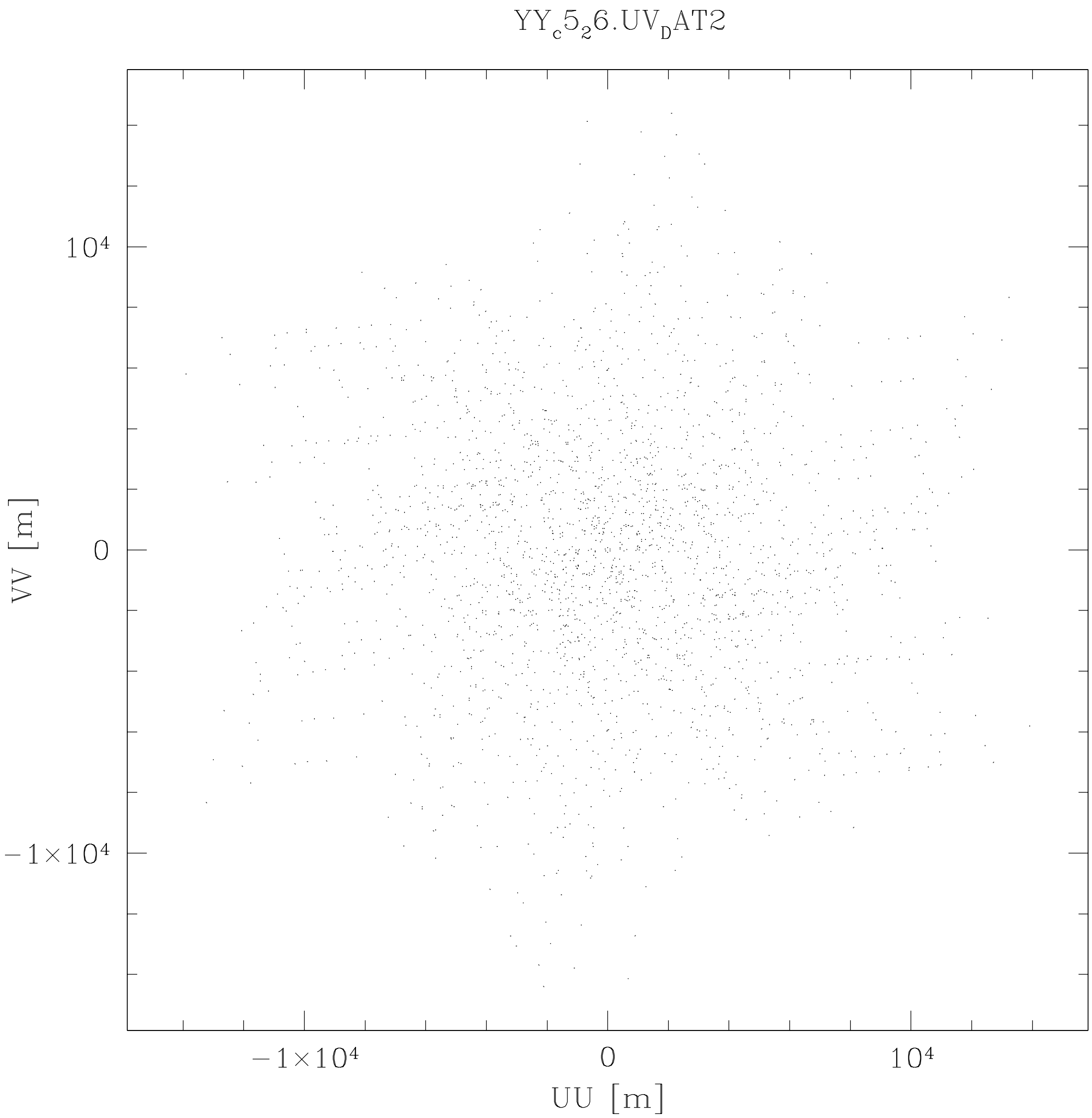

Figure 12: Snapshot coverage for configuration Y-C/26.

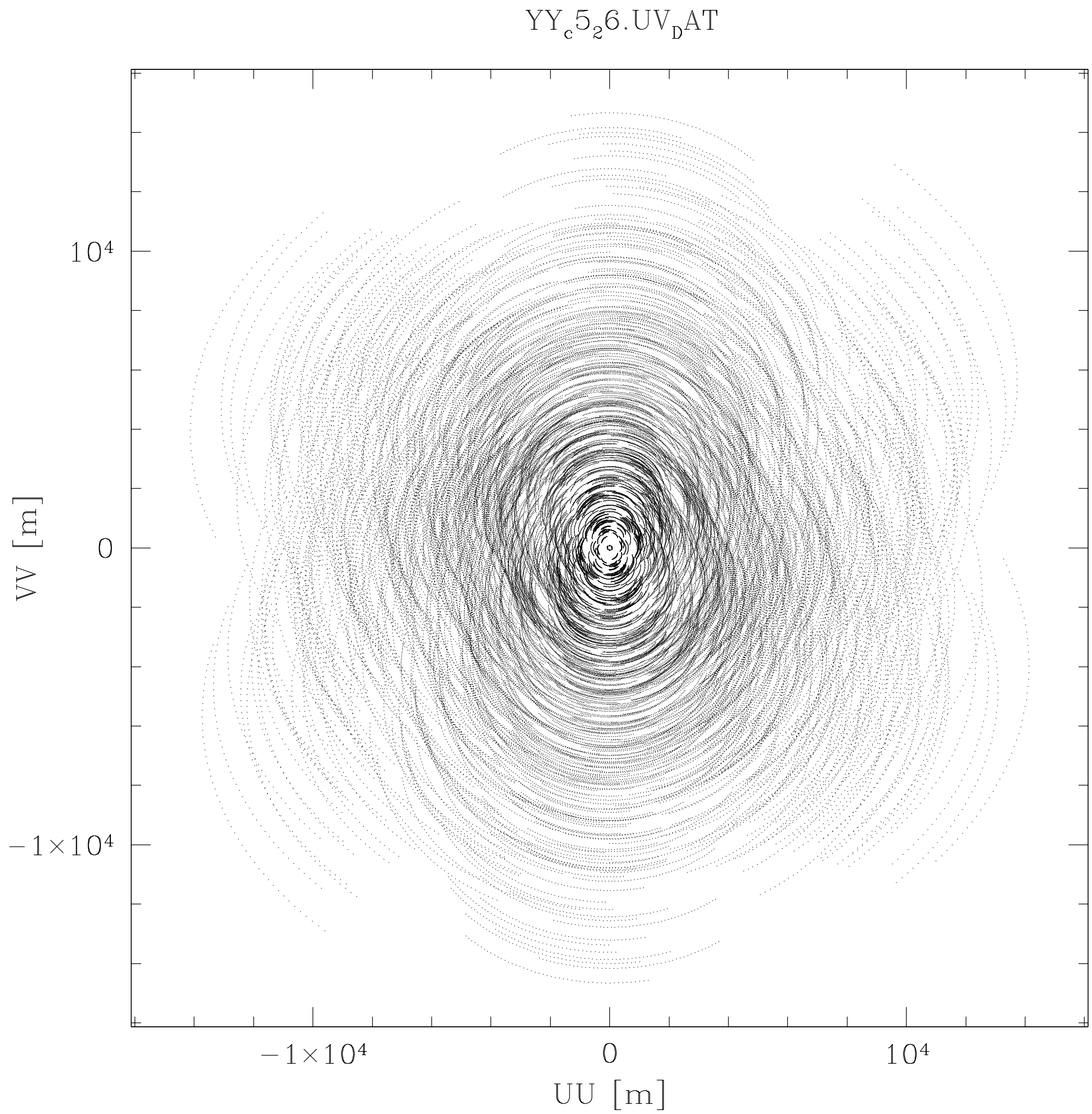

Figure 13: +/- 4 Hour coverage for configuration Y-C/26.

4 Pad Accounting

Total Y+ pads now: 42. We originally wanted 36 Y+ pads, 6 months ago we scaled back to 32. SO, 42 is 6 more than the original 36, or 10 more than the more recent 32 Y+ pads.

We have 12 pads in regions which have not been looked at before, but these will probably be OK - we must design roads and go and visit these sites.

Some pads which have designed roads are now being unused. Four pads which were abandoned (ie, when we went from 36 to 32 Y+ pads) are now being used.

I'll write this a bit better which I am awake.

5 Proposed Additional Work

- **Optimize the sub-configurations.** Configuration Y-A is made by moving 12 of the innermost antennas in Conway's outermost configuration and sending them out along the "arms of the Y+". Y-B is made by moving 12 more antennas out, and Y-C, the highest resolution Y+ array configuration, is made from 12 more antennas moved outwards. However, we expect to be able to make 4 antenna moves a day, so we need to optimize for Y-A-1, Y-A-2, and Y-A-3 arrays - actually Y-A-3 is the Y-A configuration we have specified here.

  We should not perform this optimization until after new pad positions have been accepted. There is no time pressure on this job, as it does not impact any pad positions or construction, but it should be done before my NRAO-issued computer running AIPS++ dies. I will have some time to do this in August or September. I estimate this to be a 40 hour project.

- **Optimize the inner antenna pad evacuation scheme to improve short baseline coverage.** Conway's spiral configurations follow a strict rule in selecting the antenna to pick up and move: antennas are taken off the innermost occupied pads and moved out to outer pads. The Y+ reconfiguration scheme generally follows that rule, with a major exception: there are three pairs of antennas which give very short baselines - 80m for the Y+ - in different orientations to help with flux calibration. Reconfiguration passes the antennas on these six pads by as less central antennas are evacuated to the Y+ positions.

  Single configuration imaging is not required for ALMA, as observations from multiple configurations and even mosaicing with total power data can be used if we are imaging a very large object with lots of fine structure. On the other hand, it is to our advantage to stretch our single configuration imaging capabilities if possible. Cross calibration of datasets taken at different times results in lost efficiency. The atmosphere and the flux calibrator could be very different. But perhaps the most important thing is that some high resolution observations will be of variable objects which we would prefer to observe at discrete and well-defined times with a single configuration.

  Changing the detailed order of antenna pad evacuation will have a very small effect on the beam properties we have already optimized for: PSF sidelobe levels and main beam shapes and sizes. However, improving the short baseline (u,v) coverage could have major impact on imaging for single configuration observations. In effect, work done in this direction will modestly increase the number of high resolution projects which can meet their scientific objectives with single configuration imaging.

We should not perform this optimization until after new pad positions have been accepted. There is no time pressure on this job, as it does not impact any pad positions or construction, but it should be done before my NRAO-issued computer running AIPS++ dies. I will have some time to do this in August or September. I estimate this to be a 40-80 hour project.

- /bf Work with someone in Socorro to transcribe this software from AIPS++/glish into CASA/Python. At some point, this old computer loaded with AIPS++ and SuperMongo and all the scripts I use for this work is going to die. It would probably be good to get this code translated into a more modern system. I have no real experience in CASA, so I should probably sit and work with someone who does. I am supposing this could take 25-50 hours, and would involve some travel to Socorro. If this work is performed first, then you could get someone else to perform the sub-configuration optimization and short baseline optimization.

A Configurations

UTMx - 600000 m	UTMy - 7400000 [m]	Altitude [m]	Pad
27320.0	52981.0	5025.1	1
28242.0	52816.0	5015.9	2
27593.0	53611.0	5031.0	3
27615.0	52488.0	5028.0	4
28287.0	53384.0	5016.4	5
27237.0	53285.0	5026.9	6
28261.0	52578.0	5019.8	7
27878.0	53858.0	5029.4	8
27369.0	52511.0	5019.2	9
28488.0	53134.0	5007.2	10
27265.0	53482.0	5026.1	11
28003.0	52241.0	5018.9	12
28166.0	53836.0	5022.7	13
27021.0	52792.0	5011.4	14
28593.0	52742.0	5012.6	15
27364.0	53932.0	5025.9	16
27640.0	52147.0	5028.4	17
28567.0	53703.0	5010.7	18
26779.0	53196.0	5013.0	19
28571.0	52164.0	5030.1	20
27725.0	54268.0	5029.5	21
27047.0	52073.0	5015.2	22
28948.0	53327.0	4984.2	23
26693.0	53811.0	5011.8	24
28199.0	51828.0	5035.1	25
28283.0	54433.0	5020.5	26
26543.0	52370.0	4992.9	27
29061.0	52702.0	4998.0	28
26952.0	54338.0	5024.2	29
27686.0	51501.0	5016.7	30
28978.0	54297.0	4990.6	31
26124.0	52986.0	4992.9	32
29178.0	51892.0	5058.6	33
27389.0	55123.0	5032.6	34
26640.0	51943.0	4987.6	35
27685.0	52525.0	5029.7	36
28211.0	53421.0	5019.3	37
27240.0	53368.0	5027.1	38
30815.8	55710.4	4902.8	39
30240.0	54330.0	4928.1	40
27050.0	56280.0	5048.0	41
25068.7	55189.3	4958.9	42
29490.2	50388.2	5009.5	43
29707.6	52399.0	5006.4	44
27583.8	51083.3	5002.9	45
29623.7	52088.1	5028.7	46
28092.6	55140.1	5021.8	47
28707.2	54952.2	4988.3	48
30940.0	53180.0	4931.0	49
29734.6	53889.7	4948.7	50

Table 2: Pad positions for Y-A14.

UTMx - 600000 m	UTMy - 7400000 [m]	Altitude [m]	Pad
27364.0	53932.0	5025.9	1
27640.0	52147.0	5028.4	2
28567.0	53703.0	5010.7	3
26779.0	53196.0	5013.0	4
28571.0	52164.0	5030.1	5
27725.0	54268.0	5029.5	6
27047.0	52073.0	5015.2	7
28948.0	53327.0	4984.2	8
26693.0	53811.0	5011.8	9
28199.0	51828.0	5035.1	10
28283.0	54433.0	5020.5	11
26543.0	52370.0	4992.9	12
27615.0	52488.0	5028.0	13
28287.0	53384.0	5016.4	14
27237.0	53285.0	5026.9	15
29061.0	52702.0	4998.0	16
26952.0	54338.0	5024.2	17
27686.0	51501.0	5016.7	18
28978.0	54297.0	4990.6	19
26124.0	52986.0	4992.9	20
29178.0	51892.0	5058.6	21
27389.0	55123.0	5032.6	22
26640.0	51943.0	4987.6	23
27685.0	52525.0	5029.7	24
28211.0	53421.0	5019.3	25
27240.0	53368.0	5027.1	26
30815.8	55710.4	4902.8	27
31734.4	51128.6	4958.6	28
25068.7	55189.3	4958.9	29
31358.0	55681.0	4895.3	30
26659.1	56623.9	5031.7	31
30178.0	48780.1	4835.3	32
31703.0	57742.3	4853.9	33
30121.0	55276.0	4922.6	34
31778.0	56289.0	4870.5	35
29490.2	50388.2	5009.5	36
25901.9	57210.2	5003.5	37
23451.0	55040.0	4871.0	38
32179.4	56591.2	4827.9	39
32280.0	47663.0	4761.1	40
30358.7	54983.4	4910.4	41
30780.0	53750.0	4917.7	42
24082.0	55048.0	4916.4	43
30940.0	53180.0	4931.0	44
30240.0	54330.0	4928.1	45
30645.7	54376.1	4904.2	46
31778.7	58902.7	4843.9	47
27050.0	56280.0	5048.0	48
31269.6	50944.9	4917.4	49
31556.8	58399.5	4869.6	50

Table 3: Pad positions for Y-B5.

UTMx - 600000 m	UTMy - 7400000 [m]	Altitude [m]	Pad
27615.0	52488.0	5028.0	1
28287.0	53384.0	5016.4	2
27237.0	53285.0	5026.9	3
29061.0	52702.0	4998.0	4
26952.0	54338.0	5024.2	5
27686.0	51501.0	5016.7	6
28978.0	54297.0	4990.6	7
26124.0	52986.0	4992.9	8
29178.0	51892.0	5058.6	9
27389.0	55123.0	5032.6	10
26640.0	51943.0	4987.6	11
27685.0	52525.0	5029.7	12
28211.0	53421.0	5019.3	13
27240.0	53368.0	5027.1	14
30815.8	55710.4	4902.8	15
31734.4	51128.6	4958.6	16
25068.7	55189.3	4958.9	17
31358.0	55681.0	4895.3	18
26659.1	56623.9	5031.7	19
30178.0	48780.1	4835.3	20
31703.0	57742.3	4853.9	21
30121.0	55276.0	4922.6	22
31778.0	56289.0	4870.5	23
29490.2	50388.2	5009.5	24
25901.9	57210.2	5003.5	25
23451.0	55040.0	4871.0	26
32179.4	56591.2	4827.9	27
32280.0	47663.0	4761.1	28
30358.7	54983.4	4910.4	29
30780.0	53750.0	4917.7	30
24082.0	55048.0	4916.4	31
30940.0	53180.0	4931.0	32
30240.0	54330.0	4928.1	33
30645.7	54376.1	4904.2	34
26159.9	57081.8	5010.4	35
27050.0	56280.0	5048.0	36
31269.6	50944.9	4917.4	37
31556.8	58399.5	4869.6	38
32742.0	59525.3	4815	39
31275.9	46977.7	4766.8	40
32668.2	51111.2	4970.7	41
23040.0	54968.0	4845.8	42
31114.9	47761.9	4763.6	43
21584.0	54319.0	4707.3	44
31778.7	58902.7	4843.9	45
21305.4	54940.9	4687.9	46
33309.9	62869.2	4834.5	47
20125.0	53657.0	4566.7	48
34062.0	47310.0	4728.4	49
30365.9	48430.8	4805.1	50

Table 4: Pad positions for Y-C5-24.

UTMx - 600000 m	UTMy - 7400000 [m]	Altitude [m]	Pad
27615.0	52488.0	5028.0	1
28287.0	53384.0	5016.4	2
27237.0	53285.0	5026.9	3
29061.0	52702.0	4998.0	4
26952.0	54338.0	5024.2	5
27686.0	51501.0	5016.7	6
28978.0	54297.0	4990.6	7
26124.0	52986.0	4992.9	8
29178.0	51892.0	5058.6	9
27389.0	55123.0	5032.6	10
26640.0	51943.0	4987.6	11
27685.0	52525.0	5029.7	12
28211.0	53421.0	5019.3	13
27240.0	53368.0	5027.1	14
30815.8	55710.4	4902.8	15
31734.4	51128.6	4958.6	16
25068.7	55189.3	4958.9	17
31358.0	55681.0	4895.3	18
26659.1	56623.9	5031.7	19
30178.0	48780.1	4835.3	20
31703.0	57742.3	4853.9	21
30121.0	55276.0	4922.6	22
31778.0	56289.0	4870.5	23
29490.2	50388.2	5009.5	24
25901.9	57210.2	5003.5	25
23451.0	55040.0	4871.0	26
32179.4	56591.2	4827.9	27
32280.0	47663.0	4761.1	28
30358.7	54983.4	4910.4	29
30780.0	53750.0	4917.7	30
24082.0	55048.0	4916.4	31
30940.0	53180.0	4931.0	32
30240.0	54330.0	4928.1	33
30645.7	54376.1	4904.2	34
33085.5	61307.3	4828.6	35
27050.0	56280.0	5048.0	36
31269.6	50944.9	4917.4	37
31556.8	58399.5	4869.6	38
32742.0	59525.3	4815	39
31275.9	46977.7	4766.8	40
32668.2	51111.2	4970.7	41
23040.0	54968.0	4845.8	42
31114.9	47761.9	4763.6	43
21584.0	54319.0	4707.3	44
31778.7	58902.7	4843.9	45
21305.4	54940.9	4687.9	46
33309.9	62869.2	4834.5	47
20125.0	53657.0	4566.7	48
34062.0	47310.0	4728.4	49
30365.9	48430.8	4805.1	50

Table 5: Pad positions for Y-C5-26.