Preliminary Thoughts for Compact and Intermediate Configurations for CARMA

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ABSTRACT

Here are some very preliminary thoughts on the design of compact and intermediate configurations for CARMA. I propose that we should design 15- and 23-element configurations for D array, and 15-element configurations for the larger arrays. The most compact configuration can reasonably expect to be $\gtrsim$50m in diameter, in accord with Lee's previous assumptions. I show a sample, non-optimized 23-element configuration that utilizes all minimum separations available among the six different pairs of primary elements. The uniformly weighted beams for this configuration are $\sim$11″. Given the 0.3–0.4″ beams for A array, this suggests that we should aim for intermediate configurations that yield uniformly weighted beams of $\sim$3.5″ and $\sim$1.1″ if we design four main configurations. I suggest that we do design four (rather than five) configurations, and try to share 3–5 pads among adjacent arrays where possible. Using resources that we save by sharing pads (and by eliminating a configuration), I also suggest that we design hybrid DC, CB, and BA configurations that utilize e.g. 10-12 fixed stations from each of the D, C, B, and A arrays, for observing low-declination sources. F. Boone is currently modifying his configuration optimization code to allow for heterogeneous arrays; this may be a very useful tool for CARMA array design.

1. Number of Dishes

A fundamental assumption in the optimization of any array is the number of array elements. For CARMA this is of course not completely well defined. At its core, CARMA will have available nine 6.1m BIMA dishes and and six 10.4m OVRO dishes, all operating at 3mm and at 1mm. For some of the time, CARMA will also have available the eight 3.5m SZ dishes, which will operate at 1cm and 3mm, but not 1mm. The SZ dishes can operate as either eight additional elements for the crosscorrelation array, or together as a phased, 16th element of the basic CARMA array. In addition, the SZ dishes and the OVRO dishes may work together at 1cm.

For the compact array, I propose that we ignore the possibility that the SZ dishes may work together as a phased array. This is because (1) as Mel has pointed out, a phased 3.5m beam is complex, which might be troublesome for the extended sources that we hope to image using compact arrays; and (2) we don't have the option of a phased 3.5m beam at 1mm anyway.

Even at 3mm, there may be times that we want to be in a compact array when the SZ dishes are not available. We can then try two different approaches: (1) Optimize for the positions of the 15 BIMA and OVRO dishes, fix these positions, and then optimize for the positions of the additional eight SZ dishes, allowing for small movements of the BIMA and OVRO dishes if necessary; or (2) Start over again and optimize for the 23 BIMA, OVRO, and SZ dishes; then try to reconcile the 15-element and 23-element arrays (e.g. by forcing common stations).

2. Size of the Compact Configuration, and Number of Configurations

The smallest and most sensitive array is dictated by the physical limits on close packing of the elements. But to achieve reasonable sidelobe levels, we want to allow a filling fraction f less than unity. If we assume the roughly equivalent collecting area of an array of 15 8m dishes and f=0.4, then the size of the smallest array is $S = D\sqrt{N/f}$=49m. This is in good agreement with Lee's assumption of a 50–60m central region for a compact array. This is also probably as close as we can reasonably pack the antennas, given the close-packing constraints.

If the largest array will be 2km and the smallest array will be 50m in diameter, how many configurations do we need? If we assume four configurations, then the scale factor between arrays will be 3.4, with arrays of diameter 50m, 170m, 580m, and 2km. If we assume five configurations, then the scale factor between arrays will be 2.5, with arrays of diameter 50m, 130m, 310m, 780m, and 2km. These choices are somewhat different than have what we have assumed in the past.

For the purposes of these notes, I'll assume that we will use four arrays, with the diameters roughly given as above. I'll confuse matters by referring to the most compact array as the D array. Notice that when we do have the SZ dishes included, the D array may grow somewhat larger, while the C, B and A arrays need not. Also, we might choose somewhat progressively less centrally concentrated uv distributions as the array size increases. We might therefore do well to stagger the scale factor between arrays, so that e.g. D=50m; D$\rightarrow$C = 3.2 and C=160m; C$\rightarrow$B = 3.5 and B = 560m, and B$\rightarrow$A = 3.6 so that A = 2km. (Maybe this is obvious already. I guess all I'm saying is that we can fix the resolution scale factor instead of the linear scale factor for the arrays.)

3. Sample Compact Configuration

I spent a little time while I was at Hat Creek last week playing around with Frederic Boone's antenna configuration optimization code (Boone 2001, A&A, 377, 368). This may be a very useful tool for CARMA array design, as it allows for gaussian uv distributions of any FWHM for a variety of boundary conditions. Right now the main limitation is that, since the code assumes a homogeneous array, we can't specify the minimum separations that we would like to achieve among the three different styles of antennas. For C, B, and A arrays, this isn't a serious limitation, but for the D array, the code is impractical as is. Boone is currently making modifications to his code to allow heterogeneous configurations, with different specifications for minimum spacings; this is an important and nontrivial addition for the compact array design. He expects to have this code working in about a month.

In the meantime, John Lugten and I designed a sample compact configuration by hand that is essentially a minimum-packed array for all 23 elements; it has all minimum separations allowed among the three types of dishes. The configuration is shown in Figure 1; sample uv coverages and uniformly weighted beams are shown in Figures 2 and 3. The array has not been optimized and can clearly be improved on, but we can use it to draw some initial conclusions:

(1) The maximum center-to-center separation is 44.5m, between two OVRO dishes, so it is possible to fit a reasonably compact configuration in a 55m-diameter area.

(2) The uniformly weighted beams are $10.5''$–$12''$ at $\delta \geq$ -5°. Given the 0.3–$0.4''$ beams for A array, this suggests that we should aim for intermediate configurations that yield uniformly weighted beams of $\sim 3.5''$ and $1.1''$ if we stick with four configurations.

(3) Perhaps the worst feature of the beams shown are the deep, near-in negative sidelobes, which reach levels of ∼0.12 times the peak. These can be alleviated by forcing the uv distribution to be more like a gaussian; from Figure 2, it looks like the falloff in sampling is far too abrupt. This probably means that this array is the smallest that we can reasonably expect to achieve, and that we might make much nicer beams by allowing the array to stretch a bit. I'm planning to play around with this by hand a bit, but it will really be useful to use Boone's code to optimize this array.

4. Plan of Attack

Once we have Boone's optimization code available for heterogeneous arrays, here is a rough plan of attack that I have been thinking about. We'll have to recognize that successive steps may tend to screw up results from previous iterations. I use the word "optimize" somewhat tongue-in-cheek. But I also think that, using Boone's optimization code (once it is available for heterogeneous arrays), the following is no more than about 1–2 weeks' worth of work.

(1) Optimize D array, using 15 antennas. Assume a filled, gaussian-like uv distribution. Optimize for $\delta \gtrsim -5°$(e.g. $\delta = -5°$and $\delta = 20°$) running cases for hour angle coverage of HA=$\pm 0.5h$ and HA=$\pm 2h$. Require the BIMA dishes to provide baselines as small as ∼8.3m, the OVRO dishes to provide baselines as small as ∼15m, and the BIMA-OVRO pairs to provide baselines as small as

$\sim$13.3m (i.e. one-half the minimum separation for no collisions for the BIMA-BIMA pairs, 11.6m, plus one-half the minimum separation for no collisions for the OVRO-OVRO pairs).

(2) Optimize a "DSZ" array using 23 antennas. Fix the 15 BIMA+OVRO dishes and require the 8 SZ dishes to provide baselines as small as $\sim$4.2m. Also require the SZ-BIMA minimum baseline to be $\sim$7.9m and the SZ-OVRO minimum baseline to be $\sim$9.6m.

(3) Optimize an unconstrained "DSZ" array using 23 antennas. Try to reconcile these results with those from (2) to design a reasonable strawperson array that may be used with or without the SZ dishes.

(4) Optimize C array, using 15 antennas. Assume a gaussian-like uv distribution. Optimize for $\delta \gtrsim -5°$, running cases for hour angle coverage of HA=$\pm 1h$ and HA=$\pm 4h$. Fix 3–5 antennas to D array positions. Specify minimum baselines to be (at least nearly) as close as allowed.

(4a) Optimize a "CSZ" array using the fixed 15 elements from C array and adding the SZ dishes. This probably won't be a common mode of observing, so don't spend much effort on this. Right?

(5) Using 10–12 fixed positions from the optimized D and C arrays, optimize a hybrid DC array with 15 antennas for δ=-30°, using HA=$\pm 2.5h$.

(6) Optimize a B array using some stations from C and some from A arrays. Again optimize for $\delta \gtrsim -5°$. Assume a more uniform uv distribution (i.e. a gaussian with a broader FWHM).

(7) Optimize a hybrid CB array using fixed positions from the C and B arrays, for δ=-30°.

(8) Optimize a hybrid BA array using fixed positions from the B and A arrays, for δ=-30°.

(9) As a second-order effect, optimize for multi-configuration imaging (already available in Boone's code).

(10) As a second-order effect, optimize B and A arrays for 16 elements, using 15 fixed stations and the phased SZ dishes as the 16th element. This will presumably use the SZ stations from the D array, but may affect placement of the D array on the site.

(11) I'll leave shadowing off for now, but clearly this is also a worry for D array. The OVRO-OVRO dish pairs start to shadow at 56.4° elevation for the minimum separation; the BIMA-BIMA pairs start to shadow at 48.1° elevation for minimum separation; and the SZ-SZ pairs start to shadow at 43.9° elevation for minimum separation. I still need to calculate the shadowing for the mixed-antenna pairs. We may need a model for how much shadowing is acceptable for D array.

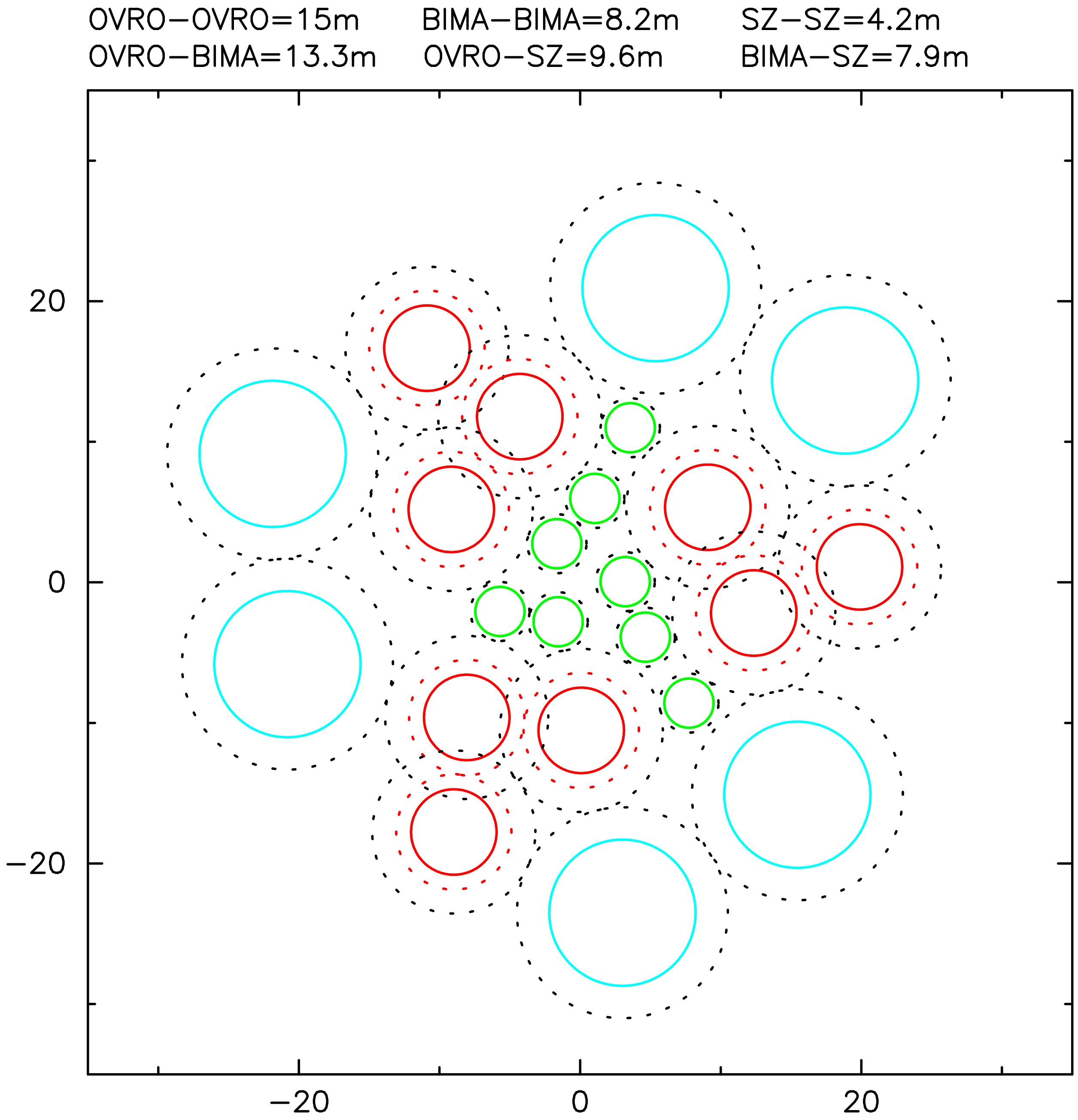

Fig. 1.— A non-optimized 23-element configuration that includes all minimum spacings allowed, as listed at the top. The OVRO dishes are shown in blue, the BIMA dishes in red, and the SZ dishes in green; the solid colored circles represent the true diameters of the dishes. The black dashed lines represent the minimum distance for collision avoidance for each of the elements. For the BIMA dishes, red dashed lines represent an 8.2m separation, which is the minimum baseline for the current BIMA D array; this uses a hardware and software collision avoidance scheme.

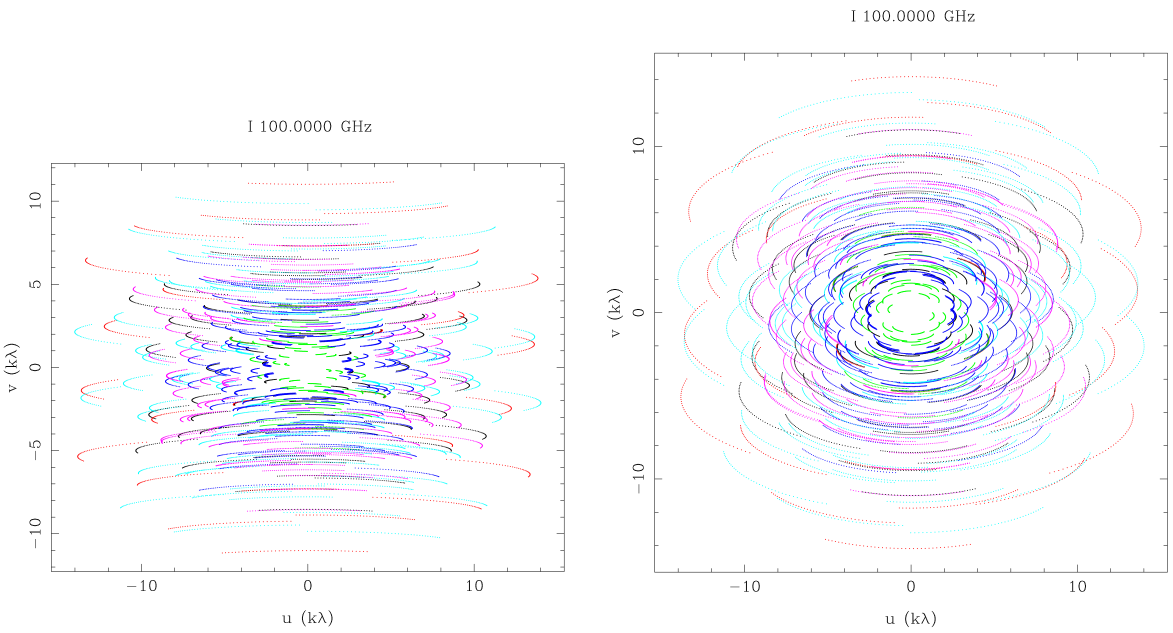

Fig. 2.— *uv* coverages for a ±2-hour track using the configuration in Figure 1 at δ=-5° (left) and δ=20° (right), for ν=100 GHz.

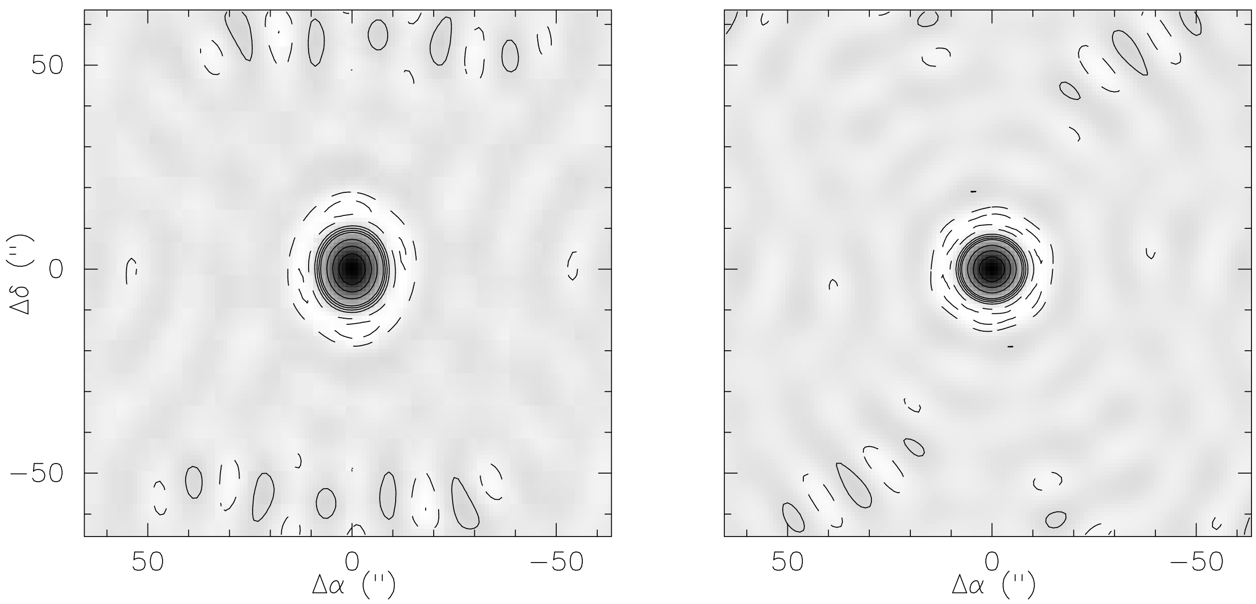

Fig. 3.— Uniformly weighted beams for the *uv* coverages shown in Figure 2; δ=-5° (left) and δ=20° (right). Contours are shown at ±.05, ±.10, .15, .20, .40, .60, .80 of the peak. The inner negative sidelobes are at a depth of -0.12 times the peak. The size of the beams are $13.2'' \times 11.0''$ (left) and $10.5'' \times 10.3''$ (right).