CARMA Sensitivity and Correlator Requirements

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ABSTRACT

We calculate the relative sensitivities for different sub-arrays of the CARMA antennas. Making all correlations of 6 x 10.4, 9 x 6.1, and 8 x 3.5 m antennas requires 253 baselines per polarization. Most of the sensitivity, $\sim$ 90% for single field, and $\sim$ 80% for mosaicing observations, can be obtained using sub-arrays with about half this number of correlations. Errors in the primary beam illumination may limit the image fidelity in mosaicing observations; this limits the usefulness of correlations between 10.4 and 3.5 m antennas.

1. Sensitivity of a Heterogeneous Array

The sensitivity of a heterogeneous array can be calculated by summing the sensitivity for each baseline. For baseline (i,j), the RMS flux density

$\delta S(i,j) = Jyperk(i,j) \times Tsys(i,j)/\sqrt{2\ B\ t(i,j)}$ — (1)

1.1. Single Field Observation

For a single field observation, the integration time on source, $t(i,j)$, is the same for all baselines. Assuming the same system temperature ($Tsys$) and bandwidth (B) on all baselines, the RMS flux density is just proportional to $Jyperk(i,j)$, or to 1/(Di Dj). i.e. the sensitivity $1/\delta S$ is proportional to the collecting area for each baseline. The sensitivity for the array is obtained by weighting each baseline by $1/((\delta S)^2)$.

Sensitivity for single field $\sim sqrt[Sum[(DiDj)^2]$ — (2)

1.2. Mosaic Observation

For a mosaic observation, the integration time on source, t(i,j), is equal the fraction of the time the source is illuminated by the primary beam, Omega(i,j), for each baseline. Omega(i,j) is proportional to 1/(Di Dj). Assuming the same system temperature (Tsys) and bandwidth (B) on all baselines, the RMS flux density is proportional to Jyperk(i,j)/sqrt[Omega(i,j)], or to 1/sqrt[Di Dj]. The sensitivity for the array is obtained by weighting each baseline by $1/((\delta S)^2)$.

Sensitivity for a mosaic observation $\sim sqrt[Sum[DiDj]$ — (3)

2. CARMA array

The CARMA array may be comprised of combinations of six 10.4m, nine 6.1m and eight 3.5m antennas. Table 1 gives the number of baselines for each combination of antennas. The subtotals are listed in the margins.

We may not wish to make all possible correlations, but divide the the antennas into sub-arrays. In this case the size of the correlator is reduced, and the routing of the signals from the antennas is changed.

Next we list the relative sensitivities for various subarrays as a percentage of the sensitivity if all cross-correlations are made. Table 2 lists the single field sensitivity, and Table 3 lists the mosaicing sensitivities corresponding to equations 2 and 3. Note that the percentage sensitivities do not add because of the sqrt in equations 2 and 3.

The sensitivity tables show that we get most of the sensitivity for both single field and mosaic observation by making only correlations which include the 10.4 antennas.

3. Primary Beam patterns

Another source of noise in the images are the pointing and primary beam errors. Of special interest is the primary beam pattern between the 10.4 and 3.5 m antennas. The primary beam is the geometric mean of the voltage patterns for the pair of antennas. Errors in this primary beam pattern caused by primary beam variations and by relative pointing errors between the pair of antennas may dominate the image errors in a mosaic observation.

For a Gaussian illumination pattern truncated to -13 db at the edge of the dish, the effective

Table 1: Number of Baselines

Antennas:	10.4	6.1	3.5	Totals
6 x 10.4	15	54	48	117
9 x 6.1		36	72	108
8 x 3.5			28	28
Totals:	15	9	148	253

primary beam between 10.4 and 6.1 m antennas is within about 1% of a Gaussian pattern corresponding to an 8 m antenna. (Conveniently close to the antenna diameter for a homogeneous array of 15 antennas with the same collecting area.) The uncertainties in the primary beam pattern are greater than the errors made by treating the 10.4 to 6.1 m antenna beam as a Gaussian. For the 10.4 to 3.5 m correlations, large uncertainties in the 10.4 m voltage pattern lie well within the illumination pattern of the 3.5 m antennas. Herein lies an opportunity and a challenge. If we can determine the primary beam response well enough, then including the 10.4 versus 3.5 m correlation provides a glue to stick the mosaic fields together; the sky is multiplied by quite different primary beam patterns from the different combinations of antennas, in principle providing data to deconvolve the primary beam responses from the image. If we can not determine the primary beam well enough, the errors will limit the image fidelity. The current mosaicing algorithms in Miriad can handle heterogeneous array imaging, but do not give a good estimate of the image errors. (A Chisq image gives some idea of the limiting noise). There is clearly a need for research in both determining the primary beam performance, and developing the mosaicing algorithms for heterogeneous array imaging.

4. Correlator Requirements

In view of the sensitivities and uncertainties in making all correlations we may not wish to build the large correlator required for all possible correlations. (4 x 253 baselines for full polarization). Most of the sensitivity, and perhaps the best image fidelity can be obtained with fewer baselines. The correlator configuration should be driven by the science requirements with an eye towards the arguments above. There are several interesting combinations which require a smaller correlator. Some possibilities:

1. The 3.5 m antennas as one subarray with the 10.4 and 6.1 m as an imaging subarray (28 + 15 + 54 + 36 = 133 baselines).

2. 3.5m + 10.4m for point source removal in SZ and better calibration of phase of 3.5m antennas; with the 6.1m antennas as a separate subarray, with 72-80 GHz capability and better spectral resolution. (28 + 15 + 48 + 36 = 127 baselines).

Table 2: Single Field Sensitivity

Antennas:	10.4	6.1	3.5	Totals
6 x 10.4	56	63	34	92
9 x 6.1		30	25	39
8 x 3.5			9	9
Totals:	56	70	43	100

Table 3: Mosaicing Sensitivity

Antennas:	10.4	6.1	3.5	Totals
6 x 10.4	40	58	42	82
9 x 6.1		37	39	54
8 x 3.5			19	19
Totals:	40	69	60	100