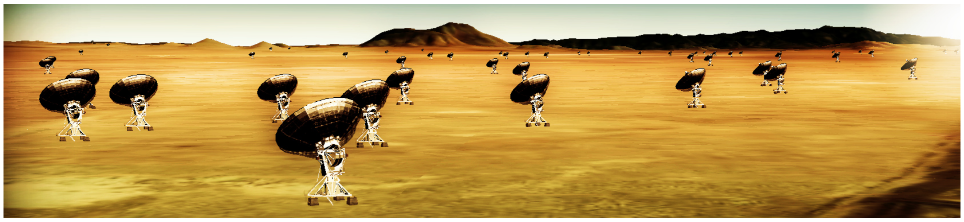

Next Generation Very Large Array Memo No. 47

Resolution and Sensitivity of ngvla-revB

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Abstract

I investigate the noise performance vs. resolution for the new ngvla-revB configuration. I fix the weighting to be Briggs with R = -0.5, and set the pixel size to be small enough, and the image size large enough, not to affect the uv-sampling or noise statistics. I then adjust the uv-taper to obtain synthesized beams with sizes ranging from about 2mas to 2" at 85GHz. I assume a 4 hour synthesis. The rms remains fairly constant at about twice the expected naturally weighted noise from 2mas to 0.9" resolution. At larger beam sizes, the noise rises sharply, since the tapering is down-weighting baselines within the Core itself.

1 Introduction

The ngVLA Rev B configuration entails a non-reconfigurable array with three effective baseline scales. The Core array has 94 semi-randomly placed antennas to baselines of about 1km. The Plains array includes the core, plus another 74 antennas in a five-arm spiral pattern out to baselines of about 30km. The full array includes the Core and Plains, with another 46 antennas extending in a rough three arm spiral, principally toward the South from the VLA site, out to about 1000km (Carilli & Erickson 2018).

As a non-reconfigurable, tri-scale array, the ngVLA presents the imaging challenge of balancing spatial resolution with sensitivity. The ngVLA memo series includes numerous studies of the imaging performance of tri-scale arrays in the context of the Key Science Goals. Ultimately, the problem is one of 'beam sculpting' using various imaging parameters, such as Briggs weighting, uv-taper, cell size, and image size, to obtain an optimal resolution, beam shape, and sensitivity for a given science program.

In this memo, I perform a more limited analysis of the imaging parameters, aimed at getting an initial estimate of the expected sensitivity vs. spatial resolution for the Rev B configuration of the ngVLA.

2 Processing

I employed the CASA simulator with the Rev B configuration. The input model was a FITS image with zero flux at 85 GHz at a declination of $+50^o$. The simulated observation was for four hours across transit. I then add noise to the visibilities appropriate for a 20 GHz bandwidth, although the processing did not employ bandwidth synthesis. The simulation process is described in ngVLA memo 12.

For imaging, the cell size was set to a small value (0.3mas), to avoid truncation of the uv-plane at large radii, and large images were made (up to 9k), to fully sample the PSF beyond the broad skirts, even for NA weighting. Briggs weighting was employed with R = -0.5. While the synthesized beams in some cases were not ideal (see below), the skirts of the PSF do drop below 10% at a radius of about the FWHM of the beam. A number of studies have shown that, while the beams may not be particularly Gaussian, such a weighting/tapering scheme does perform adequately for some of the Key Science Programs (ngVLA Memos 11 13 30 35 41).

The uv-tapers were then adjusted to obtain resolutions from about 2mas to 2". The former pertains to the longer baselines of hundreds of km. The latter pertains to the Core.

3 Results

Figure 1 shows images of the PSF for Natural weighting, and for R = -0.5 weighting with three different uv-tapers: 'outertaper = 0arcsec', 'outertaper = 0.032arcsec', and 'outertaper = 0.512arcsec'. Figure 2 shows a 1D cut through the beam in the East-West direction.

The essence of the problem is seen in the Naturally weighted beam. The beam shows three disctinct scales: (i) a narrow core of about FWHM = 4mas, (ii) an inner skirt to 40mas over the 60% and to 30% range, (iii) an outer skirt starting around the 30% level, and only dropping below 10% at 400mas radius. The CLEAN program reports a Gaussian fit of FWHM = 4mas, but clearly both the inner and outer skirts are dramatically non-Gaussian by orders of magnitude.

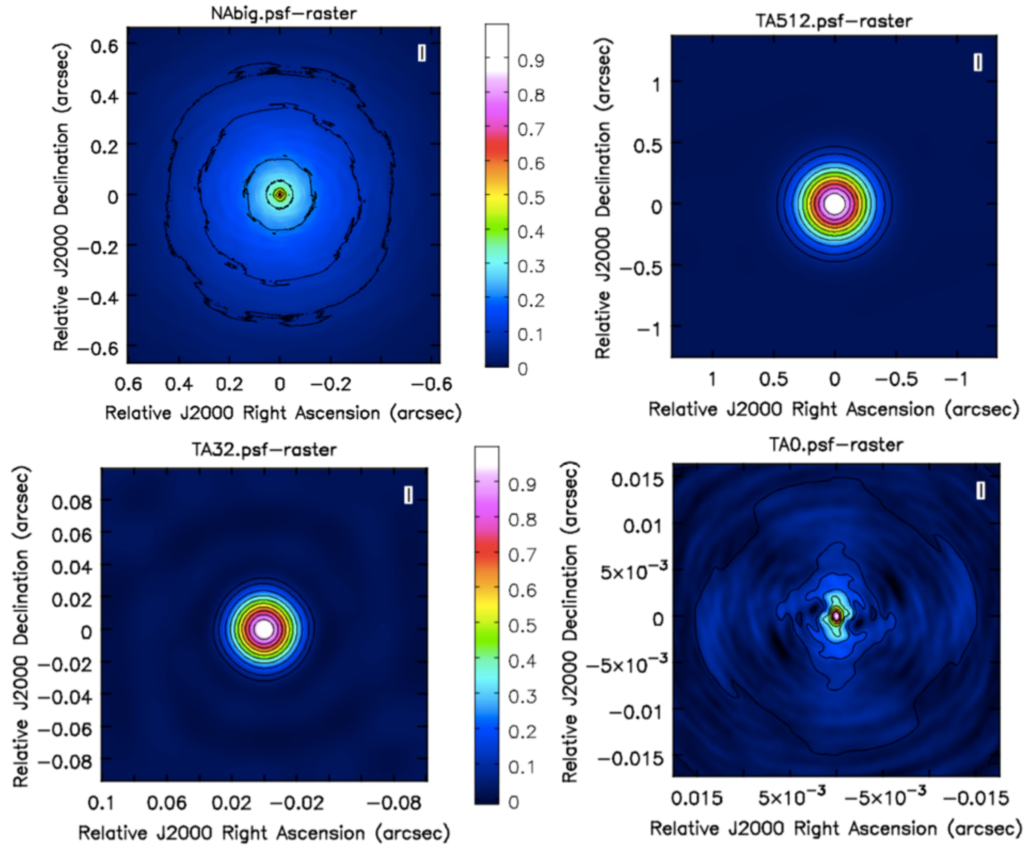

Figure 1: The resulting PSF for Natural weighting, Briggs weighting with Robust = -0.5, and outertaper = 0", 32", and 512" (as labeled in sub-frames).

For the untapered PSF with R = -0.5, the Gaussian fit FWHM = 2.0mas $\times$ 1.5mas, and the skirts do drop below 10% at a radius about equal to the FWHM (depending on direction). However, the particular E-W cut shows a plateau of lower level sidelobes at the few percent level out to about 15mas, and the inner sidelobes are even higher in the N-S direction. I adopt this beam for the sensitivity tests herein, but further exploration is required to determine the detailed performance in the context of the KSPs.

Setting the 'outertaper = 0.032arcsec' leads to a beam that appears more Gaussian, with a fit FWHM from CLEAN of 32mas. For 'outertaper = 0.512arcsec', the beam also looks Gaussian, with a fit FWHM = 450mas.

For a 4 hour continuum observation at 85GHz, the theoretical sensitivity

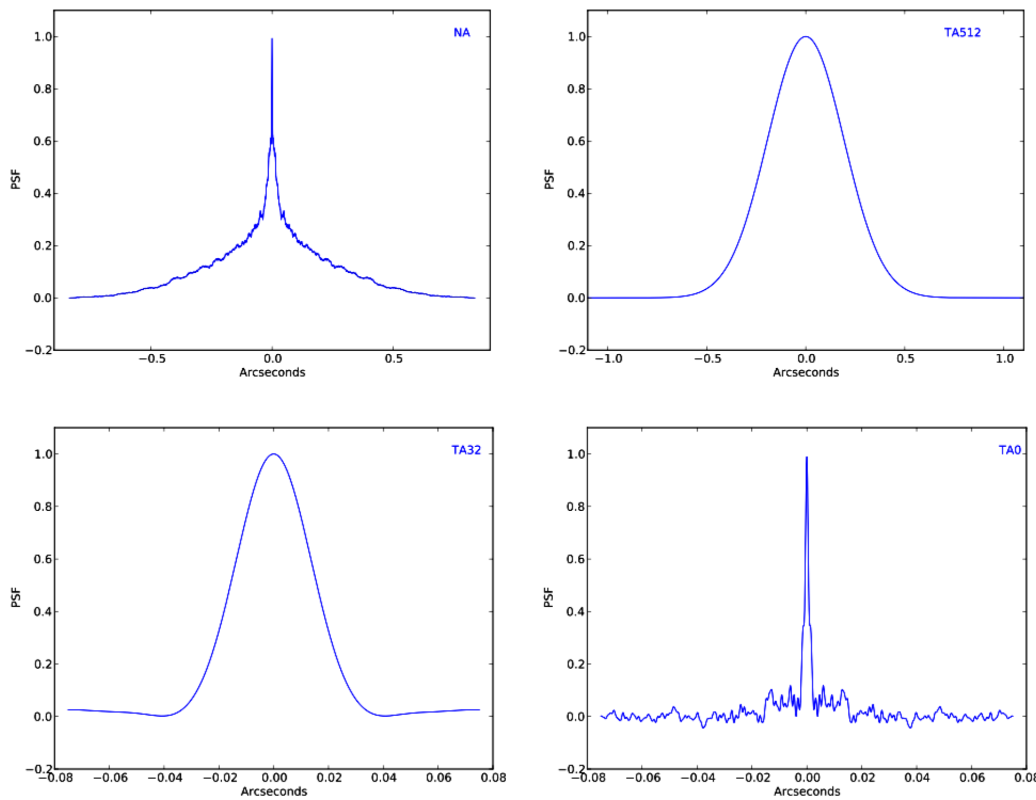

Figure 2: Slices in the East-West direction through the point spread functions shown in Figure 1, for Natural weighting, Briggs weighting with Robust = -0.5, and outertaper = 0", 32", and 512" (as labeled in sub-frames).

of the array using Natural weighting is 0.36μJy beam^{-1} (ngVLA memo 17).

I then generate a series of images with outertapers ranging from 2mas to 2000mas, and determine the noise on the image. The results for the CLEAN fit FWHM and the rms noise in the image are shown in Figure 3. Also shown is a red line corresonding to the NA noise given above.

The rms noise modulates from about 0.6μJy beam^{-1} to 0.8μJy beam^{-1} from 2mas to 0.9" resolution. The noise then rises sharly to coarser resolutions. This behavior is characteristic of the ngVLA array, in which the dense Core itself is located toward the northern part of the overall antenna distribution (ngVLA memo 16). At the largest beams ($\geq$ 1"), the tapering is simply cutting out progressively more Core baselines.

I also set R = -2 with no taper, to investigate the performance at essentially uniform weighting. The fit CLEAN beam FWHM was a factor 1.75 smaller than for R = -0.5 with no taper, and the beam shape was closer to Gaussian, ie. no inner plateau (although the inner negative sidelobes go to 10%). However, the noise value jumps to 1.7uJy beam^{-1}, or a factor five higher than Natural weighting.

4 Summary

I have investigated sensitivity vs. resolution for the ngVLA Rev B configuration. To simplify the process, I have only altered the uv-taper parameter, and adopted Briggs weighting with R = -0.5. The resulting beams at the highest resolution are not particularly Gaussian, but likely adequate for imaging in some of the KSPs, and for the noise testing herein (ie. adequate near-in skirt levels).

The noise remains roughly constant at about twice the Naturally weighted noise across a large range of spatial resolutions, from 2mas to 1". Going to even lower resolution, the noise rises quickly, since the implied baselines for the taper are well within the Core itself. Pushing to the highest resolution, with close to uniform weighting (R = -2) and no taper, leads to a beam size a factor 1.75 smaller than for R = -0.5 and no taper, and a more Gaussian beam shape, but a noise level a factor five higher than Natural weighting.

An extensive exploration of 'beam sculpting' in the context of existing tools (Briggs weighting, uv-taper, cell size, etc...), is clearly the next step in this process. Parallel investigations of alternative weighting/imaging schemes are also required, to optimize extraction of information on sky brightnesses over a large range in spatial scales using a tri-scale array.

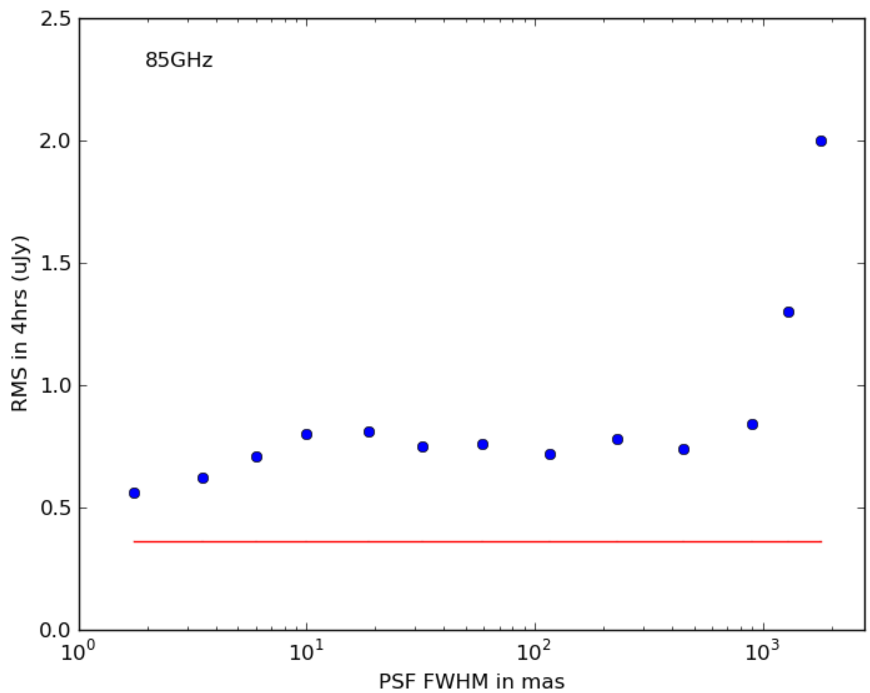

Figure 3: Blue points: the rms noise vs. resolution (FWHM from Gaussian fit to the synthesized beam). The red line indicates the theoretical noise of the Naturally weighted array response.