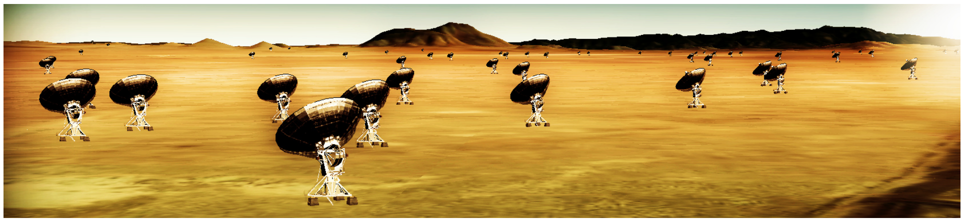

Next Generation Very Large Array Memo No. 64
High Dynamic Range Imaging

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Abstract

I have performed high dynamic range imaging simulations of a complex extended object at 8 GHz. The model was a doctored version of Cygnus A. Even for a monochromatic simulation, the ngVLA main array was able to reach a dynamic range of 50 dB at a resolution of 0.12". In the brighter regions of the radio source, the rms image fidelity, $F_{rms} \sim 0.2\%$. Even in the fainter parts of the lobes, the rms fidelity remains high: $F_{rms} \sim 3.8\%$. There is no positive or negative bias of the data relative to the model. The results imply that the ngVLA main array can reach the target specifications for high dynamic range, high fidelity imaging of complex celestial objects.

1 High Fidelity Imaging of Complex Objects

I explore the capability of the ngVLA to produce a high dynamic range, high fidelity image of an extended source with complex morphology. This requirement is delineated in:

- **SCI0108**: The ngVLA should produce high fidelity imaging ($> 90\%$) over a wide range of scales, spanning from a few arcmin to a few mas.
- **SCI0113**: The system brightness dynamic range shall be better than 50 dB to support deep field studies at 10 GHz.

Image fidelity, F, is usually defined as:

$$F = (Data - Model)/Model$$

Hence, a 90% value, as specified in SCI0108, corresponds to a fidelity factor, $F < 10\%$, in absolute value.

While SCI0113 is designed more for continuum deep fields, the desire to obtain 50 dB dynamic range on complex extended objects is implicit in numerous science programs being envisioned in the Design Reference Science Mission.

2 Model, Configuration, and Processing

The input model I employ is a high dynamic range image of Cygnus A made with the VLA at 8 GHz. In the original image, the resolution is 0.35", and the source maximum extent is $\sim 2'$. The dynamic range of the input image is $\sim 10^5$. The total flux density of Cygnus A at 8 GHz is about 240 Jy.

I then modified the model to obtain a smaller source at higher resolution, by adjusting the pixel scale down by a factor 3.3. This scaling leads to an input model resolution of 0.1", and source maximum size of 40".

The input model image was then blanked in a few ways. First, all negative pixels were set to zero, since the true continuum sky has no 'negative emission'. Second, a fairly tight window was set around the radio lobes and jets, and zeroed outside the window. Lastly, the compact radio core source was blanked in the initial input model, then re-added as a point source model in the final image.

Choosing a real source for the model image is useful in terms of having astrophysically relevant quantities as the target. However, such a choice leads to two limitations. First, the input model itself has a dynamic range of only a few $\times 10^4$. Through the blanking process, we have removed all the noise at positions off the radio source. Still, there are residuals within the radio lobes that are not real structure. In this case, the goal becomes to reproduce the model surface brightness, both real and noise. And second, the input model has an intrinsic resolution of 0.1", comparable to the target resolution of the simulation. In essance, the sky has been 'pre-convovled' before imaging (besides the core, which was set to be a point source). Most of the radio lobe structure appears to be well resolved at this resolution, as seen on the highest resolution images made at 43 GHz with the VLA (Carilli et al. 1999, AJ, 118, 2581), except perhaps the sharpest features in the radio hot spots.

I employ a single channel of 15 MHz at 8.0 GHz. This channel width is adequate to avoid significant bandwidth smearing on scales relevant to the model source.

For the configuration, I use the RevC Main array as a starting point. I target a resolution comparable to the HST, or about 0.1", so I remove the most distant 16 antennas[1].

I run SIMOBSERVE for a six hour synthesis, with 20s records. The time resolution is adequate to mitigate temporal smearing on the relevant scales of the source. The longest baselines are still too long for the target HST resolution, so I split out all baselines shorter than 167 km, to obtain the final measurement set for imaging. I then add noise to each visibility at the level appropriate for the record length and channel width.

I explored numerous CLEAN options. I found a multiscale clean was necessary, and that Uniform weighting was preferred to reach the nominal specifications of ~ 0.1" resolution and a 50 dB dynamic range. The following CLEAN inputs were employed: Uniform weighting, cell size of 0.02", outer taper = 0.12", multiscale = [0,7,25], clean threshold of 0.2 mJy. A tight box was set around the radio source for CLEANing.

3 Results

The input model image, and final CLEAN image, are shown in Figure 1. This image has an off-source rms noise of 26 μJy beam^{-1}, a peak surface brightness of 2.5 Jy beam^{-1} (on the southern hot spot), and a beam FWHM = 0.12" $\times$ 0.11". Hence, the dynamic range (peak/rms), is $\sim 1 \times 10^5$. The

[1] A94, A85, A111, A74, A76, A75, A82, A118, A115, A117, A87, A100, A113, A114, A116, A119

total flux density in both the input model, and the CLEANed image, is 241 Jy. The radio core in both cases is 1.08 Jy.

Figure 2a shows a saturated version of the CLEAN image, to emphasize the noise characteristics. Low level sidelobes can be seen, emanating primarily from the hot spot regions, indicating that the image is dynamic range limited. I note that the Natural weighted rms for the Main Array for a 15 MHz channel in 6 hours at 8GHz is 5 μJy beam^{-1}, or a factor five lower than the noise level in the CLEAN final image.

I then created a fidelity image, F, by convolving the model with the CLEAN beam, and calculating the F factor as defined above. The fidelity image is shown in Figure 2b. In the division process, I blank the model image at 10 times the rms noise, to avoid taking ratios in regions where noise itself will limit fidelity to < 0.9.

Across the brighter parts of the lobes and hot spots, the mean and rms of the fidelity factor is: $F = -0.0002 \pm 0.002$. In the tails of the lobes, and on the jets, these values increase to: $F = +0.0036 \pm 0.038$. Overall, there is no tendency for a bias, either positive or negative, of the data relative to the model (ie. the rms is 10$\times$ larger than the mean), and we easily reach the $F < 10\%$ fidelity target across the source, in both the bright hot spot regions and across the fainter radio lobes of Cygnus A.

Figure 3 shows the PSF for this simulation. The peak negative sidelobes are 3%, and the PSF drops to $< 10\%$ at a radius of ~ 0.12".

4 Summary

I have performed high dynamic range imaging simulations of a complex extended object at 8 GHz. Even for a monochromatic simulation, the ngVLA main array was able to reach a dynamic range of $\sim 1 \times 10^5$ at a resolution of 0.12".

The rms image fidelity, $F_{rms} \sim 0.2\%$ in the brighter regions, and even in the fainter parts of the lobes, the rms fidelity remains high: $F_{rms} \sim 3.8\%$. There is no positive or negative bias of the data relative to the model.

The next step in the simulations process will be to incorporate multi-frequency synthesis. The imaging and deconvolution process then becomes computing intensive, when including both MFS and a multiscale clean, for a complex source, and an array with 200 antennas.

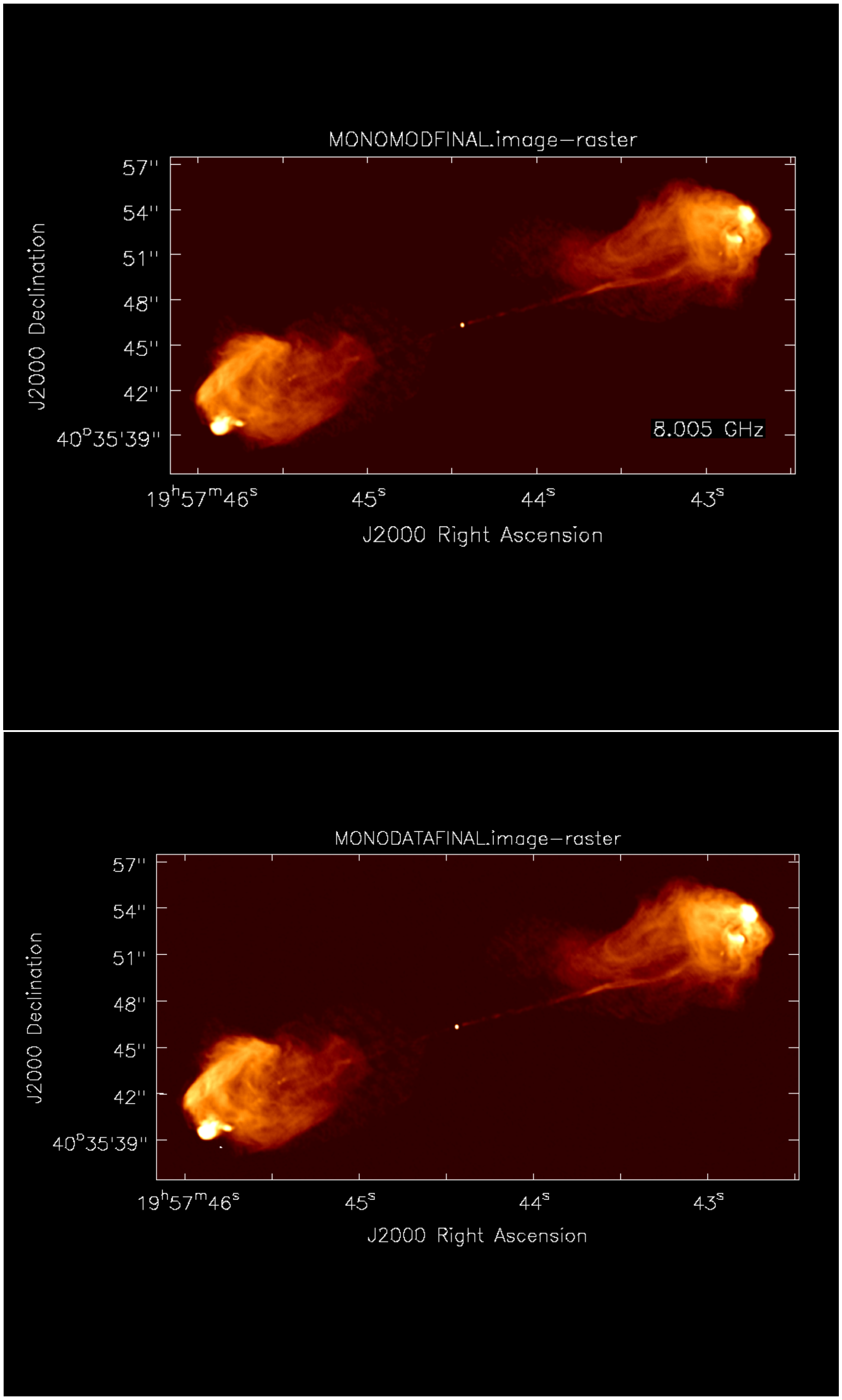

Figure 1: *Top: Input model of Cygnus A at 8GHz, adjusted as explained in Sec. 2. Bottom: 8GHz simulated observation from the ngVLA Main Array The resolution is* 0.12", *the peak surface brightness is 2.5 Jy beam*$^{-1}$*, and the rms noise is 26* μ*Jy beam*$^{-1}$*.*

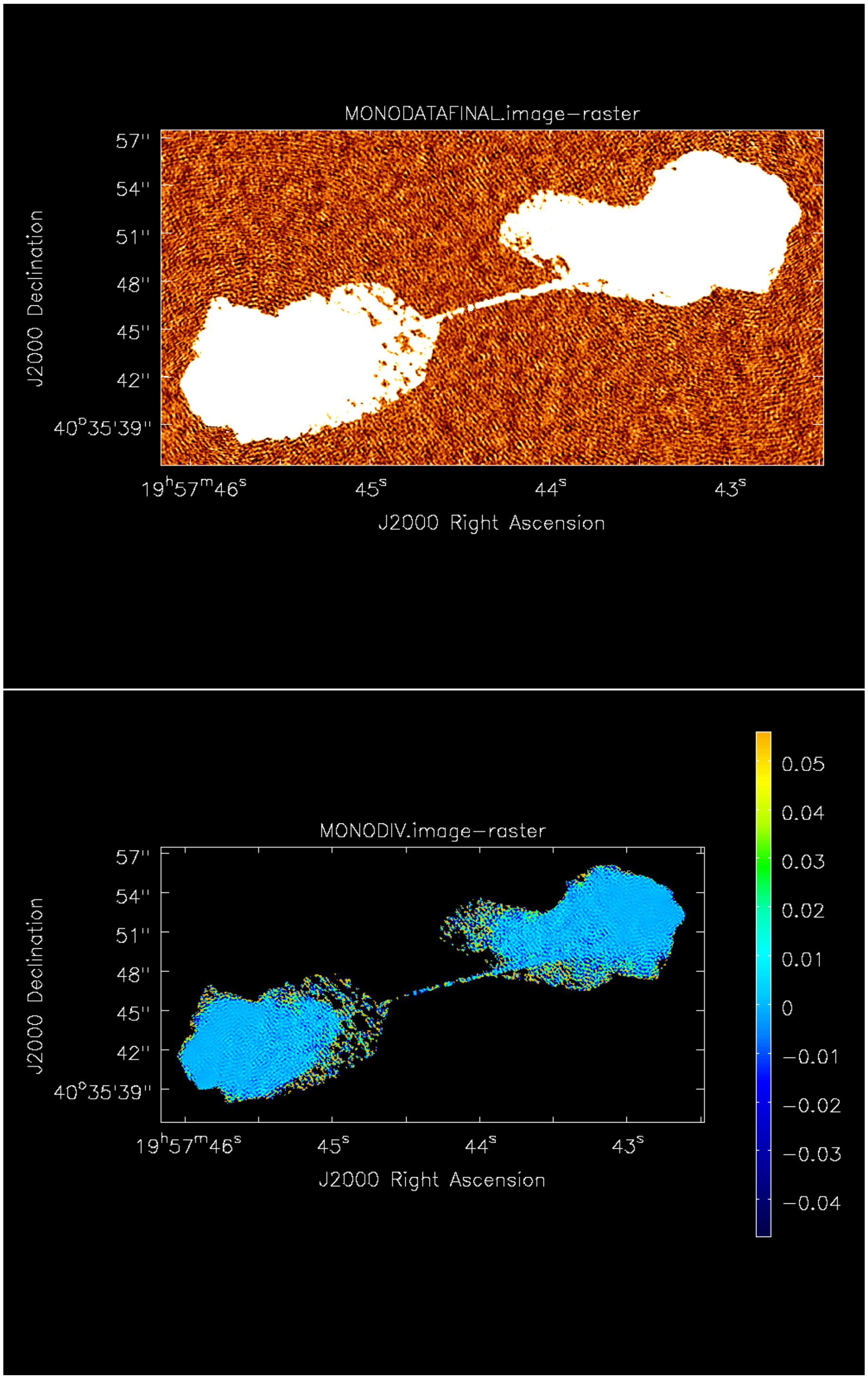

Figure 2: *Top: Same 8GHz simulated observation as in Fig 1, now saturated to show the noise characteristics. Bottom: Fidelity image, defined as:* $F = (data - model)/model$.

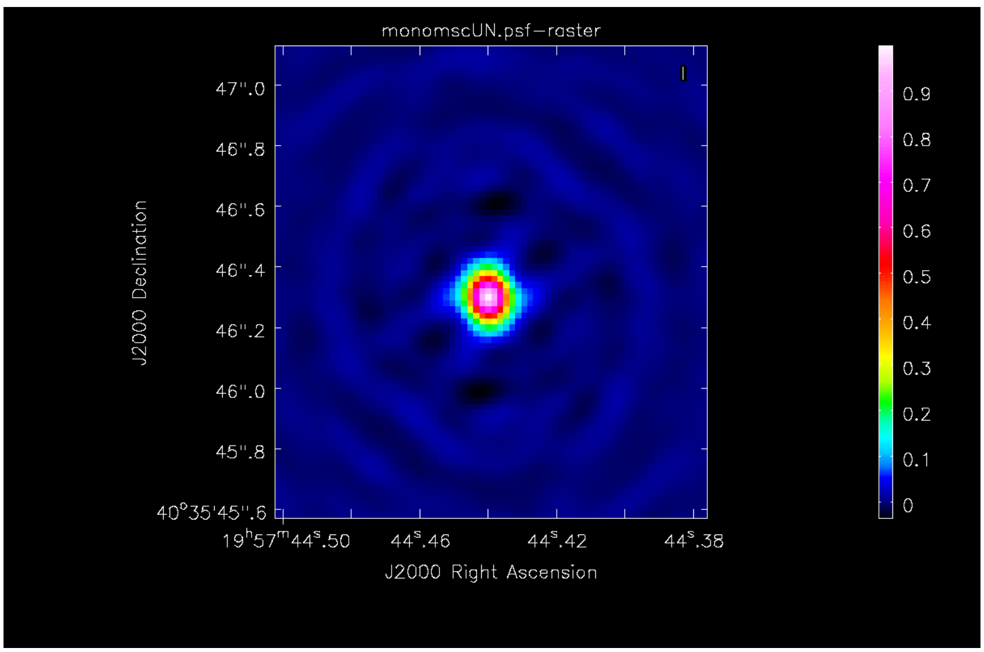

Figure 3: *The PSF of the 8GHz simulated observation. resolution*