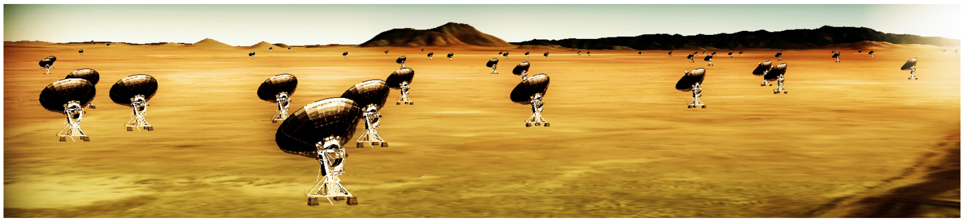

Next Generation Very Large Array Memo No. 86
Imaging Evaluation of Two Mid Configurations

C.L. Carilli, R.C. Walker, B.S. Mason, J.P. Carilli

Abstract

We consider the performance of two alternative configuration to the Mid configuration in the Southwest USA and Mexico, on baselines out to 1000 km. One involves the original Mid configuration of Rev C, and the second is an approximate five arm spiral described in Walker (2018 ngVLA memo 49). Both have the same number of Mid antennas (46). The UV-coverage for the Walker configuration is considerably better than Rev C, avoiding the large holes in the outer parts of the UV-plane, and with better overall long baseline coverage. Consequently, the synthesized beam for the Walker configuration is also considerably better, with peak sidelobes a factor two lower than for the original Mid Rev C configuration. The image quality metrics, for a strongly dynamic range limited source model, are also better for the Walker configuraton, but only by 50% or less.

1 Introduction

The Rev C Mid component of the ngVLA configuration entails 46 antennas extending from the outer reaches of the Spiral component, on 30km scales, to baselines up to 1000 km (Carilli et al. 2020, ngVLA memo 82). Walker (2018, ngVLA memo 49) proposed an alternative to the current Rev C Mid configuration, with five relatively well defined spiral arms.

In this memo, we explore the imaging performance of the current Rev C Mid configuration with that proposed by Walker. We follow a similar procedure, and use scaled versions of the same models, as was employed in the evaluation of the 5 arm vs. 7 arm Spiral configurations (Carilli 2019, ngVLA memo 64).

2 Models, Configurations, and Simulations

We adopt the 8 GHz model for Cygnus A, processed as described in Carilli (2019, ngVLA memo 64). We adopt two models of different angular sizes. The 'complex' model has a size of 5" × 2", or roughly 5×10^4 synthesized beam over the full source area. The simple model is a factor 25 smaller in area, or about 2000 synthesized beams over the source area. The two models are needed because we find that the snapshot uv-coverage for either configuration is inadequate to image the complex model (see Sect. 6). The two models, convolved with the relevant Gaussian beams from the imaging process, are shown in Figure 1.

The two configurations are shown in Figure 2. The Mid RevC configuration is described in Carilli et al. (2020, ngVLA memo 82). This configuration entails 46 antennas, starting at the outer reaches of the Spiral component of the array (on the Plains of San Augustin), or 30 km baselines, and extending to baselines of 1000 km. The dominant components of this configuration include a line of antennas running down routes 12 and 180 to the southwest of the VLA site, and an arm of antennas extending into Eastern NM. The configuration includes 3 antennas in Mexico, 6 antennas in TX, and 1 in AZ.

The Walker configuration (2018, ngVLA memo 49), also has 46 antennas, but now more evenly distributed between five rough spiral arms. The main changes are 9 antennas in AZ, 5 in Mexico, and still 6 in TX. There are fewer antennas on the Eastern NM plains. We note that by moving antennas from Eastern NM to the high country of AZ, the high frequency observing conditions should improve.

In all simulations we include the Rev C 5arm Spiral configuration out to 30km baselines, and 10 antennas from the Core out to 1 km baselines. This subarray will be standard practice, based on the Key Science Programs and the Reference Observing Program (Wrobel et al. 2019, ngVLA Document 020.10.15.05.10-0001-REP-B).

We perform a 6hr synthesis simulation using SIMOBSERVE and the Complex model. We also perform a 20min synthesis simulation using the Simple model. We do not include thermal noise, since these are tests of image quality and fidelity[1]

[1] We did perform one simulation adding the appropriate thermal noise. The difference between the CLEANed images with and without thermal noise were at the $\sim 0.2\%$ level, both for the source surface brightness distribution, and the off-source rms noise. The reason for the very close similarity is because the source is so bright. Hence, all the 'noise' seen off-source is due to what can be termed 'dynamic range', meaning imperfections in the UV-sampling and the subsequent deconvolution. A test of this kind can be consideration

We adopt the TCLEAN algorithm in CASA to perform the imaging and deconvolution, using Briggs weighting with R = -2, a loop gain of 0.03, and apply a Gaussian taper of 0.01". The resulting parameters for the Gaussian fit to the synthesized beam are given in Table 1.

3 PSF and UV-coverage

Figure 3 shows the UV-coverage for the two configurations for the 6hr and 20min syntheses. The Walker configuration shows a more uniform distribution, in particular for the short synthesis, avoiding the larger holes seen in the Mid Rev C UV-coverage. Importantly, as pointed out in Walker (2018), much of the imaging sensitivity at high resolution comes on baselines between the outer Mid antennas and the Spiral and Core antennas. This effect can be seen as the dense blue clumps in the UV-distribution. Again, the Walker configuration avoids the larger holes in the UV-plane seen for the Mid Rev C configuration. The Walker configuration also has better long baseline coverage.

The synthesized beams are shown in Figure 4. As expected based on the UV-coverage, the Walker configuration shows much reduced sidelobes relative to the Mid Rev C configuration, by a factor two or more. The values for the peak sidelobes in each case are given in Table 1.

4 Images

Figure 5 shows the resulting images for the 6hr observation of the Complex model using Mid Rev C. We include a highly saturated view, to show the imaging artifacts off-source. Figure 6 shows the same, but for the Walker configuration.

Figure 7 shows the resulting images for the 20min observation of the Simple model using Mid Rev C. Again, we include a highly saturated view, to show the imaging artifacts off-source. Figure 8 shows the same, but for the Walker configuration.

Values for the image peak surface brightness, the off-source rms noise, and the minimum (peak negative) surface brightness on the image, are given

a combination of testing the UV-coverage, and the ability of the deconvolution algorithms to interpolate the missing baselines. For reference, the NA rms thermal noise in a 20min image using a 2GHz bandwidth for 130 ngVLA antennas is about 1 μJy beam^{-1}, or a factor 3000 below the measured values herein.

in Table 1. The rms and minimum surface brightnesses are lower by about 10% to 20% for the Walker configuration vs. the Mid Rev C configuration.

5 Image Quality and Fidelity

Table 2 lists image quality parameters, including: Dynamic Range (DNR) = (peak surface brightness)/rms, the peak sidelobe of the synthesized beam, and the image fidelity metrics. The fidelity metric here is defined as in ngVLA Memo 64: Fidelity = (Image - Model)/Model, where the model is convolved with the same fitted CLEAN beam as the image. Figure 10 and Figure 9 show the images of the fidelity, blanked at 10σ surface brightness. In Table 2 we list two numbers: the rms scatter in the fidelity image in the brighter heads of the lobes (F1), and the same for the fainter tails of the lobes (F2). The fidelity images show stripes at the few% level, indicative of a CLEAN instability.

We also evaluated the image fidelity with the flux weighted metric adopted by the NGVLA project, F_3 (B. Mason, ngVLA memo 67 and Murphy et al., ngVLA Document 020.10.15.00-0001-REQ). These fidelities are presented in Tables 2 and 3, which also present the ALMA fidelity metrics A evaluated at three levels, from 0.1% to 10% of peak model image brightness; this metric is more sensitive to small differences, as discussed in ngVLA memo 67.

Regardless of metric used, the image fidelity in all cases is excellent, with fidelity errors typically below 1%, even in fainter regions of the source. In terms of image dynamic range and fidelity, the Walker configuration performs better than Rev C, but only by 10% to 50%.

We note that the simulations performed herein entailed a very bright source, where imaging dynamic range (meaning, incompleteness in UV-coverage, and subsequent artifacts arising due to the limitations of deconvolution), dominates over thermal noise by orders of magnitude. In the future, we will consider a simulation of a weaker source, where the thermal noise is comparable to the expected imaging artifacts. In this case, it may be that the differences between Mid Rev C and the Walker configurations become more pronounced, due to the more sensitive coverage of the longer baselines with the Walker configuration. Such an analysis will necessarily include a consideration of configuration 'taperability' to achieve both good sensitivity and a well behaved synthesized beam, as per Rosero (2019, ngVLA memo 55).

6 Snapshot Imaging of a Complex Model

We perform a final imaging test of the complex model, but using a 5min snapshot observation. The result is shown in Figure 11. Clearly, a snapshot observation has inadequate UV-coverage to restore a complex sky model. Moreover, by making a relatively small image (implying a large UV-cell size), and using close to Uniform weighting, all the Core antennas, and many of the inner Spiral antennas, end up in a few gridded UV-cells. In essence, the UV-coverage relevant to images at 10 mas resolution, is contributed predominantly by the 46 Mid antennas, and the outer Spiral antennas. This distribution is insufficient to image the Complex model, with 5×10^4 synthesized beams across the full source area.

7 Summary

We have compared imaging performance of Mid Rev C vs. Walker Mid configurations. Both include 46 antennas, so cost-neutral, in terms of antennas. We have employed a complex (big) and simple (small) model for a 6hr and 20min simulated observation, respectively. Our main conclusions are:

- Walker results show substantially better UV-coverage, avoiding the large holes in the UV-plane inherent in the current Rev C Mid.
- Consequently, the synthesized beam shape is considerably better for the Walker configuration, by about a factor two in terms of peak sidelobes.
- All the simulations result in reasonable image fidelity, at better than a percent for the Complex model, and a few percent for the simple model.
- The image quality metrics (DNR, peak sidelobe, fidelity) are better with Walker configuration by 10% to 50%
- Neither configuration can image a complex source with a very short snapshot.

Table 1: Mid Rev C vs. Walker Imaging Parameters

Array	Model	Syn. Beam mas	Total Jy	Peak Jy beam^{-1}	rms mJy beam^{-1}	Min mJy beam^{-1}
Mid Rev C, 6hr	5" × 2"	11.9×10.3, 9^o	241	2.28	0.066	-0.68
Walker, 6hr	5" × 2"	10.7×10.4, 9^o	241	2.07	0.055	-0.56
Mid Rev C, 20min	1" × 0.4"	15.0×11.4, -7^o	241	28.0	3.7	-22.5
Walker, 20min	1" × 0.4"	13.4×11.2, -2^o	241	26.7	3.2	-17.4

Table 2: Mid Rev C vs. Walker Imaging Quality

Configuration	DNR Peak/rms	PSF peak SL	F1 Head rms	F2 Lobe rms
Mid Rev C, 6hr	35000	0.055	0.006	0.015
Walker, 6hr	37000	0.019	0.004	0.010
Mid Rev C, 20min	7600	0.15	0.020	0.061
Walker, 20min	8300	0.095	0.015	0.065

Table 3: Mid Rev C vs. Walker Image Fidelity

Configuration	F_3	$A_{0.1\%}$	$A_{1\%}$	$A_{10\%}$
Mid Rev C, 6hr	0.997	171	360	425
Walker, 6hr	0.997	215	480	410
Mid Rev C, 20min	0.996	33	68	268
Walker, 20min	0.997	30	69	691

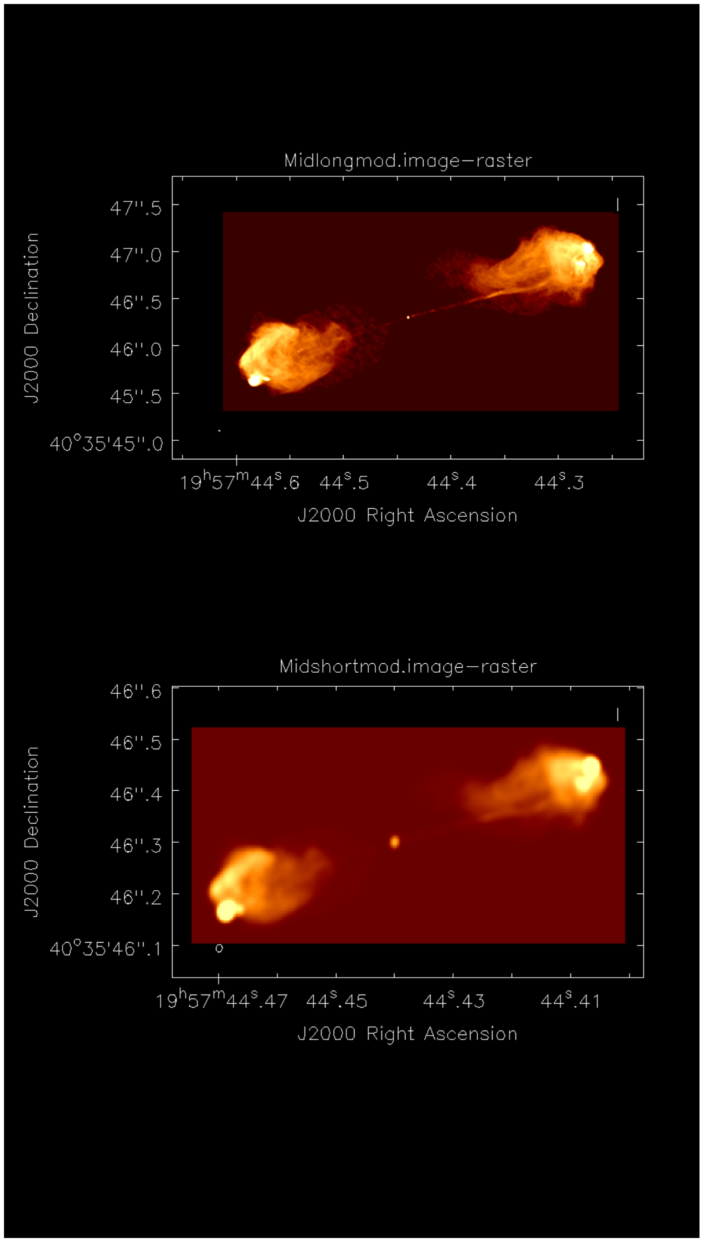

Figure 1: Images of the input complex (= big) model and the simple (= small) model of Cygnus A, convolved with the Gaussian CLEAN beams for the 6hr (top) and 20min (bottom) observations (Table 1).

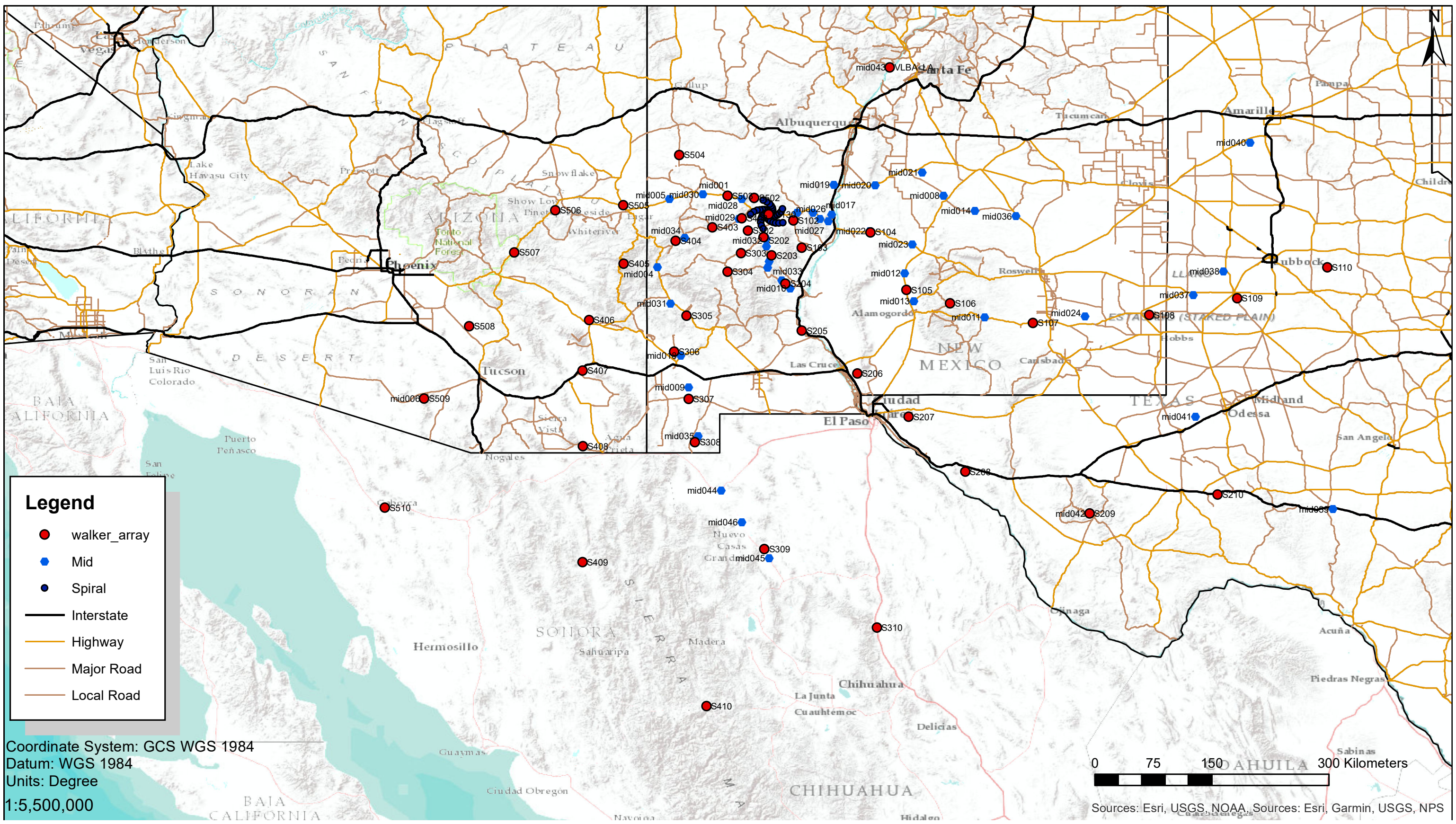

Figure 2: Antenna locations for the Rev C Mid, and the Walker Mid configurations being considered. The 5 arm Spiral and Core are included, for reference.

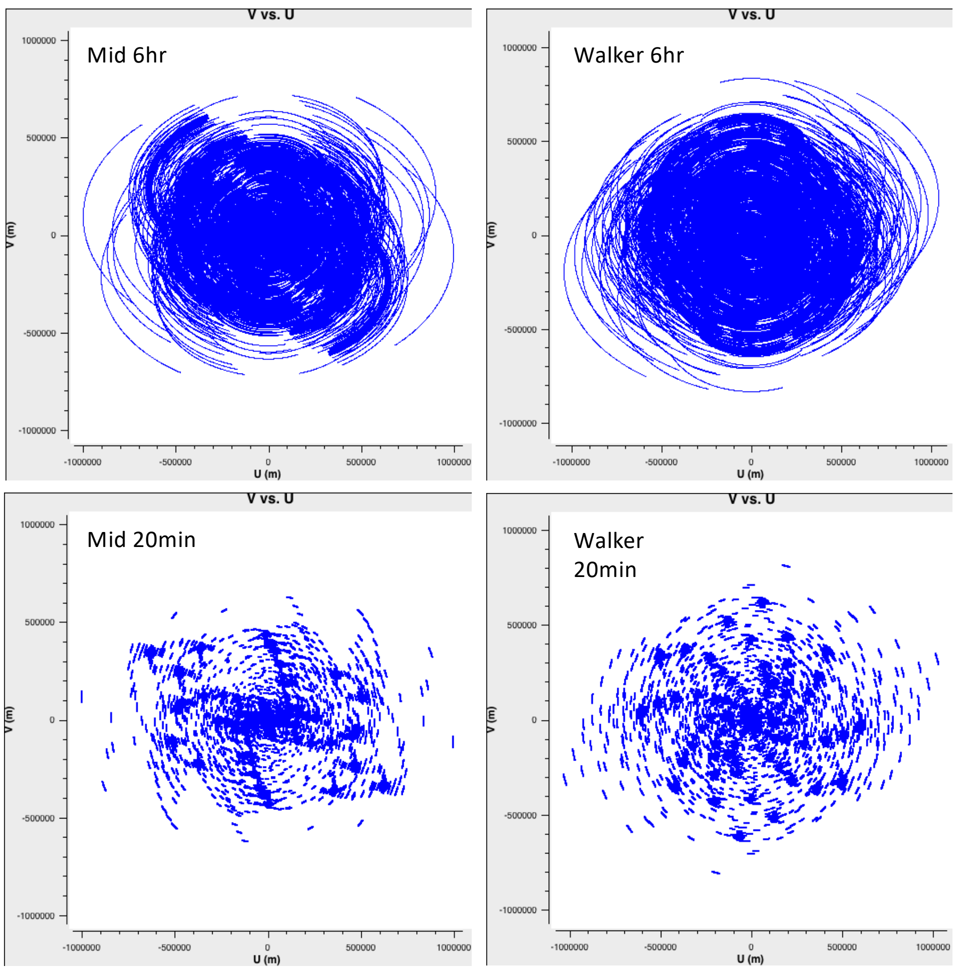

Figure 3: The uv-coverage of the Mid (left) and Walker (right) configurations. Top is the 6hr snapshot coverage, bottom is the 20min synthesis.

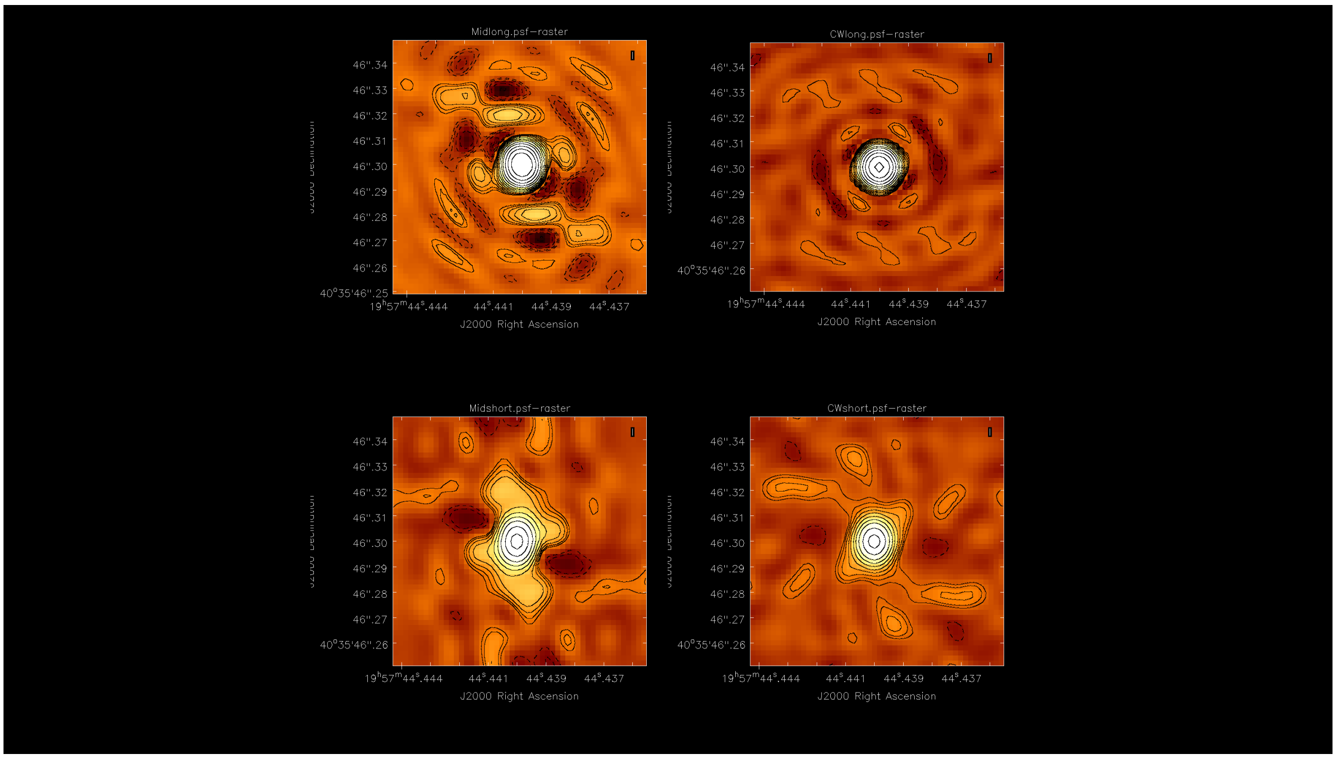

Figure 4: Images of the Synthesized Beam for the Mid (left) and Walker (right) configurations. Top is for a 6hr synthesis. The contour levels are a geometric progression in the square root two, such that each two contours is a factor two in surface brightness. The starting contour level is 0.01, and negative values are dashed. Bottom is the same, but for the 20min synthesis, and the starting contour level is 0.04.

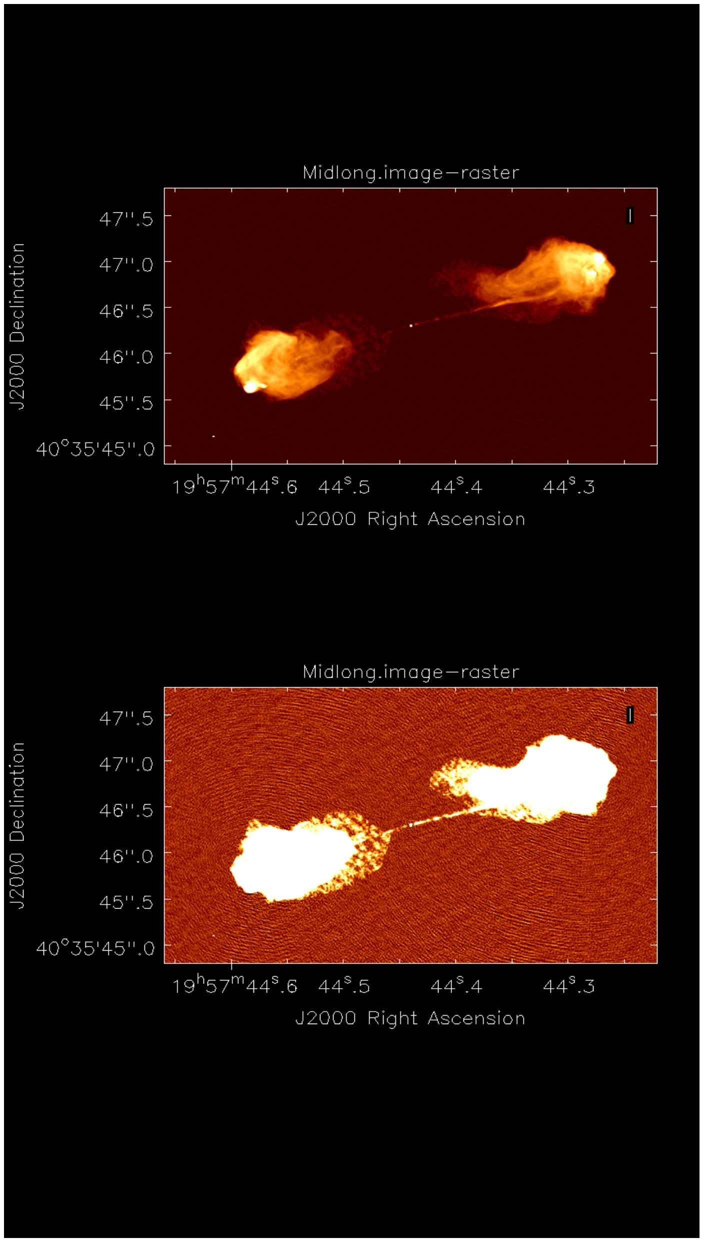

Figure 5: Images of the complex model using a 6hr synthesis with the Rev C Mid configuration. Lower image is saturated to show the image artifacts.

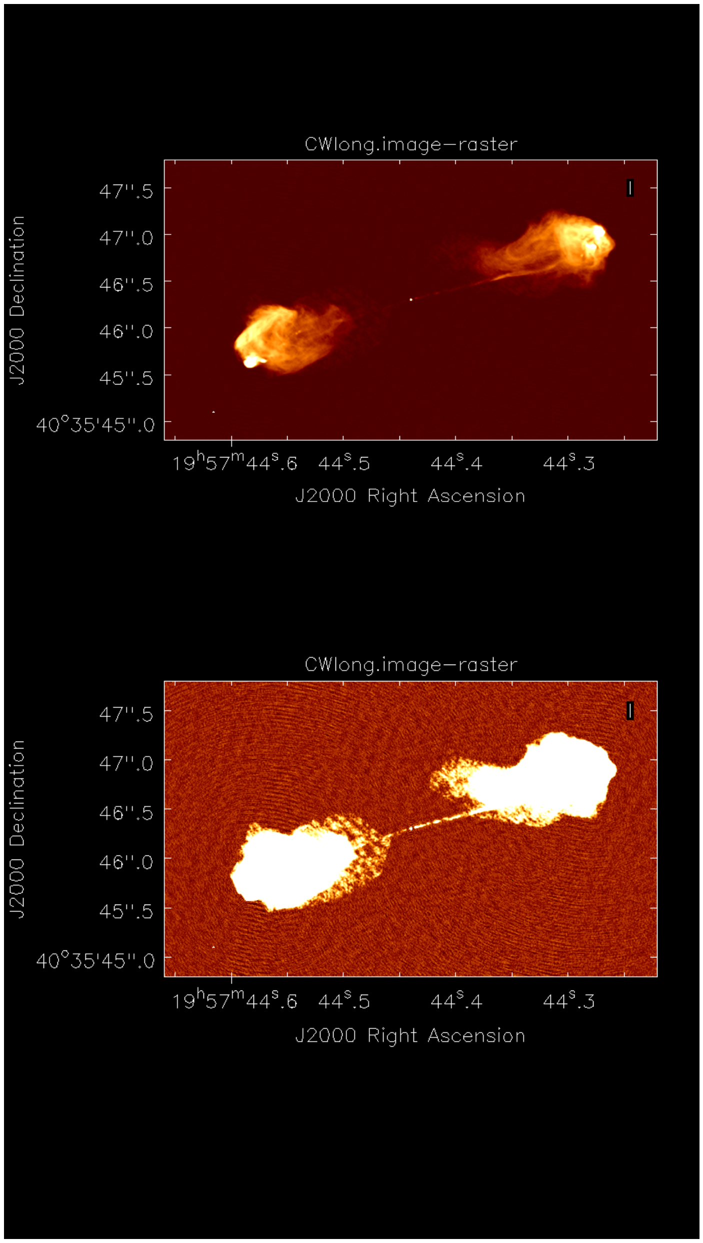

Figure 6: Images of the complex model using a 6hr synthesis with the Walker configuration. Lower image is saturated to show the image artifacts.

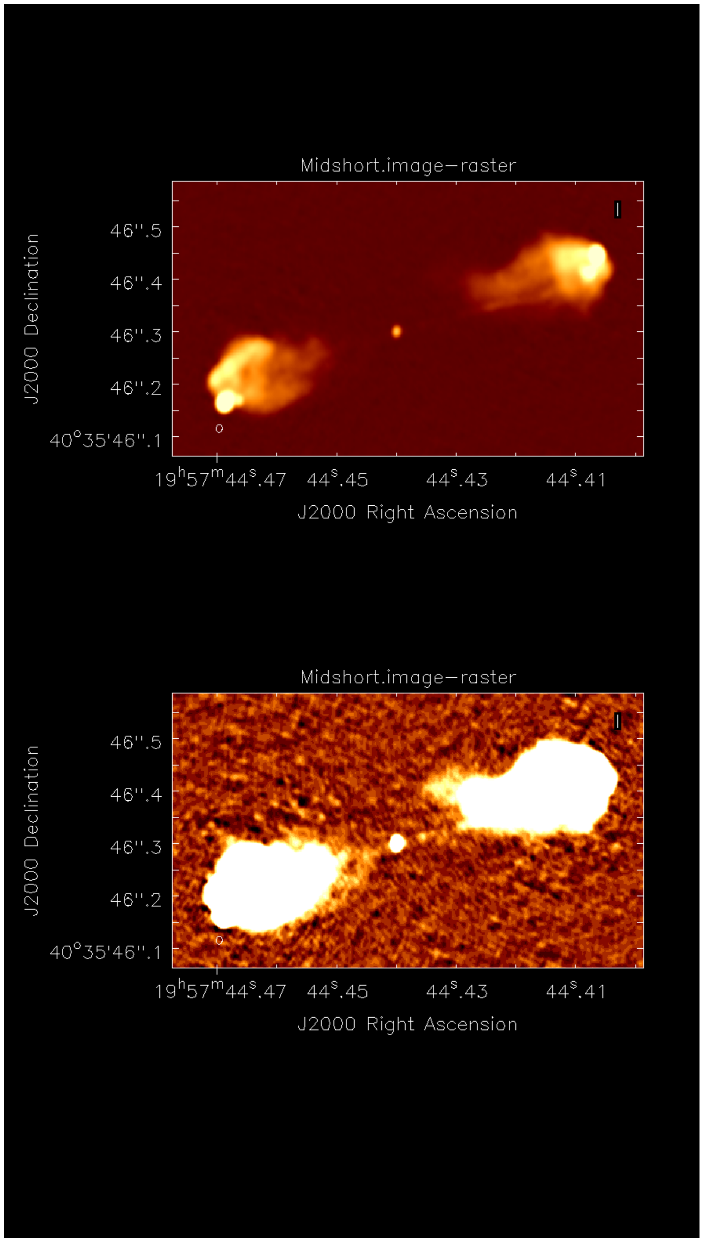

Figure 7: Images of the simple model using a 20min synthesis with the Rev C Mid configuration. Lower image is saturated to show the image artifacts.

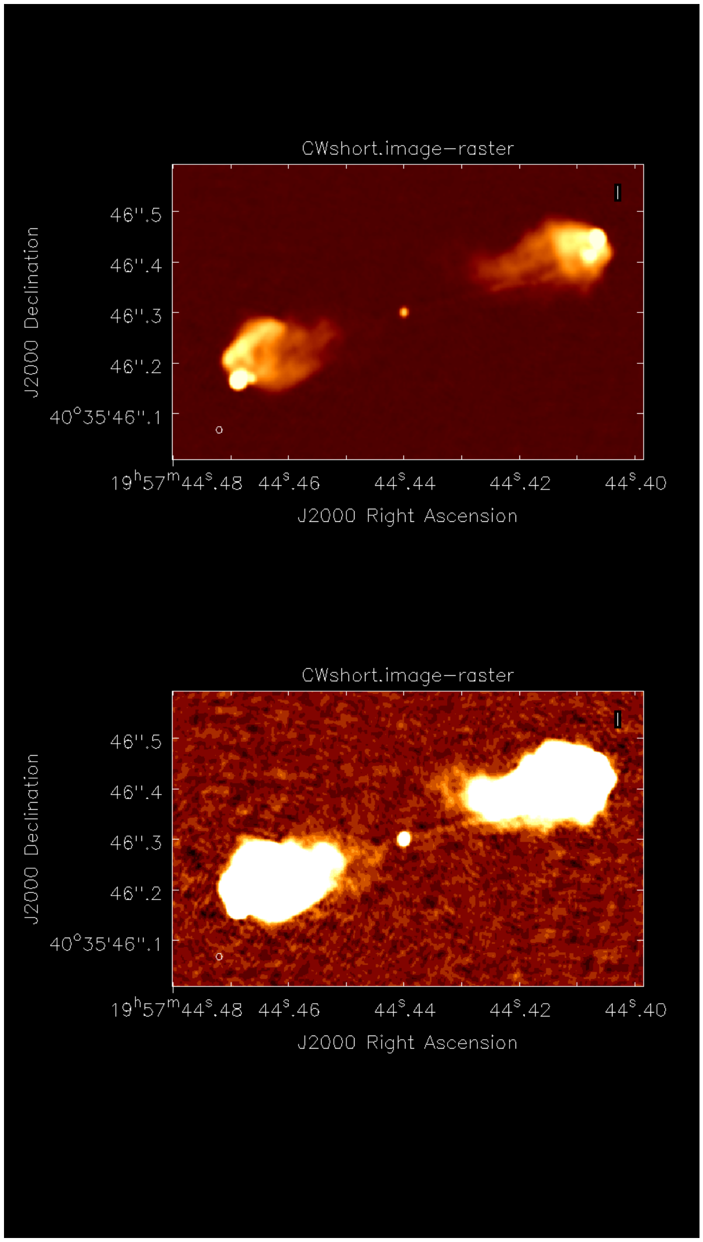

Figure 8: Images of the simple model using a 20min synthesis with the Walker configuration. Lower image is saturated to show the image artifacts.

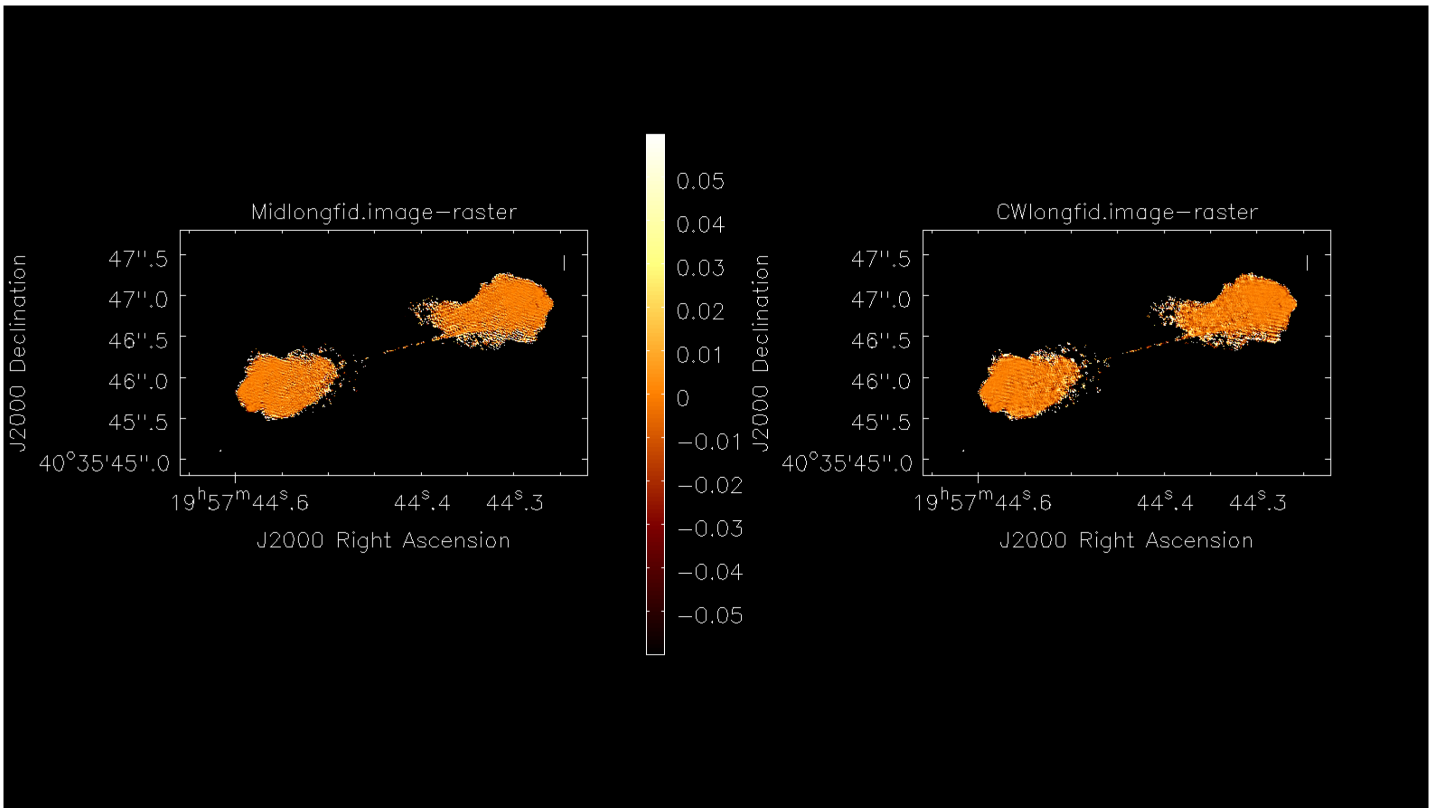

Figure 9: Images of the fidelity using the complex model and a 6hr synthesis. Left is for the Rev C Mid, and right for Walker configuration.

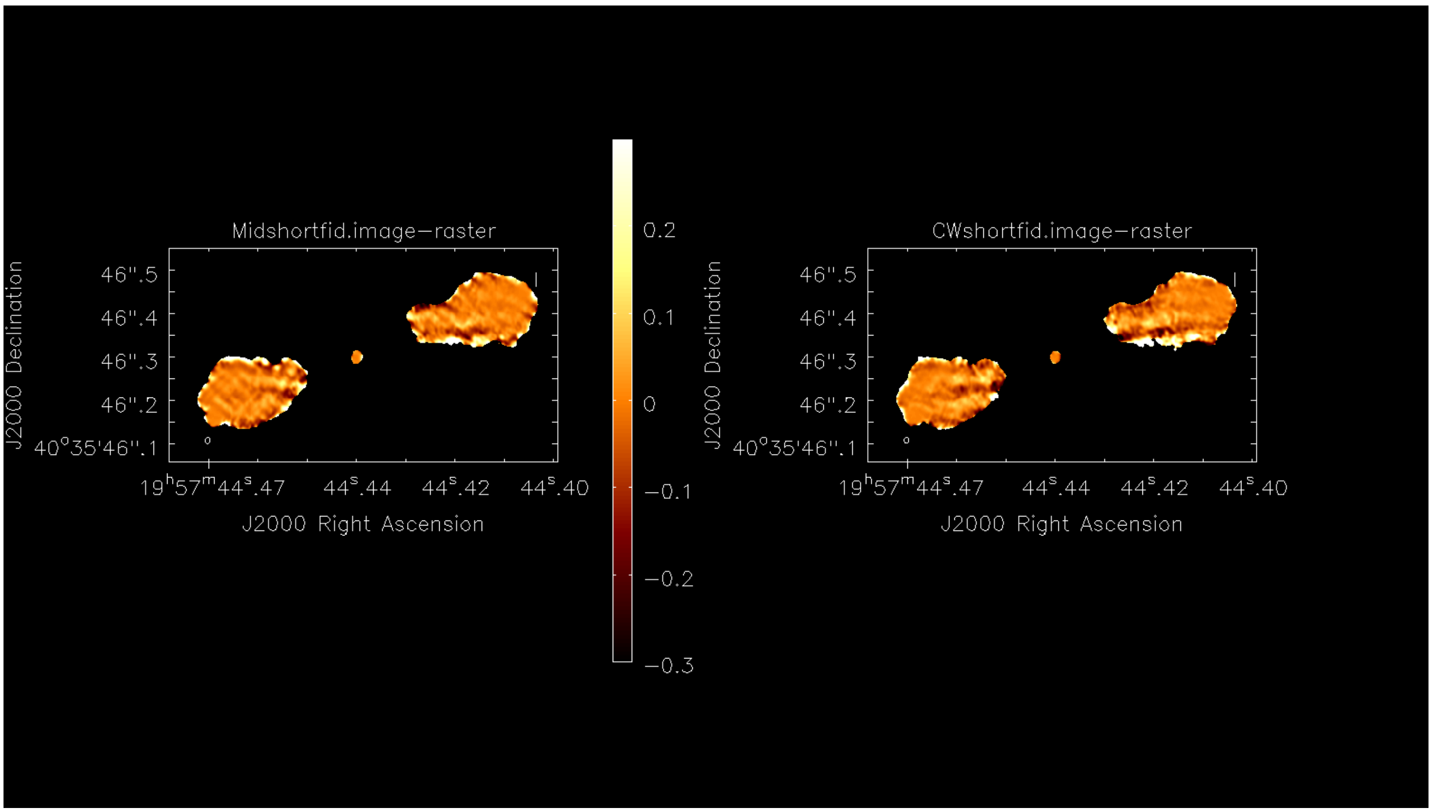

Figure 10: Images of the fidelity using the simple model and a 20min synthesis. Left is for the Rev C Mid, and right for Walker configuration.

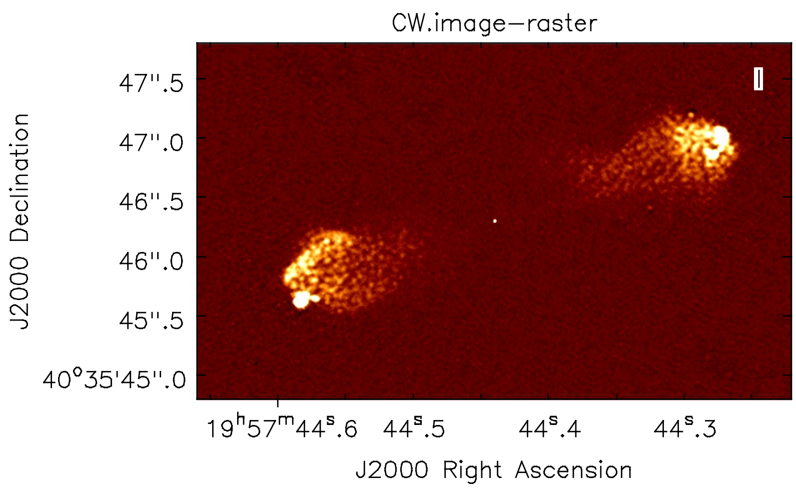

Figure 11: Image of the complex model, with a 5min snapshot observations using the Walker configuration.