Addendum to Next Generation Very Large Array Memo 85
Imaging an HL Tau-like Disk including 5arm vs. 7arm Spiral

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Abstract

We perform imaging simulations of an HL Tau-like protoplanetary disks at 10 mas resolution at 25 GHz. The configuration includes the Walker-Mid configuration, with baselines between 30 km and 1000 km, 10 antennas from the Core (baselines 50 m to 1000 m), and the Spiral component on the Plains of San Augustin, with baselines from 1 km to 30 km. Two spirals are considered: a 5 arm spiral with 74 antennas, and a 7 arm spiral with 104 antennas. Both configurations perform the disk imaging to within specified fidelity goals (flux-weighted fidelity metric: $F_3 > 0.93$. We find no substantial difference between the image fidelity for either configuration for the long synthesis, and a 20% lower noise for the 7 arm configuration, consistent with the relative number of antennas in each configuration.

1 Configurations and Model

We return to the question of a 5arm vs. 7arm spiral on the plains of San Augustin, on scales from 1 km to 30km. This question was considered at length in ngVLA memo 85.

In this report, we address the question of imaging an HL Tau-like protoplanetary disk at 25 GHz. While this program requires both longer baselines than just the Spiral, and long integrations, we felt it important to verify that the configurations can perform what is one of the most prominent key science programs of the ngVLA.

The details of the dust surface brightness model are given in ngVLA memos 11 and 41. The model entails thermal dust emission at 25 GHz from a protoplanetery disk associated with a 1Myr old, 1 $M_\odot$ proto-star, and a 0.1 $M_\odot$ dusty disk, at a distance of 140pc. The total flux density in the model at 25GHz is 2.7 mJy. The disk has gaps at 6 AU and 13 AU, driven by formation of Jupiter and Saturn sized planets.

The goal is to image the source at 1 AU resolution, corresponding 10mas. This resolution requires baselines out to 200 km, so must include both the spiral on the plains, and the inner MID-antennas. We adopt a configuration

that includes: (i) the Walker mid-configuration on scales from 30 km to 1000 km with 46 antennas (memo 84), (ii) 10 antennas from the Core (baselines of 50m to 1000m, and (iii) the 5 arm (74 antennas), or 7 arm (104 antennas) spiral on baselines from 1km to 30 km.

We synthesize a 100 hr observation, comprised of 4 hour blocks. We include thermal noise, which, for this long observation, implies a NA weighted thermal noise of 38 nJy beam^{-1} for the 5 arm spiral layout (130 total antennas), and 31 nJy beam^{-1} for the 7 arm spiral layout (160 total antennas). We image using TCLEAN with R = 0 and a uvtaper to 10mas resolution, with multiscale clean to 100 nJy minimum clean component (about 2σ), with a loop gain of 0.03.

2 Results

Figure 1 shows the input model and resulting images. We have calculated the standard image fidelity parameters, as per ngVLA memo 85. Table 1 lists some of the image parameters.

Both images appear grainy. This is likely the result of the clean instability when deconvolving a large, uniform surface brightness object. Visually, the image produced with the configuration including the 7arm spiral appears less grainy, but, quantitatively, the rms fluctuations in the grainy regions are about the same between the two images, with a value in the outer disk of about 0.7μJy beam^{-1}, well above the measured noise off-source. The measured off-source rms noise is roughly consistent with the number of antennas in each configuration, plus the down-weighting of the outer antennas in the Mid configuration via robust and taper.

We evaluate the image fidelity with the 'classic' image fidelity as defined by: $F_c = 1$ - (Max(image - model)/Max(model)), and using the flux weighted metric adopted by the NGVLA project, F_3 (B. Mason, ngVLA memo 67; Murphy et al., ngVLA Document 020.10.15.00-0001-REQ). These fidelities are presented in Tables 1, which also present the ALMA fidelity metrics evaluated at four levels: 0.1%, 1%, 3%, 10% of peak model image brightness. The ALMA metric is more sensitive to small differences, as discussed in ngVLA memo 67.

Figure 2 shows the fractional error relative to the model for the two simulated images. Typical rms values are 8% overall, and about 3% in the inner disk. The 7 arm results are not appreciably better than the 5 arm results. In terms of the flux-weighted fidelity metric F_3, both images meet the minimum required 90% fidelity.

Table 1: 5arm and 7arm HL Tau image fidelity

Configuration + Walker Mid + 10Core	rms nJy beam^{-1}	F_c	F_3	$A_{0.1\%}$	$A_{1\%}$	$A_{3\%}$	$A_{10\%}$
5 arm	55	0.83	0.93	2.52e-5	3.0	10.7	12.6
7 arm	44	0.80	0.94	2.32e-5	5.1	10.3	12.0

Figure 3 shows the integrated flux density as a function of aperture size. Curiously, both configurations restore more total flux density than the total in the model, by 4% and 7% for the 5 arm and 7 arm configurations, respectively.

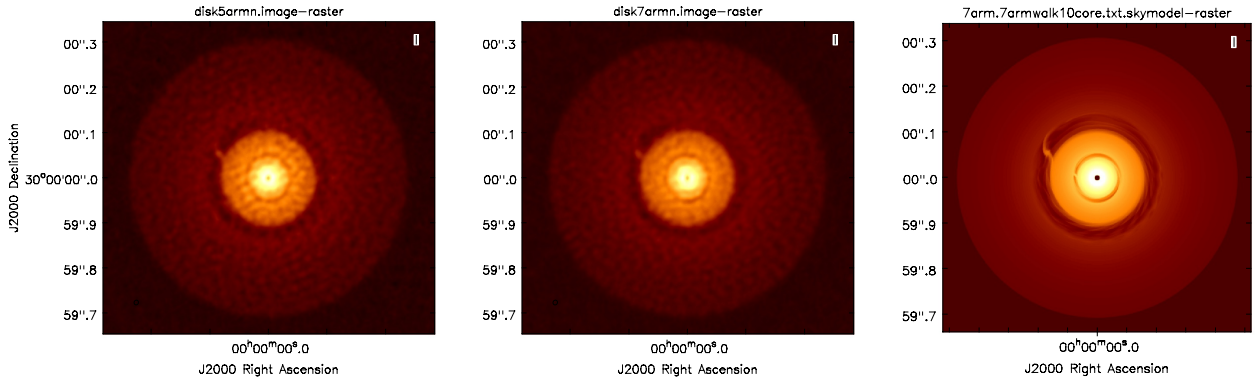

Figure 1: Images of thermal dust emission at 25 GHz of an HL Tau like proto-planetary disk at 140 pc distance, with a forming Jupiter and Saturn at 6 AU and 13 AU, respectively. The left image is for the 5 arm layout, the center is for the 7 arm layout, and the right is the input model. The resolution is 10mas.

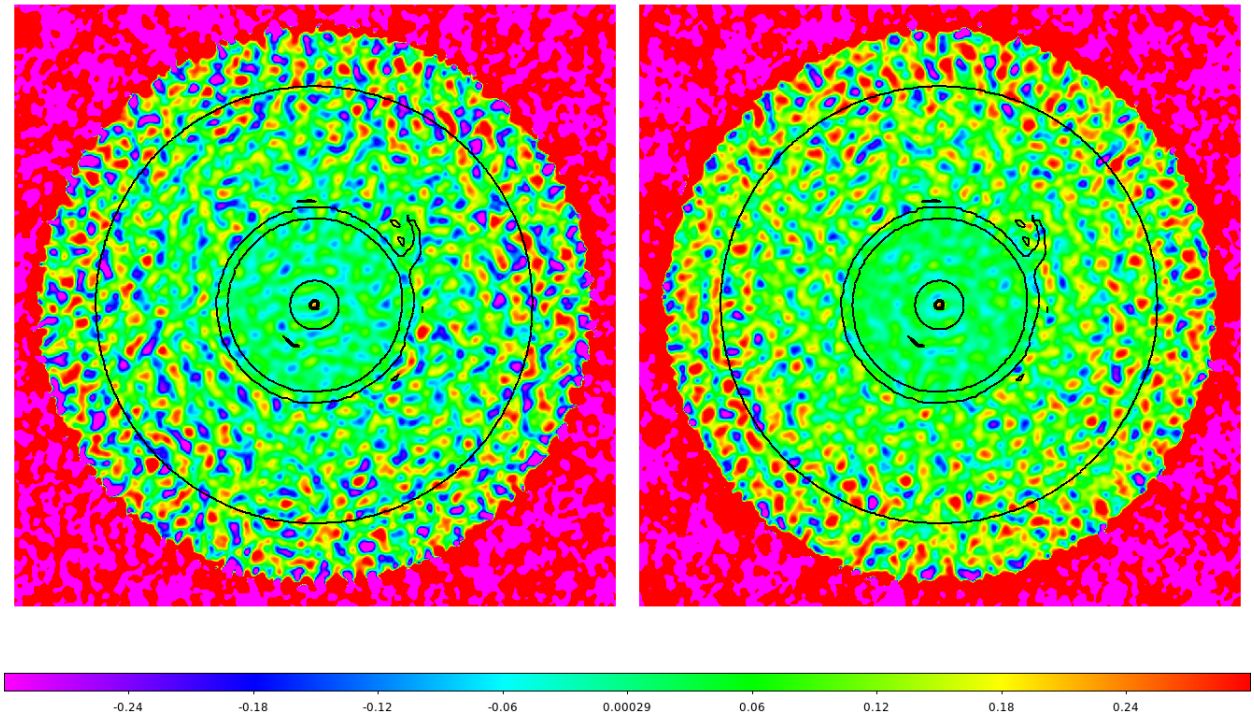

Figure 2: Fractional error in reconstructed image for 5 arm spiral (left) and 7 arm spiral (right). Contours indicate the input model, starting at the peak surface brightness near the center and decreasing by a factor of two for each contour. Color scales are common. The magenta and red area on the outside is where the input model is close to zero. Both images have fractional errors of $\sim 8\%$ (RMS); this metric is dominated by contributions from the outer, low surface brightness region, with fidelity in the higher surface brightness, interior region being a factor of 2-3 better.

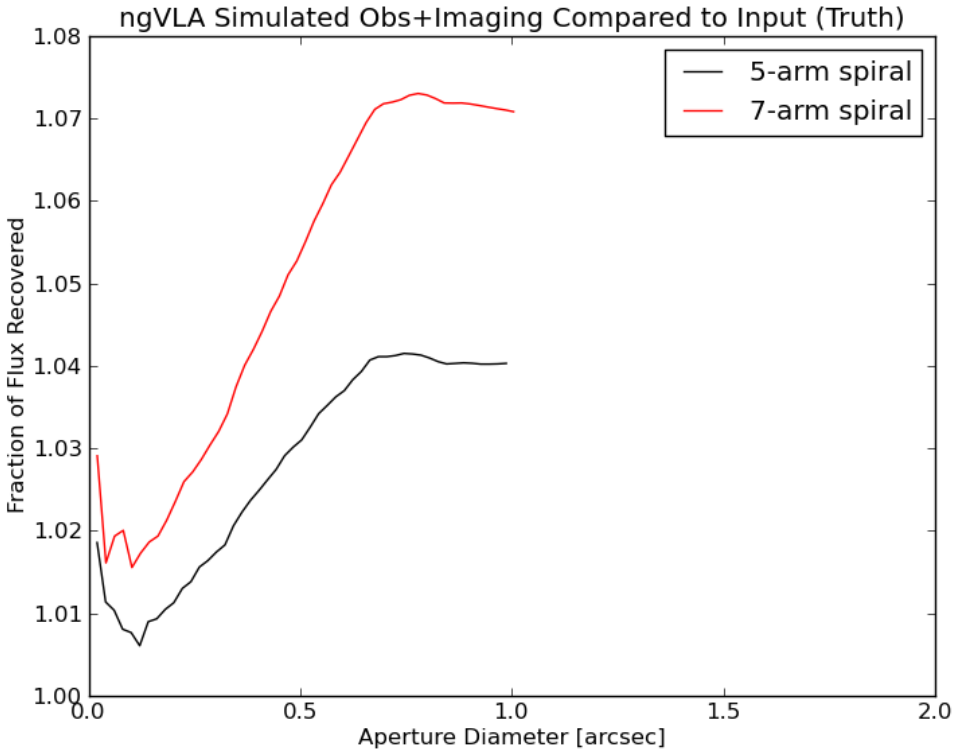

Figure 3: Total recovered flux density relative to the input model, for different aperture sizes, centered on the star, for the 5 arm and 7 arm configuration layout.