Comparing MMA and VLA Capabilities in the 36-50 GHz Band

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Abstract

I explore the capabilities of the MMA and the VLA, both current and upgraded, in the 36-50 GHz band. The current VLA is 1.5 orders of magnitude behind the MMA in point source sensitivity and 5 orders of magnitude behind the MMA in low resolution mosaicing speed. Even if the VLA is upgraded, the point source sensitivity will be only comparable to the MMA, and the MMA will still be 25 times faster in a wide field point source survey and 2-3 orders of magnitude faster at wide field imaging of low surface brightness structure, such as the Sunyaev-Zel'dovich effect or free-free emission from nearby galaxies. This study shows that the MMA and VLA 36-50 GHz systems are complementary rather than redundant.

1 Introduction

The 36-50 GHz band (Q band) on the MMA has been a point of controversy because it drove the optics design of the MMA antennas, the scientific rewards of ths band seemed by some to be less impressive than the higher frequencies, and the VLA now covers most of the band. However, the current antenna designs allow Q band observations without adversely affecting the higher frequencies by reflecting the low frequency beam down a different optical path. I will demonstrate here that the difference in dish size, baselines length, and total power capability of the MMA and VLA lead us to believe that the MMA and VLA will do very different science in the 36-50 GHz band, which argues for both instruments having this band.

2 The Instruments

I use the following quantities to derive the various sensitivities and speeds reported in the next section:

- **MMA.** The MMA, with 40 8 m antennas, will have baselines as short as 10 m, though all antennas will have total power capability, allowing arbitrarily large sources to be imaged. The MMA's compact configuration is designed for optimal surface brightness sensitivity.

For sensitivity comparisons, we assume an aperture efficiency of 0.7, a bandwidth of 4 GHz per polarization, and a system temperature of 40 K.

- **Current VLA.** The VLA will soon have 13 antennas with Q-band systems. Each antenna is 25 m in diameter, and the shortest possible baseline is 39 m, though the VLA's compact array is hardly optimized for looking at extended low surface brightness emission. Currently, the antennas equipped with Q band systems are never placed at the innermost D array stations, so we cannot get the optimal surface brightness sensitivity, and the antennas are never placed at the outermost A array stations, so we never get the highest resolution possible. The VLA does not have reliable total power capability. For sensitivity comparisons, we assume an aperture efficiency of 0.15 (at 43 GHz), a bandwidth of 100 MHz per polarization, and a system temperature of about 120 K (at 43 GHz). The band is limited to 40-50 GHz, and the performance degrades drastically at the high frequency end due to both Ruze losses and to increasing atmospheric opacity.

- **Upgraded VLA.** For the upgraded VLA, we assume all 27 antennas will have Q band systems, blood sweet and tears will increase the aperture efficiency to 0.25 (at 43 GHz), the bandwidth will increase to 1 GHz per polarization, and the system temperature will improve to 70 K (at 43 GHz). In addition, the upgraded systems will cover the entire 36-50 GHz band, and total power may be available. However, there will still be a large gap between the total power measurements and the shortest baseline, hampering large field observations.

- **Upgraded VLA with E2 Configuration.** One option in the VLA upgrade plan is to build new antenna stations in a more compact configuration, resulting in more short spacings and higher surface brightness sensitivity. I consider the improvements which result from the more drastic E2 configuration, which doubles the VLA's surface brightness sensitivity over the D array an will permit mosaicing of very large objects. In addition, stations intermediate between the VLA and the inner VLBA stations can be used in concert with the VLA A array, increasing the resolution of the VLA "A+" array by a factor of 10 over the current A array.

In addition to the easily quantifiable factors which affect the instruments' sensitivities, I make the qualitative assertion that the VLA will not be able to mosaic well at Q band. The VLA will never have very fast setup and correlator dump times. Unless the antennas are replaced, the VLA will never have a very clean beam or very small pointing errors compared to the beam in the 36-50 GHz band. Hence, the VLA's wide field imaging capabilities will always be limited at these high frequencies. By contrast, the MMA will be designed to have a very clean beam and very small pointing errors at *300 GHz*, so the mosaicing capabilities will be unmatched at 36-50 GHz.

3 Comparison of the MMA and VLA

To underscore the primary differences between the MMA and the VLA, Figure 1 shows an overlay of the snapshot (u,v) coverages of the two instruments' compact configurations. The VLA has only a few (u,v) samples within the region fully sampled by the MMA. Also, consider the two instruments' primary beam size: the VLA will require 10 times as many pointings as the MMA to cover the same region of the sky (see Figure 2). These two figures alone are strong indication that the VLA will be used more for imaging compact objects, and the MMA will be used to image very large sources. I quantify these differences in Tables 1 and 2.

Telescope	Largest Object [arcsec]	Highest Resolution [mas]	Frequencies Covered [GHz]
VLA now	30	40	40-50
VLA upgrade	30	40	36-50
VLA upg + E2	∞	4	36-50
MMA	∞	400	36-50

Table 1: Comparison of the largest source which can be imaged, resolution and frequency coverage of Q band for the present VLA, the upgraded VLA, the upgraded VLA with new E2 and A+ configurations, and the MMA.

Telescope	Point Source Sensitivity in 1 minute [mJy]	Brightness Sensitivity at 17" in 1 min [mK]	Brightness Sensitivity at 6" in 1 min [mK]	Point Survey Speed [min/sq deg at 1 mJy]	Mosaicing Speed at 17" [min/sq deg at 1 mK]
VLA now	4.2	55	144	110000	1.9×10^7
VLA upgrade	0.22	2.8	7.6	320	5.0×10^4
VLA upg + E2	0.22	1.6	4.1	320	1.8×10^4
MMA	0.14	0.33	2.6	13	71

Table 2: Quantitative comparison of the sensitivities at 43 GHz of the present VLA, the upgraded VLA, the upgraded VLA with new E2 configuration, and the MMA.

4 Conclusions

The current VLA sensitivities in the 40-50 GHz band are not at all competitive with the MMA's sensitivities. Even in spectral line, the MMA is superior, and the VLA's current correlator is woefully inadequate for Q band observing. The only advantage which the VLA currently holds above the MMA is high resolution. This is a strong argument for including the 36-50 GHz band on the MMA since the VLA upgrade is not certain to be funded.

An upgraded VLA will have continuum point source sensitivity which is comparable to the MMA, and slightly better spectral line point source sensitivity. However, since many of the most interesting sources in the sky at 36-50 GHz are extended, the point source sensitivity does not explain the situation adequately. The brightness sensitivity depends upon the number of baselines which are contributing to a beam of a given size, and as Figure 1 demonstrates, there are only a few VLA baselines shorter than 70 m, the diameter of the MMA's compact array. Hence, the MMA has superior surface brightness sensitivity, especially at the lowest resolution. The "point survey speed", the time which the instruments take to survey a large region of the sky down to some point source sensitivity, is proportional to the point source sensitivity squared divided by the primary beam area. Since the MMA's primary beam area is 10 times larger than the VLA's, the MMA will be a much faster point source survey instrument. Finally, the "mosaicing speed", the time which is required to mosaic a large region of sky to some brightness sensitivity, is proportional to the brightness sensitivity squared divided by the primary beam area. The MMA is astronomically superior to the upgraded VLA in this category.

It is clear that the VLA and MMA will perform very different kinds of observations in the 36-50 GHz band, and that it is quite reasonable for both instruments to have this band.

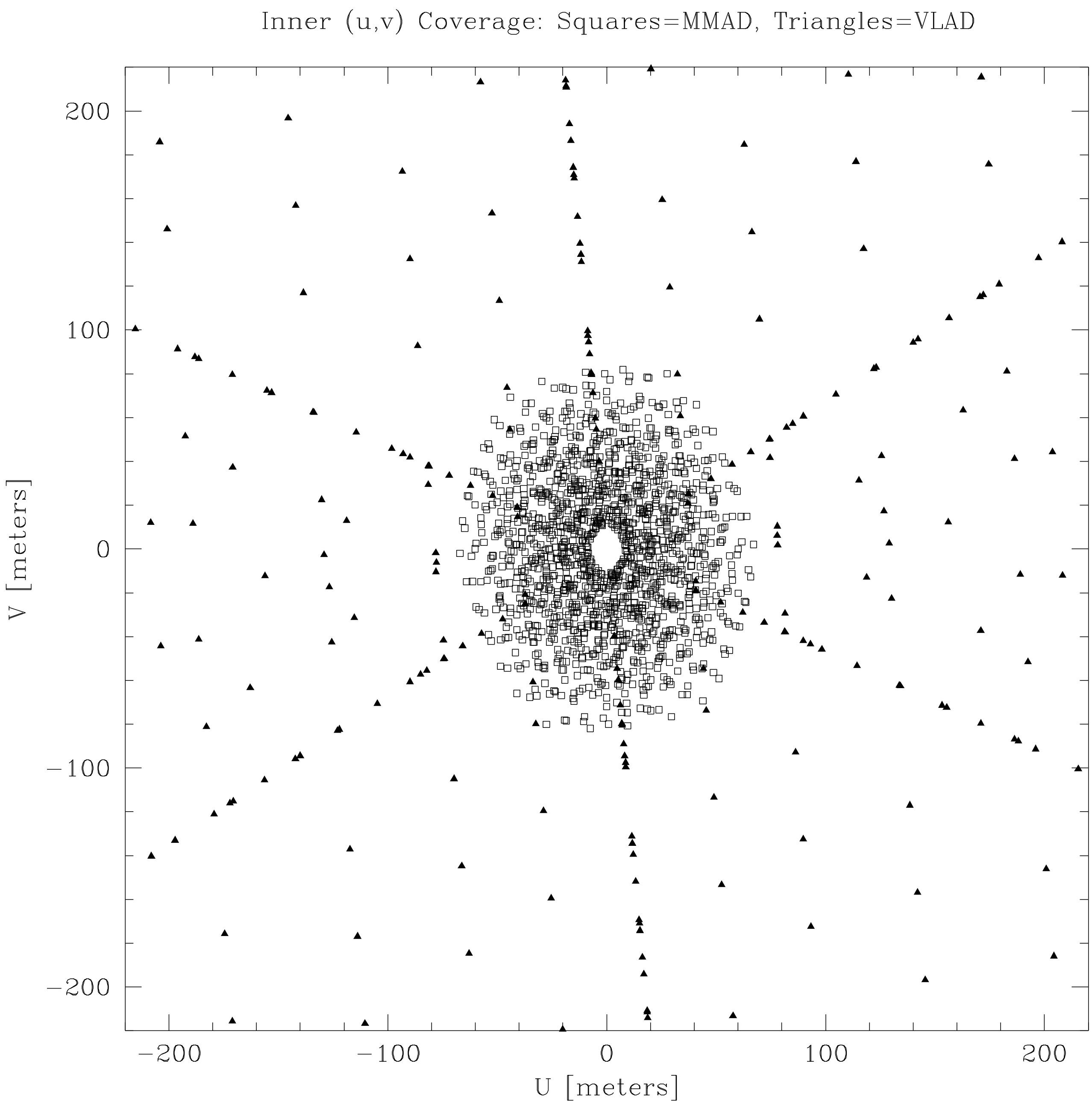

Figure 1: The inner snapshot (u,v) coverage of the VLA and MMA compact arrays.

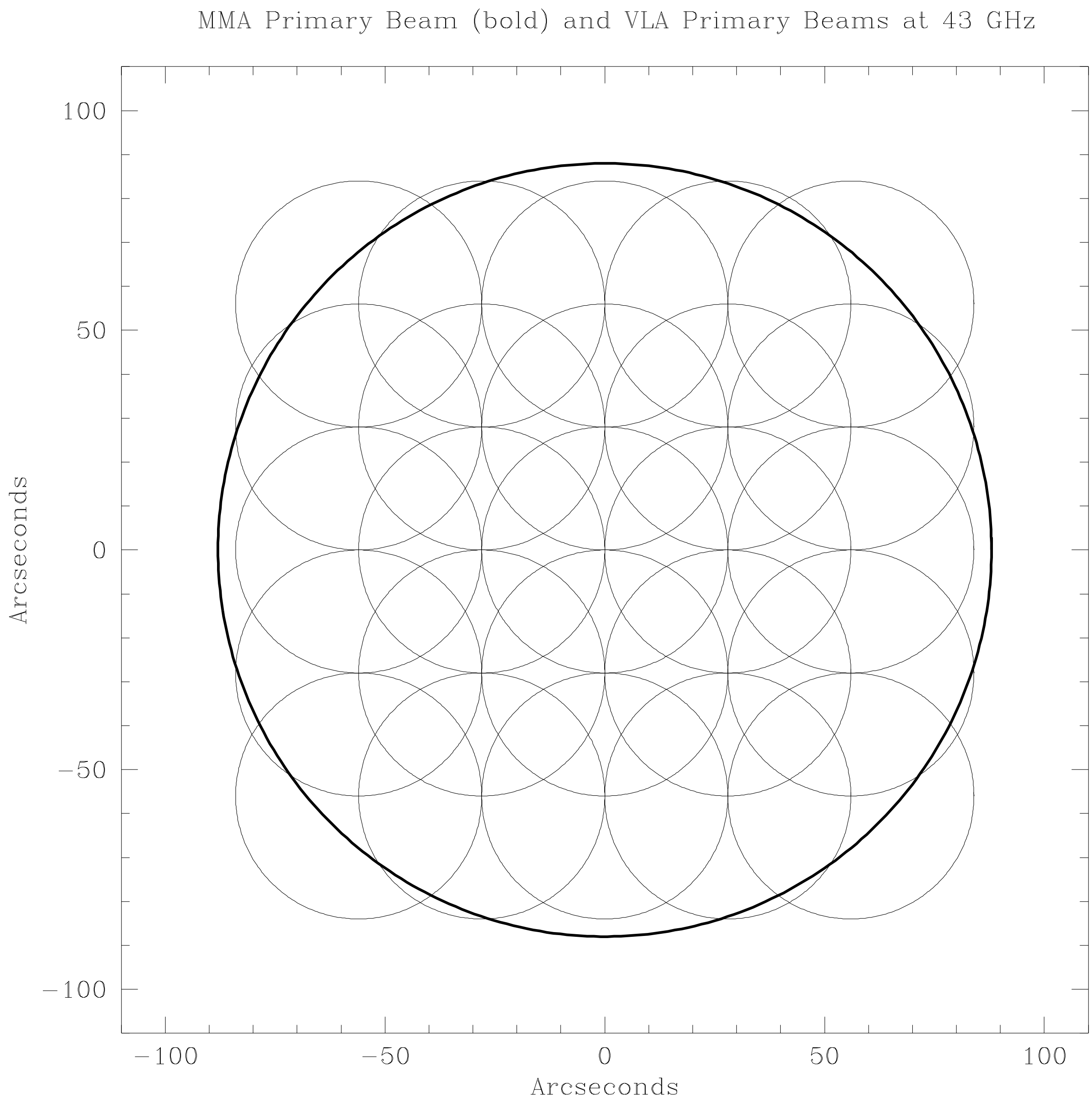

Figure 2: The VLA will require 10 times as many pointings on the sky as the MMA to image some region. The circles represent the half power full width primary beams of the two instruments, and the VLA's primary beams are Nyquist sampled for proper mosaicing.