Confusion, Dynamic Range and Array Size for the ATA

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Abstract

Source counts of radio sources as a function of flux density and frequency set limits on the sensitivity and dynamic range of the ATA. These limits are sensitive to the maximum baseline of the array and the diameter of individual elements. Unresolved faint radio sources create a confusion limit. Bright but less common radio sources create dynamic range limitations that will impact imaging techniques. We consider two straw array sizes, compact ($b_{max} = 0.750$ km) and extended ($b_{max} = 3$ km).

In the compact configuration, continuum observations at 1.4 GHz will be strongly limited by confusion noise ($\sigma_c = 85\mu$Jy). In the extended configuration, the confusion noise ($\sigma_c = 12\mu$Jy) is sufficiently low to permit observation of a wide range of continuum sources. At 5 GHz, confusion noise is less than 5 μJy in the compact configuration and less than 0.5 μJy in the extended configuration. Configurations that are compact than 300 m have detection thresholds greater than 1 mJy for $\nu < 1.4$ GHz

The large field of view of the ATA will encompass a substantial number of bright sources. At 1.4 GHz, we expect ~ 6 sources above 100 mJy for a 5-m aperture. At 5 GHz, we expect that many sources above 10 mJy. Thus, reaching the confusion limit for the extended configuration at 5 GHz will require a dynamic range of $> 10^4$. This has implications for attempts to measure variable sources which are weaker than the confusion limit.

These results indicate that if the ATA is to be effective in the study of non-variable, or slowly variable, continuum sources, careful design is necessary.

1 ATA Models

We consider two straw models for the ATA. In the compact configuration, the longest baseline is 0.75 km. In the extended configuration, the longest baseline is 3 km. The resolution at 1.4 GHz for each of these is 50 and 13 arcsec, respectively. Each array consists of 500 5-m aperture dishes with a total $A_{eff}/T_{sys} = 170$ m^{2}K^{-1}. The SEFD is 16.5 Jy. With a continuum bandwidth of 100 MHz, 60 seconds of integration will produce a thermal noise of 150 μJy.

2 Confusion Noise

Condon (1974) derived the standard equations for confusion noise due to faint background sources. The results depend solely on the differential number count of sources per unit solid angle

$$n(S)dS = kS^{-\gamma}dS \tag{1}$$

and on the telescope resolution. The confusion noise is

$$\sigma_c = \left(\frac{q^{3-\gamma}}{3-\gamma}\right)^{\frac{1}{\gamma-1}} (k\Omega_e)^{\frac{1}{\gamma-1}} . \tag{2}$$

Ω_e is the effective beam area

$$\Omega_e = \frac{\pi}{4}\theta_1\theta_2 / \left[(\gamma-1)\ln 2\right], \tag{3}$$

where θ_1 and θ_2 are the major and minor FWHM axes of the telescope beam. q is an arbitrary parameter of the integration which is typically set to 5. Changing q by a factor of 20 leads to a factor of 3 change in the confusion noise.

The detection threshold of an array is ~ 5 times the confusion noise for a nonvariable source.

The radio source count function $n(S)dS$ has been measured over a wide range of flux densities and frequencies (e.g., Condon (1984)). In Figure 1, we reprint the results of Richards (2000) at 1.4 GHz. For $S \sim 1$ Jy, $\gamma \approx 2.5$ which is the Euclidean value. The number counts drop off steeply ($\gamma \approx 2$) in the range 1 mJy $< S <$ 1 Jy, indicative of the cosmological evolution of active galactic nuclei. For $S <$ 1 mJy, the source counts are dominated by nearby galaxies and are nearly Euclidean $\gamma \approx 2.4$ (Fomalont et al 1991, Richards et al 1999, Richards 2000).

In Table 1 and Figure 2, we show the confusion noise σ_c at 1.4 and 5 GHz based on the source counts. These results are in agreement with a measured confusion limit at 1.49 GHz with the VLA in a resolution of 17.5 arcsec. Mitchell & Condon (1984) measured $\sigma_c = 11\mu$Jy.

Table 1: Confusion Noise as a Function of Frequency and Resolution (μJy)

b_{max}	0.30 km	0.75 km	3.0 km
ν			
1.4 GHz	310	85	12
5.0 GHz	22	6	0.6

At 1.4 GHz, we will reach the confusion limit in 3 and 160 minutes for the two arrays, respectively. At 5 GHz, we will reach the confusion limit in 10 and 1000 hours, respectively.

3 Dynamic Range

The number of confusing sources in the beam will limit the dynamic range for continuum imaging. In Table 2 and Figure 3, we give the estimated number of bright sources in the primary beam at 0.843, 1.4 and 5 GHz.

Table 2: Expected Number of Bright Sources in the Primary Beam

	$S > 1$ mJy	$S > 10$ mJy	$S > 100$ mJy
ν			
0.843	1560	250	30
1.4	270	60	6
5.0	20	5	0.2

The large number of sources in the beam indicate that sidelobe suppression will be an important component of any imaging or beam-forming scheme. This may be accomplished through careful array design that minimizes sidelobes of the synthesized array and/or self-calibration of the visibilities after observation.

4 References

Condon, J.J. 1974, ApJ, 188, 279

Condon, J.J. 1984, ApJ, 287, 461

Fomalont, E.B. et al, 1991, AJ, 102, 1258

Mitchell, K.J. & Condon, J.J. 1984, AJ, 90, 1957

Richards, E.A. 2000, ApJ, 533, 611

Richards, E.A. et al 1999, ApJL, 526, 73

Figure 1: Source counts at 1.4 GHz from Richards (2000). These are differential source counts normalized by an Euclidean model.

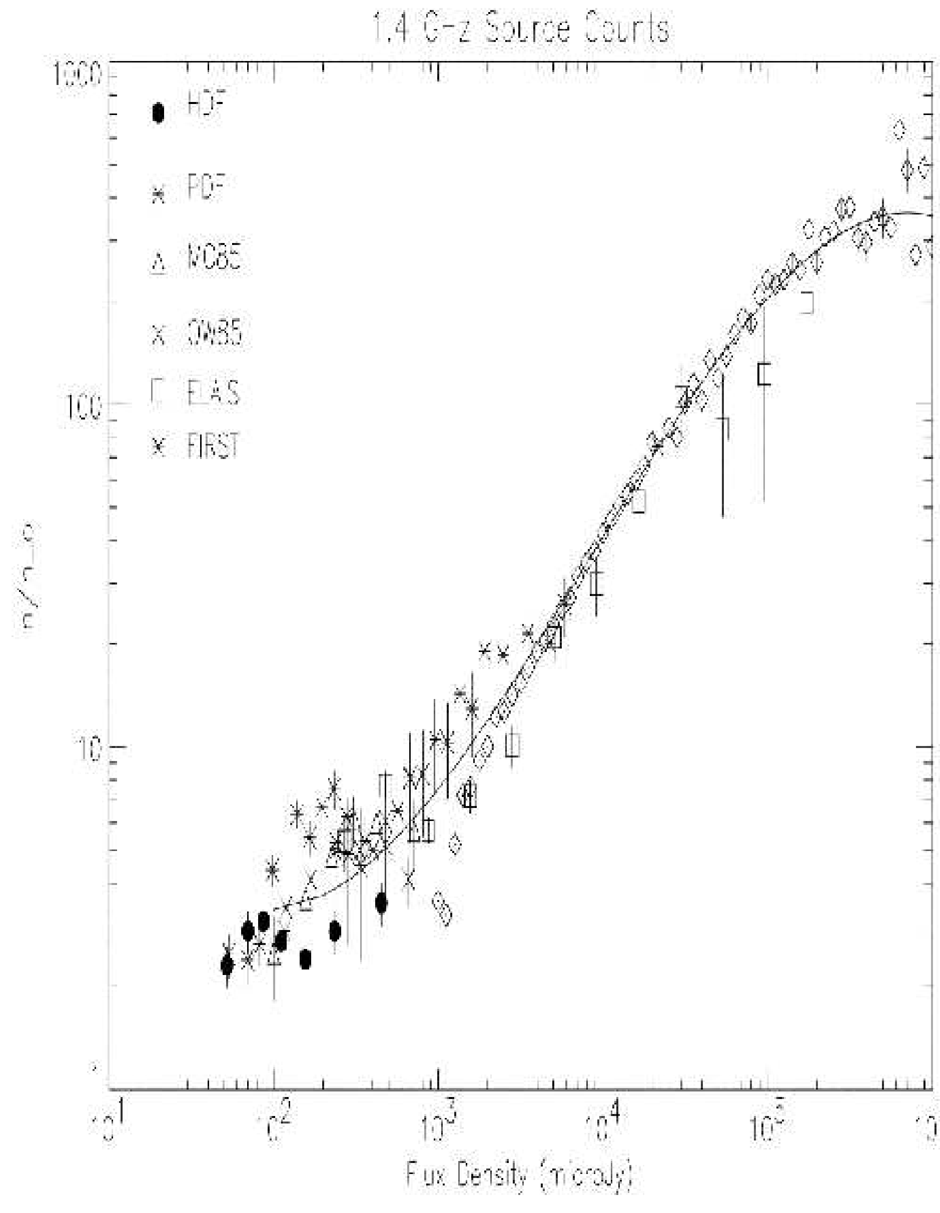

Figure 2: RMS confusion noise as a function of maximum baseline length at 1.4 GHz (solid line) and 5 GHz (dotted line). The confusion noise is computed from source counts. The cross is a VLA C-array measurement of confusion noise at 1.49 GHz with a resolution of 17.5 arcsec (Mitchell & Condon 1984). The short-dashed and the long-dashed lines represent the sensitivity of the array with 100 MHz of bandwidth in 1 minute and 1 hour, respectively.

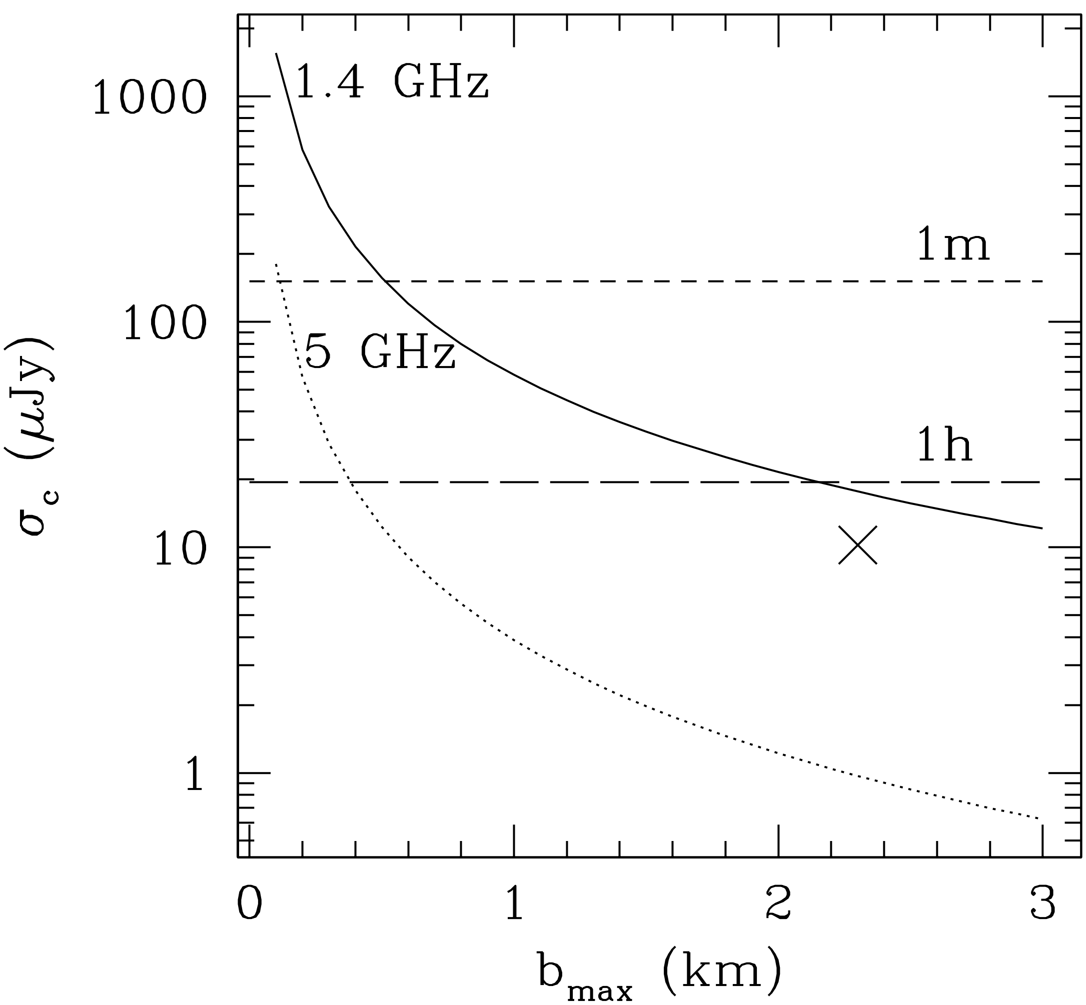

Figure 3: Number of bright sources in the primary beam at 0.843, 1.4 and 5 GHz. This assumes a 5-m dish.