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What is the Expected Sensitivity of the SMA?
SMA Memo #125

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ABSTRACT

We estimate the SMA sensitivity at 230, 345 and 650 GHz employing current expectations for the receivers, antennas and atmospheric opacities. We briefly comment on the relative sensitivities of the SMA and MMA, and the implications for detecting redshifted dust emission from young galaxies.

1. Introduction

As a first step toward defining the science goals of the SMA, we need to quantify the sensitivity that we expect will be achieved at various frequencies. This issue was addressed in the Yellow Book, but it's time for an update using the more detailed information now available. We consider only the "baseline" SMA, an array of 8 antennas of 6 m diameter; we do not consider any possible augmentation with the JCMT and CSO.

2. SMA Sensitivity

2.1. Point Source Sensitivity of a Synthesis Array

Following closely the notation of Bob Brown in his memo "Technical Specifications of the Millimeter Array", the flux density sensitivity (natural weight) of an array is given by

$$\Delta S = \frac{2kT_{sys}}{\eta_j \eta_q [\eta_a \pi (D/2)^2][n_p N(N-1)\Delta\nu \Delta t]^{0.5}} \quad (1)$$

where

D is the antenna diameter,

N is the number of antennas in the array,

n_p is the number of orthogonal polarizations correlated (1 or 2),

$\Delta\nu$ is the bandwidth,

Δt is the integration time,

η_q is the correlator quantum efficiency,

η_a is the aperture efficiency,

η_j is a phase jitter efficiency (electronics or atmosphere),

and T_{sys} is the system temperature,

$$T_{sys} = T_{RX} e^{\tau_0 A} + \eta_l T'_{atm} (e^{\tau_0 A} - 1) + (1 - \eta_l) T'_{sbr} e^{\tau_0 A} + T_{cmb} \quad (2)$$

where

$T' = (h\nu/k)[e^{h\nu/kT} - 1]$, i.e. corrected radiation temperature,

T_{RX} is the receiver temperature,

τ_0 is the zenith optical depth,

A is the airmass,

T'_{atm} is the ambient temperature,

T'_{sbr} is the temperature for spillover and blockage,

η_l is the (warm) spillover efficiency,

T_{cmb} is the cosmic microwave background temperature.

Note that the four terms in the T_{sys} expression represent contributions from (1) the receiver, (2) the atmosphere, (3) the antennas, and (4) the cosmic microwave background. This expression ignores the source contribution, a factor that might be important for, e.g., the largest planets.

2.2. Estimates of SMA Parameters

2.2.1. Frequency Independent Parameters

Table 1 presents estimates of the relevant parameters for the SMA. Note that the main frequency dependent factors in equation 1 are the aperture efficiency and the system temperature. Leaving these factors explicit for the moment, equation 1 becomes

$$\Delta S = 11.4 \text{ mJy} \left(\frac{\eta_a}{0.75}\right)^{-1} \left(\frac{T_{sys}}{200\ K}\right) \left(\frac{\Delta t}{60\ s}\right)^{-0.5} \tag{3}$$

2.2.2. *Frequency Dependent Parameters*

Next we estimate the frequency dependent terms at 230, 345, and 650 GHz. The maximum efficiency of the SMA antennas, accounting for illumination, blockage, etc. is 80.5% (see project book). This is reduced by Ruze losses, a factor $e^{[-(4\pi\sigma/\lambda)^2]}$, where σ is the rms distortion and λ is the wavelength of observation. For $\sigma = 25\mu$m, a value that should not be too difficult to achieve through holography, the aperture efficiencies are 0.76, 0.71, and 0.51 at 230, 345, and 650 GHz, respectively. The receivers for 230 and 345 GHz routinely achieve noise figures of $3h\nu/k$ (DSB) or even better in the lab, and for these frequencies we assume $T_{RX} = 6h\nu/k$ (SSB). For 650 GHz, current receiver performance is significantly worse; a reasonable guess might be 200 K (DSB), though $T_{RX} = 3h\nu/k$ (DSB) is probably not out of the question for a future generation of receivers. The atmospheric opacity at the nearby CSO site has been characterized at 225 GHz with tipping radiometers. We will make use of the quartile values of the 225 GHz opacity at the CSO site of 0.052, 0.080, and 0.146 reported for the year 1992–93 (Schwab 1994). These values should be considered representative. To estimate the opacities at the higher frequencies, we follow the Matsuo et al. (1998) scalings determined from FTS measurements in Chile, i.e. $\tau_{345} \approx 3.54 \times \tau_{225}$, $\tau_{650} \approx 20.7 \times \tau_{225}$. Similar scalings are thought to hold on Mauna Kea.

2.3. System Temperatures for Quartile Opacities

Table 2 breaks out the contributions from the four terms in equation 2 for the quartile opacities and lists the expected system temperatures (at zenith) together with the continuum sensitivity in a 1 minute integration. For the 650 GHz band, Table 2 also lists values in italics that assume $T_{RX} = 3h\nu/k$ (DSB) and extremely good weather (650 GHz opacity 0.58). Any residual decorrelation will worsen these sensitivities. A future memo will address what sensitivity is realistic tracking a source for 8 hours taking into account the variation in source elevation.

3. Comparison with the MMA

The expected MMA sensitivity is at least a factor of 25 better than the SMA (Brown 1998). Where does the improvement come from? The larger collecting area of the MMA is the single most important factor– an array of 40 antennas of 8 m diameter has 8.9 times the collecting area of the SMA. The IF system of the MMA, with 8 GHz continuum bandwidth and dual polarization, buys another factor of $2\sqrt{2}$. The antenna spillover efficiency is also assumed to be somewhat better, 0.95 for the MMA antennas versus 0.90 for the SMA antennas.

3.1. Implications for Dusty Galaxies at High Redshift

Since much of the MMA science discussion revolves around the detection of redshifted dust emission from young galaxies, it is instructive to look at the impact of the high sensitivity of the MMA in this field.

Given the sensitivity estimate above, the SMA can reasonably detect a 1 mJy source at 230 GHz in 8 hours, and also a 1 mJy source at 345 GHz with somewhat more effort. How many dusty young galaxies will be this bright at these frequencies? A paper by Franchesini et al. (1991), oft-cited in the MMA literature, estimates 1 mJy counts over the whole sky of 1.5×10^7 at 230 GHz and 7.5×10^7 at 345 GHz. Thus a lot of dusty galaxies are potentially *detectable* with the SMA. However, the number of objects at the 1 mJy level expected in any one SMA primary beam is only about 0.06 at 230 GHz, and 0.14 at 345 GHz. At a sensitivity level of 0.1 mJy, 10 times fainter, there are thought to be 25 times as many sources. Therefore, the MMA should detect some dusty galaxies in every field of view after an integration time of order 1 hour. Note that the first deep images from SCUBA on the JCMT are starting to provide more reliable source counts (i.e. based on data, not on enormous extrapolations from *IRAS* counts and a lot of uncertain physics); the above estimates should be repeated when the SCUBA counts are available. In any case, it is unlikely the SMA will turn up many dusty young galaxies serendipitously. More likely, the major impact of the SMA in this area will be to make images of dusty galaxies already known to show modestly strong submillimeter emission. Any source that is well detected by the JCMT with SCUBA but unresolved can be imaged by the SMA. There is already one example, SMM 02399-0136 at $z = 2.80$, with flux density 26 mJy at 345 GHz (Ivision et al. 1998). The object may be lensed, though it is difficult to know without high resolution images. Since the typical size scale for galaxies at cosmological distances is $1''$, this places a premium on obtaining the highest angular resolution with the SMA. Of course, some of the most interesting work will be done soon at 230 GHz with existing millimeter arrays at subarcsecond resolution (IRAM, OVRO, BIMA).

One might consider as a possible project for the SMA a very deep integration (the "SMA Deep Field") to mimic a 1 hour observation with the MMA and approach the regime where single dish telescopes become confusion limited. Assuming roughly 50% observing efficiency around the clock, this project would take of order 50 days. It is unlikely that the JCMT or CSO would ever be able to make a comparably deep integration.

REFERENCES

Brown, R.L. 1998, http://colobus.aoc.nrao.edu/library/library.html

Franchesini, A. et al. 1991, A&AS, 89, 285

Ivision, R. et al. 1998, MNRAS, in press

Matsuo et al. 1998, preprint

Schwab, F. 1994, MMA memo #118

This preprint was prepared with the AAS LaTeX macros v4.0.

		notes
D	6 m	by design
N	8	include Taiwan antennas
n_p	1	2 (someday) for 345 GHz
$\Delta\nu$	2 GHz	max bandwidth (continuum)
Δt	60 s	arbitrary integration time
η_q	0.88	4 level correlator
η_a	0.805	not including Ruze losses
σ	25μm	check holography data
η_j	1	assume no phase jitter
T_{RX}	$3h\nu/k$	DSB (for 230 & 345 GHz)
τ_0	$f(\nu)$	check site test data
A	> 1	needs more thought
T_{atm}	300 K	a guess
T_{sbr}	300 K	a guess
η_l	0.90	from Scott Paine's notes
T_{cmb}	2.7 K	Penzias & Wilson

Table 1: Parameters for SMA Sensitivity Estimates

freq (GHz)	τ	rec. (K)	atm. (K)	ant. (K)	T_{cmb} (K)	T_{sys} (el=90) (K)	ΔS (mJy/min$^{0.5}$)
230	0.052	69.7	14.1	31.0	2.7	117	6.6
	0.080	71.7	22.1	31.9	2.7	128	7.2
	0.146	76.6	41.7	34.1	2.7	155	8.7
345	0.184	119.4	53.1	35.1	2.7	210	12.6
	0.283	131.8	85.9	38.7	2.7	259	15.6
	0.517	166.5	177.8	48.9	2.7	396	23.8
650	1.076	1173	495	84	2.7	1755	147
	1.656	2095	1086	149	2.7	3333	279
	3.022	8213	5005	585	2.7	13806	1157
650[a]	*0.58*	*334*	*201*	*51*	*2.7*	*589*	*49*

Table 2: Contributions to T_{sys} and Continuum Sensitivity for Quartile Opacities

[a]assumes $T_{RX} = 6h\nu/k$ (SSB) and excellent 225 GHz transparency