

ALMA/NOEMA

Sensitivity

AF ALMA/NOEMA
Observatoire de Paris
Nov 19th, 2014

Philippe Salomé

Credits: IRAM Interferometry School Lectures
(in particular : S. Guilloteau, R. Neri)

Single Dish

The antenna system temperature T_{ant} is :

$$\begin{aligned} T_{\text{ant}} &= T_{\text{bg}} + T_{\text{sky}} + T_{\text{spill}} + T_{\text{loss}} + T_{\text{rec}} \\ &= T_{\text{bg}} && \text{(Cosmic background)} \\ &+ \eta_f(1 - e^{-\tau_{\text{atm}}})T_{\text{atm}} && \text{(Sky noise)} \\ &+ (1 - \eta_f - \eta_{\text{loss}})T_{\text{ground}} && \text{(Ground noise pickup)} \\ &+ \eta_{\text{loss}}T_{\text{cabin}} && \text{(Losses in receiver cabin)} \\ &+ T_{\text{rec}} && \text{(Receiver noise)} \end{aligned}$$

by convention, the system temperature T_{sys} is defined as the temperature of a perfect antenna (with $\eta_f=1$) located outside the atmosphere:

$$\begin{aligned} T_{\text{sys}} &= e^{\tau_{\text{atm}}}T_{\text{ant}}/\eta_f \\ T_{\text{a}^*} &= e^{\tau_{\text{atm}}}T_{\text{a}}/\eta_f \end{aligned}$$

T_{a} is the source antenna temperature. It is the temperature of an equivalent black-body that would fill full 2π steradians antenna beam pattern.

By convention, the signal is also referred to as the antenna temperature T_{a}^* (temperature of a perfect antenna located outside the atmosphere)

Interferometer

The noise power is T_{sys} , the signal is T_a^* . For 2 antenna, there are $2\Delta\nu\Delta t$ independent samples to measure a correlation product during Δt , so the Signal to Noise is

$$\frac{\text{Signal}}{\text{Noise}} = \sqrt{2\Delta\nu\Delta t} \frac{T_a^*}{T_{\text{sys}}}$$

The antenna temperature T_a^* is related to the source flux S_ν by quantities that only depends on the antenna properties (efficiency η_a and aperture A):

$$T_a^* = \eta_a A S_\nu / 2k$$

For one baseline, the point source sensitivity is thus

$$\Delta S = \frac{2k}{\eta_a A} \frac{T_{\text{sys}}}{\sqrt{2\Delta\nu\Delta t}}$$

and for N antenna :

$$\Delta S = \frac{2k}{\eta_a A} \frac{T_{\text{sys}}}{\sqrt{N(N-1)\Delta\nu\Delta t}}$$

Interferometer

The point source sensitivity

$$\sigma_S = \frac{2k}{\eta_A A} \times \frac{\langle T_{SYS} \rangle}{\eta_C \eta_J \eta_P \sqrt{N(N-1) \Delta\nu \Delta t}} \times \frac{1}{\sqrt{N_P}}$$

A	Collecting Area of a Single Antenna (177 m ²)
η_A	Aperture Efficiency (0.70 @ 3mm; 0.45 @ 1mm)
η_C	Correlator Efficiency (0.88)
η_J	Instrumental Jitter $\exp(-\sigma_J^2/2) \simeq 0.95$
η_P	Atmospheric Decorrelation $\exp(-\sigma_P^2/2) \leq 0.95$
N_P	Linear Polarizations (1 - 2)
T_{SYS}	System Temperature (K)
$\Delta\nu$	Spectral Bandwidth (39 kHz - 3600 MHz)
Δt	Integration Time On-Source (sec)

Interferometer

Single Dish Efficiency (Jy/K)

$$\sigma_S = \frac{2k}{\eta_A A} \times \frac{\langle T_{SYS} \rangle}{\eta_C \eta_J \eta_P \sqrt{N(N-1)} \Delta\nu \Delta t} \times \frac{1}{\sqrt{N_P}}$$

ATMOSPHERE (SITE)
Seeing Transparency

Antenna Correlator Local Oscillators

INSTRUMENTAL PERFORMANCE

Interferometer

Point source sensitivities:

$$\sigma_S = \frac{2k}{\eta_{AA} \times \eta_C \eta_J} \times \frac{\langle T_{SYS} \rangle}{\eta_P \sqrt{N(N-1) \Delta\nu \Delta t}} \times \frac{1}{\sqrt{N_P}}$$
$$= \frac{2k}{\eta_{AA} \times \eta_C \eta_J} \times \sigma_T$$

- $22 \times \sigma_T$ [Jy] @ 3mm Calibration precision $\leq 10\%$
- $26 \times \sigma_T$ [Jy] @ 2mm Calibration precision $\leq 15\%$
- $35 \times \sigma_T$ [Jy] @ 1mm Calibration precision $\leq 20\%$

ALMA sensitivity calculator

<http://almascience.eso.org/proposing/sensitivity-calculator>

Common Parameters

Dec

Polarization

Observing Frequency

Bandwidth per Polarization

Water Vapour Column Density Automatic Choice Manual Choice

tau/Tsky

Tsys

Individual Parameters

	12m Array	7m Array	Total Power Array
Number of Antennas	<input type="text" value="34"/>	<input type="text" value="9"/>	<input type="text" value="2"/>
Resolution	<input type="text" value="2.0"/> <input type="text" value="arcsec"/>	<input type="text" value="5,974554 arcsec"/>	<input type="text" value="17,923662 arcsec"/>
Sensitivity(rms)	<input type="text" value="1,00000"/> <input type="text" value="mJy"/>	<input type="text" value="1.00000"/> <input type="text" value="mJy"/>	<input type="text" value="1.00000"/> <input type="text" value="mJy"/>
(equivalent to)	<input type="text" value="2,56815"/> <input type="text" value="mK"/>	<input type="text" value="0,00029"/> <input type="text" value="K"/>	<input type="text" value="0,00003"/> <input type="text" value="K"/>
Integration Time	<input type="text" value="11,48597"/> <input type="text" value="s"/>	<input type="text" value="23,44977"/> <input type="text" value="min"/>	<input type="text" value="1,78990"/> <input type="text" value="h"/>
		Integration Time Unit Option	<input type="text" value="Automatic"/>

Calculate Integration Time

Calculate Sensitivity

ALMA sensitivity calculator

<http://almascience.eso.org/proposing/sensitivity-calculator>

Common Parameters

Dec

Polarization

Observing Frequency

Bandwidth per Polarization

Water Vapour Column Density Automatic Choice Manual Choice

tau/Tsky

Tsys

Individual Parameters

	12m Array	7m Array	Total Power Array
Number of Antennas	<input type="text" value="34"/>	<input type="text" value="9"/>	<input type="text" value="2"/>
Resolution	<input type="text" value="0.2"/> <input type="text" value="arcsec"/>	<input type="text" value="5,974554 arcsec"/>	<input type="text" value="17,923662 arcsec"/>
Sensitivity(rms)	<input type="text" value="1,00000"/> <input type="text" value="mJy"/>	<input type="text" value="1.00000"/> <input type="text" value="mJy"/>	<input type="text" value="1.00000"/> <input type="text" value="mJy"/>
(equivalent to)	<input type="text" value="256,81476"/> <input type="text" value="mK"/>	<input type="text" value="0,00029"/> <input type="text" value="K"/>	<input type="text" value="0,00003"/> <input type="text" value="K"/>
Integration Time	<input type="text" value="11,48597"/> <input type="text" value="s"/>	<input type="text" value="23,44977"/> <input type="text" value="min"/>	<input type="text" value="1,78990"/> <input type="text" value="h"/>

Integration Time Unit Option

Calculate Integration Time

Calculate Sensitivity

The Planck formula in the RJ regime lead to the Brightness temperature

$$T_b[K] = \frac{c^2}{2k\nu} B\nu(T) \quad (1)$$

with $B\nu(T)$ in $\text{erg.s}^{-1}.\text{cm}^{-2}.\text{Hz}^{-1}.\text{str}^{-1}$ ie Jy.str^{-1}

The temperature scale in unit of Kelvin is like a surface brightness in unit of Jy.str^{-1}

The flux to brightness conversion is thus given by

$$S[\text{Jy}] = \frac{2kT_b\Omega_{\text{source}}}{\lambda^2} = \frac{2kT_{\text{mb}}\Omega_{\text{beam}}}{\lambda^2} = \frac{2kT_{\text{mb}}\pi\theta_{\text{beam}}^2}{4\ln(2)\lambda^2} \quad (2)$$

for a synthetised main beam of solid angle Ω_{beam}
(ie a Gaussian of FWHM θ_{beam})

For a given expected flux (in Jansky), the expected surface brightness (in Temperature unit of mK) will increase as the square of the spatial resolution requested θ_{beam}

GILDAS / Astro

The screenshot displays the GILDAS / Astro software interface. On the left, a window titled "astro GUI" shows a menu with options: "Proposal Sensitivity estimator", "Detailed Sensitivity estimator", "Find calibrators", and "New project". Below the menu is a plot of "Elevation (degrees)" on the y-axis (0 to 90) and an unlabeled x-axis (-180 to -150). In the center, a dialog box titled "PdBI Sensitivity Estimator (proposal)" contains the following parameters:

Receiver generation	2006
Observing session	winter
Observation kind	line
Bandwidth resolution input kind	velocity
Signal sideband	lsb
Number of polarizations with the same setup	2
Source declination [deg]	25
Observing Frequency [GHz]	230
Velocity resolution [km/s]	0.25
Frequency resolution [MHz]	0.19179935473894
On-source integration time [hrs]	6
Spatial resolution [arcsec]	1 1

At the bottom of the dialog box are buttons for "Aidg", "Go", and "Eermer". On the right, a terminal window titled "philippe - astro - 80x39" shows the following output:

```
I-OBSERVATORY, Selected BURE observatory
I-OBSERVATORY, Time needs to be reset
I-PDBI-SENSITIVITY-ESTIMATOR, Line observation
I-TASK, Created .check File /Users/philippe/.gag/scratch/131452/inter-sensitivi
ty.check
I-RUN, Task inter-sensitivity running, logfile is
I-RUN, /Users/philippe/.gag/logs/inter-sensitivity.gildas

I-GLOBAL>GDF_STBL, Setting 1 starting blocks

Interferometer Sensitivity
-----
Frequency:                230.000 GHz
wavelength:              1.303 mm

Number of polarizations:  2
Frequency resolution:    0.192 MHz
Velocity resolution:     0.250 km/s

Tsyst:                    200.000 K
Decorrelation coefficient: 0.800
On-source integration time: 6.000 hrs

Number of available antennas: 6
Antenna efficiency:      35.000 Jy/K
Beam:                    1.0 x 1.0 arcsec

Conversion factor:       23.102 K[Tmb] per Jy/beam
Point source sensitivity: 17.550 mJy
rms brightness temperature: 0.405 K[Tmb]

-----

I-RUN, Elapsed .0, User .0, System .0
I-RUN, Task inter-sensitivity completed successfully
ASTRO>
```

Two values in the terminal output are circled in red: "200.000 K" for Tsyst and "23.102 K[Tmb] per Jy/beam" for the Conversion factor.

ALMA sensitivity calculator

<http://almascience.eso.org/proposing/sensitivity-calculator>

Common Parameters

Dec

Polarization

Observing Frequency

Bandwidth per Polarization

Water Vapour Column Density Automatic Choice Manual Choice

tau/Tsky

Tsys

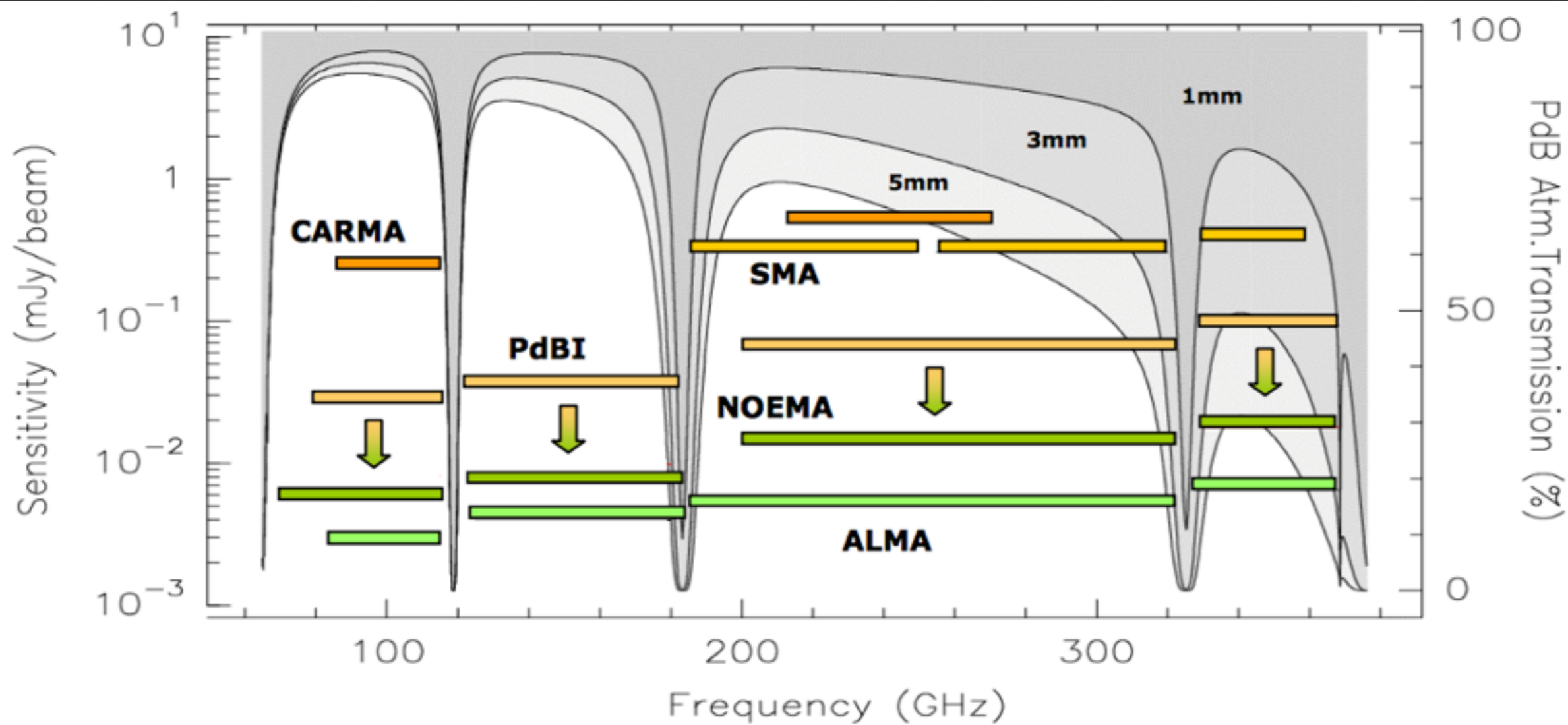
Individual Parameters

	12m Array	7m Array	Total Power Array
Number of Antennas	<input type="text" value="34"/>	<input type="text" value="9"/>	<input type="text" value="2"/>
Resolution	<input type="text" value="1.0"/> <input type="text" value="arcsec"/>	<input type="text" value="8,961831"/> <input type="text" value="arcsec"/>	<input type="text" value="26,885493"/> <input type="text" value="arcsec"/>
Sensitivity(rms)	<input type="text" value="1,34719"/> <input type="text" value="mJy"/>	<input type="text" value="15,30531"/> <input type="text" value="mJy"/>	<input type="text" value="31,90872"/> <input type="text" value="mJy"/>
(equivalent to)	<input type="text" value="31,13798"/> <input type="text" value="mK"/>	<input type="text" value="0,00440"/> <input type="text" value="K"/>	<input type="text" value="0,00102"/> <input type="text" value="K"/>
Integration Time	<input type="text" value="6"/> <input type="text" value="h"/>	<input type="text" value="6"/> <input type="text" value="h"/>	<input type="text" value="6"/> <input type="text" value="h"/>

Integration Time Unit Option

Calculate Integration Time

Calculate Sensitivity



Elevation of 45deg
8 hr of integration

Point Source Sensitivities at 90 GHz

	η_A	NPOL	BW (MHz)	Continuum (μ Jy)	Line (mJy/1MHz)
IRAM PDBI	0.72	2	4000	29	1.8
CARMA	0.62	1	1500	290	18
NMA	0.64	1	1000	890	28
IRAM NOEMA	0.72	2	16000	6.5	0.8
ALMA	0.80	2	8000	2.9	0.3

Point Source Sensitivities at 230 GHz

	η_A	NPOL	BW (MHz)	Continuum (μ Jy)	Line (mJy/1MHz)
IRAM PDBI	0.60	2	4000	67	4.3
CARMA	0.60	1	1500	549	27
eSMA	0.77	1	2000	376	31
IRAM NOEMA	0.67	2	16000	14	1.7
ALMA	0.80	2	8000	5.2	0.5

Point Source Sensitivites at 345 GHz

	η_A	NPOL	BW (MHz)	Continuum (μ Jy)	Line (mJy/1MHz)
IRAM PDBI	0.50	2	4000	117	7.4
eSMA	0.72	1	2000	948	60
IRAM NOEMA	0.62	2	16000	21.3	2.7
ALMA	0.70	2	8000	12.4	1.1