

ALMA/NOEMA

Sensitivity

AF ALMA/NOEMA
Observatoire de Paris
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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:

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

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)

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

The term $\frac{2k}{\eta_A A}$ is circled in blue.

Red arrows point from the text "Antenna" and "Local Oscillators" to the terms $\eta_A A$ and $\eta_C \eta_J \eta_P$ respectively in the equation.

Red arrows point from the text "Correlator" to the term $\langle T_{\text{SYS}} \rangle$ in the equation.

Red arrows point from the text "ATMOSPHERE (SITE)" and "Seeing Transparency" to the term $\frac{1}{\sqrt{N_P}}$ in the equation.

INSTRUMENTAL PERFORMANCE

Interferometer

Point source sensitivities:

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

- $22 \times \sigma_T$ [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 | 00:00:00.000 |
| Polarization | Dual |
| Observing Frequency | 345.0 GHz |
| Bandwidth per Polarization | 2.0 GHz |
| Water Vapour Column Density | <input checked="" type="radio"/> Automatic Choice <input type="radio"/> Manual Choice 0.913mm (3rd Octile) |
| tau/Tsky | tau0=0.158, Tsky=39,538 |
| Tsys | 157,027 K |

Individual Parameters

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

ALMA sensitivity calculator

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Common Parameters

| | |
|-----------------------------|---|
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| Polarization | Dual |
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| Water Vapour Column Density | <input checked="" type="radio"/> Automatic Choice <input type="radio"/> Manual Choice 0.913mm (3rd Octile) |
| tau/Tsky | tau0=0,158, Tsky=39,538 |
| Tsys | 157,027 K |

Individual Parameters

| | 12m Array | 7m Array | Total Power Array |
|--------------------|--------------|------------------------------|-------------------|
| Number of Antennas | 34 | 9 | 2 |
| Resolution | 0.2 arcsec | 5,974554 arcsec | 17,923662 arcsec |
| Sensitivity(rms) | 1,00000 mJy | 1.00000 mJy | 1.00000 mJy |
| (equivalent to) | 256,81476 mK | 0,00029 K | 0,00003 K |
| Integration Time | 11,48597 s | 23,44977 min | 1,78990 h |
| | | Integration Time Unit Option | Automatic |

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

astro GUI

SIC Window GREG Plateau de Bure Pico Veleta Demos Help

Proposal Sensitivity estimator
Detailed Sensitivity estimator
Find calibrators
New project

PdBI Sensitivity Estimator (proposal)

Elevation (degrees)

90
75
60
45
30
15
0

-180 -150

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

Aide Go Fermer

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-sensitivity.check
I-RUN, Task inter-sensitivity running, logfile is /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

Tsys: 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>

ALMA sensitivity calculator

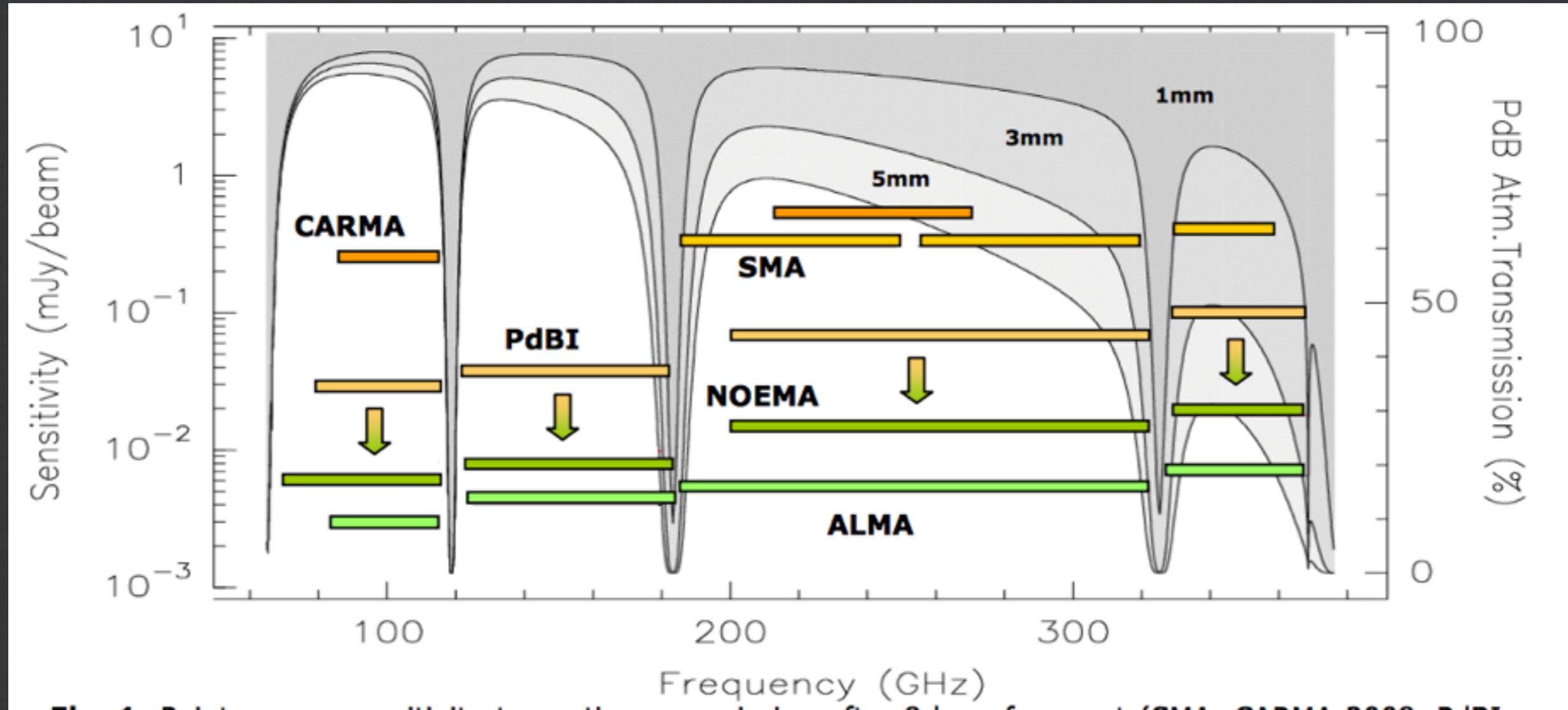
<http://almascience.eso.org/proposing/sensitivity-calculator>

Common Parameters

| | |
|-----------------------------|---|
| Dec | 00:00:00.000 |
| Polarization | Dual |
| Observing Frequency | 230.0 GHz |
| Bandwidth per Polarization | 0.25 km/s |
| Water Vapour Column Density | <input checked="" type="radio"/> Automatic Choice <input type="radio"/> Manual Choice 1.262mm (4th Octile) |
| tau/Tsky | tau0=0,067, Tsky=17,963 |
| Tsys | 96,603 K |

Individual Parameters

| | 12m Array | 7m Array | Total Power Array |
|--------------------|-------------|------------------------------|-------------------|
| Number of Antennas | 34 | 9 | 2 |
| Resolution | 1.0 arcsec | 8,961831 arcsec | 26,885493 arcsec |
| Sensitivity(rms) | 1,34719 mJy | 15,30531 mJy | 31,90872 mJy |
| (equivalent to) | 31,13798 mK | 0,00440 K | 0,00102 K |
| Integration Time | 6 h | 6 h | 6 h |
| | | Integration Time Unit Option | Automatic |



Elevation of 45deg

8 hr of integration

Point Source Sensitivities at 90 GHz

| | η_A | NPOL | BW (MHz) | Continuum (μJy) | 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 (μJy) | 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 Sensitivities at 345 GHz

| | η_A | NPOL | BW (MHz) | Continuum (μJy) | 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 |