ALMA/NOEMA Sensitivity

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

Single Dish

The antenna system temperature T_{ant} is :

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

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

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

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

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

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):

$$T_{\text{a}}^* = \eta_a A S_\nu / 2k$$

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 :

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

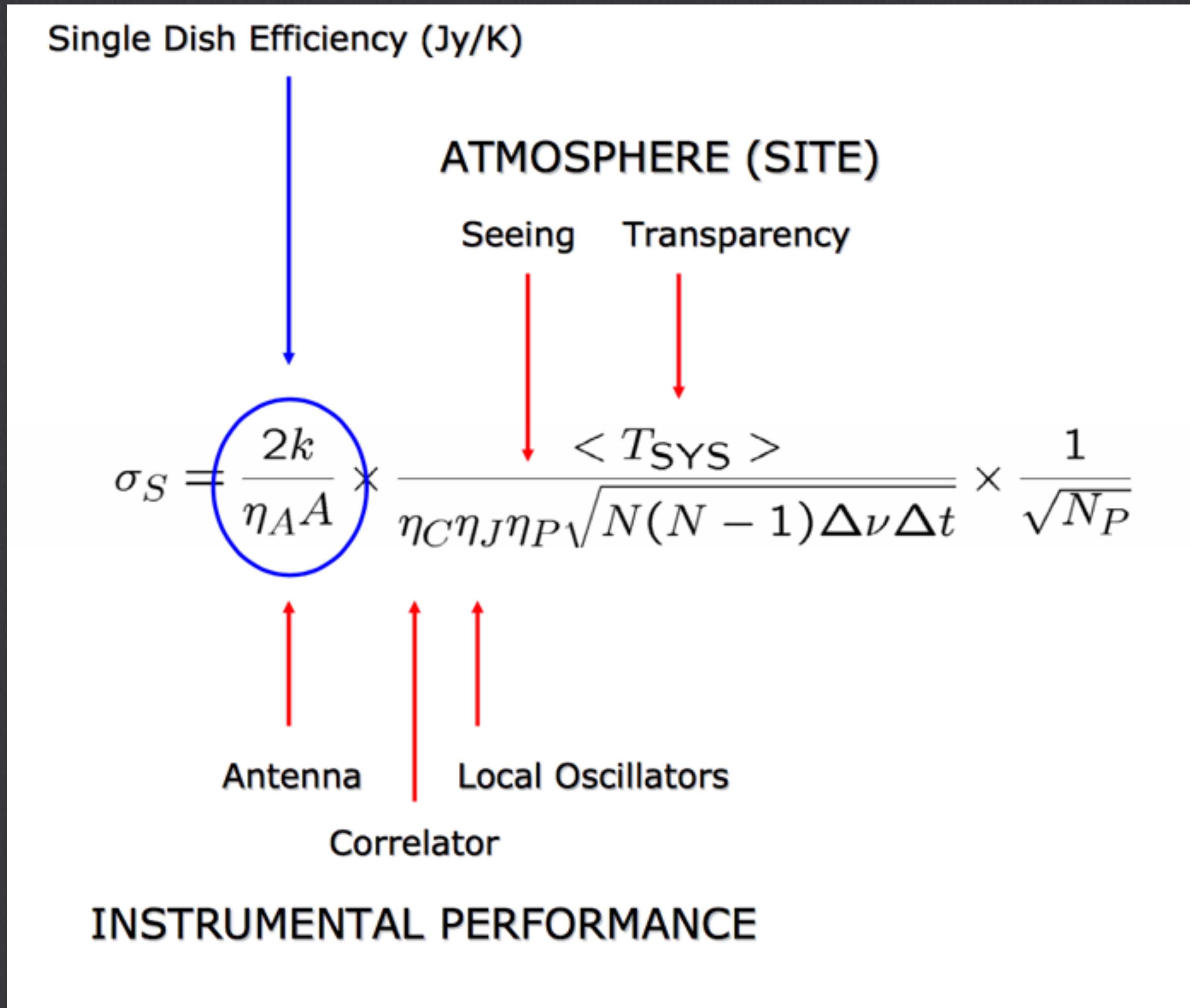
Interferometer

The point source sensitivity

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

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



Interferometer

Point source sensitivities:

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

$$= \frac{2k}{\eta_A A \times \eta_C \eta_J} \times \sigma_T$$

$\rightarrow 22 \times \sigma_T$ [Jy] @ 3mm Calibration precision $\leq 10\%$

$\rightarrow 26 \times \sigma_T$ [Jy] @ 2mm Calibration precision $\leq 15\%$

$\rightarrow 35 \times \sigma_T$ [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	(•) Automatic Choice ( ) 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

[Calculate Integration Time] [Calculate Sensitivity]

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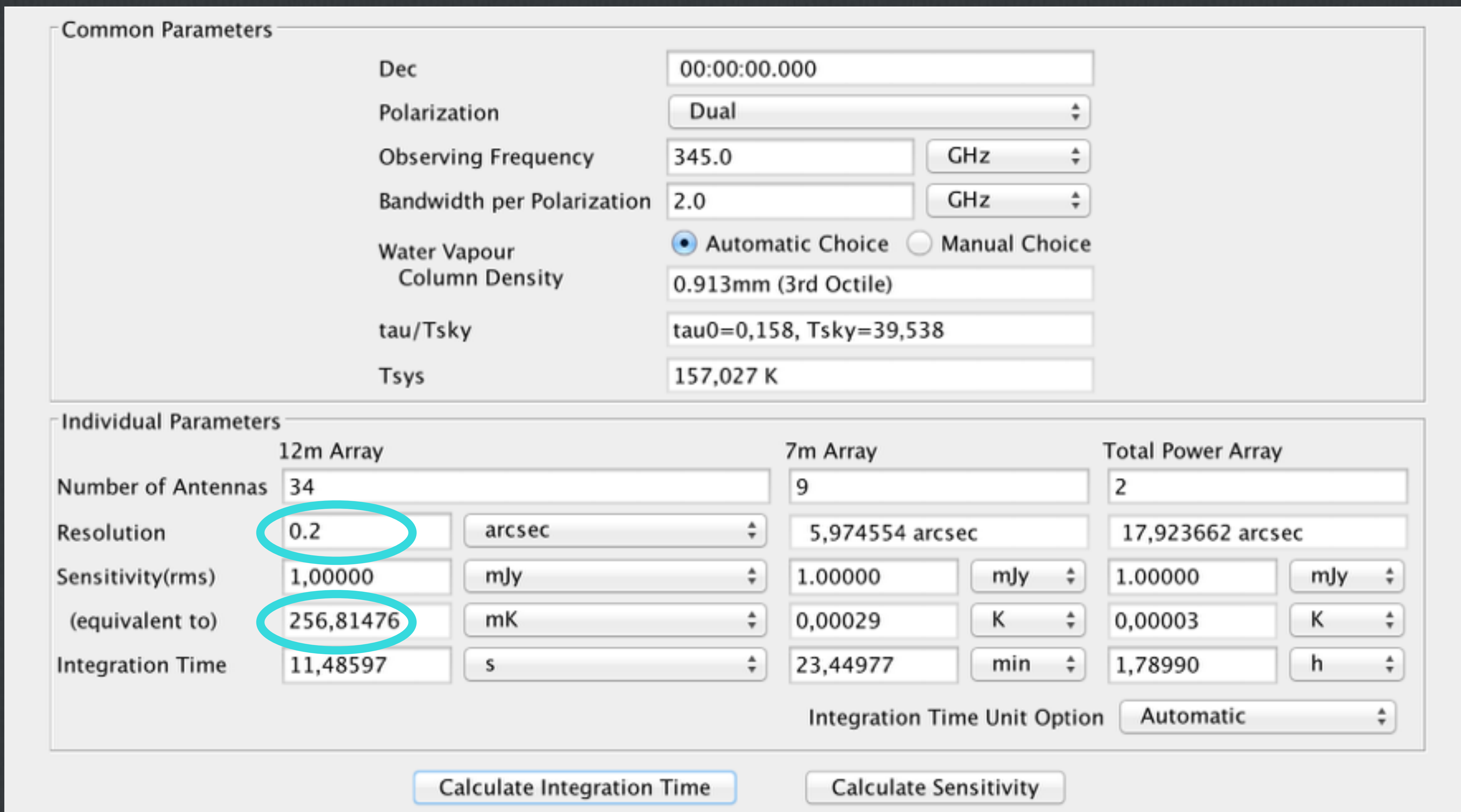


The Planck formula in the RJ regime lead to the Brightness temperature

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

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

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

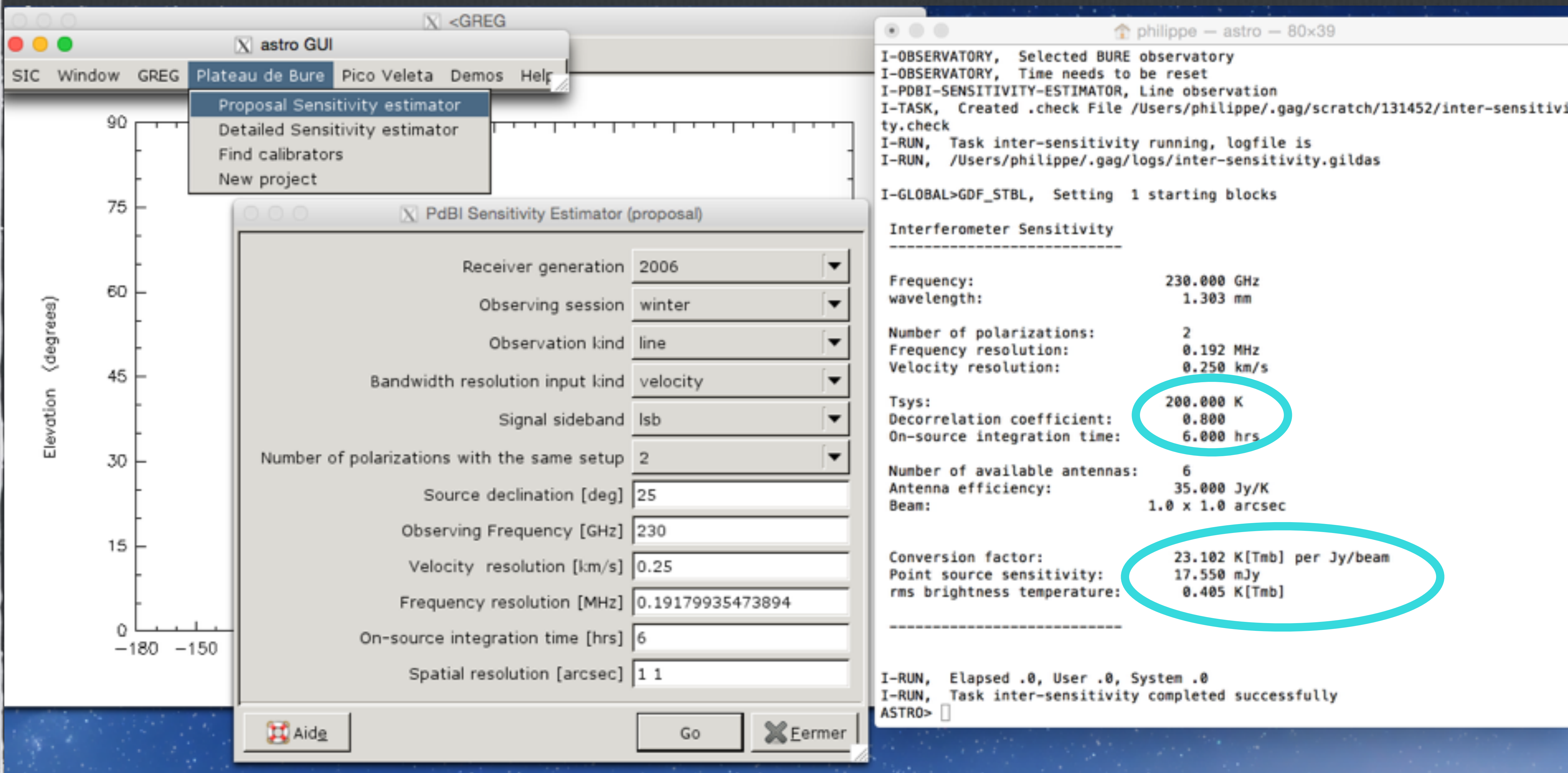
The flux to brightness conversion is thus given by

$$\mathrm{S[Jy]} = \frac{2kT_b\Omega_{\mathrm{source}}}{\lambda^2} = \frac{2kT_{\mathrm{mb}}\Omega_{\mathrm{beam}}}{\lambda^2} = \frac{2kT_{\mathrm{mb}}\pi\theta^2_{\mathrm{beam}}}{4\ln(2)\lambda^2} \tag{2}$$

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



ALMA sensitivity calculator

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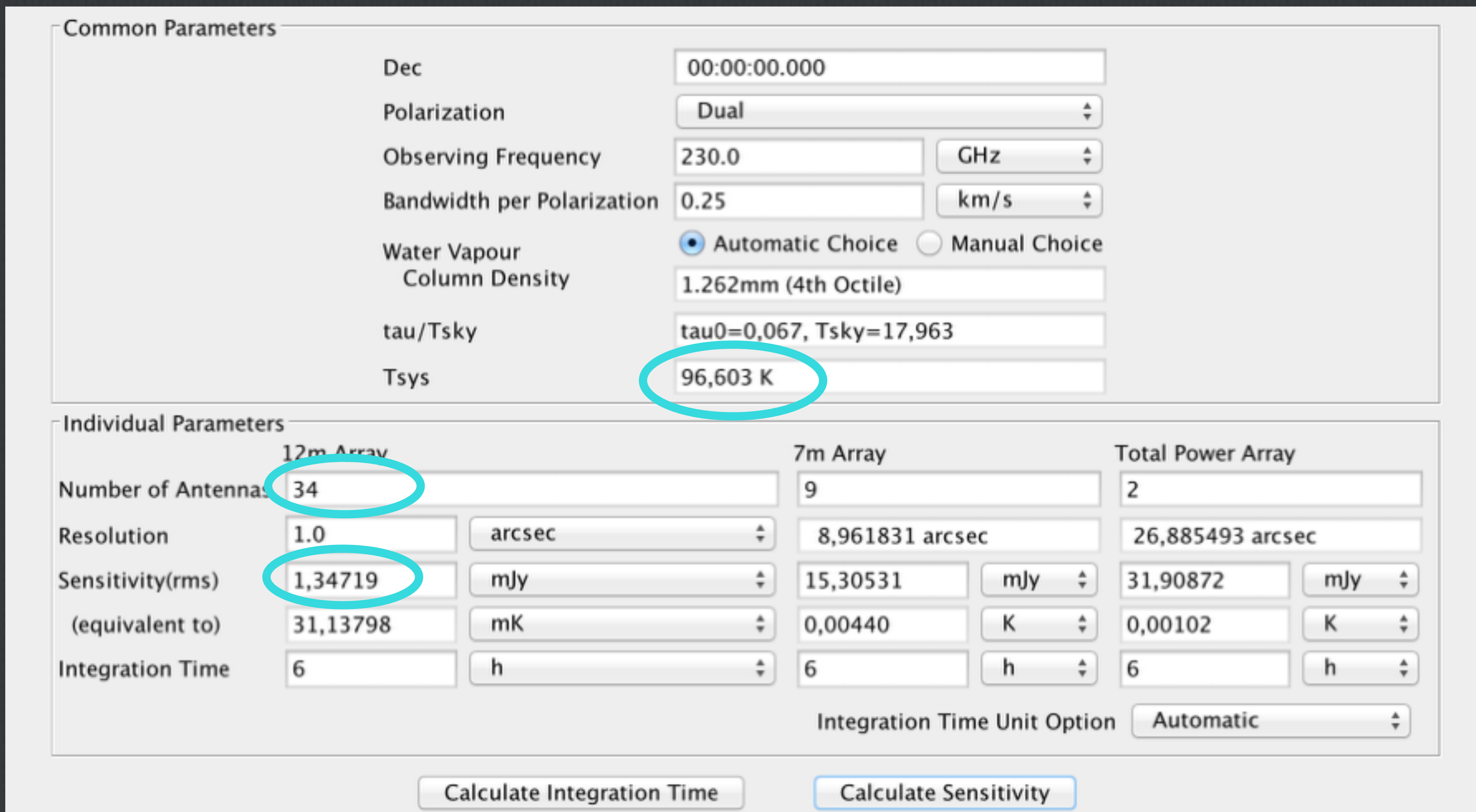

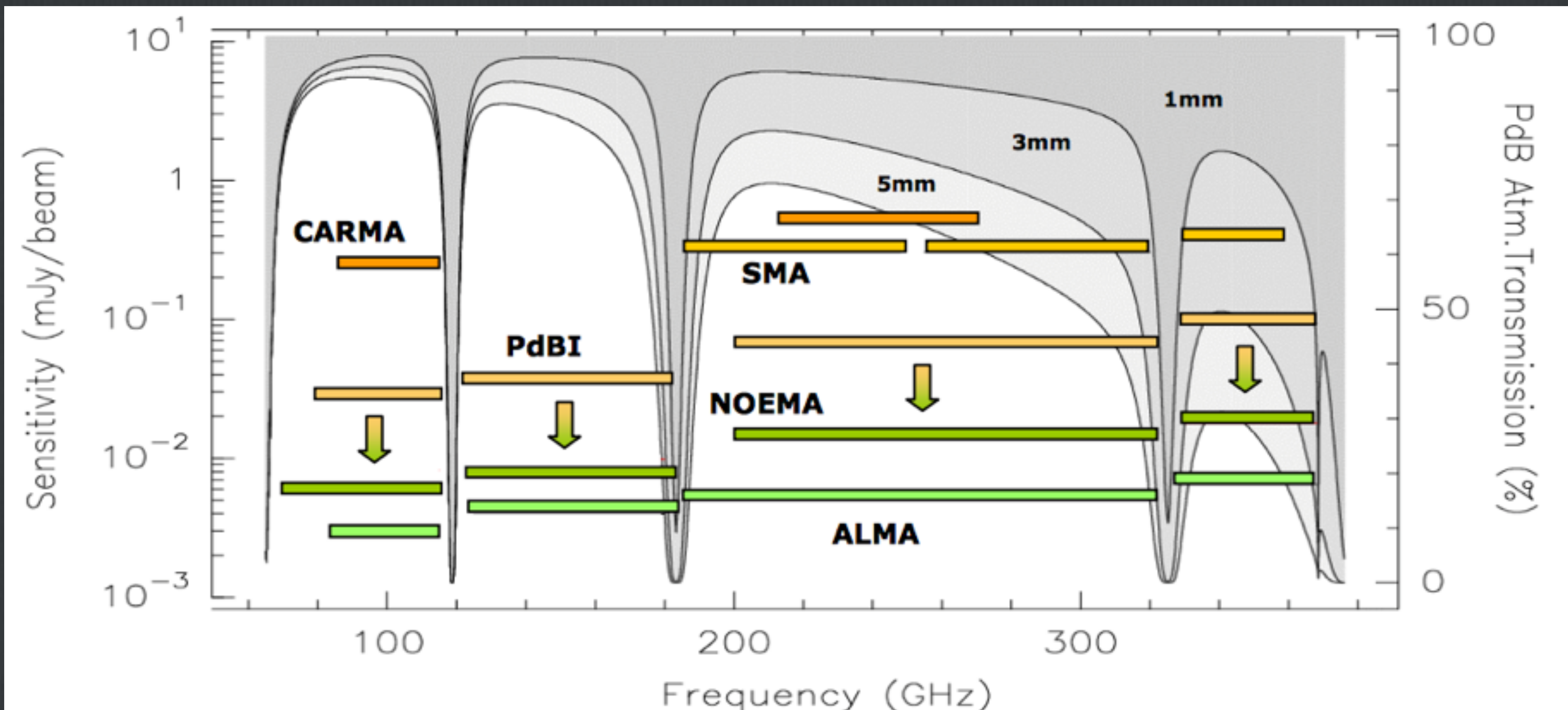

10^1
1
10^{-1}
10^{-2}
10^{-3}
Sensitivity (mJy/beam)
100
200
300
Frequency (GHz)
100
50
0
PdB Atm.Transmission (%)
1mm
3mm
5mm
CARMA
SMA
PdBI
NOEMA
ALMA

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 Sensitivites 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