# ALMA/NOEMA Sensitivity

AF ALMA/NOEMA
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Philippe Salomé

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

# Single Dish

The antenna system temperature $\mathrm{T_{ant}}$ is :

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

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

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

$\mathrm{T}_a$ is the source antenna temperature. It is the temperature of an equivalent black-body that would fill full $2\pi$ steradians antenna beam pattern.
By convention, the signal is also referred to as the antenna temperature $\mathrm{T_a^*}$ (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 $\Delta t$, 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 $S_\nu$ by quantities that only depends on the antenna properties (efficiency $\eta_a$ 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**

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

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

# Interferometer

Single Dish Efficiency (Jy/K)

ATMOSPHERE (SITE)

Seeing    Transparency

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

Antenna    Local Oscillators

Correlator

INSTRUMENTAL PERFORMANCE

# Interferometer

**Point source sensitivities:**

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

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

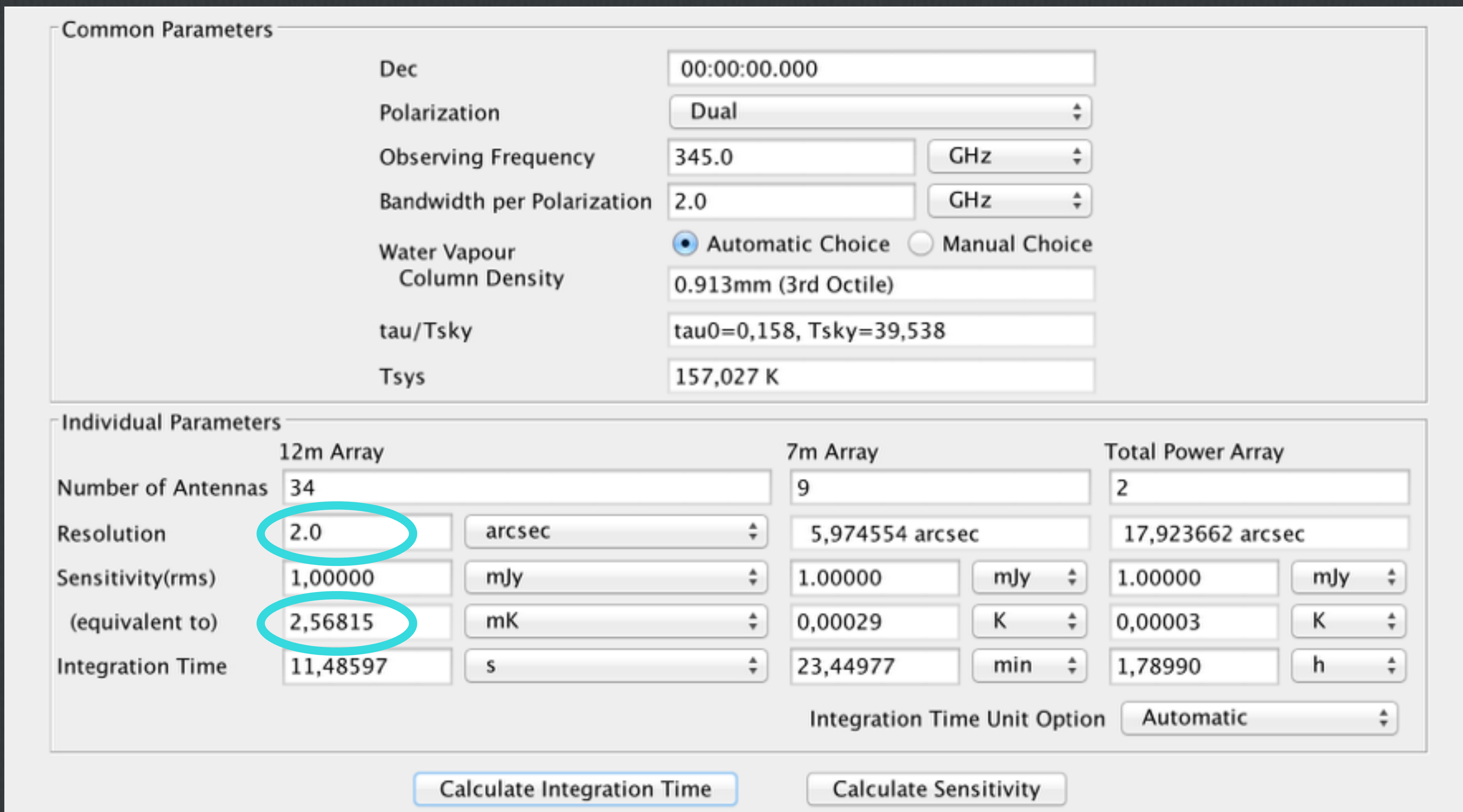
$\rightarrow 22 \times \sigma_T$ [Jy] @ 3mm Calibration precision $\leq 10\%$

$\rightarrow 26 \times \sigma_T$ [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



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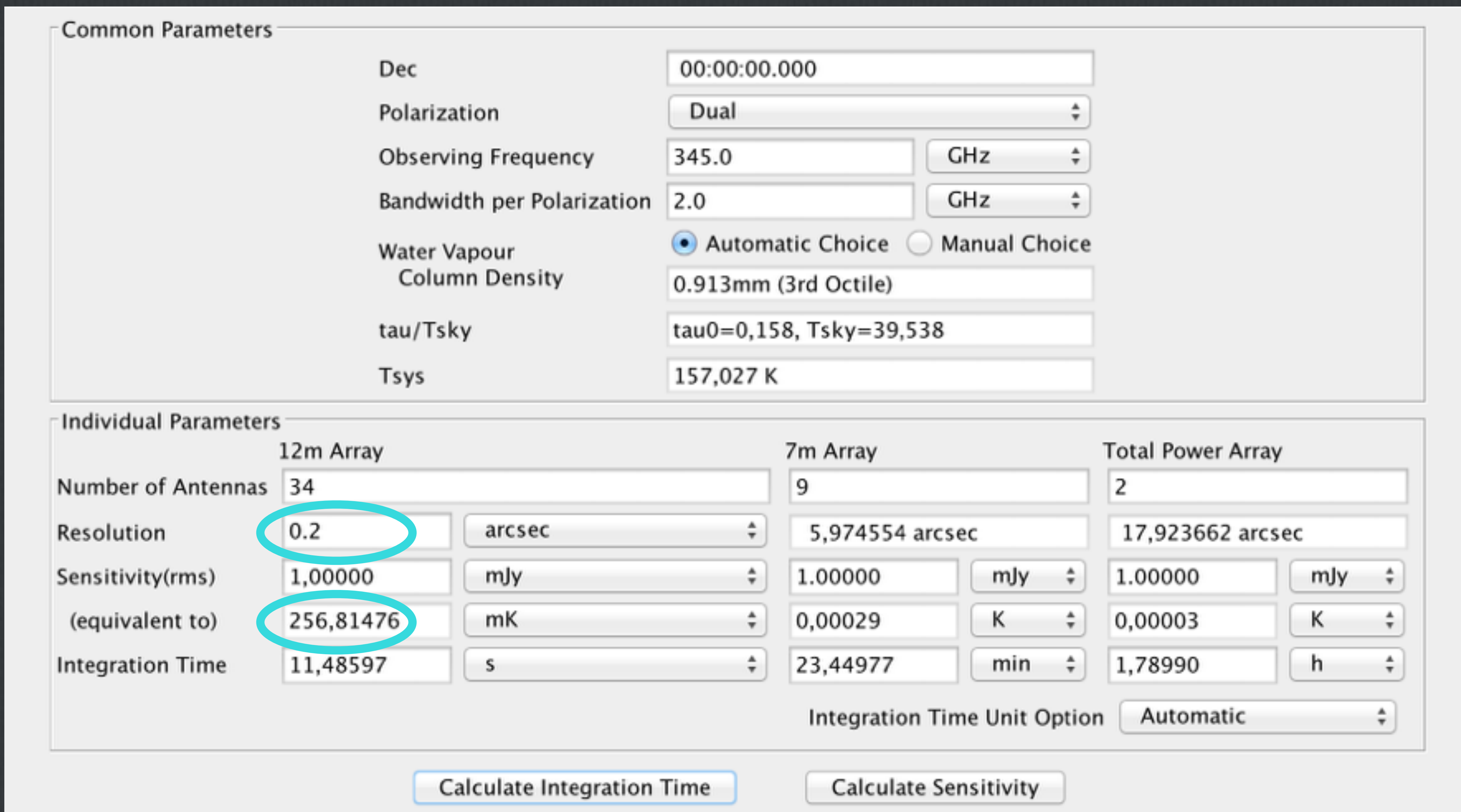


The Planck formula in the RJ regime lead to the Brightness temperature

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

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$\mathrm{Jy.str^{-1}}$

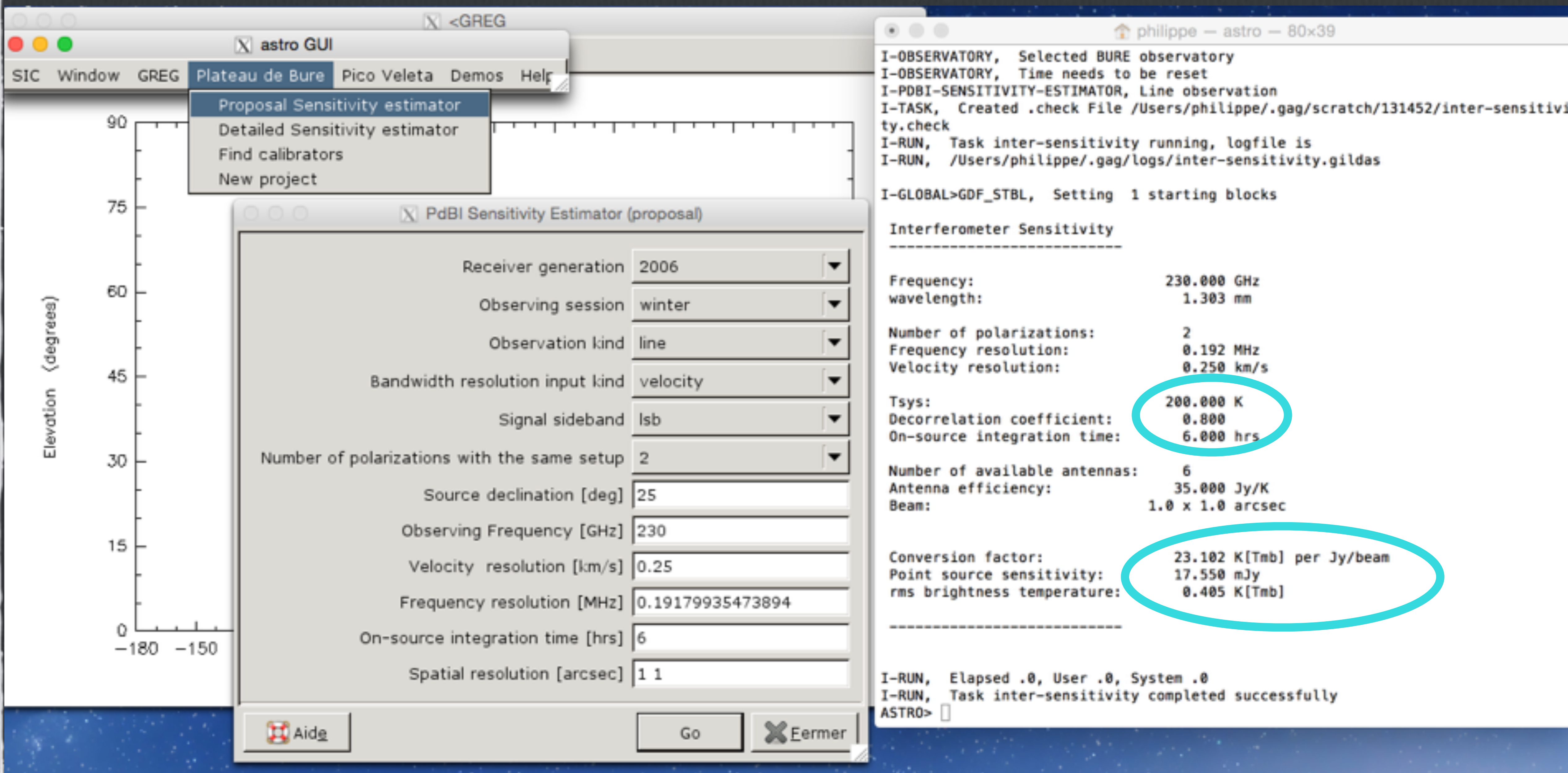
The flux to brightness conversion is thus given by

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

for a synthetised main beam of solid angle $\Omega_{\mathrm{beam}}$
(ie a Gaussian of FWHM $\theta_{\mathrm{beam}}$)

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 $\theta_{\mathrm{beam}}$

# GILDAS / Astro



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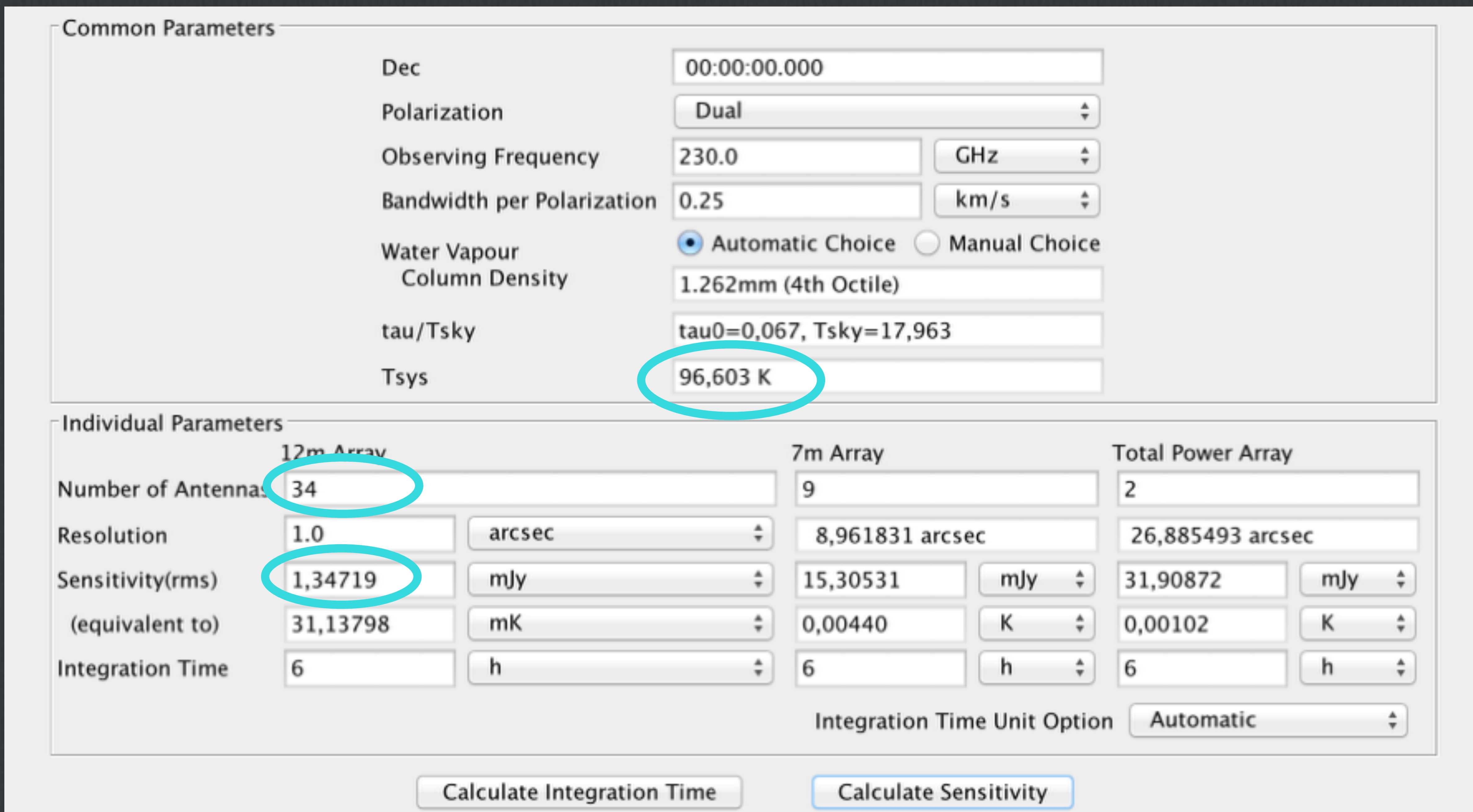

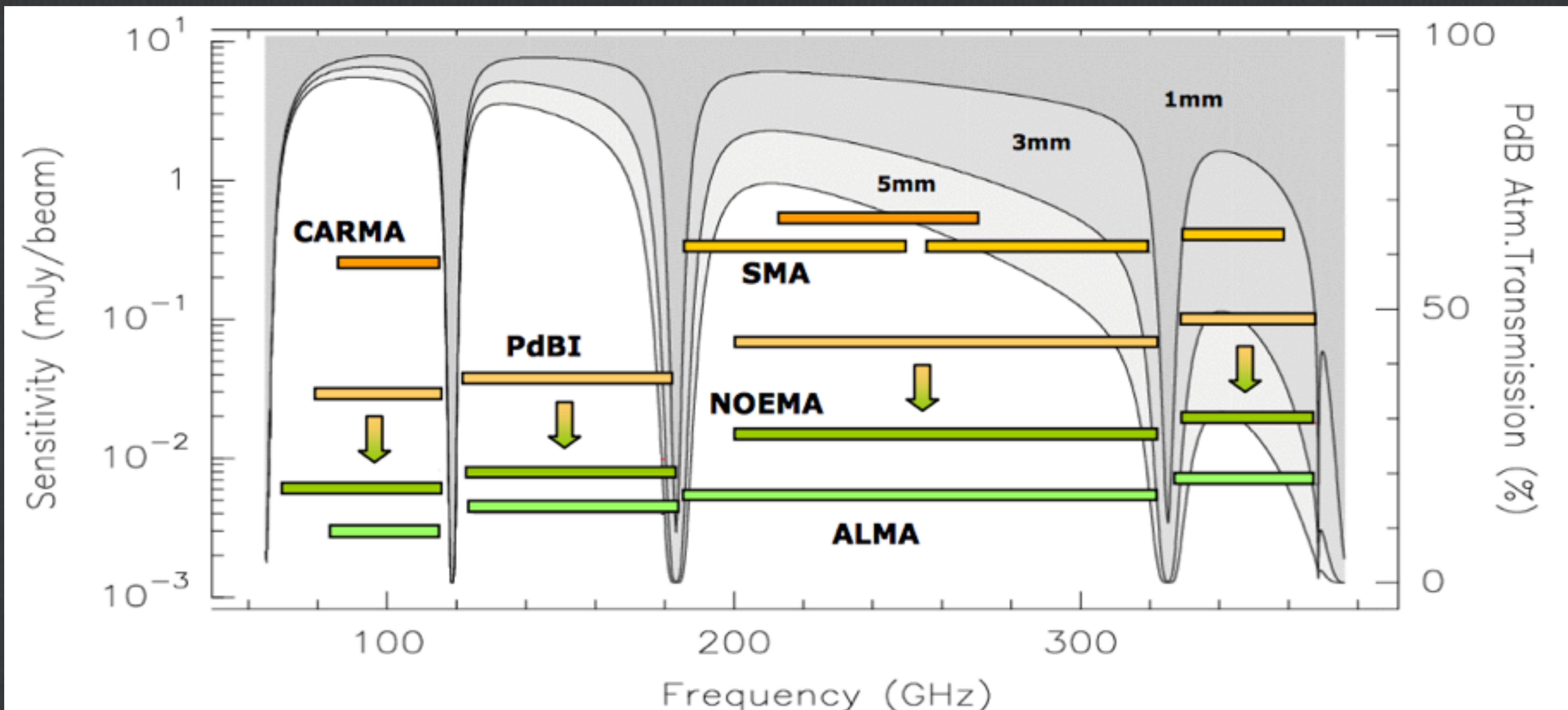

$10^1$
1
$10^{-1}$
$10^{-2}$
$10^{-3}$
Sensitivity (mJy/beam)
100
200
300
Frequency (GHz)
100
50
0
PdB Atm.Transmission (%)
1mm
3mm
5mm
CARMA
SMA
PdBI
NOEMA
ALMA

Elevation of 45deg

8 hr of integration

## Point Source Sensitivities at 90 GHz

| | $\eta_A$ | 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

| | $\eta_A$ | 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

| | $\eta_A$ | 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 |