

ALMA sensitivity calculations

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Benjamin Magnelli: Swiss ALMA Community Day 2017

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The power received by an antenna from a source is given by :

$$P_{\nu}^{\text{src}} = I_{\nu}^{\text{src}} dA d\Omega$$

where I_{ν}^{src} is in $\text{erg s}^{-1} \text{Hz}^{-1} \text{cm}^{-2} \text{sr}^{-1}$, dA is the collecting area of the antenna and $d\Omega$ its solid angle

$$= \frac{2k T_{\text{src}}}{\lambda^2} dA d\Omega$$

in the Rayleigh-Jeans approximation

Unfortunately, the antenna received also other signal (contamination), so:

$$P_{\nu}^{\text{tot}} = 2k (T_{\text{src}} + T_{\text{sys}}) \frac{dA d\Omega}{\lambda^2}$$

where $T_{\text{sys}} \approx T_{\text{sky}} + T_{\text{Rx}} + \eta_{\text{amb}} T_{\text{amb}}$ and $T_{\text{sys}} \gg T_{\text{src}}$



The signal and thus the noise received by the antenna is dominated by T_{sys}

The noise affecting our signal is thus given by :

$$\sigma \propto \frac{T_{\text{sys}}}{\sqrt{N_{\text{sampling}}}}$$

For an interferometer :

$$\sigma_S \approx \frac{2 k T_{\text{sys}}}{A_{\text{eff}} \sqrt{n(n-1)} \times \Delta\nu \times \eta_{\text{pol}} \times t_{\text{int}}} \text{ [Jy]}$$

$$\sigma_T = \frac{\sigma_S \lambda^2}{2 k d\Omega_{\text{array}}} \text{ [K]}$$

- where :
- A_{eff} is the effective collecting area
 - $n(n-1)$ is the number of baseline and n the number of antenna
 - $\Delta\nu$ is the bandwidth
 - η_{pol} = 1 for single polarisation and 2 for dual polarisation
 - t_{int} is the integration time
 - $d\Omega_{\text{array}}$ is the synthesized beam, i.e. $d\Omega_{\text{array}} \approx 1.14 \frac{\lambda^2}{B^2}$

We want :

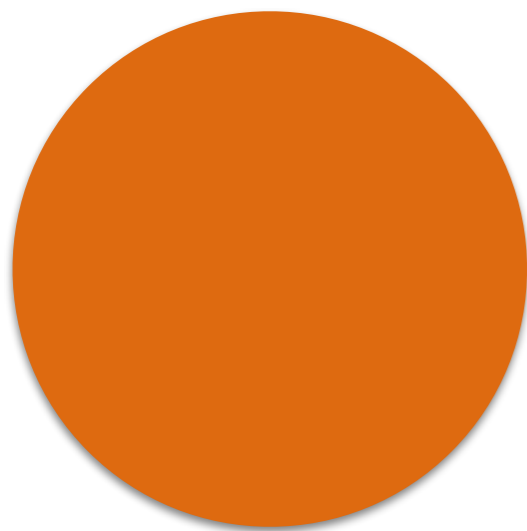
$$S_{\text{src}}[\text{Jy}] > (3 - 5) \sigma_S$$

$$T_{\text{src}}[\text{K}] > (3 - 5) \sigma_T$$

where $T_{\text{src}}[\text{K}]$ and $S_{\text{src}}[\text{Jy}]$ are the mean brightness temperature and the flux density of your source within the ALMA synthesised beam, i.e., $d\Omega_{\text{array}}$ (for line observations, it usually refers to the peak of the line emission)

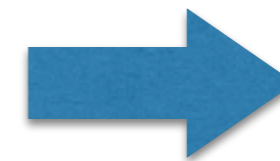
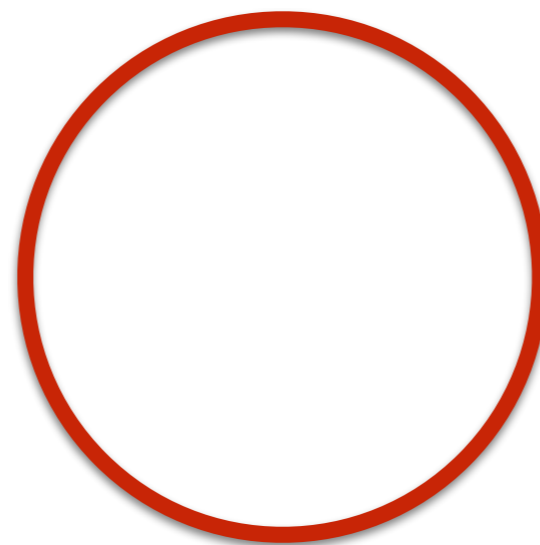
Source

$$T_{\text{src}}^{\text{tot}}[\text{K}] \quad S_{\text{src}}^{\text{tot}}[\text{Jy}] \quad d\Omega_{\text{src}}$$



ALMA Beam

$$d\Omega_{\text{array}}$$



$$T_{\text{src}}[\text{K}] = T_{\text{src}}^{\text{tot}}[\text{K}]$$

$$S_{\text{src}}[\text{Jy}] = S_{\text{src}}^{\text{tot}}[\text{Jy}]$$

We want :

$$S_{\text{src}}[\text{Jy}] > (3 - 5) \sigma_S$$

$$T_{\text{src}}[\text{K}] > (3 - 5) \sigma_T$$

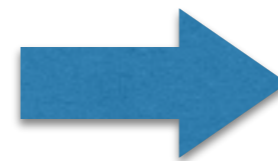
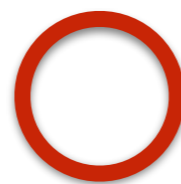
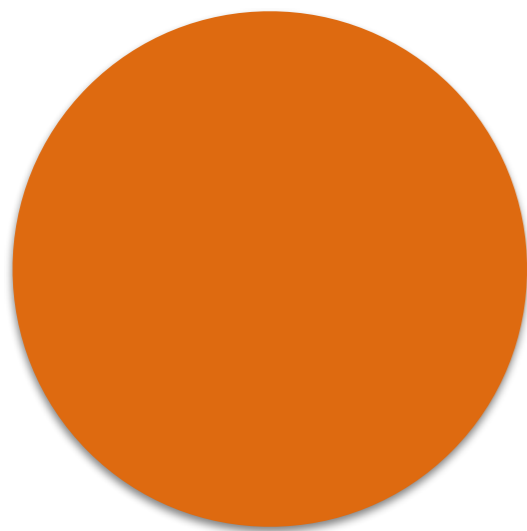
where $T_{\text{src}}[\text{K}]$ and $S_{\text{src}}[\text{Jy}]$ are the mean brightness temperature and the flux density of your source within the ALMA synthesised beam, i.e., $d\Omega_{\text{array}}$ (for line observation, they usually refer to the peak of the line)

Source

$$T_{\text{src}}^{\text{tot}}[\text{K}] \quad S_{\text{src}}^{\text{tot}}[\text{Jy}] \quad d\Omega_{\text{src}}$$

ALMA Beam

$$d\Omega_{\text{array}}$$



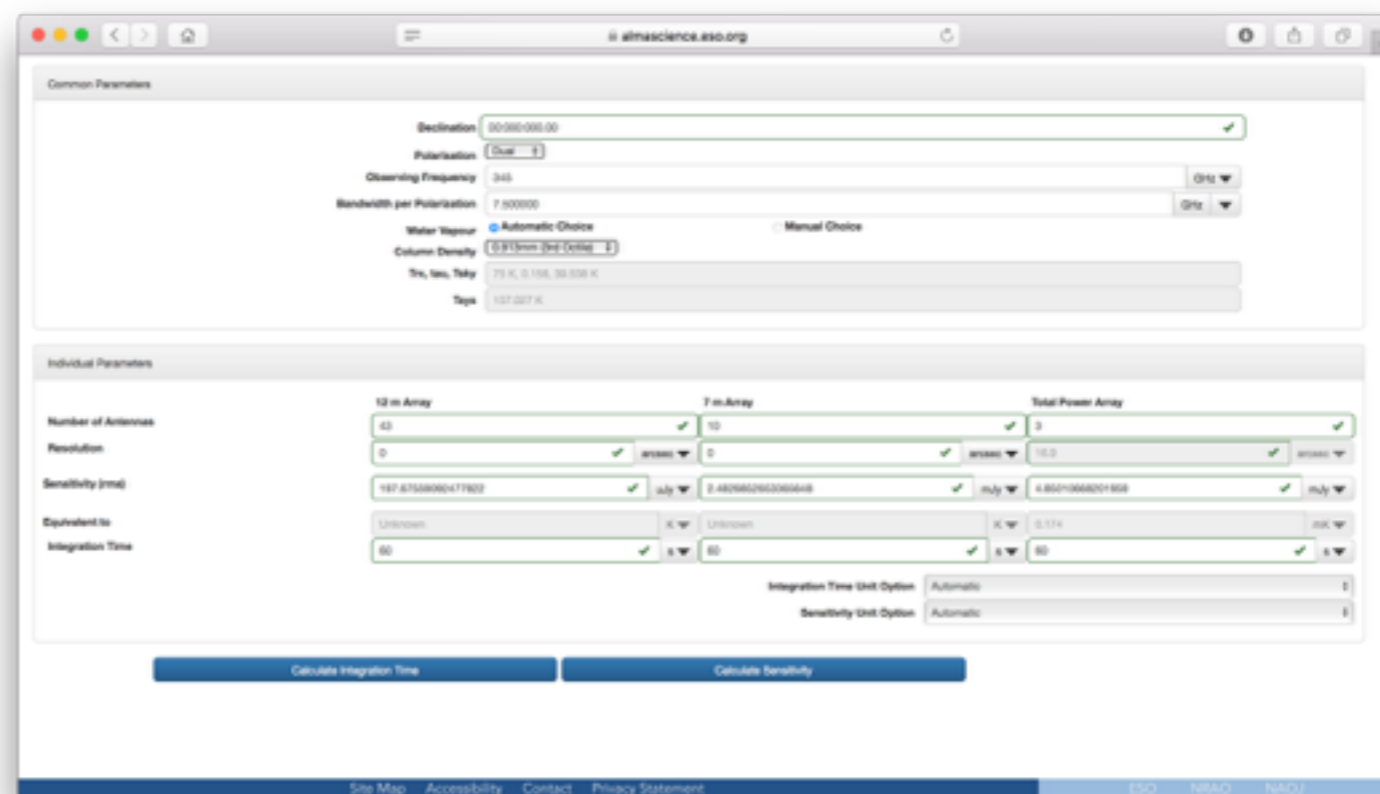
$$T_{\text{src}}[\text{K}] = T_{\text{src}}^{\text{tot}}[\text{K}]$$

$$S_{\text{src}}[\text{Jy}] = \frac{d\Omega_{\text{array}}}{d\Omega_{\text{src}}} S_{\text{src}}^{\text{tot}}[\text{Jy}]$$

The ALMA sensitivity calculator

$$S_{\text{src}} [\text{Jy}] \xleftrightarrow{\text{You}} \sigma_s [\text{Jy}] \xleftrightarrow{\text{ASC}} t_{\text{int}} \quad \text{using} \quad \frac{2 k T_{\text{sys}}}{A_{\text{eff}} \sqrt{n(n-1)} \times \Delta\nu \times \eta_{\text{pol}} \times t_{\text{int}}} [\text{Jy}]$$

- Two versions of ALMA Sensitivity Calculator (ASC): integrated into the ALMA OT and stand-alone, available online at the ALMA Science Portal



The ALMA sensitivity calculator

Inputs :

Sensitivity Calculator

Common Parameters

Dec: 00:00:00.000

Polarization: Dual

Observing Frequency: 345.00000 GHz

Bandwidth per Polarization: 7.50000 GHz

Water Vapour Column Density: Automatic Choice Manual Choice

Trx, tau, Tsky: 75 K, 0.158, 39.538 K

Tsys: 157.027 K

Individual Parameters

	12m Array	7m Array	Total Power Array
Number of Antennas	43	10	3
Resolution	0.00000 arcsec	0.00000 arcsec	16.9 arcsec
Sensitivity (rms)	0.00000 uJy	0.00000 uJy	0.00000 uJy
(equivalent to)	Unknown K	Unknown K	0.00000 K
Integration Time	60.00000 s	60.00000 s	60.00000 s

Integration Time Unit Option: Automatic

Sensitivity Unit Option: Automatic

Buttons: Calculate Integration Time, Calculate Sensitivity, Close

Inputs :

- Declination

—> to evaluate the atmospheric transmission and Tsky

Sensitivity Calculator

Common Parameters

Dec: 00:00:00.000

Polarization: Dual

Observing Frequency: 345.00000 GHz

Bandwidth per Polarization: 7.50000 GHz

Water Vapour Column Density: Automatic Choice Manual Choice

0.913mm (3rd Octile)

Trx, tau, Tsky: 75 K, 0.158, 39.538 K

Tsys: 157.027 K

Individual Parameters

	12m Array		7m Array		Total Power Array	
Number of Antennas	43		10		3	
Resolution	0.00000	arcsec	0.00000	arcsec	16.9	arcsec
Sensitivity (rms)	0.00000	ujy	0.00000	ujy	0.00000	ujy
(equivalent to)	Unknown	K	Unknown	K	0.00000	K
Integration Time	60.00000	s	60.00000	s	60.00000	s

Integration Time Unit Option: Automatic

Sensitivity Unit Option: Automatic

Calculate Integration Time Calculate Sensitivity Close

Sensitivity Calculator

Common Parameters

Dec: 00:00:00.000

Polarization: Dual

Observing Frequency: 345.00000 GHz

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Integration Time	60.00000 s	60.00000 s	60.00000 s

Integration Time Unit Option: Automatic

Sensitivity Unit Option: Automatic

Buttons: Calculate Integration Time, Calculate Sensitivity, Close

Inputs :

- Declination
- Polarisation

—> to evaluate η_{pol}

Sensitivity Calculator

Common Parameters

Dec: 00:00:00.000

Polarization: Dual

Observing Frequency: 345.00000 GHz

Bandwidth per Polarization: 7.50000 GHz

Water Vapour Column Density: Automatic Choice Manual Choice
0.913mm (3rd Octile)

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Sensitivity (rms)	0.00000	ujy	0.00000	ujy	0.00000	ujy
(equivalent to)	Unknown	K	Unknown	K	0.00000	K
Integration Time	60.00000	s	60.00000	s	60.00000	s

Integration Time Unit Option: Automatic

Sensitivity Unit Option: Automatic

Buttons: Calculate Integration Time, Calculate Sensitivity, Close

Inputs :

- Declination
- Polarisation
- Observing Frequency

—> to evaluate the atmospheric transmission and Tsky

Sensitivity Calculator

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Inputs :

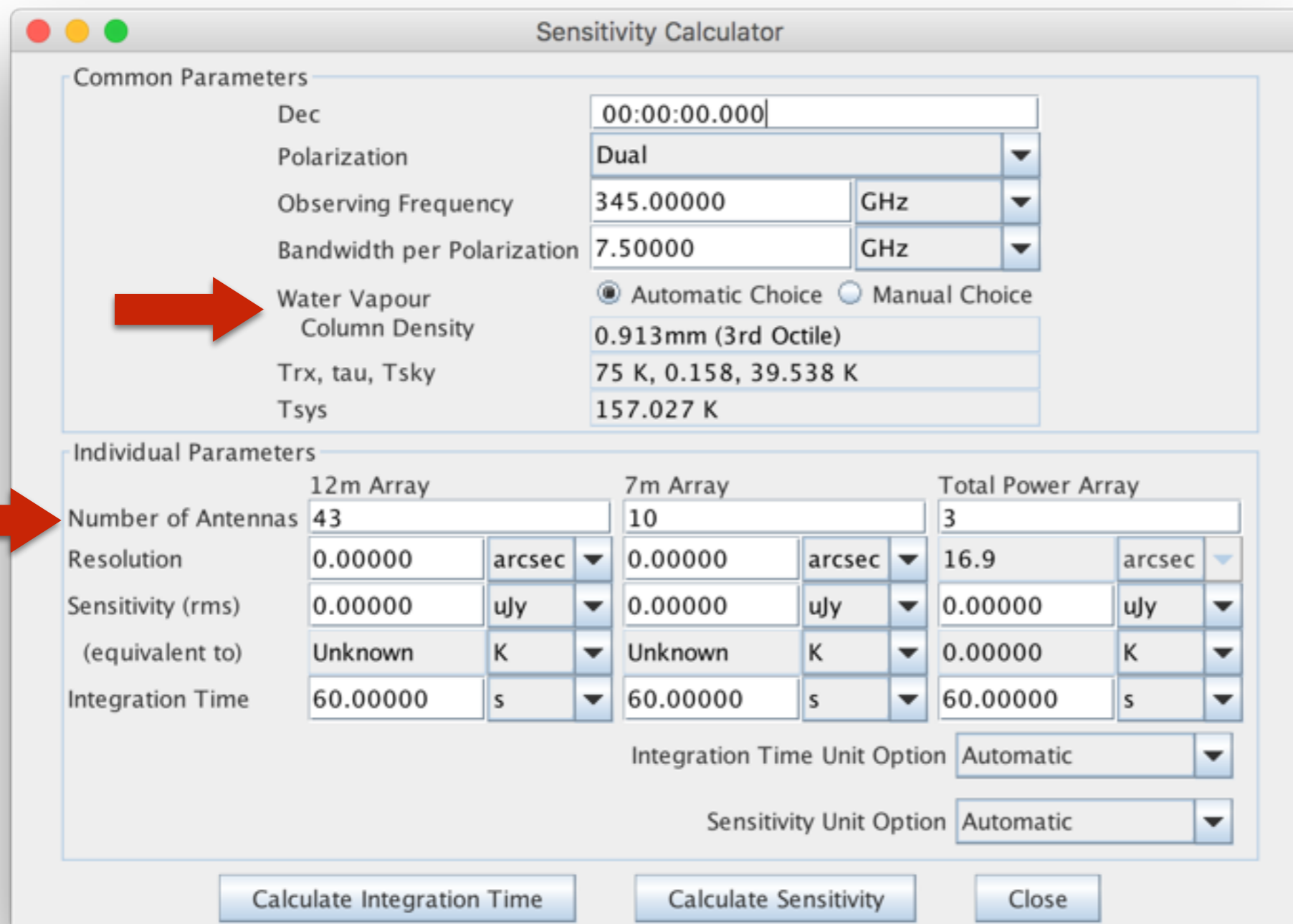
- Declination
- Polarisation
- Observing Frequency
- Bandwidth

—> 7.5GHz for continuum obs.

—> width of the resolution element desired for line obs., usually $\Delta\nu > \text{FWHM}_{\text{line}} / 4$

Inputs :

- Declination
- Polarisation
- Observing Frequency
- Bandwidth
- Water Vapour
- Nb. Antenna



Sensitivity Calculator

Common Parameters

Dec: 00:00:00.000

Polarization: Dual

Observing Frequency: 345.00000 GHz

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(equivalent to)	Unknown K	Unknown K	0.00000 K
Integration Time	60.00000 s	60.00000 s	60.00000 s

Integration Time Unit Option: Automatic

Sensitivity Unit Option: Automatic

Buttons: Calculate Integration Time, Calculate Sensitivity, Close

—> You should most likely keep the default values

Inputs :

- Declination
- Polarisation
- Observing Frequency
- Bandwidth
- Water Vapour
- Nb. Antenna
- Angular resolution

Sensitivity Calculator

Common Parameters

Dec: 00:00:00.000

Polarization: Dual

Observing Frequency: 345.00000 GHz

Bandwidth per Polarization: 7.50000 GHz

Water Vapour Column Density: Automatic Choice Manual Choice

Trx, tau, Tsky: 75 K, 0.158, 39.538 K

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Sensitivity Unit Option: Automatic

Buttons: Calculate Integration Time, Calculate Sensitivity, Close

Sensitivity Calculator

Common Parameters

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Integration Time	60.00000 s	60.00000 s	60.00000 s

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Sensitivity Unit Option: Automatic

Buttons: Calculate Integration Time, Calculate Sensitivity, Close

Inputs :

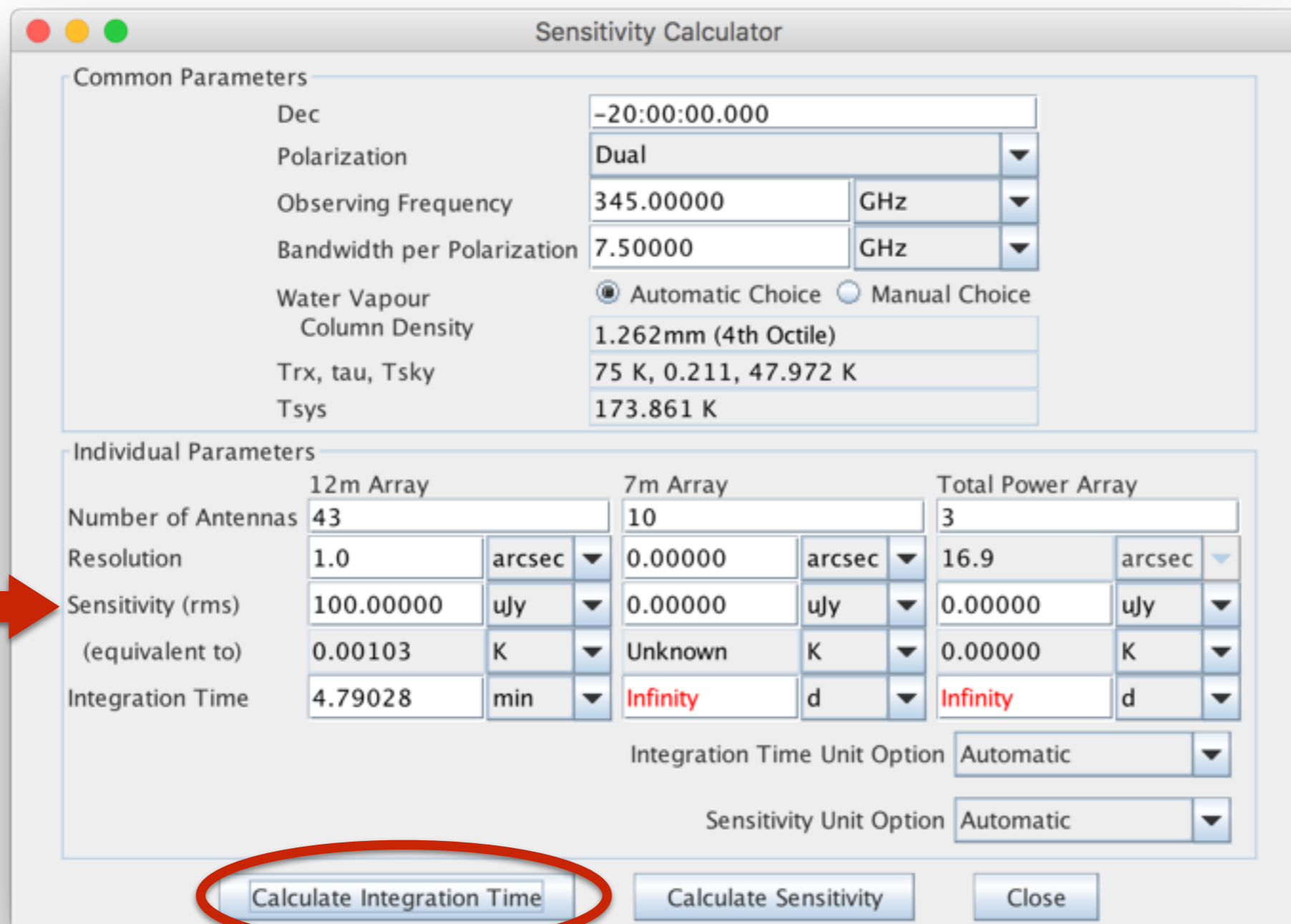
- Declination
- Polarisation
- Observing Frequency
- Bandwidth
- Water Vapour
- Nb. Antenna
- Angular resolution
- **Sensitivity**

→ σ_T [K] or σ_S [Jy]

Inputs :

- Declination
- Polarisation
- Observing Frequency
- Bandwidth
- Water Vapour
- Nb. Antenna
- Angular resolution
- **Sensitivity**

→ σ_T [K] or σ_S [Jy]



Common Parameters

Dec: -20:00:00.000
Polarization: Dual
Observing Frequency: 345.00000 GHz
Bandwidth per Polarization: 7.50000 GHz
Water Vapour Column Density: 1.262mm (4th Octile)
Trx, tau, Tsky: 75 K, 0.211, 47.972 K
Tsys: 173.861 K

Individual Parameters

	12m Array	7m Array	Total Power Array
Number of Antennas	43	10	3
Resolution	1.0 arcsec	0.00000 arcsec	16.9 arcsec
Sensitivity (rms)	100.00000 uJy	0.00000 uJy	0.00000 uJy
(equivalent to)	0.00103 K	Unknown K	0.00000 K
Integration Time	4.79028 min	Infinity d	Infinity d

Integration Time Unit Option: Automatic
Sensitivity Unit Option: Automatic

Buttons: Calculate Integration Time, Calculate Sensitivity, Close

Sensitivity Calculator

Common Parameters

Dec: -20:00:00.000

Polarization: Dual

Observing Frequency: 345.00000 GHz

Bandwidth per Polarization: 7.50000 GHz

Water Vapour Column Density: Automatic Choice Manual Choice

Trx, tau, Tsky: 75 K, 0.211, 47.972 K

Tsys: 173.861 K

Individual Parameters

	12m Array	7m Array	Total Power Array
Number of Antennas	43	10	3
Resolution	1.0 arcsec	0.00000 arcsec	16.9 arcsec
Sensitivity (rms)	100.00000 uJy	0.00000 uJy	0.00000 uJy
(equivalent to)	0.00103 K	Unknown K	0.00000 K
Integration Time	4.79028 min	Infinity d	Infinity d

Integration Time Unit Option: Automatic

Sensitivity Unit Option: Automatic

Buttons: Calculate Integration Time, Calculate Sensitivity, Close

Inputs :

- Declination
- Polarisation
- Observing Frequency
- Bandwidth
- Water Vapour
- Nb. Antenna
- Angular resolution
- **Sensitivity**

Outputs :

- On-source
Integration time

Inputs :

- Declination
- Polarisation
- Observing Frequency
- Bandwidth
- Water Vapour
- Nb. Antenna
- Angular resolution
- **On-source t_{int}**

Sensitivity Calculator

Common Parameters

Dec: -20:00:00.000

Polarization: Dual

Observing Frequency: 345.00000 GHz

Bandwidth per Polarization: 7.50000 GHz

Water Vapour Column Density: Automatic Choice Manual Choice
1.262mm (4th Octile)

Trx, tau, Tsky: 75 K, 0.211, 47.972 K

Tsys: 173.861 K

Individual Parameters

	12m Array	7m Array	Total Power Array
Number of Antennas	43	10	3
Resolution	1.0 arcsec	0.00000 arcsec	16.9 arcsec
Sensitivity (rms)	28.25562 uJy	0.00000 uJy	0.00000 uJy
(equivalent to)	0.00029 K	Unknown K	0.00000 K
Integration Time	60.0 min	Infinity d	Infinity d

Integration Time Unit Option: Automatic

Sensitivity Unit Option: Automatic

Buttons: Calculate Integration Time, Calculate Sensitivity, Close

Sensitivity Calculator

Common Parameters

Dec: -20:00:00.000

Polarization: Dual

Observing Frequency: 345.00000 GHz

Bandwidth per Polarization: 7.50000 GHz

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Sensitivity (rms)	28.25562 uJy	0.00000 uJy	0.00000 uJy
(equivalent to)	0.00029 K	Unknown K	0.00000 K
Integration Time	60.0 min	Infinity d	Infinity d

Integration Time Unit Option: Automatic

Sensitivity Unit Option: Automatic

Buttons: Calculate Integration Time, **Calculate Sensitivity**, Close

Inputs :

- Declination
- Polarisation
- Observing Frequency
- Bandwidth
- Water Vapour
- Nb. Antenna
- Angular resolution
- **On-source t_{int}**

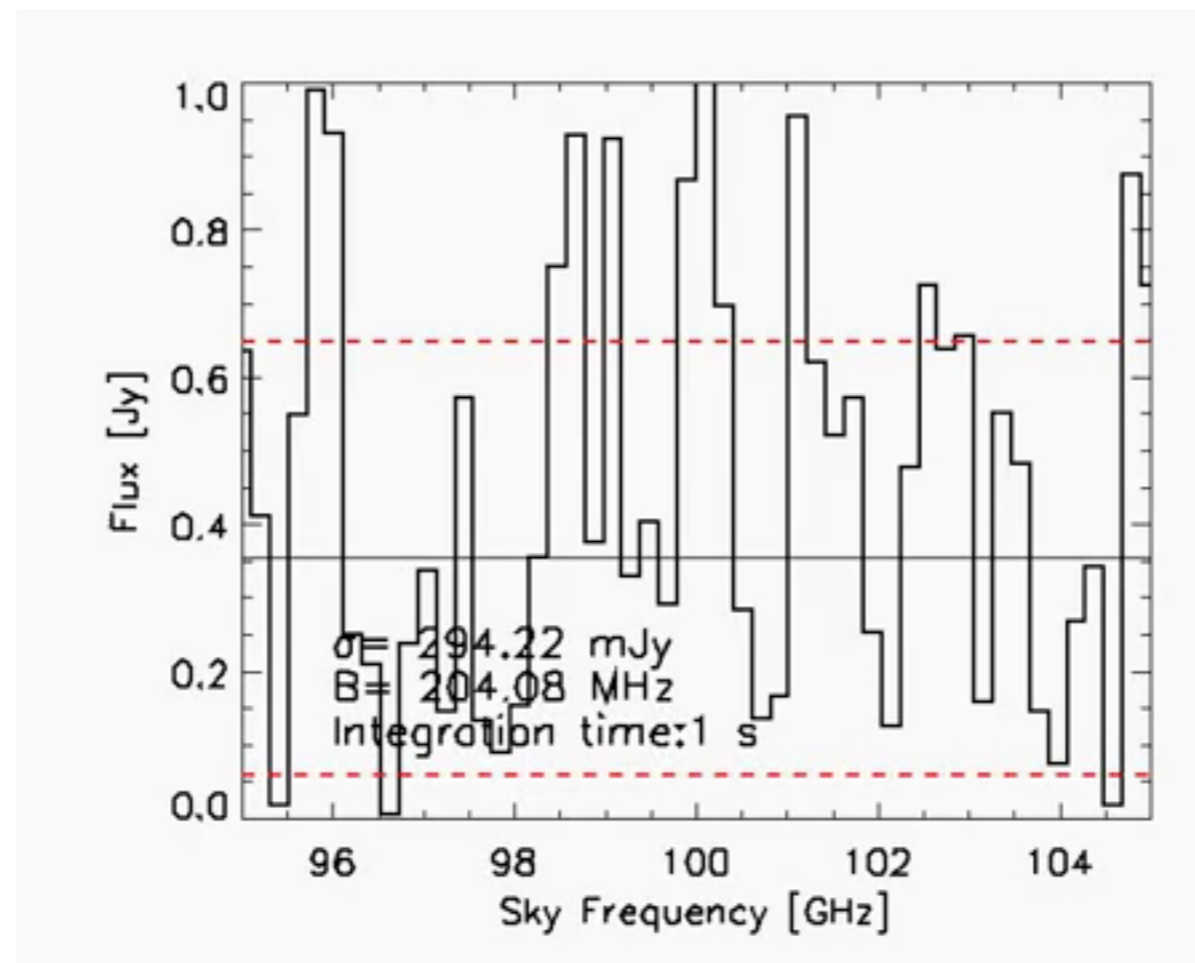
Outputs :

- Sensitivity

- The **ALMA sensitivity calculator** is a nice tool to rapidly evaluate the feasibility of a project
- **WARNING** : the **ALMA sensitivity calculator** outputs **ON-SOURCE** integration time. You have to factor in overhead (i.e. create a full project in the **ALMA OT**)

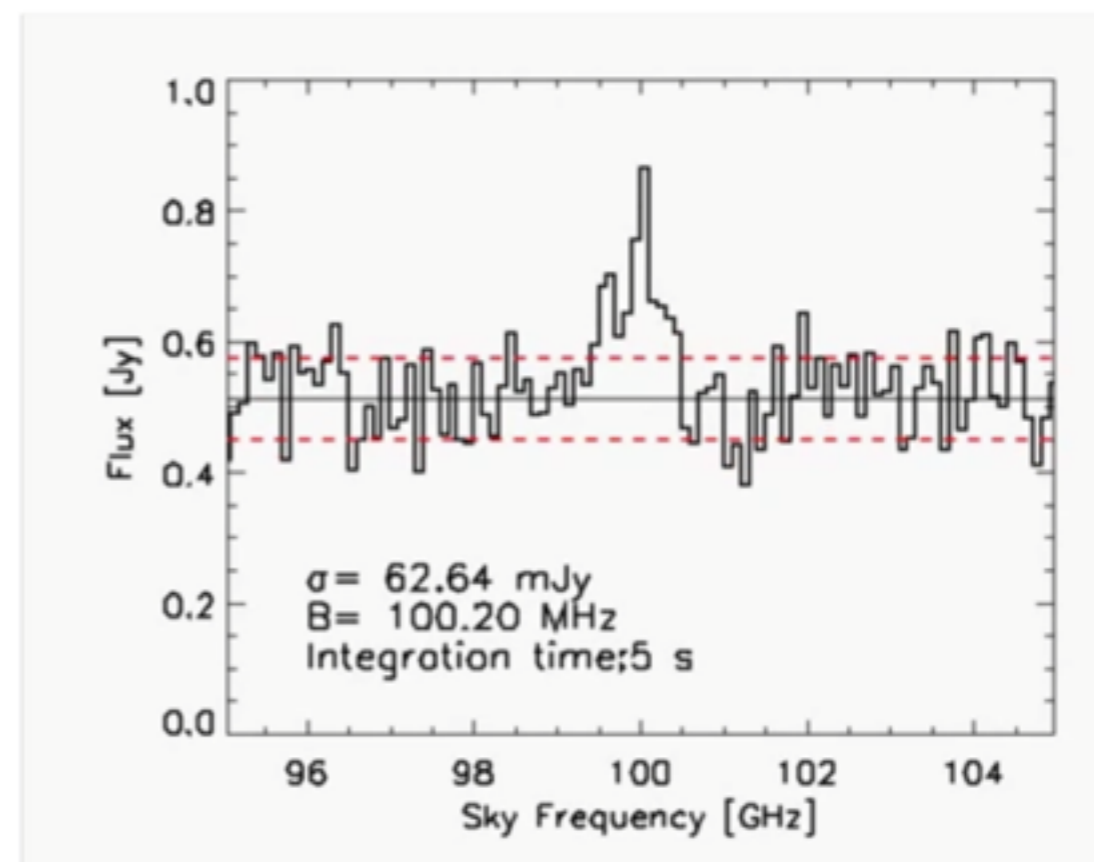
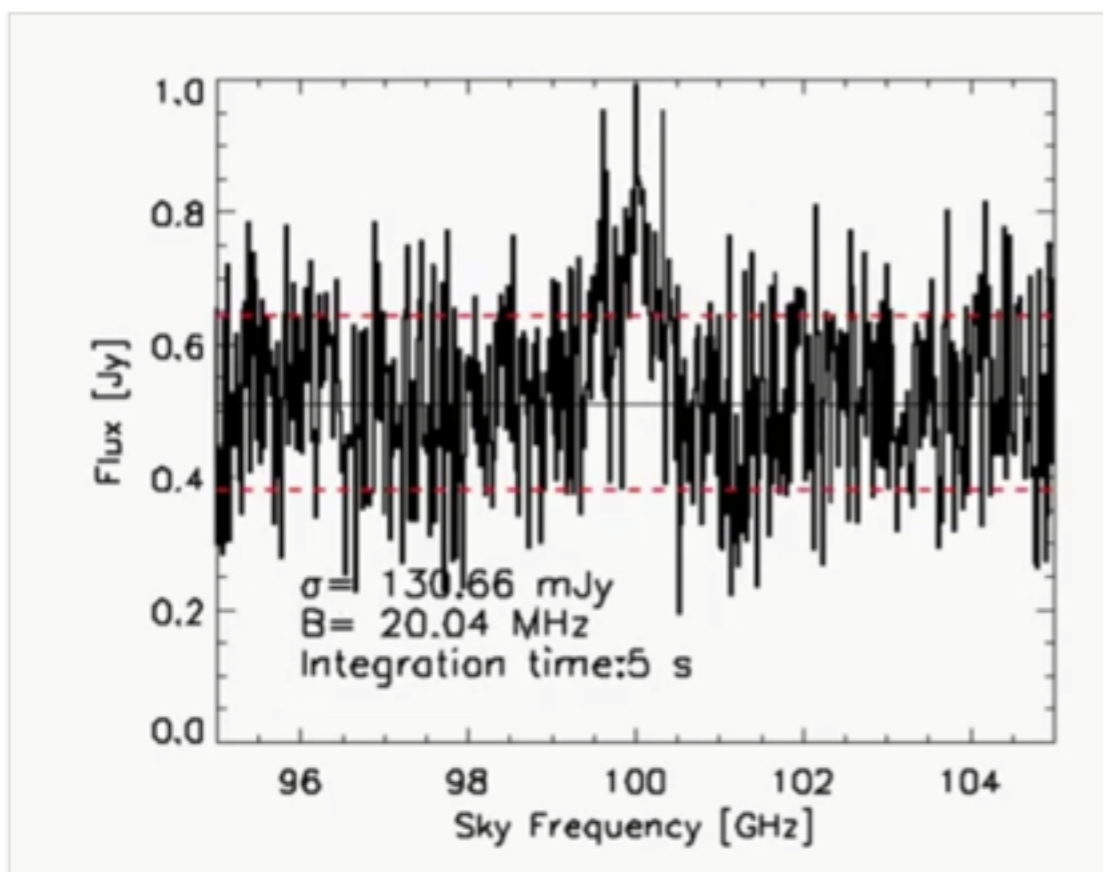
$$\sigma_S \approx \frac{2 k T_{\text{sys}}}{A_{\text{eff}} \sqrt{n(n-1)} \times \Delta\nu \times \eta_{\text{pol}} \times t_{\text{int}}} \text{ [Jy]}$$

Effect of increasing the integration time



$$\sigma_S \approx \frac{2 k T_{\text{sys}}}{A_{\text{eff}} \sqrt{n(n-1)} \times \Delta\nu \times \eta_{\text{pol}} \times t_{\text{int}}} \text{ [Jy]}$$

Effect of increasing the bandwidth



$$\sigma_s \approx \frac{2 k T_{\text{sys}}}{A_{\text{eff}} \sqrt{n(n-1)} \times \Delta\nu \times \eta_{\text{pol}} \times t_{\text{int}}} \text{ [Jy]}$$

Effect of increasing the number of antenna

