ALMA sensitivity calculations

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ALMA sensitivity: theoretical background

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

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

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

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

in the Rayleigh-Jeans approximation

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

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

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

- $T_{\rm sky}$: CMB and galactic foreground atmospheric emission (Water Vapour)
- $T_{\rm Rx}$: Receiver temp.
- $T_{\rm amb}$: Ambient temp. (earth emission)

The signal and thus the noise received by the antenna is dominated by Tsys

ALMA sensitivity: theoretical background

The noise affecting our signal is thus given by :

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

For an interferometer :

$$\sigma_{\rm S} \approx \frac{2\,k\,T_{\rm sys}}{A_{\rm eff}\,\sqrt{n(n-1)\times\Delta\nu\times\eta_{\rm pol}\times t_{\rm int}}}\ [\rm Jy] \qquad \sigma_{\rm T} = \frac{\sigma_{\rm S}\,\lambda^2}{2\,k\,d\Omega_{\rm array}}\ [\rm K]$$

where :

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

ALMA sensitivity: source properties

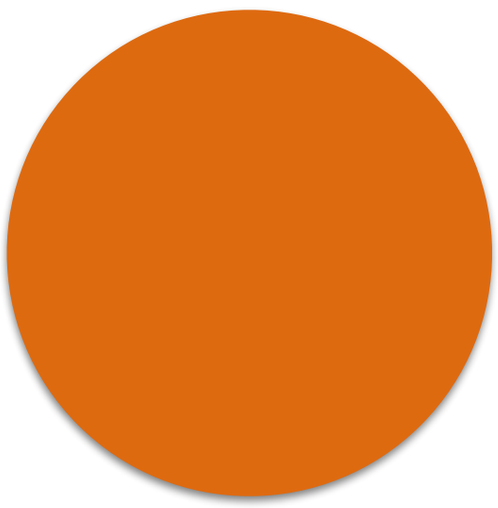
We want :

$$S_{\rm src}[{\rm Jy}] > (3-5)\,\sigma_{\rm S} \qquad\qquad T_{\rm src}[{\rm K}] > (3-5)\,\sigma_{\rm T}$$

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

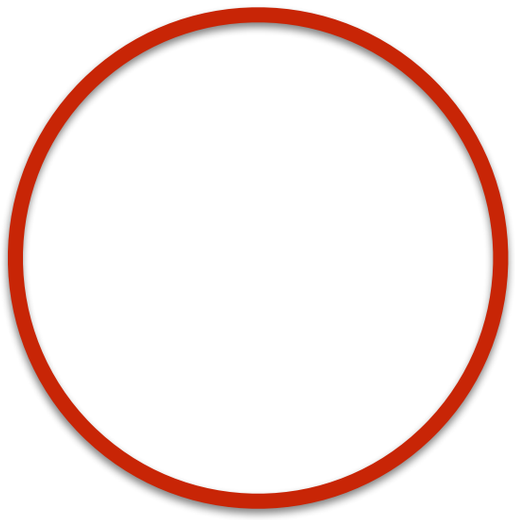
Source

$T^{\rm tot}_{\rm src}[{\rm K}]$ $S^{\rm tot}_{\rm src}[{\rm Jy}]$ $d\Omega_{\rm src}$



ALMA Beam

$d\Omega_{\rm array}$



$$T_{\rm src}[{\rm K}] = T^{\rm tot}_{\rm src}[{\rm K}]$$

$$S_{\rm src}[{\rm Jy}] = S^{\rm tot}_{\rm src}[{\rm Jy}]$$

ALMA sensitivity: source properties

We want :

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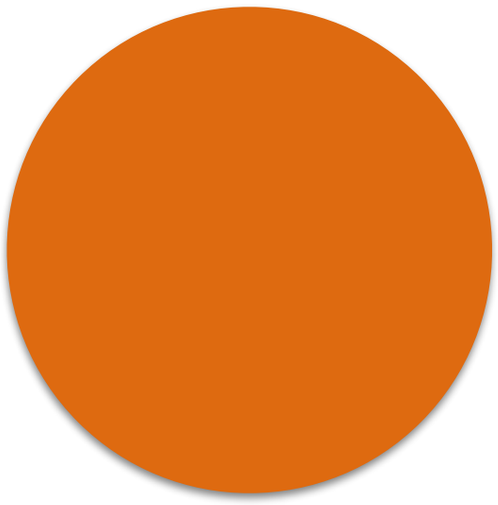
(for line observation, they usually refer to the peak of the line)

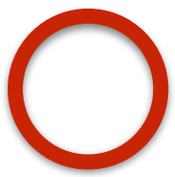
Source

$T^{\rm tot}_{\rm src}[{\rm K}]$ $S^{\rm tot}_{\rm src}[{\rm Jy}]$ $d\Omega_{\rm src}$

ALMA Beam

$d\Omega_{\rm array}$





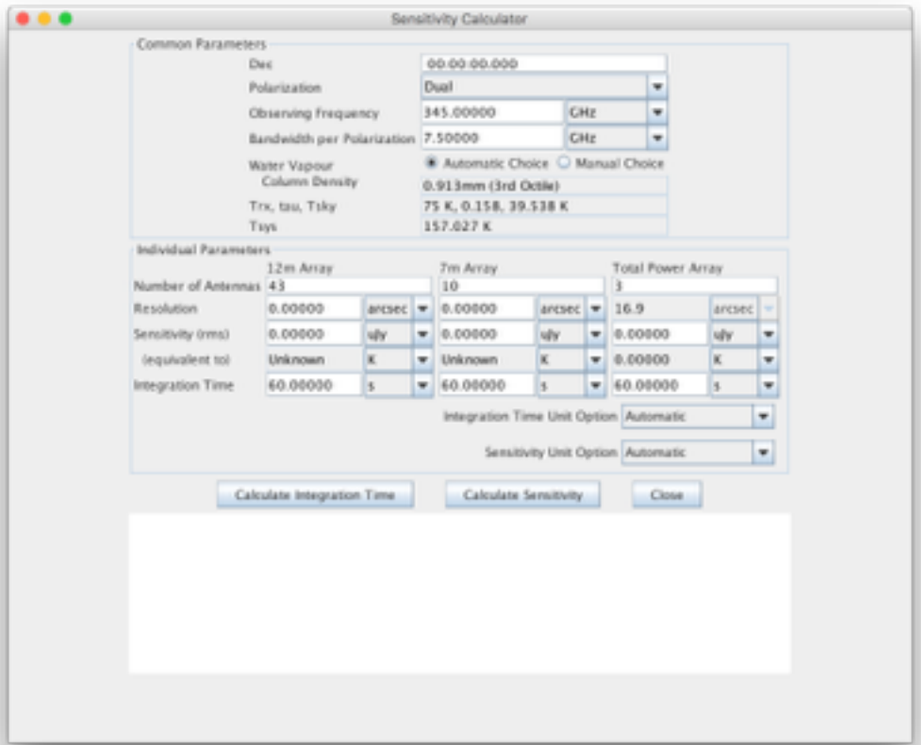
$$T_{\rm src}[{\rm K}] = T^{\rm tot}_{\rm src}[{\rm K}]$$

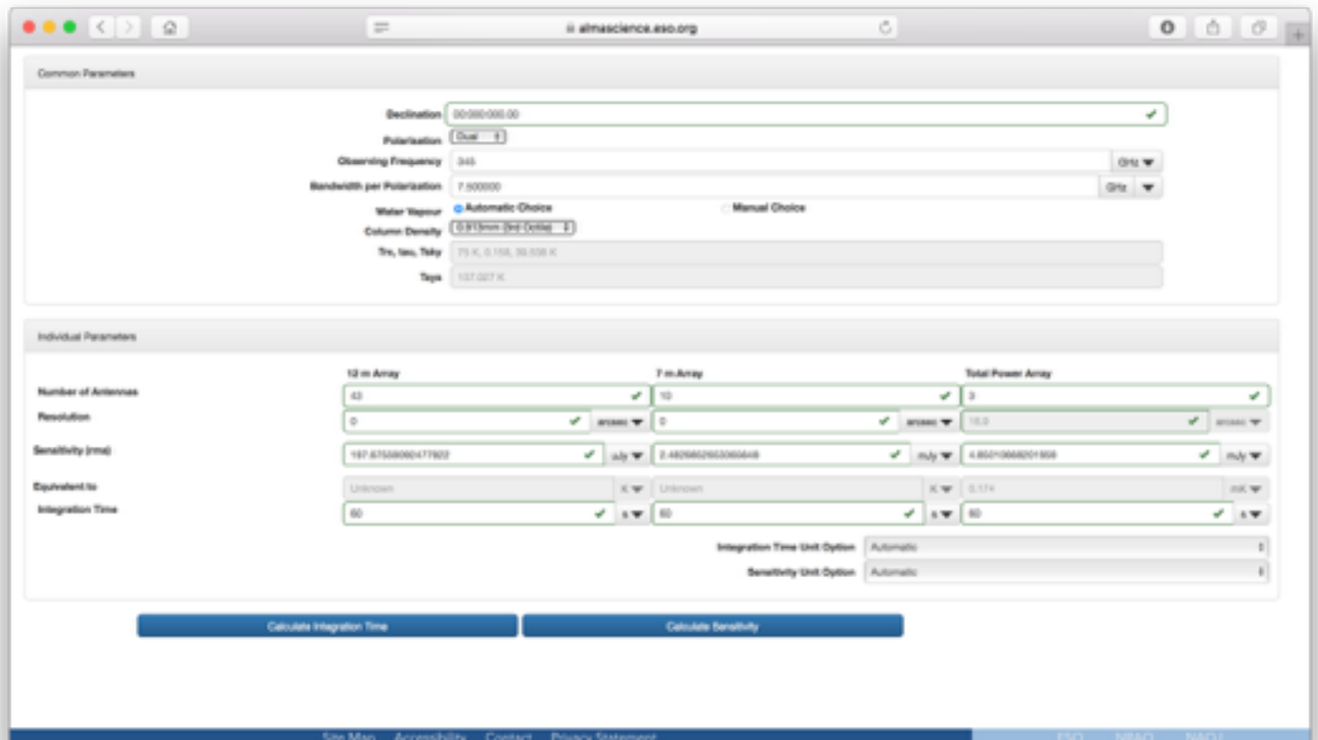
$$S_{\rm src}[{\rm Jy}] = \frac{d\Omega_{\rm array}}{d\Omega_{\rm src}}\, S^{\rm tot}_{\rm src}[{\rm Jy}]$$

The ALMA sensitivity calculator

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

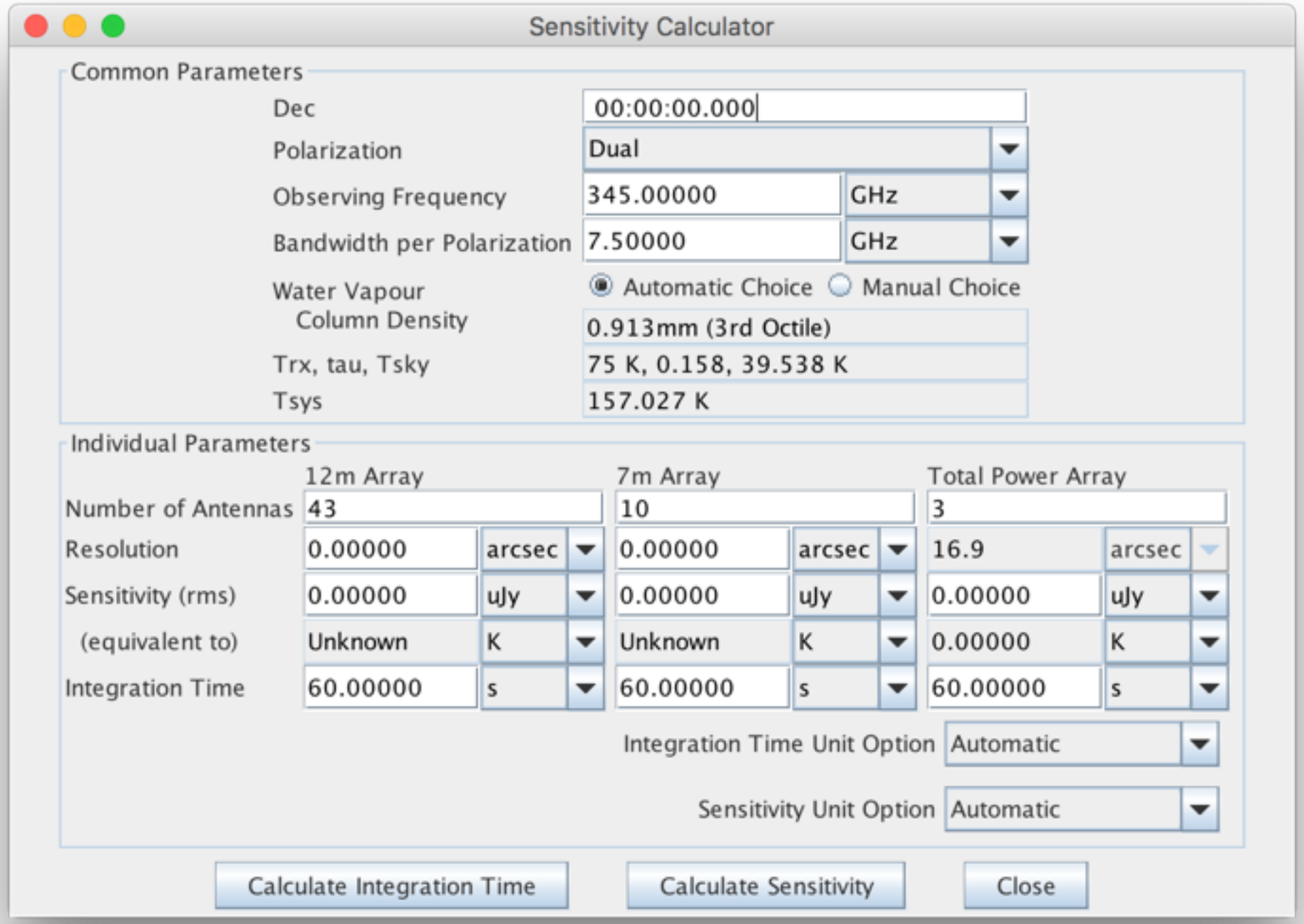
- Two versions of ALMA Sensitivity Calculator (ASC): integrated into the ALMA OT and stand-alone, available online at the ALMA Science Portal



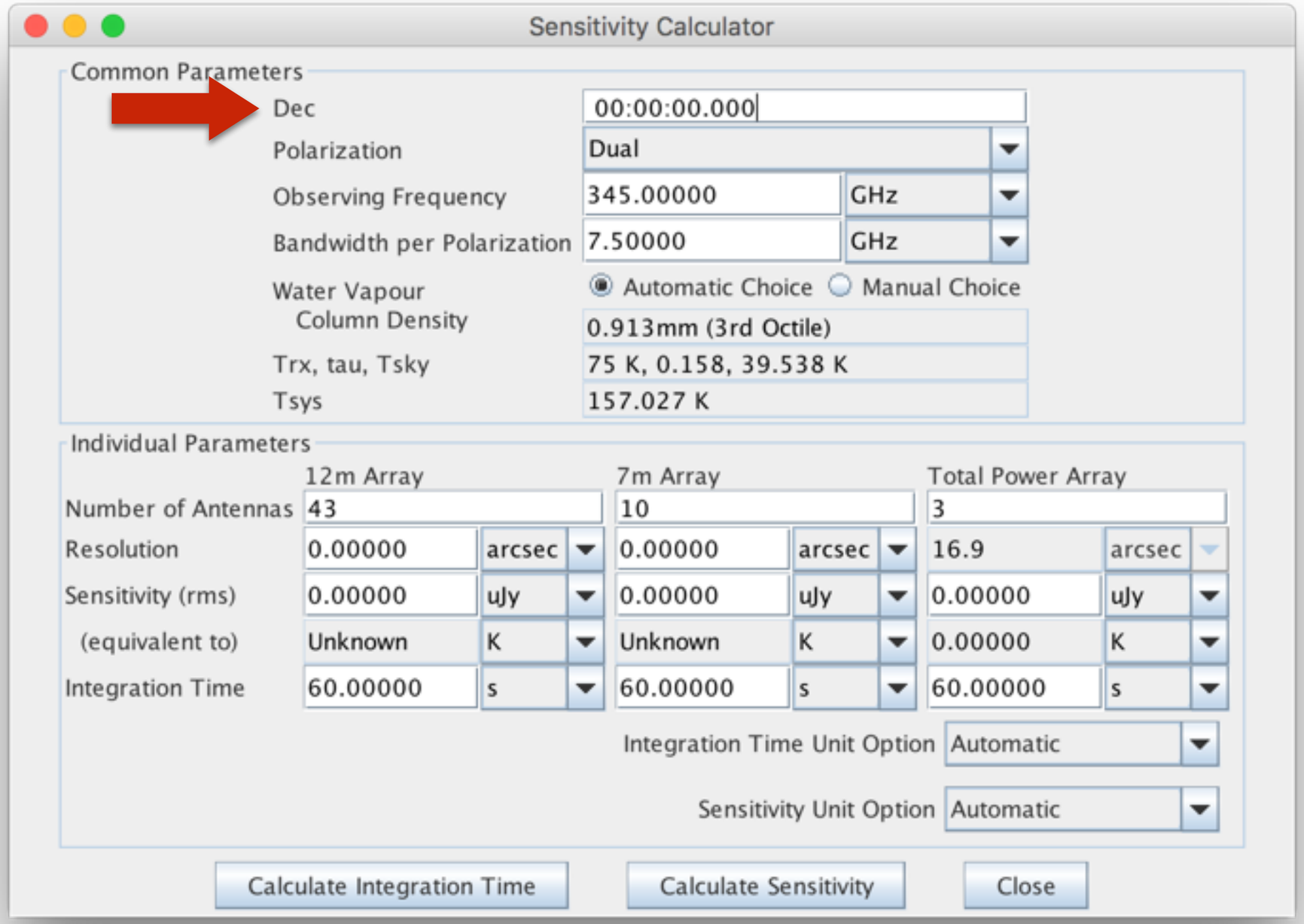


The ALMA sensitivity calculator

Inputs :



The ALMA sensitivity calculator

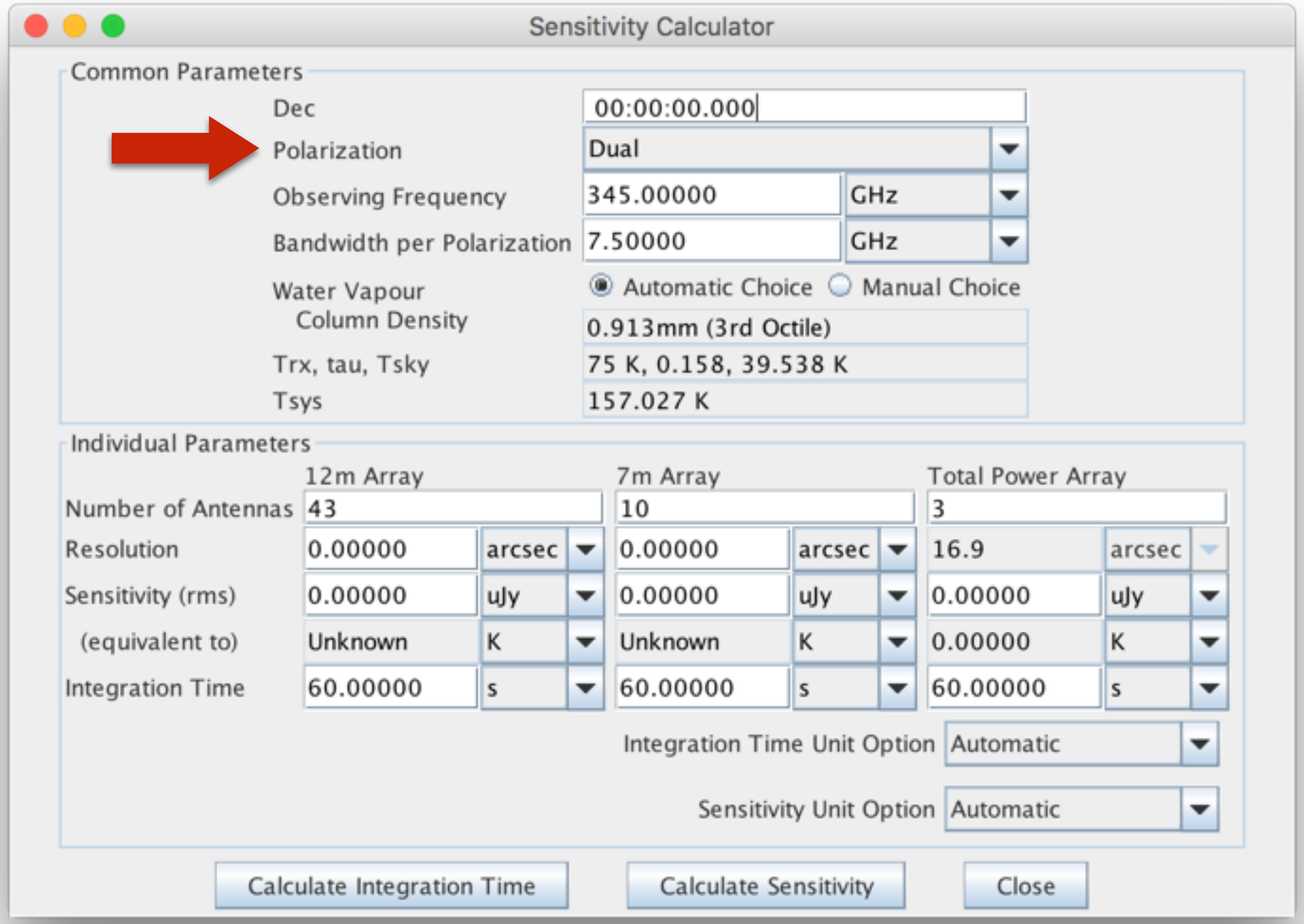


Inputs :

- Declination

—> to evaluate the atmospheric transmission and Tsky

The ALMA sensitivity calculator

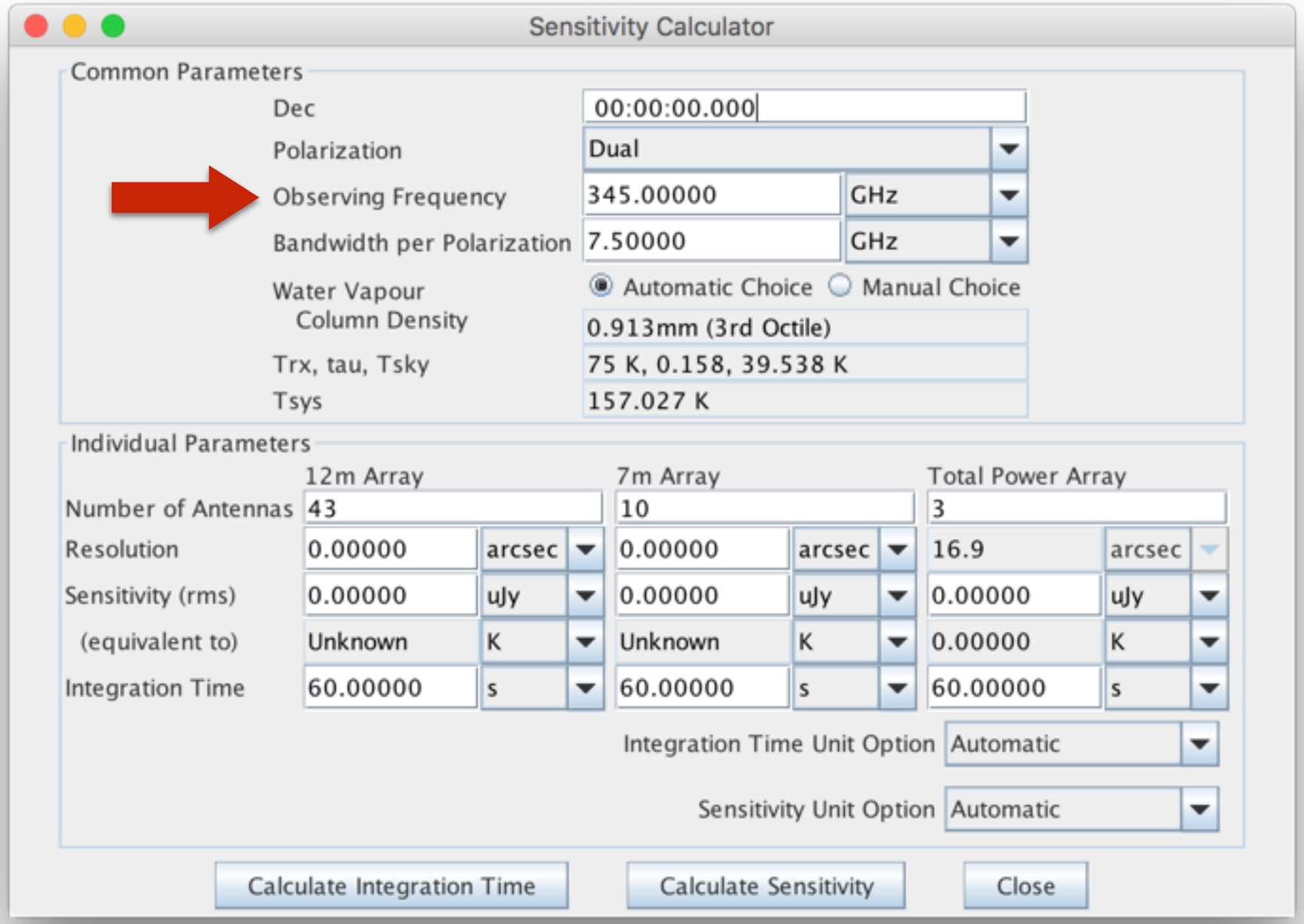


Inputs :

- Declination
- Polarisation

—> to evaluate η_{pol}

The ALMA sensitivity calculator

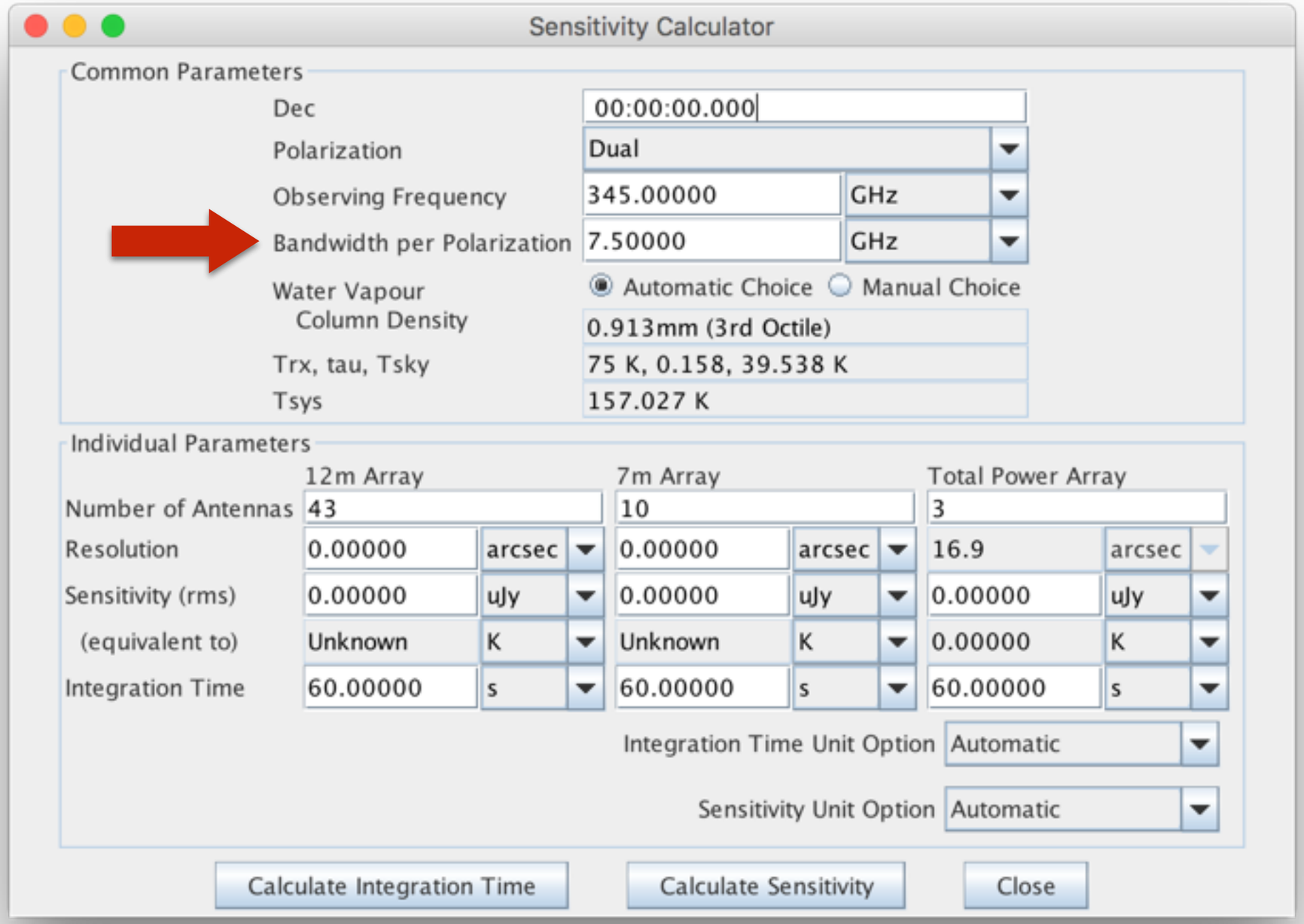


Inputs :

- Declination
- Polarisation
- Observing Frequency

—> to evaluate the atmospheric transmission and Tsky

The ALMA sensitivity calculator



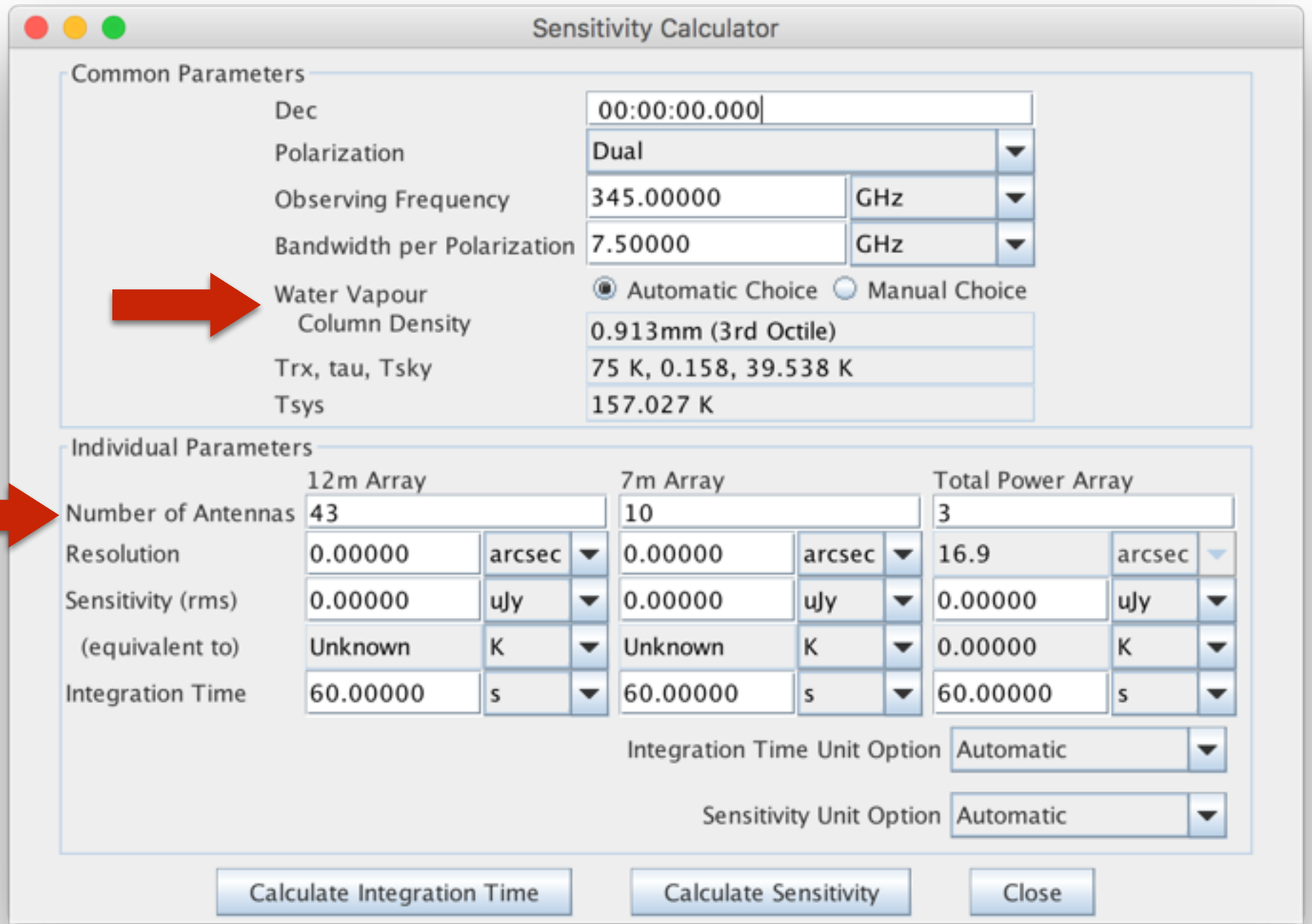
Inputs :

- Declination
- Polarisation
- Observing Frequency
- Bandwidth

—> 7.5GHz for continuum obs.

—> width of the resolution element desired for line obs., usually $\Delta v > FWHM_{line} / 4$

The ALMA sensitivity calculator

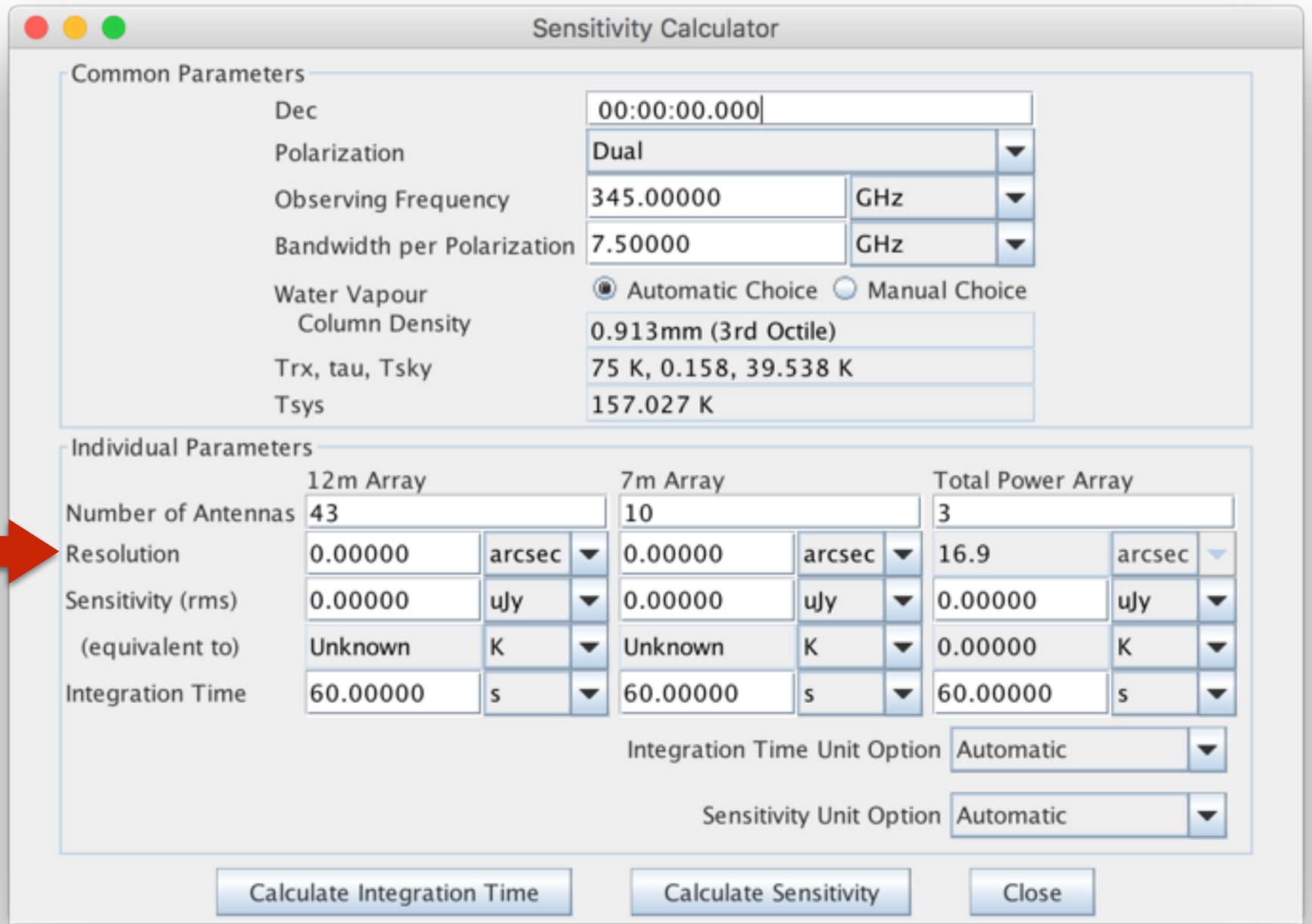


Inputs :

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

—> You should most likely keep the default values

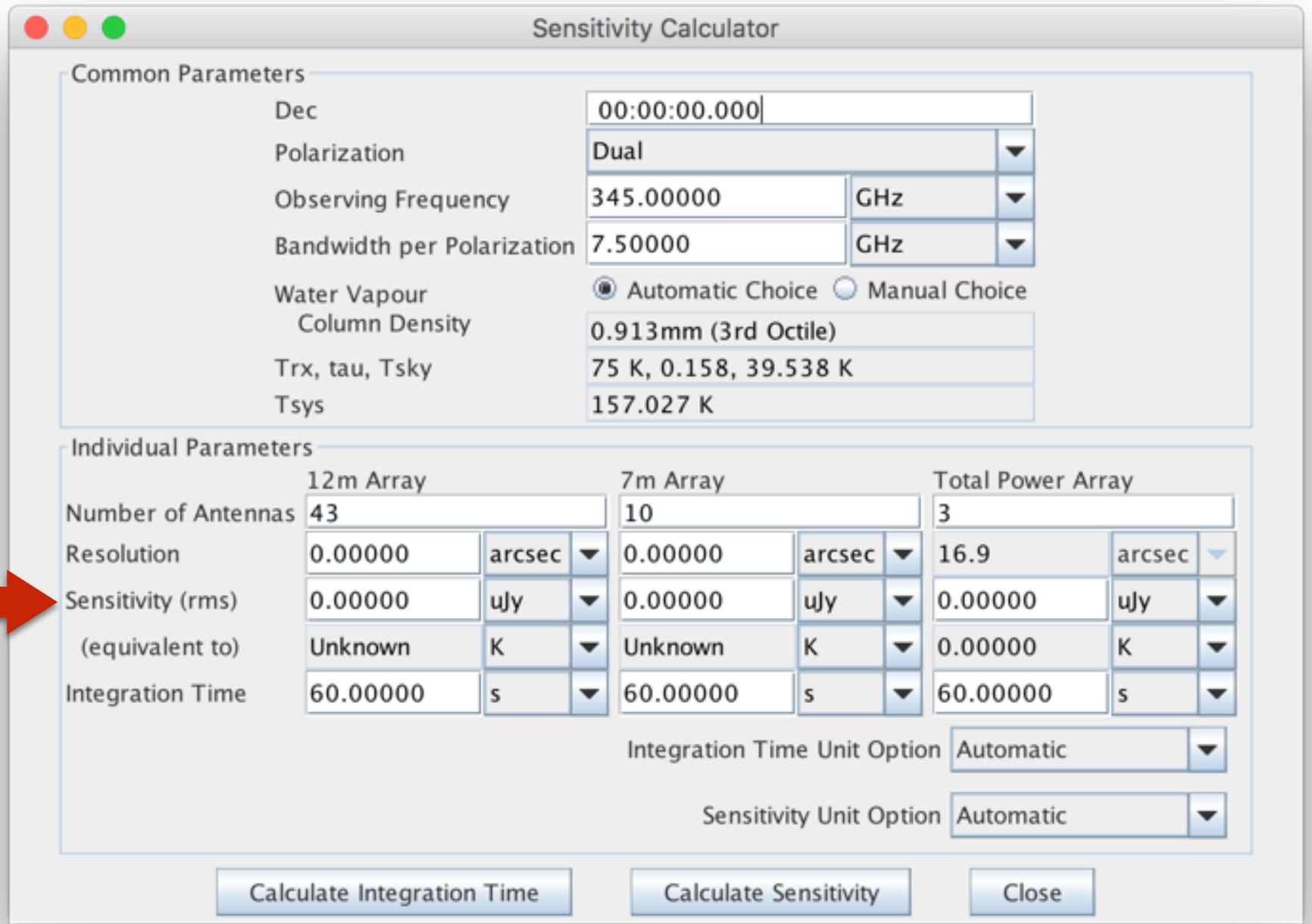
The ALMA sensitivity calculator



Inputs :

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

The ALMA sensitivity calculator

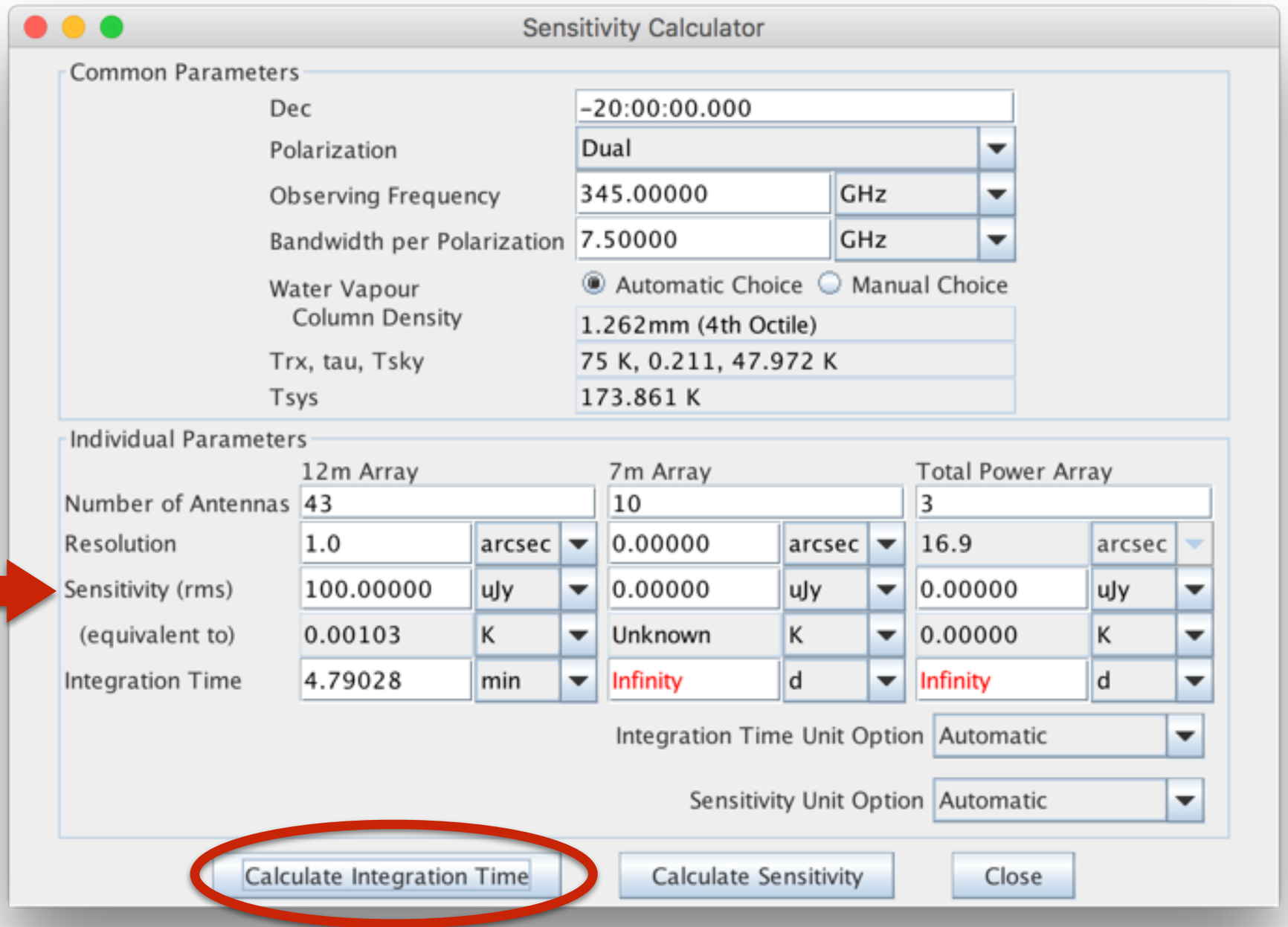


Inputs :

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

—> σ_{T} [K] or σ_{S} [Jy]

The ALMA sensitivity calculator

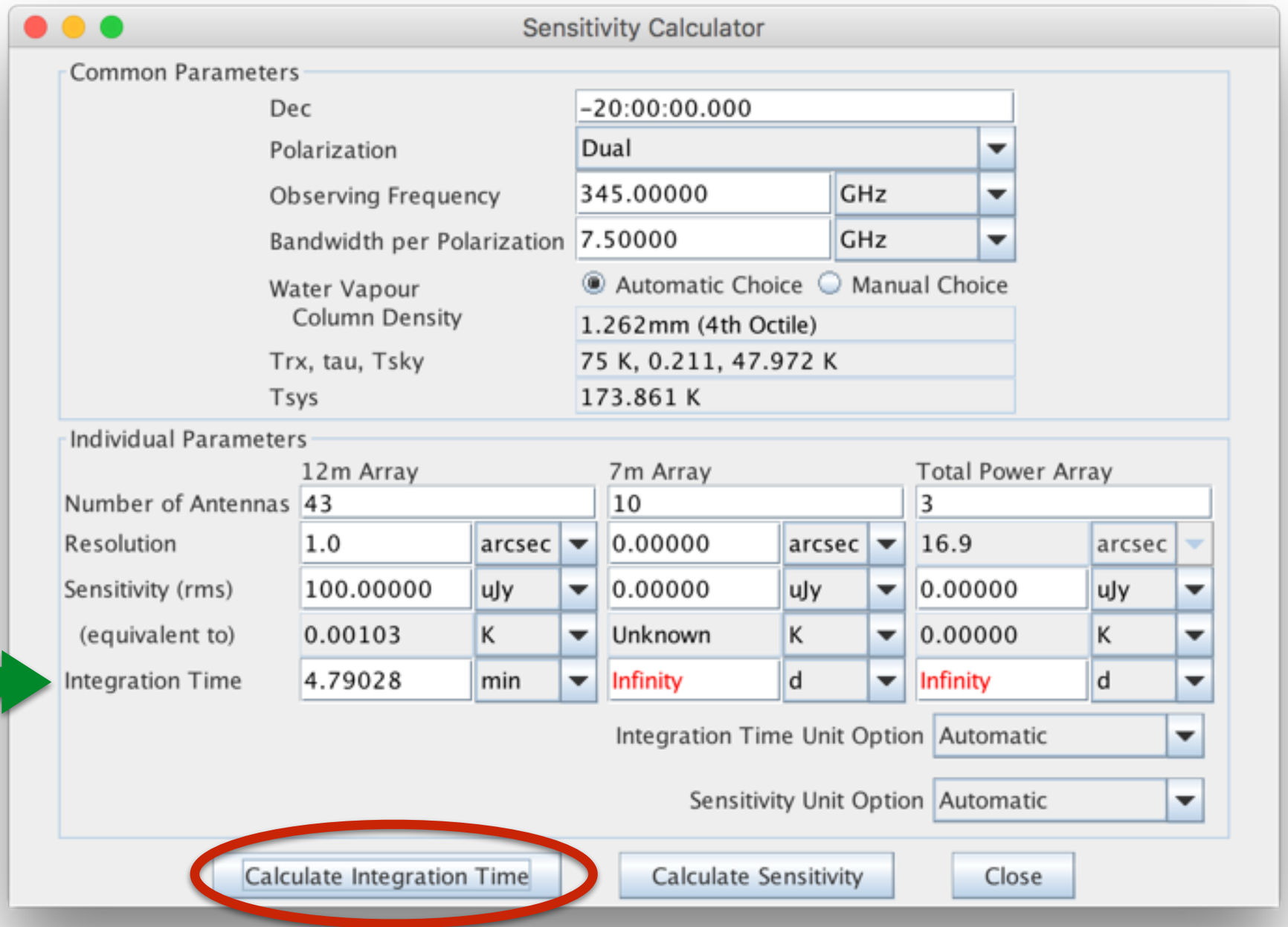


Inputs :

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

—> σ_{T} [K] or σ_{S} [Jy]

The ALMA sensitivity calculator



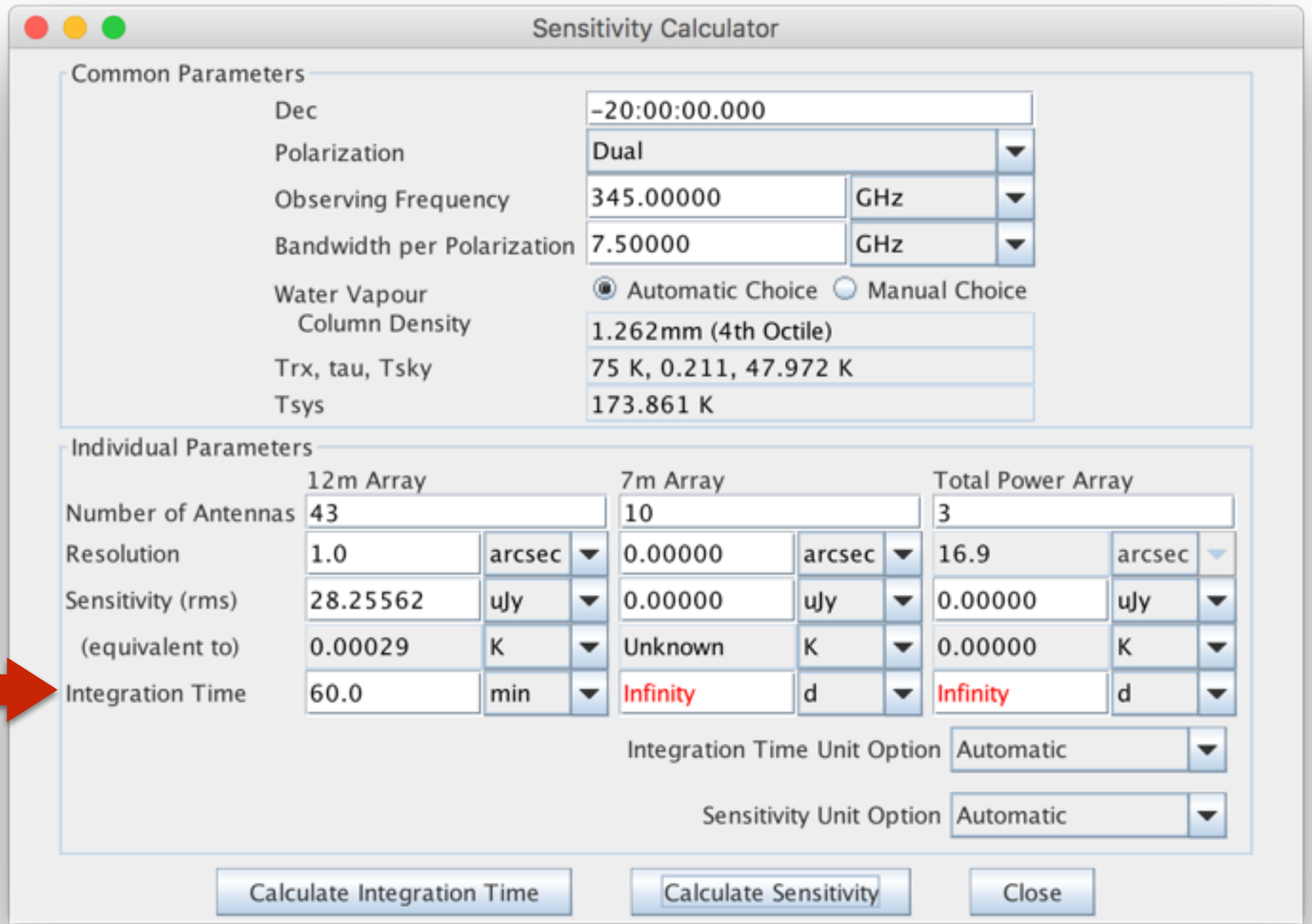
Inputs :

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

Outputs :

- On-source Integration time

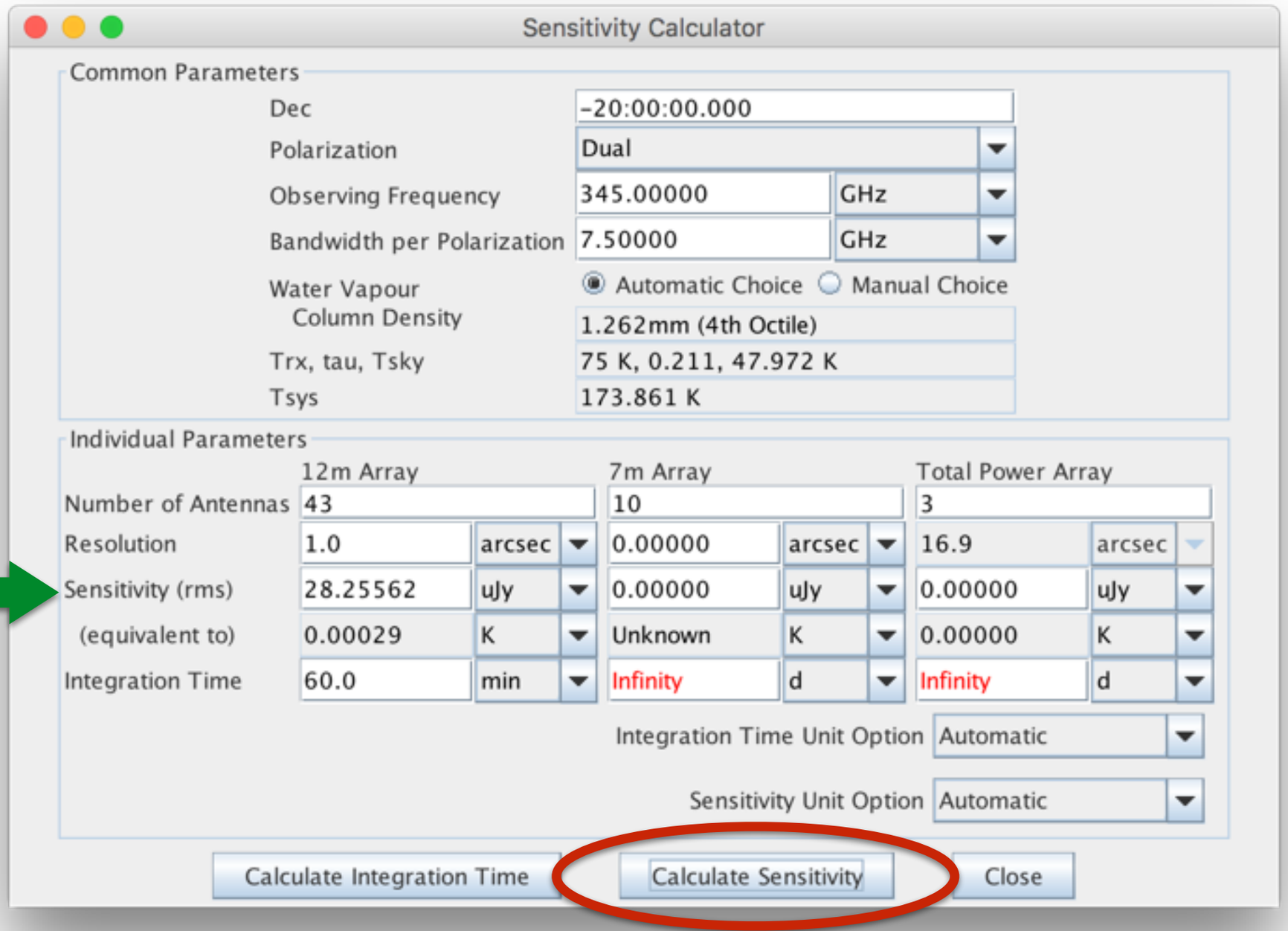
The ALMA sensitivity calculator



Inputs :

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

The ALMA sensitivity calculator



Inputs :

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

Outputs :

- Sensitivity

Conclusive Remarks

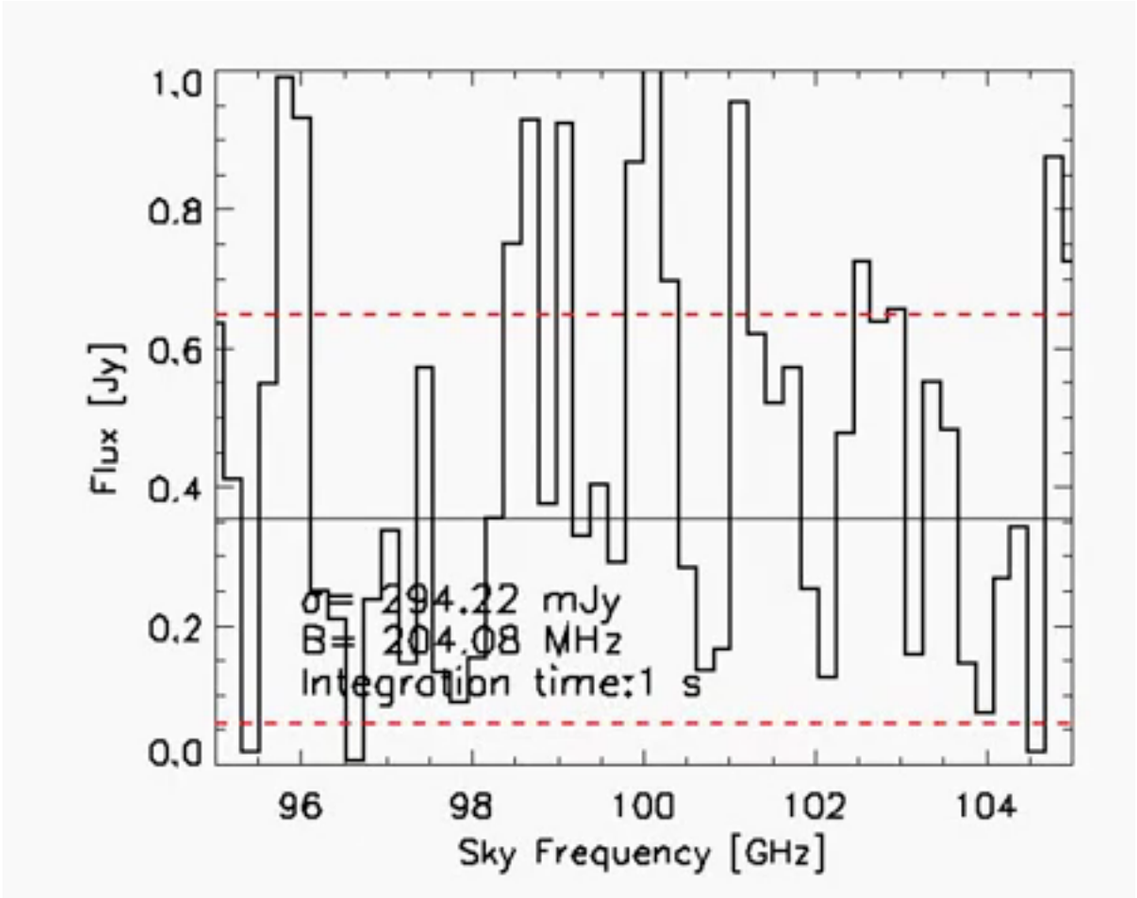
- **The ALMA sensitivity calculator is an nice tool to rapidly evaluate the feasibility of a project**

- **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)**

ALMA sensitivity: theoretical background

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

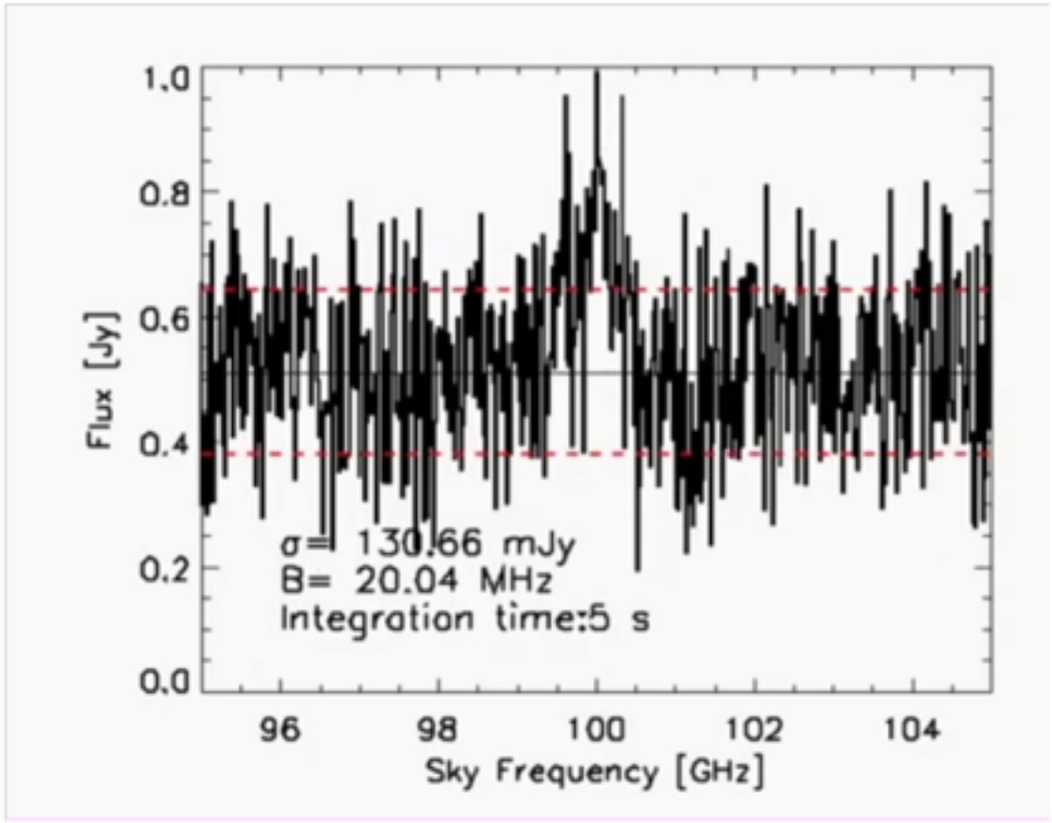
Effect of increasing the integration time

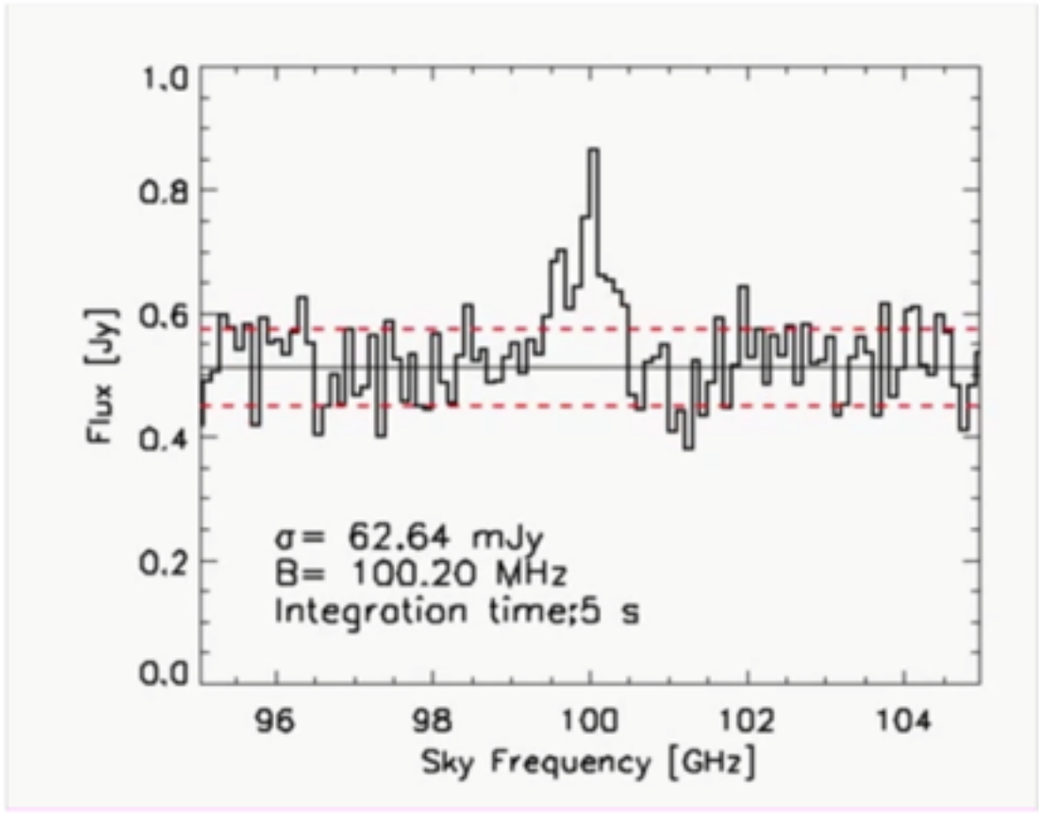


ALMA sensitivity: theoretical background

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

Effect of increasing the bandwidth





ALMA sensitivity: theoretical background

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

Effect of increasing the number of antenna