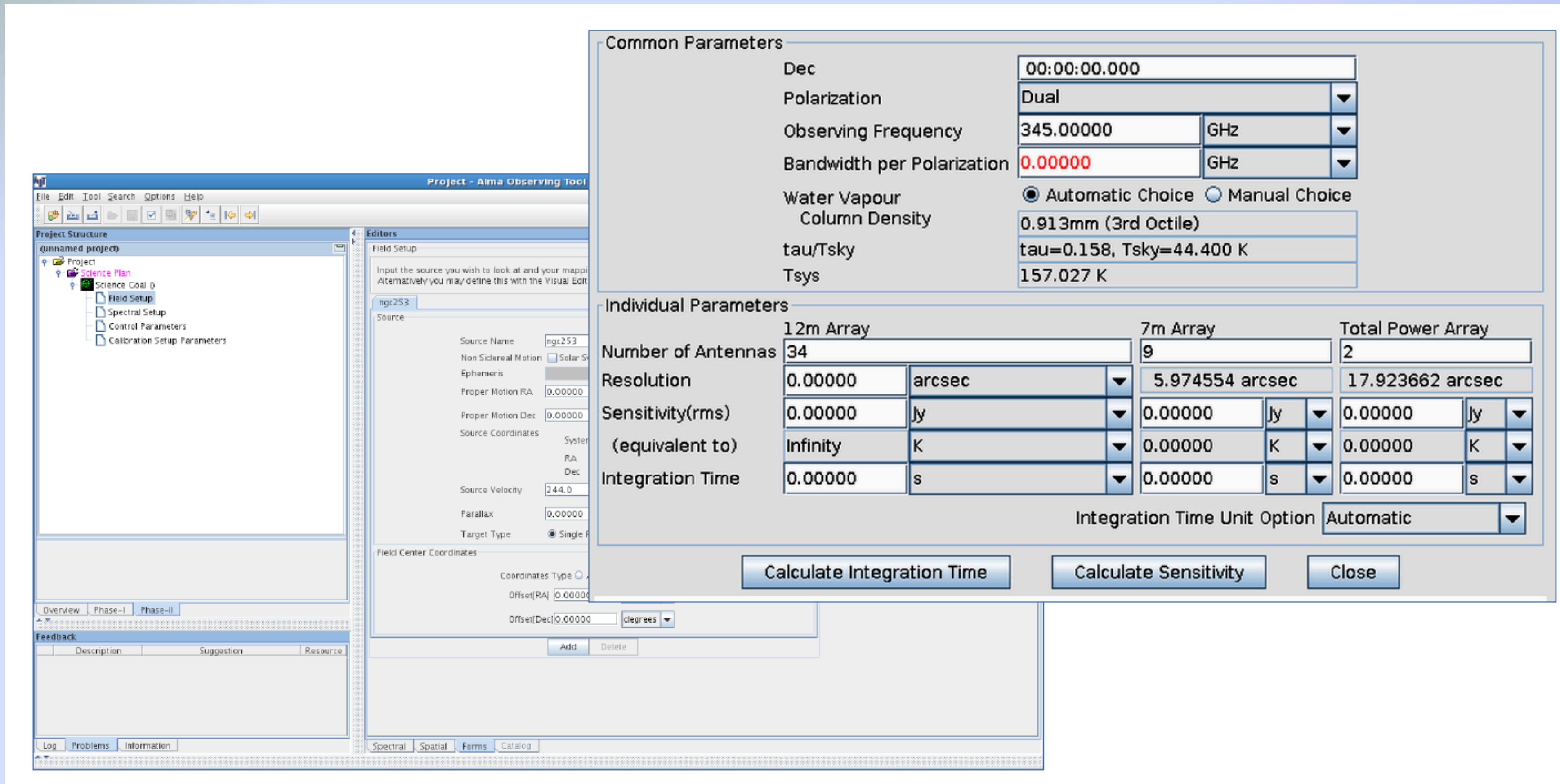
ALMA Sensitivity Calculator



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EUROPEAN ARC
ALMA Regional Centre || Germany

- Two versions of ALMA Sensitivity Calculator (ASC): integrated into the OT and stand-alone, available online at the ALMA Science Portal
- They are *almost* identical and use the same algorithms
- But when the integration times are estimated for your project using the OT ASC, it knows a little bit more about your project (e. g. the correlation modes) and always assumes the default values for some parameters (number of antennas and PWV)

- **Some theoretical background**
  Refer to Ch. 9 of the ALMA Cycle 5 Technical Handbook for more details

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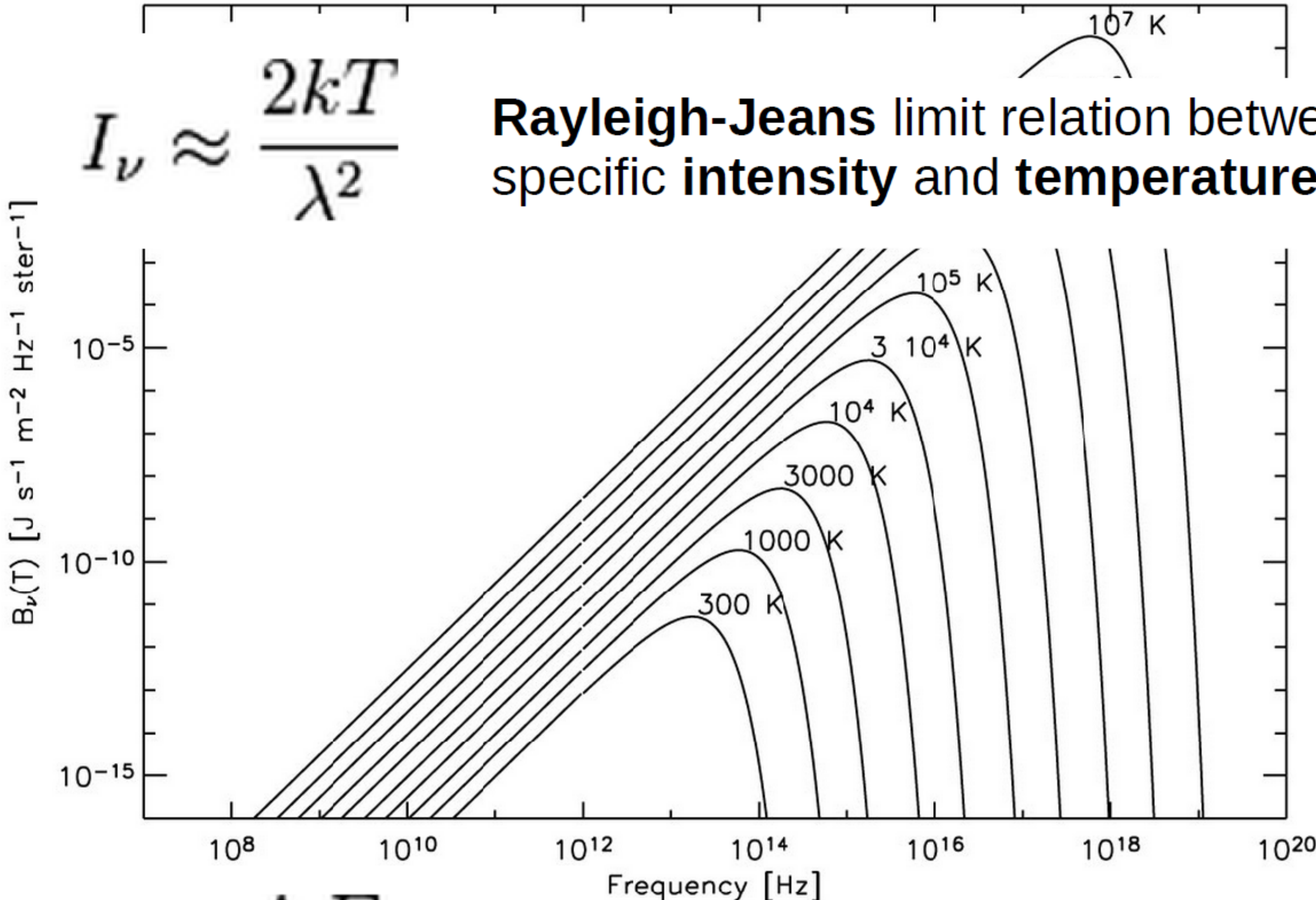
ALMA Cycle 5 Technical Handbook

ALMA

$$I_\nu \approx \frac{2kT}{\lambda^2}$$

Rayleigh-Jeans limit relation between specific **intensity** and **temperature**.



$$I_\nu = \frac{\Delta E}{\Delta\Omega \Delta A \Delta t \Delta\nu} \quad [erg\ s^{-1}\ cm^{-2}\ Hz^{-1}\ Sr^{-1}]$$

$$P_\nu = I_\nu dA d\Omega$$

$$= \frac{2kT_{src}}{\lambda^2} dA d\Omega$$

$$= 2kT_{src}$$

RJ limit means: power ~ specific intensity ~ (brightness) temperature

$$T_{sys} = T_{sky} + T_{Rx}$$

Something we don't need!

$$T_{sys} >> T_{src}$$

We need T_{src}! What to do?

$$T_{sys} >> T_{src}$$

This is usually the case!

$$T_{src} > T_{rms}$$

This is what we need to get a measurement!

$$T_{rms} = \frac{T_{sys}}{\sqrt{N}}$$

Reduce T_{rms} by sampling T_{sys}...

the sky component

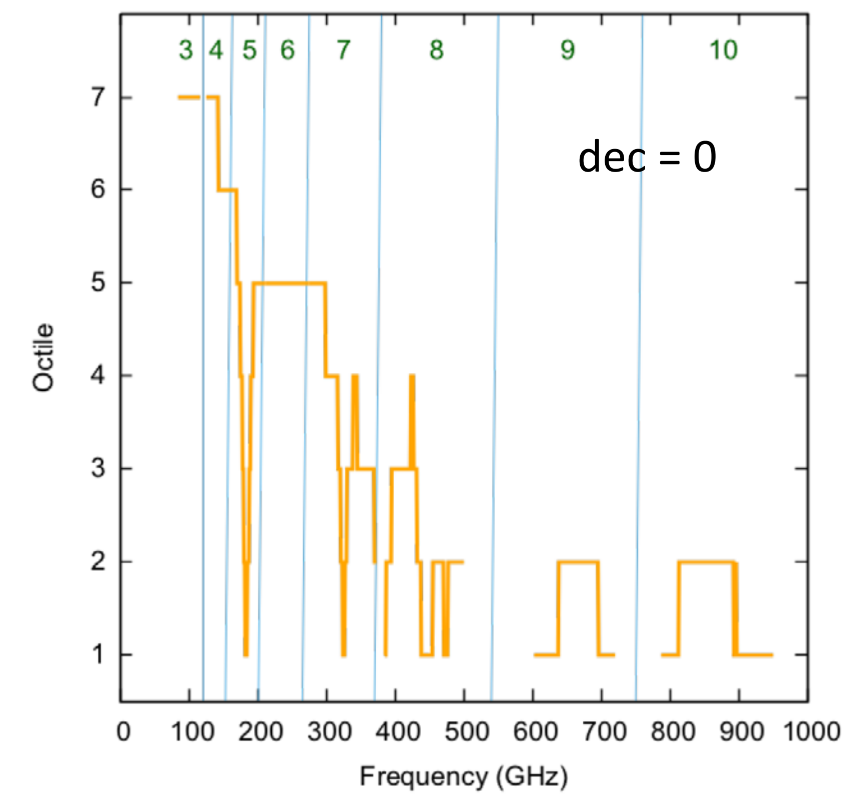
$$T_{\rm sky}(z) = T_{\rm sky}(z=0)\frac{(1-e^{-\tau_0 \sec z})}{(1-e^{-\tau_0})}$$

- z – zenith angle
- T_{sky}(z=0) and the atmospheric zenith opacity τ_0 are determined by the Atmospheric Transmission at Microwaves (ATM) code (Pardo et al. 2001) based on experimental measurements
- It includes the CMB as well as the Planck correction

Octile	PWV (mm)
1	0.472
2	0.658
3	0.913
4	1.262
5	1.796
6	2.748
7	5.186

Table 9.1: Octiles of PWV measured at the ALMA site from years of monitoring data and used in the ASC. The first octile corresponds to the best weather conditions and shows that 12.5% of the time, PWV values at least as good as 0.472 mm can be expected. Subsequent octiles give the corresponding value for 25%, 37.5%. etc.

- Automatic choice of the PWV octile: the worst, for which the int. time needed is still less than twice the previous one
- Generally higher freq. requires better weather
- But some lines are prominent (like e. g. 183 GHz water line in band 5)
- Source declination determines the elevation, in assumption of transit, so *extreme cases also need better PWV*
- **You can play with PWV during the preparation, but for the final calculation of int. time OT will force the automatic choice!**



the Rx component

ALMA Band	Receiver Type	$T_{\rm rx,spec}$ (K)	$T_{\rm rx,ASC}$ (K)
1	SSB	17	17
2	SSB	30	30
3	2SB	37	**45**
4	2SB	51	51
5	2SB	65	**55**
6	2SB	83	**55**
7	2SB	147	**75**
8	2SB	196	**150**
9	DSB	175	**110**
10	DSB	230	230

Table 9.2: Receiver temperatures (and their specifications) assumed in the ASC as a function of ALMA band. For most of the bands it is currently assumed the ALMA specification for the receiver temperature that should be achieved across 80% of the band, $T_{\rm rx,spec}$. In practice, the receivers actually outperform the specification and for Bands 3, 6, 7, 8 and 9 the ASC uses "typical temperatures measured in the laboratory" (highlighted in bold text).

- at the moment no freq. dependence across the band
  and the actually measured values included only for some bands
  (specification for the others)
- note that usually ALMA receivers *outperform* the specification!

the spillover component

- assumes the typical T_{amb}=270K ambient temperature (which still results in frequency dependence due to the Planck correction)
- assumes the fixed coupling factor or forward efficiency η_{eff} = 0.95, i. e. 5% spillover

the total Tsys

$$T_{\mathrm{sys,ndsb}} = \frac{1}{\eta_{\mathrm{eff}} e^{-\tau_0 \sec z}} \left(T_{\mathrm{rx}} + \eta_{\mathrm{eff}} T_{\mathrm{sky,s}} + (1 - \eta_{\mathrm{eff}}) \times T_{\mathrm{amb,s}} \right)$$

- This expression is for non-DSB receivers, i. e. single sideband (SSB) in bands 1-2 or sideband-separating (2SB) in bands 3-8.
- For bands 9-10 and their double sideband (DSB) receivers see the handbook for some complications!

the final sensitivity expression

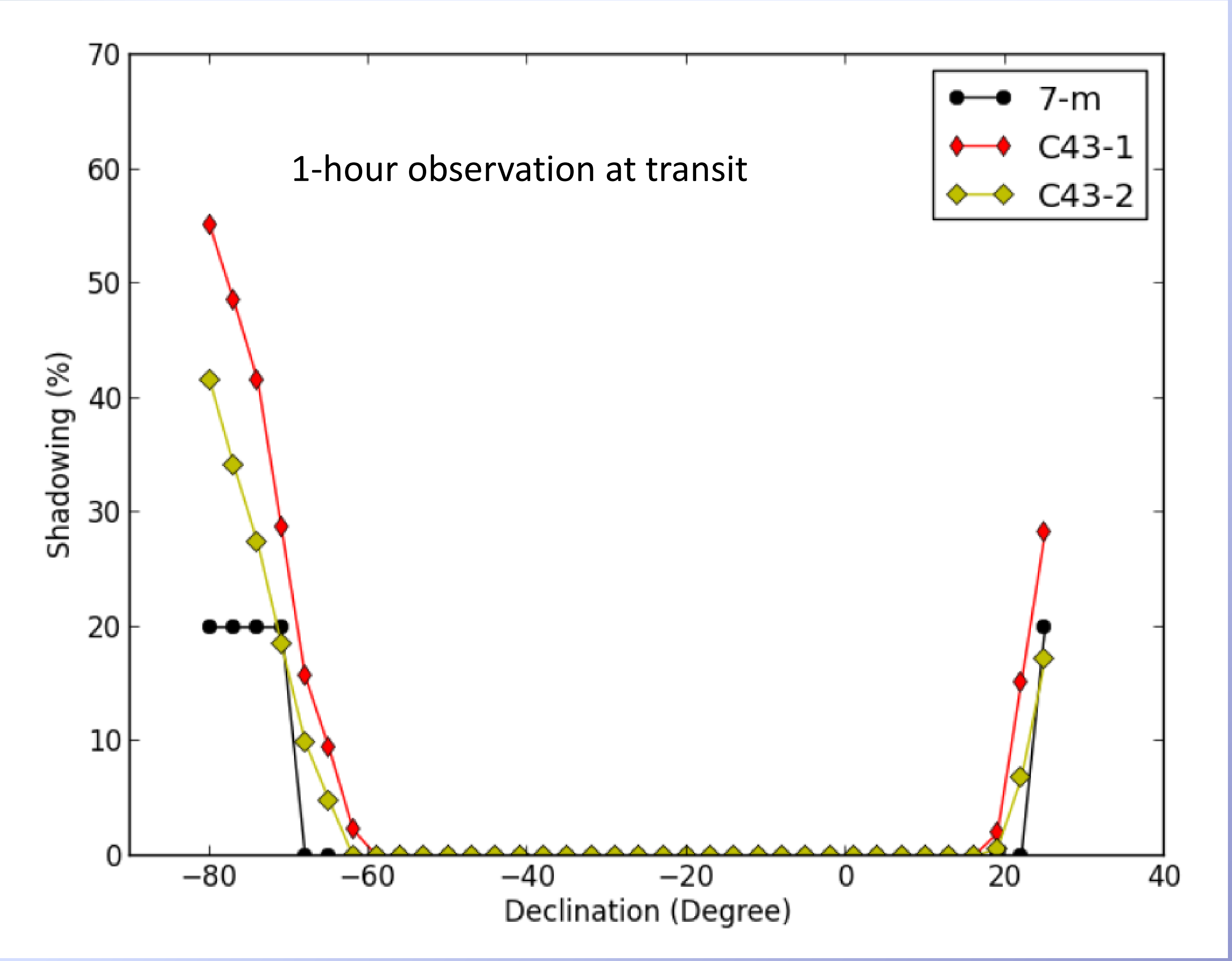
(point-source sensitivity in Jy)

$$\sigma_{\rm S} = \frac{w_r\, 2\, k\, T_{\rm sys}}{\eta_{\rm q}\eta_{\rm c} A_{\rm eff}(1 - f_s)\sqrt{N(N-1)\, n_{\rm p}\, \Delta\nu\, t_{\rm int}}}.$$

- slightly simpler for the total power array, refer to the handbook for details
- includes a few factors close to 1: ω_r=1.1 (robust weighting factor, assuming Briggs weighting 0.5); η_q = 0.96 (3-bit quantization efficiency), η_c = 0.88 (correlator efficiency assuming 64-input mode)
- n_p = 1 for single pol and 2 for dual/full pol

  sometimes $n_p \Delta v$ is called "effective bandwidth"

- f_s – shadowing fraction



- A_{eff} – the effective area

Band	Frequency (GHz)	$\eta_{ap,12\ m}$ (%)	$\eta_{ap,7\ m}$ (%)
3	100	71	71
4	145	70	71
6	230	68	69
7	345	63	66
8	405	60	64
9	690	43	52
10	870	31	42

Table 9.3: Aperture efficiencies at typical continuum frequencies for both the 12 and 7 m antennas. The effective area, A_{eff}, is equal to η_{ap} multiplied by the physical area of the dish i.e. 113.1 m^2 and 38.5 m^2 for the 12 and 7 m antennas respectively.

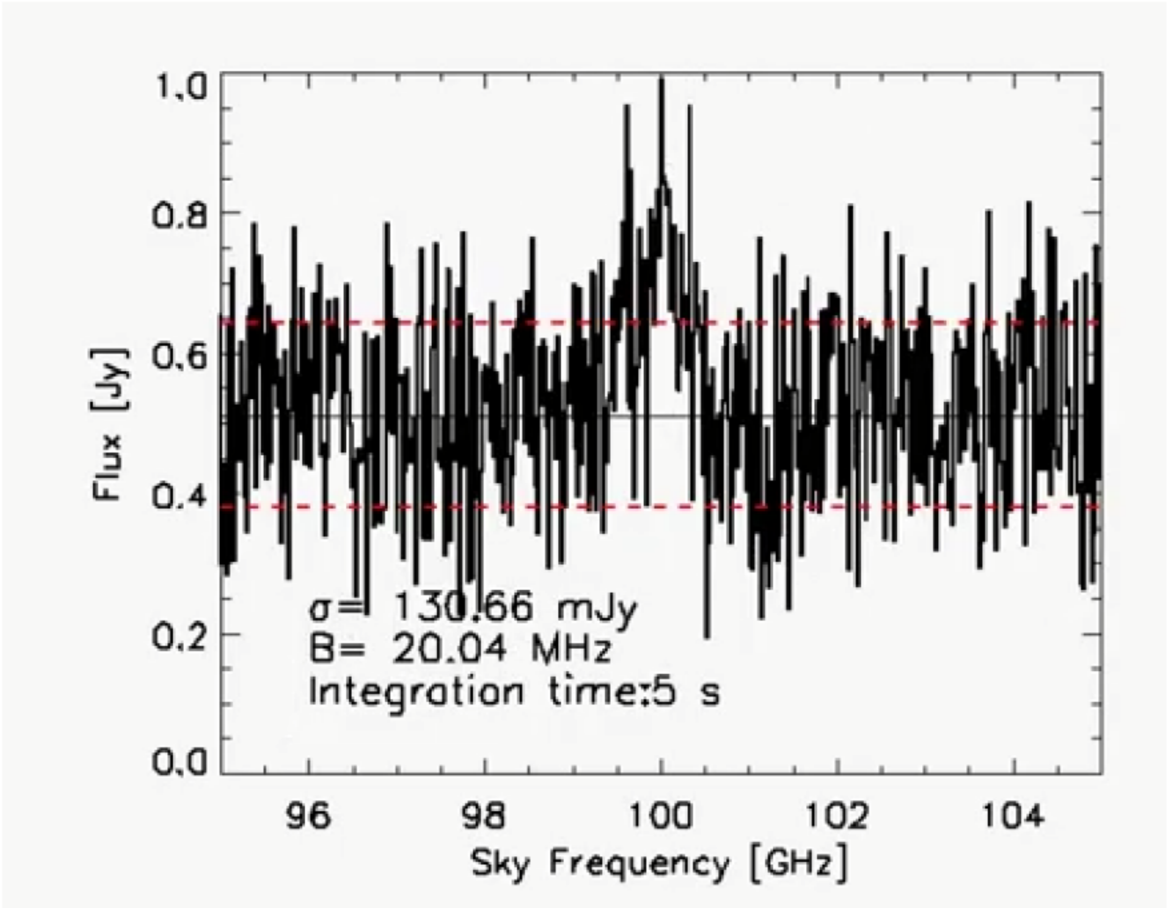
- a simpler version

System **E**quivalent **F**lux **D**ensity

$$S_{rms} \simeq \frac{SEFD}{\sqrt{n(n-1)\cdot \Delta\nu \cdot t}} [\mathrm{Jy}]$$

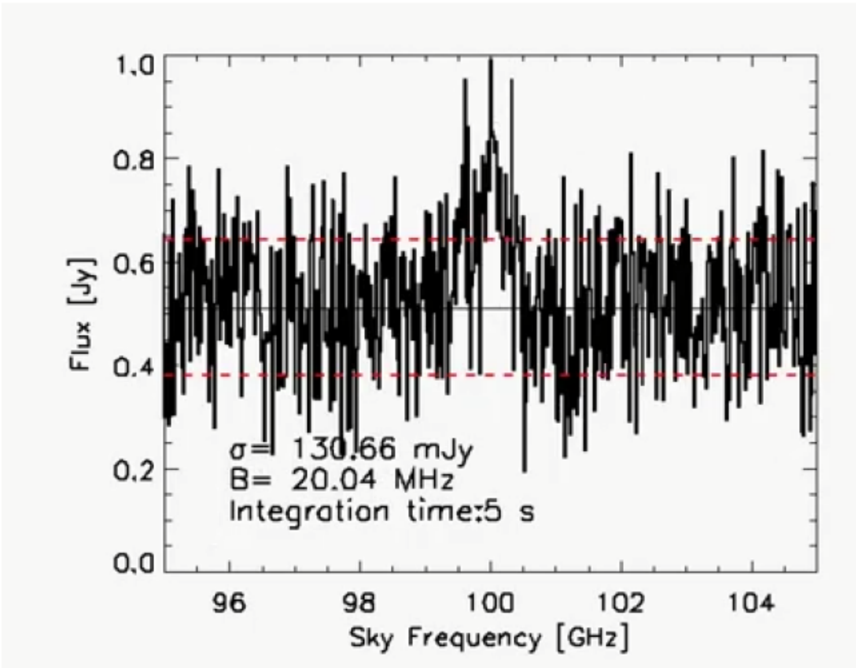
n(n-1) = number of baselines, n is the number of antennas
Δν = frequency range (bandwidth) in Hz
t = exposure time (on source time) in seconds

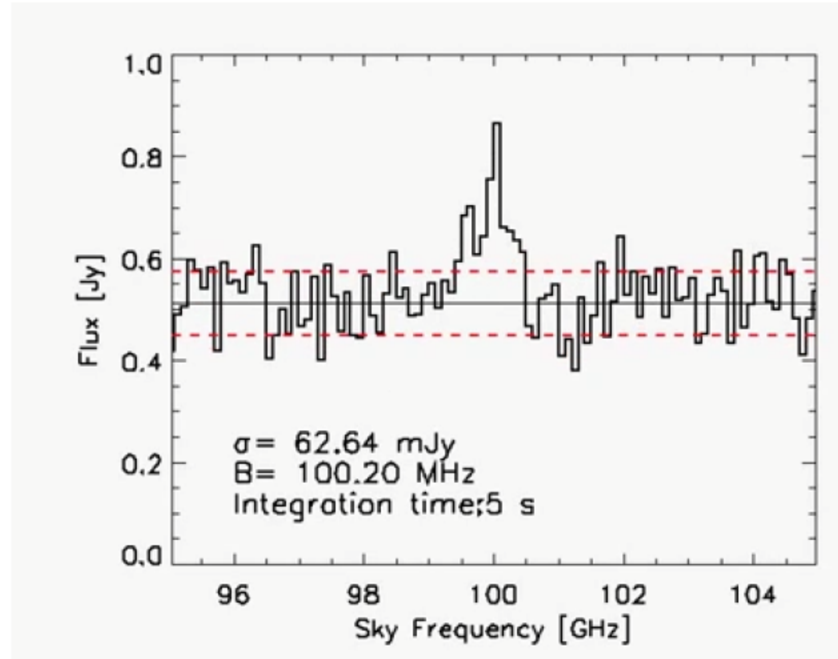
Effects of time on source



$$S_{rms} \simeq \frac{SEFD}{\sqrt{n(n-1)\cdot \Delta \nu \cdot t}} [\mathrm{Jy}]$$

Effects of Resolution

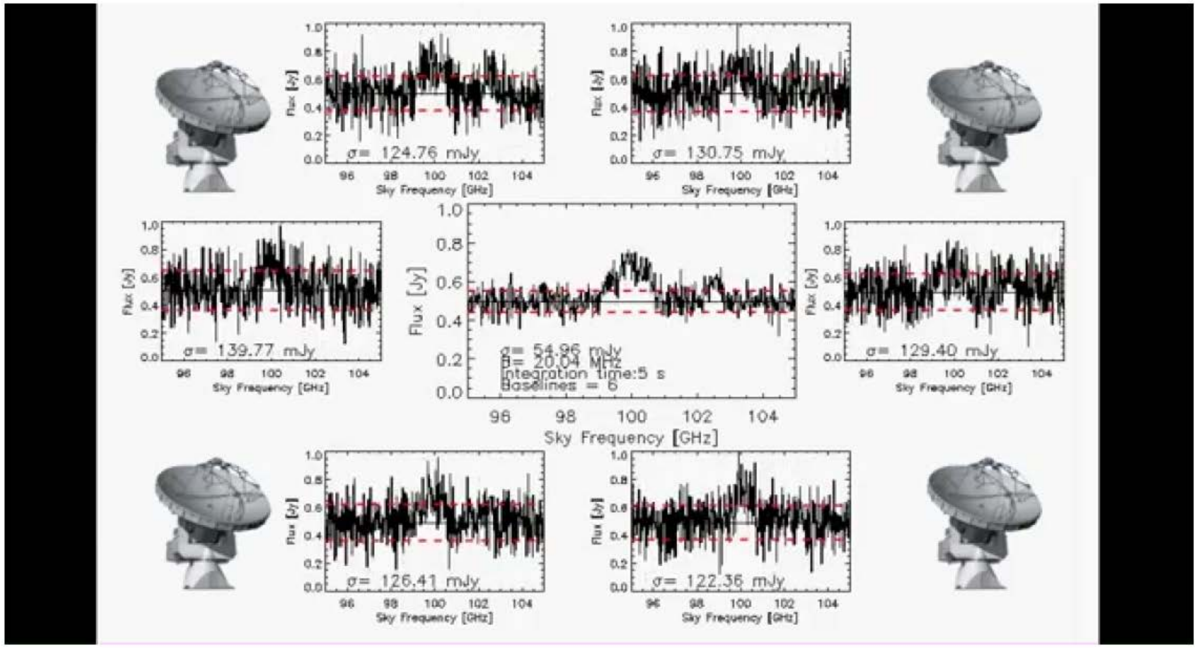




Note: 7.5 GHz = 4 x 1.875 GHz should be used for "continuum bandwidth"

$$S_{rms} \simeq \frac{SEFD}{\sqrt{n(n-1)\cdot B \cdot t}} [\mathrm{Jy}]$$

Adding More Antennas...



$$S_{rms} \simeq \frac{SEFD}{\sqrt{n(n-1)\cdot B\cdot t}}\,[\mathrm{Jy}]$$

Note: for the final sensitivity calculation the OT will always use a "standard" number of antennas for this cycle: 43 for the 12-m array and 10 for the 7-m array!

$$\sigma_T = \frac{\sigma_S \lambda^2}{2k\ \Omega}$$

σ_T – surface brightness sensitivity in K as related the point-source sensitivity in Jy (σ_S)

$$\Omega = \frac{\pi\theta^2}{4\ln 2}.$$

A circular Gaussian beam related to the half-power beam width θ (the ASC input parameter)

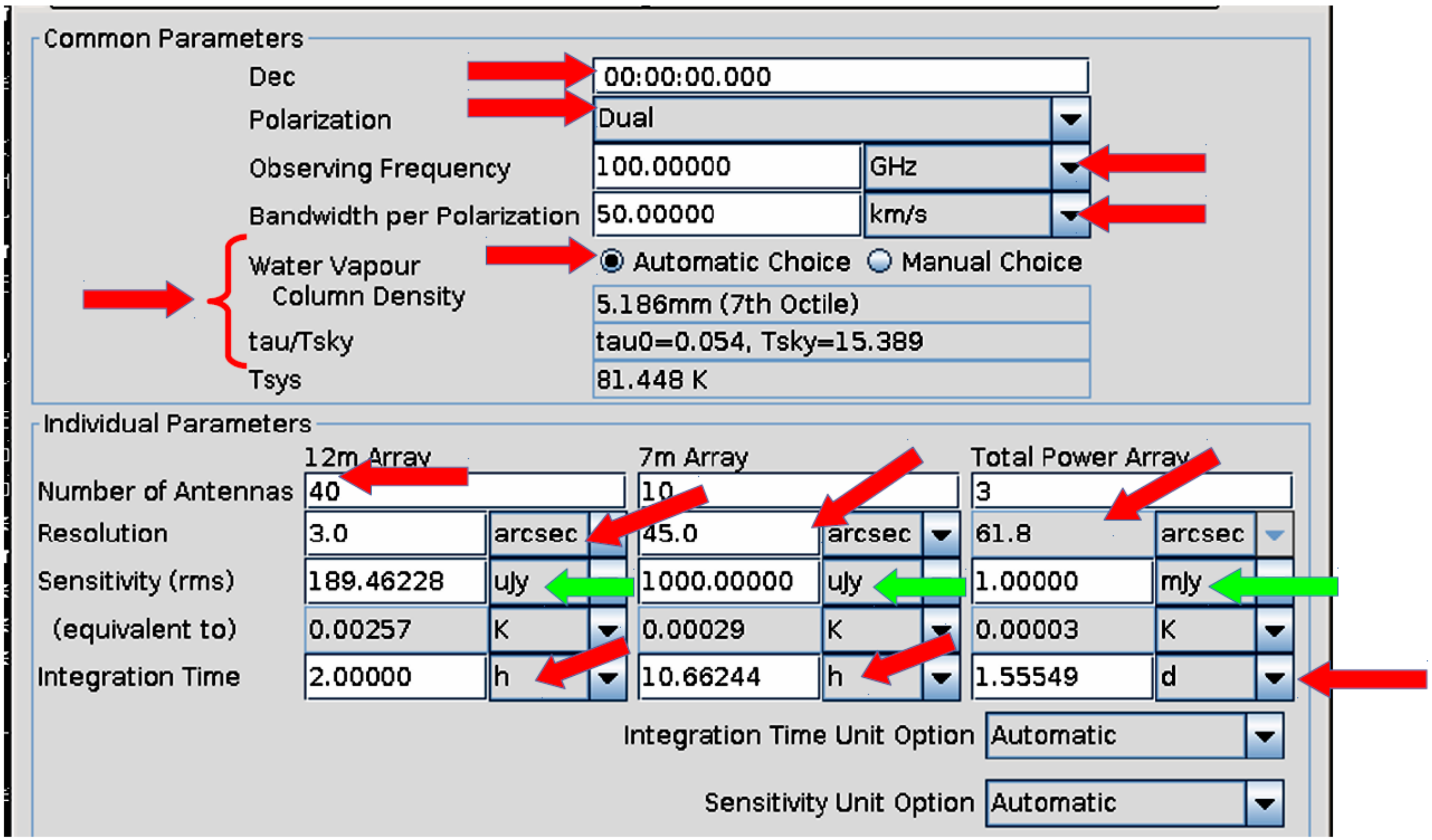
The ASC calculates both σ_T and σ_S !

Inputs to calculator:

- declination (for elevation)
- frequency (e.g. for atmospheric absorbtion etc.)
- weather (optional)
- number of antennas (gives number of baselines)
- resolution (gives the Δν)
- integration time (gives the value of t)

Output:

- Sensitivity reached

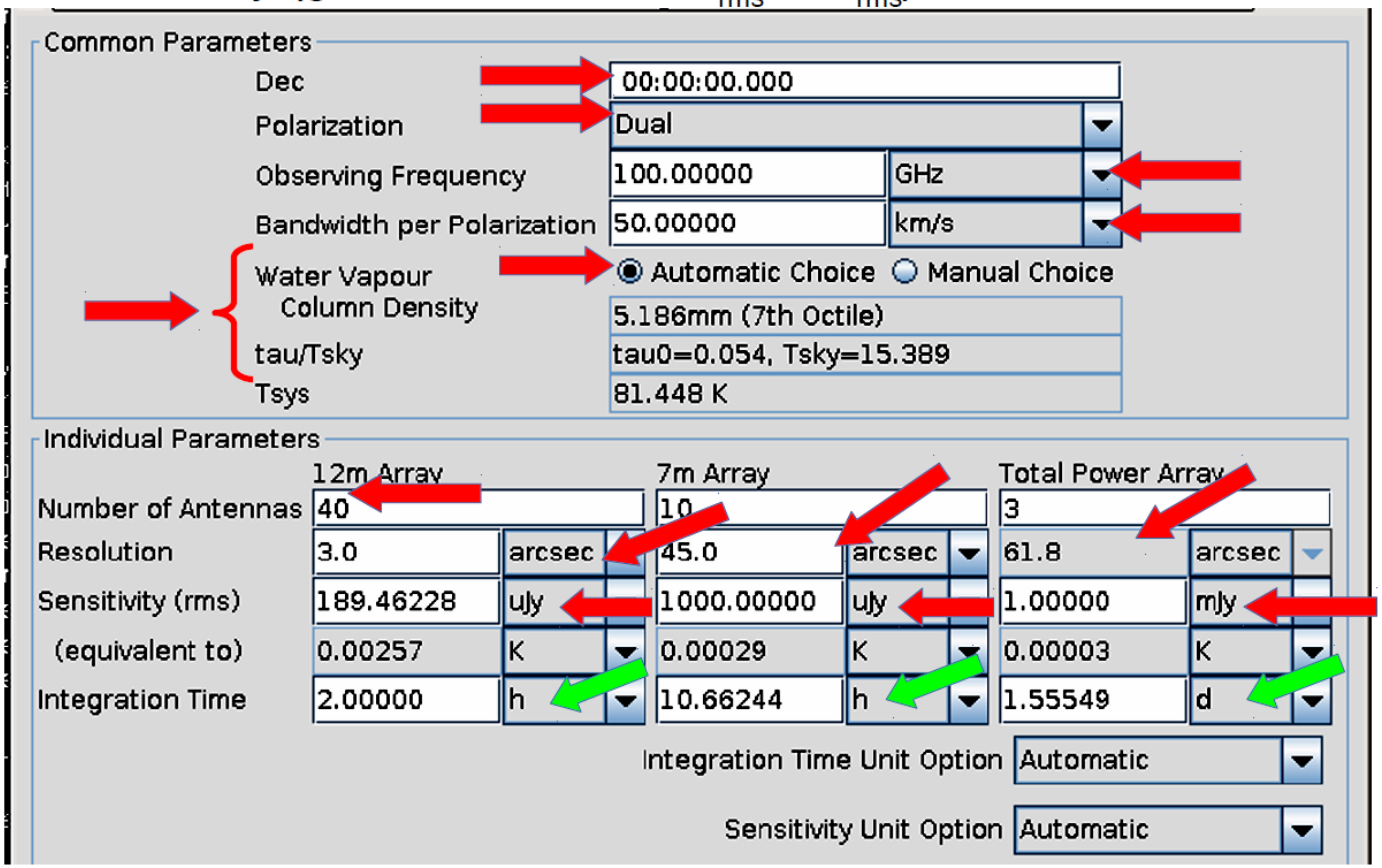


Inputs to calculator:

- declination (for elevation)
- frequency (e.g. for atmospheric absorbtion etc.)
- weather (optional)
- number of antennas (gives number of baselines)
- resolution (gives the Δν)
- desired sensitivity (gives the value of S_{rms} or T_{rms})

Output:

- Integration time required



Not magic!

- The ASC does not know about certain things (e. g. some telescope and software limitations) and makes some ideal assumptions
- The most important one: ALL time is assumed to be the on-source integration time. It is YOUR responsibility to allow the overhead for calibration etc. and check the OT's final estimate!