

Zermatt Millimeter Telescope

Guideline sensitivities

This document provides guideline sensitivities for two separate dish+receiver combinations, and for both single-dish operations (Sect. 1) and interferometry with a homogeneous dish array (Sect. 2). These sensitivity estimates apply to generally favourable observing conditions (target source close to zenith, winter weather) and do not take into account all variations of the system temperature as a function of frequency within the individual receiver tuning bands, as a function of target elevation, and/or due to local atmospheric conditions. They should thus be regarded as indicative performance estimates, and are suitable only for initial proof-of-concept calculations.

The formulae and reference values below represent performance estimates for *individual* receiver bands. When deriving total telescope time estimates for use cases requiring observations in multiple receiver bands, it should be born in mind that modern correlators in many cases enable multi-band observations to be executed *simultaneously*. Simultaneous multi-band observations generate substantial time savings compared to the straight sum of the per-band telescope times.

1. SINGLE-DISH OBSERVATIONS

The rms spectral noise level σ and the time t_{on} spent on-source observing the target in single-dish mode are related via

$$\left(\frac{\sigma}{\text{Jy}}\right) = \frac{1}{\eta_c} \sqrt{\frac{2}{n_{\text{pol}}}} \left(\frac{\mathcal{J}}{\text{Jy/K}}\right) \left(\frac{T_{\text{sys}}}{\text{K}}\right) \left(\frac{\Delta\nu}{\text{Hz}}\right)^{-1/2} \left(\frac{t_{\text{on}}}{\text{s}}\right)^{-1/2}. \quad (1)$$

Here T_{sys} is the system temperature, $\Delta\nu$ the bandwidth over which the signal is integrated, and n_{pol} the number of linear polarisation directions combined ($n_{\text{pol}} = 2$, usually). η_c is an efficiency factor (related to signal-to-noise losses during the digitization process in the backend) that is typically close to unity. $\mathcal{J}$ is the Jansky-per-Kelvin conversion factor, which is inversely proportional to the effective dish area $\eta_a A_{\text{dish}}$ (η_a is the aperture efficiency).

Eq. (1) assumes tracked observations in simple *position switching* mode¹ (e.g., wobbler switching), where an off-measurement is obtained by pointing the telescope to a nearby sky location. An off-measurement is required, as the total power measurement obtained at the target position includes contributions from, e.g., the atmosphere or large-scale astrophysical emission in addition to the desired signal. The emission from the target itself can then be recovered by constructing

¹ Adjustments to eq. (1) for other switching or target tracking modes are discussed in, e.g., IRAM Memo 2009-1.

TABLE 1. Antenna+receiver system parameters for two dish models, at three reference frequencies ν_{ref} (chosen to approx. minimize T_{sys} in each of the three receiver bands). Representative full tuning ranges of these receiver bands are: 70–120 GHz (3 mm band), 195–275 GHz (1 mm band) and 275–375 GHz (0.8 mm band).

dish model	band	ν_{ref} [GHz]	T_{sys} [K]	$\mathcal{J}$ [Jy/K]	θ_{bm} [arcsec]
(1)	(2)	(3)	(4)	(5)	(6)
ngEHT ($D = 13$ m)	3 mm	86	80	27.3	67.5
	1 mm	230	175	29.3	25.2
	0.8 mm	345	370	32.6	16.8
NOEMA ($D = 15$ m)	3 mm	86	80	22.0	58.5
	1 mm	230	175	23.6	21.9
	0.8 mm	345	370	25.6	14.6

a difference spectrum from the signals recorded in the ‘on’ and ‘off’ positions. In position switching the overall on-sky time required is $t_{\text{on+off}} = 2 \cdot t_{\text{on}}$, and the total telescope time $t_{\text{tel}} = t_{\text{on+off}}/\epsilon_{\text{tel}}$. The telescope efficiency factor ϵ_{tel} – which accounts for overheads for calibration and slewing overheads, but not for receiver tuning – is in general ~ 0.5 .

Table 1 lists T_{sys} values and Jansky-per-Kelvin factors $\mathcal{J}$ for three different receiver bands in the 0.86 to 3 mm range, for both the ngEHT 13 m dish design² and a 15 m IRAM/NOEMA³ dish. Full width at half maximum (FWHM) beam widths θ_{bm} of the antennae – calculated as $\theta_{\text{bm}} = 1.22 \lambda/D$ – are given in col. 6.

For reference, in Table 2, we provide both continuum sensitivities (integrated over a frequency window $\Delta\nu = 4$ GHz) and line sensitivities (for a $\Delta\nu = 10$ km/s channel⁴), for $t_{\text{on}} = 1$ hr on-source integrations.

In keeping with eq. (1), the rms noise levels tabulated can be scaled to other line widths, or different integration windows for continuum flux density measurements, via the square root of the ratios of the respective frequency intervals $\Delta\nu$ (e.g., for a 100 km/s line: $\sigma_{\text{line}}^{100} = \sigma_{\text{line}}^{10} \times \sqrt{10/100}$, where $\sigma_{\text{line}}^{10}$ is the rms noise level given in col. 4 of Table 2). For continuum measurements, bandwidths up to 12 or 16 GHz in dual polarization mode are likely to be feasible. However, depending on the specific telescope/observing mode (e.g., dual vs. single-band),

² <https://www.ngeht.org/project-design-docs>

³ <https://iram-institute.org/observatories/noema/>

⁴ A constant velocity width Δv maps into a frequency interval $\Delta\nu$ via $\Delta\nu = \nu_{\text{obs}} \cdot \Delta v/c$.

TABLE 2. Line and continuum sensitivities for 1 hr on-source integrations in single-dish observing mode, obtained from eq. (1). σ_{line} is calculated within a 10 km/s channel; σ_{cont} assumes a 4 GHz frequency window. All values tabulated assume the antenna+receiver parameters of Table 1, plus $n_{\text{pol}} = 2$ and $\eta_c = 1$.

dish model (1)	band (2)	ν_{ref} [GHz] (3)	σ_{line} [mJy] (4)	σ_{cont} [mJy] (5)
ngEHT ($D = 13$ m)	3 mm	86	21.49	0.58
	1 mm	230	30.85	1.35
	0.8 mm	345	59.26	3.18
NOEMA ($D = 15$ m)	3 mm	86	17.32	0.46
	1 mm	230	24.85	1.09
	0.8 mm	345	46.54	2.50

the maximal available instantaneous bandwidth in a given receiver band may be smaller than this.

2. INTERFEROMETRIC OBSERVATIONS

For a homogeneous array consisting of N_a identical antennae, the 1σ point source sensitivity can be calculated via

$$\left(\frac{\sigma}{\text{Jy}}\right) = \frac{1}{\zeta \eta_c \sqrt{n_{\text{pol}} N_a (N_a - 1)}} \left(\frac{\mathcal{J}}{\text{Jy/K}}\right) \left(\frac{T_{\text{sys}}}{\text{K}}\right) \left(\frac{\Delta\nu}{\text{Hz}}\right)^{-1/2} \left(\frac{t_{\text{on}}}{\text{s}}\right)^{-1/2}. \quad (2)$$

The efficiency factor $\zeta = \eta_{\text{instr}} \cdot \eta_{\text{atm}}$ accounts for frequency-dependent instrumental (e.g., due to oscillator phase jitter, pointing inaccuracies, etc.) and atmospheric de-correlation. Representative values for η_{atm} range from 0.9 (3 mm band) to 0.7 (0.8 mm band), while the parameter η_{instr} is approx. unity at 3 mm and decreases to ~ 0.7 (~ 0.6) in the 1 mm (0.8 mm) band. All other system/instrumental parameters in this equation can be taken from Table 1.

As for single-dish projects, a representative observing efficiency factor ϵ_{tel} for array operations is ~ 0.5 . However, dedicated off-measurements as for single-dish observing (see Sect. 1) are not required when performing interferometry, because the scale dependent sensitivity of the array causes undesired large-scale (wide-angle) atmospheric and astrophysical backgrounds to be filtered out. The

total telescope time required thus becomes $t_{\text{tel}} = t_{\text{on}}/\epsilon_{\text{tel}}$ for straightforward single-source, single-field observations⁵.

We note that, at fixed on-target observing time t_{on} and bandwidth $\Delta\nu$, the rms spectral noise achieved by a homogeneous array of N_{a} antennae can be derived from the single-dish sensitivities in Table 2 by dividing the latter by a factor $\zeta \eta_{\text{atm}} \times \sqrt{2N_{\text{a}}(N_{\text{a}} - 1)}$.

The maximal angular resolution of sky maps obtained via interferometric imaging is $\left(\frac{\theta_{\text{synth}}}{\text{arcsec}}\right) \simeq 1.22 C \left(\frac{\lambda}{\text{mm}}\right) \left(\frac{B_{\text{max}}}{\text{km}}\right)^{-1}$, where B_{max} is the maximum baseline length between array antennae. The constant $C = 0.206$ takes care of the conversion from SI units to representative size/length scales and from radians to arcsec. A measure of the array field-of-view is provided by the single-dish FWHM beam sizes θ_{bm} reported in column 6 of Table 1.

Document author: *Mark Sargent* – September 28, 2026

Please address questions to: mark.sargent@epfl.ch

⁵ The overhead calculation may change for different array observing strategies (e.g., mosaicking or track-sharing); for more details see, e.g., IRAM Memo 2015-2.