Guidelines for observing time estimates with the NIKA2 continuum camera at the IRAM-30m Telescope

B. Ladjelate, A. Ritacco, P. García, F.-X. Désert, S. Leclercq, C. Kramer & A. Sievers
Updated by I. Myserlis and Á. Bongiovanni

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Abstract

The present document explains how the total integration time t_{total} on total intensity for a given map size to be observed with the NIKA2 camera is calculated, for both total intensity and polarization (1.2 mm band only) observations. The formula for t_{total} is derived step-by-step and the Python script used to calculate t_{total} is described using some examples, for point-like and extended sources. This document has been updated for the 2025 semesters according to the parameters given in the reference article [1], the summary of the NIKA2 polarization commissioning report [6], and the preliminary tests that followed the recent upgrade of the instrument. This manuscript is partially based on the previous document for GISMO and NIKA observations [2], calculations done by F.-X. Désert.

1 The NIKA2 Camera

The New IRAM KID Array 2 (NIKA2) camera is the kilo-pixel expansion of the NIKA prototype camera. It is a dual-band imaging camera built for the 30m telescope [3, 4, 5] by an international consortium lead by Alain Benoit and Alessandro Monfardini from the *Institut Néel* in Grenoble, France. The camera is equipped with a novel type of superconducting detector called KID (Kinetic Inductance Detector). The focal plane consists of three filled arrays: a 2 mm array, and two 1.2 mm arrays for horizontal and vertical polarization measurements. They operate at ∼170 mK, delivered by a continuous closed-cycle dilution fridge, and optimized for observations in the atmospheric windows at 2 mm and 1.2 mm. A dichroic is used to split the long/short wavelengths such that both channels observe the sky simultaneously with a common instantaneous field-of-view (FoV) of 6.5' in diameter. The 2 mm (1.2 mm) array is made up of 616 (2×1140 for Horizontal and Vertical polarization) square pixels. Currently, the observing mode for **extended and point sources** with NIKA2 is the OTF (*zig-zag*) observing mode in which, while the telescope drives continuously in a certain direction, data and positional information are recorded for later map reconstruction. Following links provide further information about scripting and observing with NIKA2.

2 Observing Time Estimate

First of all, **it is essential that the NIKA2 user define the minimum scan size according to what is specified in Section 3, and adopt a value of precipitable water vapor (pwv [mm]) as less restrictive as possible, depending on the season of interest (cf. Table 4)**. Having said that, the equations and parameters that govern the operation of the NIKA2 observing time estimator are as follows.

The expected noise flux density per beam of a map is given by:

$$\sigma = \frac{\text{NEFD}}{\sqrt{t_{beam}}}, \tag{1}$$

where σ is expressed in [mJy/beam], NEFD is the Noise Equivalent Flux Density in [mJy$\cdot\sqrt{s}$], and t_{beam} is the integration time per beam in seconds. The NEFD can further be expressed as:

$$\text{NEFD} = \text{NEFD}_0 \cdot e^{\tau/\sin(el)} \cdot h_{\text{filter}}, \tag{2}$$

where NEFD_0 is the instrumental NEFD without the atmosphere, τ is the zenith opacity at the reference frequency, el is the elevation of source in radian, and h_{filter} is a dimensionless factor that accounts for post-processing noise filtering. The sensitivity penalty for retrieving extended emission in NIKA2 observations leads to values $1.0 \leqslant h_{\text{filter}} \leqslant 2.0$, depending on the source extent.

The **integration time per beam** on total and polarized intensity is derived from the total integration time of the observation t_{int} (excluding overheads), the FoV of the camera, and the area covered by the observations. If the scanning pattern covers a rectangular area A_{map} of sides Δ_{x} and Δ_{y}, then the integration time per beam is expressed as:

$$t_{\text{beam}} = \frac{A_{\text{FoV}}}{A_{\text{map}}} \cdot t_{\text{int}}, \tag{3}$$

where $A_{\text{map}} \sim \Delta_{\text{x}} \cdot \Delta_{\text{y}} + A_{\text{FoV}}$, and the ratio $A_{\text{FoV}}/A_{\text{map}}$ represents the average fractional coverage[1]. Notice that the product $\Delta_{\text{x}} \cdot \Delta_{\text{y}}$ is the area covered by the central pixel of the array. Due to differences in performance, a small fraction of the pixels covering the camera FoV will not be available for the measurements (bad pixels), reducing the nominal FoV area to an *effective* FoV area. If the fraction of good pixels in the array is f_{pix}, then the effective FoV area of the camera can be expressed as $f_{\text{pix}} \cdot A_{\text{FoV}}$.

Putting the above information together, the following general formula that describes the total observing time t_{total} required to reach a given flux uncertainty of σ is obtained:

$$t_{\text{total}} = \left(\frac{\text{NEFD}_0 \cdot e^{\tau/\sin(el)}}{\sigma} \cdot h_{\text{filter}} \right)^2 \times \left(1 + \frac{\Delta_{\text{x}} \cdot \Delta_{\text{y}}}{f_{\text{pix}} A_{\text{FoV}}} \right) \times h_{\text{overhead}} \tag{4}$$

The h_{overhead} factor accounts for telescope overheads (slewing, pointing, focusing, calibration), i.e. all telescope time that is not spent integrating on-source. This overhead factor depends strongly on the observing project. For instance, deep integrations on a single source lead to small overheads while short integrations on multiple sources spread over the sky lead to significantly larger overheads due to the increased telescope slew time. **We recommend using $1.5 \leqslant h_{\text{overhead}} \leqslant 2.0$, depending on the project; $h_{\text{overhead}} \sim 2$ if you wanted to be conservative in this regard**. The right term within brackets accounts for small maps where a point source is always within the FoV (so there is always time ON-source in the OTF scans), and larger maps, where the FoV goes OFF-source a fraction of the time. In order to achieve a homogeneous RMS distribution within the $\Delta_{\text{x}} \cdot \Delta_{\text{y}}$ area, we recommend carrying out maps with lengths $\geqslant 2$ [arcmin]. In Equation 4, is it assumed that for 1.2 mm observations in total power, both horizontal and vertical polarizations are combined for the estimation of t_{total}. Table 1 summarizes the NIKA2 instrument's specifications while in Table 2 the parameters used in the time estimator are listed. For deep integrations ($< 0.5 - 1$ [mJy/beam]) we remind proposers to consider estimating confusion noise levels as it might prevent reaching such low rms values. Also useful for large-scale mapping is to estimate the mapping speed of the array in units of [arcmin^2 hour^{-1} mJy^{-2}]. This can be derived by noticing that the total integration time in Equation 4 can be expressed as:

$$t_{\text{total}} = \left(\frac{A_{\text{map}}}{S_{\text{map}}} \right) \times \frac{1}{\sigma^2}, \tag{5}$$

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[1]Note that the approximation $A_{\text{map}} \sim \Delta_{\text{x}} \cdot \Delta_{\text{y}} + A_{\text{FoV}}$ overestimates the covered area if the source stays on-array during the observation, in which case $t_{\text{beam}} \sim t_{\text{int}}$

where S_{map} is the mapping speed of the array. Using Equations 2 and 4, solving for S_{map} we obtain:

$$S_{\mathrm{map}} = \left(\frac{f_{\mathrm{pix}}\, A_{\mathrm{FoV}}}{\mathrm{NEFD}^2} \right) \times \frac{1}{h_{\mathrm{overhead}}}. \tag{6}$$

The values of the mapping speed for the example cases in Section 4 are listed in Table 4.

2.1 NIKA2 polarization observations considerations

For polarization observations (1.2 mm band), the key parameter driving the estimated time, in addition to total intensity, is the polarization degree or polarization fraction. The polarization degree can be as low as a few percent in molecular clouds (e.g. Fig. 9 in [7]). Therefore, measurements of the linear polarization require deep, time consuming integrations. For example, if the total intensity (Stokes I) is 100 mJy/beam and reached with a S/N of 3 (i.e. Stokes I rms of $\sim$33.3 mJy/beam), a 6% polarization degree requires a deep integration down to $0.06 \times 100 = 6$ mJy/beam to reach a S/N of 3 in polarized intensity (i.e. Stokes Q and U rms of 2 mJy/beam). As the integration time is proportional to the rms squared, the degree of polarization is the dominant driver of the integration time.

In addition, for NIKA2 polarization projects it is recommended to use $h_{overhead} = 2$, to account for project-specific overheads such as slewing, local pointing, and worse weather conditions than anticipated. The increased overhead time is also favorable for extra time needed for polarization-specific calibration observations, e.g. observations of strong, (un)polarized quasars, which can improve the instrumental polarization calibration of your project. Finally, note that the observing system design for polarimetric observations with NIKA2 poses an upper limit to the scanning speed of the observations, namely $\sim$35-40 arcsec/s, to minimize the contamination between Stokes parameters I, Q and U and to allow a Nyquist sampling of the beam in time per each phase of the rotating HWP. We point the reader to Chapter 6 of PIIC manual for more details.

Table 1: NIKA2 instrument's specifications (cf. [1]).

Definition	Symbol	NIKA2	
Band		1	2
Central Wavelength	λ [mm]	1.2	2.0
Adopted central Frequency	ν [GHz]	260	150
Frequency Bandwidth[1]	$\Delta\nu$ [GHz]	$240 - 280$	$125 - 170$
Number of design pixels	N_{pix}	2×1140	616
Pixel Spacing	[$\lambda_{\mathrm{fraction}}$]	1.1	0.9
Half-Power Beam Width (HPBW)	Θ_{res} [arcsec]	11.1	17.6

[1] The new bandwidths after the instrument upgrade of March 2025 are slightly larger and a report about this topic is in preparation.

3 Recommended scan sizes for science projects

To optimize the correction of data instabilities, the length of NIKA2 sub-scans, i.e. the size of scans along the scan direction (Xsize) should be at least:

NIKA2 FOV (6.5') + 2 × NIKA2 beam width (12" at 1mm, 18" at 2mm) + source size above the noise + 2s × scan speed.

Table 2: Parameters used in the time estimator.

Definition	Symbol	NIKA2	
Band		1	2
Noise equivalent flux density	NEFD$_\circ$ [mJy$\cdot\sqrt{s}$]	20[1]	9
		(13 in pol-Q & U)[2]	
Fraction of good pixels	f_{pix}	0.86	0.83
Field-of-View diameter	D$_{\mathrm{FoV}}$ [arcmin]	6.5	
Field-of-View area	A$_{\mathrm{FoV}}$ [arcmin^2]	33.2	
Post-processing overhead	h_{filter}	$1.0 \lesssim h_{\mathrm{filter}} \lesssim 2.0$	
Telescope overheads	h_{overhead}	$1.5 \lesssim h_{\mathrm{overhead}} \lesssim 2.0$	
Noise goal	σ [mJy]	user-defined	
Xsize of A_{map}	Δ_{x} [arcmin]	user-defined	
Ysize of A_{map}	Δ_{y} [arcmin]	user-defined	

[1] The sensitivity on total intensity at 1.2 mm is obtained after combining the measurements of the two 1.2 mm arrays. The values of NEFD$_\circ$ refer to [1]. The f_{pix} values are subject to statistics of the instrument gathered in 2022.

[2] According to [6] and the preliminary tests that followed the recent (March 2025) upgrade of the instrument.

The third term makes sure that KIDs instabilities are properly corrected by data reduction. The fourth term is added because known tracking deviations of the 30m telescope can hinder the quality of data records, up to 2s after the beginning of each sub-scan. Perpendicularly to the scan direction, there is no minimum size limit, but too long single scans (i.e. $\gtrsim$ 20 min.) can expose the observer to a risk of losing tuning over time. Note that the size computed in this way is the Δ_{x} described here (and in the help menu of the exposure time estimator code) and not the size of the final map. The former is larger by one FOV size.

4 Time Estimator Test Cases

A Python 3.X script performs the calculations to obtain the total integration time for a given project. A help menu describing each script's option is displayed by running the following instruction in a terminal:

```
> python NIKA2_Time_Estimator_2025_v0.py3 --help
```

In the following, some illustrative examples of the time estimator results for OTF mapping are presented. The results are summarized in Table 3 and typical weather conditions at the 30m telescope site are compiled in Table 4. In case of doubt, please contact a member of the NIKA2 Pool Managing (see the NIKA2 homepage).

- **Point Source:** to observe a single point source of flux 1 [mJy/beam] at 2 mm and 1.5 [mJy/beam] at 1.2 mm (total intensity) with NIKA2, we would use the OTF observing mode at a scanning speed of 20 arcsec/sec with an estimated map size of $\Delta_{\mathrm{x}} = \Delta_{\mathrm{y}} = 8.5'$, and the most aggressive filtering scheme for with $h_{\mathrm{filter}} = 1.0$, which is optimized for point source photometry. For a 5-σ detection of this source, one requires a flux uncertainty $\sigma = 0.2$ [mJy/beam] at 2 mm and 0.3 [mJy/beam] at 1.2 mm. Assuming 4 mm of precipitable water vapor (pwv), i.e. an opacity $\tau \sim 0.10$ at 2 mm and $\tau \sim 0.30$ at 1.2 mm, and a typical source elevation of 50 degrees, Equation 4 gives a total observing time of 4.0 hours for the 2.0 mm band, and 14.4 hours for the 1.2 mm band (6.1 hours to reach such rms

in Stokes Q & U for polarimetry mode), including overheads ($h_{\text{overhead}} \sim 1.5$). Note that, in practice, we would split this long observation into smaller observing blocks.

- **Nearby Galaxy:** to observe a nearby galaxy of size which size is 7′ at a scanning speed of 40 arcsec/sec, we estimate a map size of $\Delta_{\text{x}} = 15.5$, $\Delta_{\text{y}} = 11.0$, where extended emission at a level of 1.26 [mJy/beam] at 2 mm and 2.22 [mJy/beam] at 1.2 mm (total intensity) shall be detected, we would use the OTF observing mode with the least aggressive filtering scheme with $h_{\text{filter}} = 2.0$, which is optimized for extended emission. For a 3-σ detection of this source, one requires a flux uncertainty $\sigma = 0.42$ [mJy/beam] and 0.74 [mJy/beam] for the 2 mm and 1.2 mm bands, respectively. Assuming 2 mm of pwv (which is below what is typical for any semester), i.e. an opacity $\tau \sim 0.15$ at 1.2 mm and $\tau \sim 0.05$ at 2 mm, and a typical source elevation of 45 degrees, Equation 4 gives a total observing time of 8.5 hours for the 2.0 mm band and 17.4 hours for the 1.2 mm band (7.3 hours to reach such rms in Stokes Q & U for polarimetry mode), including overheads ($h_{\text{overhead}} \sim 2.0$). Note that, in practice, we would split this long observation into smaller observing blocks.

- **Polarized point Source:** to observe a single point source with total intensity of 50 [mJy/beam] at 1.2 mm and a polarization degree of 5% with NIKA2, we would use the OTF observing mode at a scanning speed of 35 arcsec/sec with an estimated map size of $\Delta_{\text{x}} = \Delta_{\text{y}} = 8.5'$, and the most aggressive filtering scheme for with $h_{\text{filter}} = 1.0$, which is optimized for point source photometry. For a 5-σ detection of the polarized intensity in this source, which is $0.05 \times 50 = 2.5$ [mJy/beam], one requires a flux uncertainty $\sigma_{\text{pol}} = 0.5$ [mJy/beam]. Assuming 4 mm of pwv, i.e. an opacity $\tau \sim 0.30$ at 1.2 mm, and a typical source elevation of 50 degrees, Equation 4 gives a total observing time of 2.9 hours for the 1.2 mm band, including overheads (assuming $h_{\text{overhead}} \sim 2.0$). Note that the maximum scanning speed in polarization observations is $\sim$ 35-40 arcsec/s, for the reasons described in Section 2.1. Also note that, in practice, we would split this long observation into smaller observing blocks.

- **Polarized extended source:** to observe an extended source which size is 5′ at a scanning speed of 35 arcsec/sec, we estimate a map size of $\Delta_{\text{x}} = 13.0$, $\Delta_{\text{y}} = 9.0$, where extended emission at a level of 18 [mJy/beam] in total intensity at 1.2 mm and 10% polarization shall be detected, we would use the OTF observing mode with the least aggressive filtering scheme with $h_{\text{filter}} = 2.0$, which is appropriate for extended emission. For a 3-σ detection of this source, which is $0.1 \times 18 = 1.8$ [mJy/beam], one requires a flux uncertainty $\sigma_{\text{pol}} = 0.6$ [mJy/beam]. Assuming 2 mm of pwv (which is below what is typical for any semester), i.e. an opacity $\tau \sim 0.15$ at 1.2 mm, and a typical source elevation of 60 degrees, Equation 4 gives a total observing time of 7.5 hours including overheads (assuming $h_{\text{overhead}} \sim 2.0$). This amount of observing time not only ensures that the polarized intensity of the extended emission will be detected at a 3-σ level, but the total intensity at a much higher significance level (20-σ, $\sigma_{\text{I}} = 0.92$). Again, note that the maximum scanning speed in polarization observations is $\sim$ 35-40 arcsec/s, for the reasons described in Section 2.1. Likewise, in practice, we would split this long observation into smaller observing blocks.

Table 3: Summary of time estimates and mapping speeds from examples given in Section 4.

parameter	Point source		Nearby galaxy		Polarized point source	Polarized extended source
band	1.2 mm	2.0 mm	1.2 mm	2.0 mm	1.2 mm	1.2 mm
Δ_x [arcmin]	8.5	8.5	15.5	11.0	8.5	13.0
Δ_y [arcmin]	8.5	8.5	15.5	11.0	8.5	9.0
pwv [mm]	4	4	2	2	4	2
τ	0.30	0.10	0.15	0.05	0.3	0.15
El [deg]	50	50	45	45	50	60
h_{filter}	1.0	1.0	2.0	2.0	1.0	2.0
h_{overhead}	1.5	1.5	2.0	2.0	2.0	2.0
total intensity [mJy/beam]	1.5	1.0	2.22	1.26	50.0	18.0
polarization degree [%]	-	-	-	-	5	10
rms [mJy/beam]	0.30	0.20	0.74	0.42	0.5	0.6
	Total Integration Time Results					
$\mathbf{t}_{\mathrm{spec}}$ [hours]	14.4	4.0	17.4	8.5	2.9	7.5
	Mapping Speed					
$\mathbf{S}_{\mathrm{map}}$ [arcmin^2 hour^{-1} mJy^{-2}]	78.0	626.9	20.9	132.5	138.5	53.6

Table 4: Typical Summer/Winter weather conditions at the 30m telescope's site

	Winter Conditions			Summer Conditions		
	excellent	good	average	excellent	good	average
pwv [mm]	1	2	4	2	4	7
τ (1.2 mm band)	0.08	0.15	0.30	0.15	0.30	0.53
τ (2.0 mm band)	0.03	0.05	0.10	0.05	0.10	0.18

References

[1] Perotto, L., Ponthieu, N., Macías-Pérez, J. F., et al. 2020, A&A, 637, A71

[2] Guidelines for observing time estimates with IRAM-30m continuum cameras. N. Billot, C. Kramer, S. Leclercq, I. Hermelo, X. Desert & A. Kovács, August 4, 2014

[3] Improved mm-wave photometry for kinetic inductance detectors. Calvo, M., Roesch, M., Désert, F.-X., et al. 2013, A&A, 551, L12

[4] Performance and calibration of the NIKA camera at the IRAM 30 m telescope. Catalano, A., Calvo, M., Ponthieu, N., et al. 2014, A&A, 569, A9

[5] The NIKA2 Instrument, A Dual-Band Kilopixel KID Array for Millimetric Astronomy. Calvo, M., Benoit, A., Catalano, A., et al. 2016, arXiv:1601.02774

[6] NIKA2-Pol: summary of polarization commissioning report. NIKA2-Pol commissioning team (H. Ajeddig, Ph. André, F.-X. Désert, S. Leclercq, J.F. Macías-Pérez, A. Maury, I. Myserlis, N. Ponthieu, A. Ritacco), January 2024.

[7] Beuther, H., Gieser, C., Soler, J. D., et al. 2024, AA, 682, A81