# Guidelines for observing time estimates with IRAM-30m continuum cameras

Winter semester 2013

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July 22, 2013

## 1 Continuum cameras at the 30m telescope

IRAM currently offers two continuum cameras to be used on the 30m telescope, NIKA and GISMO. In this section we briefly describe the characteristics and performances of both cameras. More details can be found on dedicated web pages available from the `IRAM web site`.

### 1.1 GISMO

The Goddard-IRAM Superconducting 2 mm Observer (GISMO) is a bolometer camera built at the Goddard Space Flight Center (Greenbelt/Maryland) under the lead of Johannes Staguhn for the IRAM 30m telescope. GISMO consists of $8 \times 16$ close-packed pixels with super conducting transition edge sensors (TES). The pixels are spaced by $13.75''$ and they fill the entire field of view of the camera $1.83' \times 3.66'$. The telescope half-power beamwidth was measured to be near or just above the expected diffraction limit of $16.7''$. More information on GISMO can be found in Staguhn et al. [1], or at

`http://www.iram.es/IRAMES/mainWiki/GoddardIramSuperconductingTwoMillimeterCamera.`

Based on past GISMO observing runs, we have compiled two reports (Bruni et al. [2], Hermelo et al. [3]) that describe the instrument performance as measured at the telescope. In particular the reports provide details on the camera sensitivity, the telescope overheads, the flux reproducibility, and the sensitivity penalties when trying to recover extended emission. They are both available at the above mentioned URL.

### 1.2 NIKA

The New IRAM KID Array (NIKA) is a dual-band imaging camera built for the 30m telescope 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 supraconducting detectors called KIDs (Kinetic Inductance Detectors). The focal plane consists of two filled arrays operating at 100 mK, delivered by a continuous closed-cycle dilution fridge, and optimized for observations in the atmospheric windows at 2 mm (155 GHz) and 1.2 mm (245 GHz), with broad spectral band-passes of 35 and 50 GHz, respectively. 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 of $2.3'$ in diameter. The 2 mm (1.2 mm) array is made up of 132 (224) square pixels spaced by $9.8''$ ($6.8''$) providing a sampling of $0.7\,F\lambda$ ($0.8\,F\lambda$). The half-power beamwidths were measured to be $17.5''$ and $12''$ at 2 and 1.2 mm, respectively.

More information about NIKA, in particular results from previous technical campaigns, and reference publications have been compiled and are available at the following URL:

`http://www.iram.es/IRAMES/mainWiki/NeelBolometer`

# 2 Observing modes

For both continuum imaging cameras, we offer two standard observing modes where data are taken continuously on-the-fly while the telescope follows either Lissajous curves, or zig-zag patterns. Neither mode makes use of the secondary mirror to modulate the signal. Lissajous patterns provide a good sky coverage with a high spatial redundancy necessary to filter out noise in the map-making process (most pixels "see" the source), while they also minimize telescope overheads for reasonably sized maps (comparable or smaller than the camera field of view). Traditional zig-zag patterns are only used to cover areas larger than the camera field of view (up to $30' \times 30'$). We describe below two lissajous observing templates that were heavily used during the past GISMO observing campaigns, and which produced high-quality maps.

The **Compact Source** observing template is designed to observe individual sources that are point-like or slightly resolved by the telescope optics. In that case, the central pixel of the camera follows a lissajous trajectory contained into a small square, typically $1.5'$ a side for GISMO (left column of figure 1). This produces a map with a nearly uniform coverage over an area of $1.5' \times 2'$, which allows reliable background and noise estimates in the vicinity of the source. With the smaller and quasi-circular field of view of NIKA, we recommend to execute $1' \times 1'$ lissajous patterns to keep the source on-array at all times during the observation to maximize the observing efficiency.

The **Large Map** observing template is most appropriate to observe sources with spatially extended emission, or to cover a distribution of close-spaced sources in a single observation rather than pointing individual objects. For GISMO observations, we have been mostly using single – or a mosaic of – $4' \times 4'$ lissajous pattern maps, which produces a nearly uniform coverage (right column of figure 1). Larger GISMO maps are preferentially done with the zig-zag scanning pattern for a more homogeneous coverage. With NIKA's smaller field of view, it is preferable to execute zig-zag scanning patterns for maps larger than a few square arcminutes.

Although these two templates are in principle sufficient to cover most scientific cases, observers will have more flexibility in the choice of observing parameters to accommodate special constraints, e.g. rectangular maps to cover elongated extended sources. Specific guidelines concerning the preparation of observations will be given at a later stage.

# 3 Observing Time Estimate

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

$$\sigma = \frac{\mathrm{NEFD} \cdot e^{\tau/\sin(el)}}{\sqrt{t_{beam}}} \cdot f_{filter}, \tag{1}$$

where $\sigma$ is expressed in mJy/beam, NEFD is the Noise Equivalent Flux Density out of the atmosphere in mJy$\cdot\sqrt{\mathrm{s}}$, $\tau$ is the zenith opacity at the reference frequency, $el$ is the source elevation in radian, $t_{beam}$ is the integration time per beam in seconds, and $f_{filter}$ is a dimensionless factor that accounts for post-processing noise filtering.

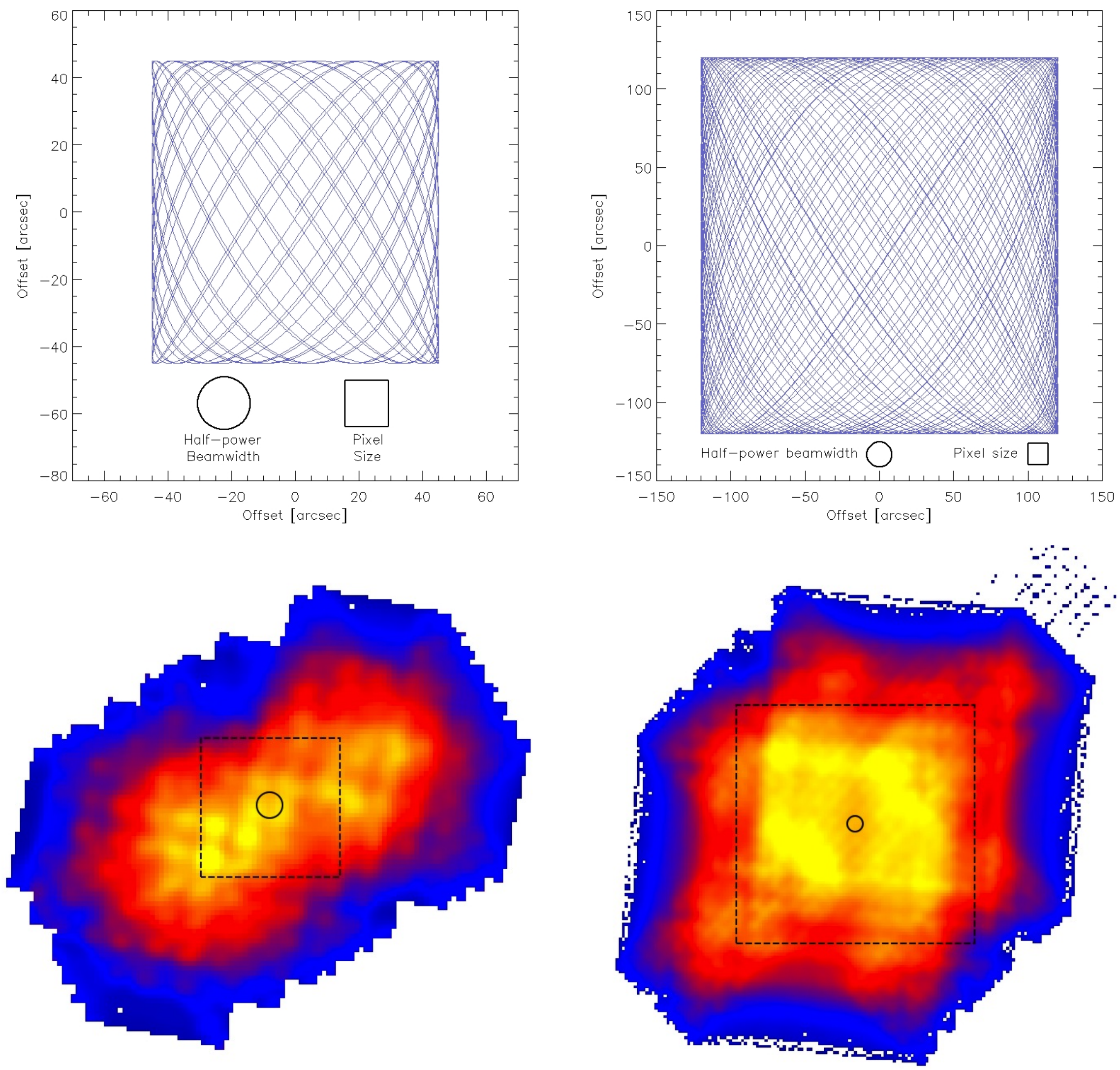


Figure 1: *Top*: Lissajous trajectories of the central pixel of the camera for the Compact Source (left) and Large Map (right) observing templates. The GISMO half-power beamwidth and pixel size are shown for indication. *Bottom*: Typical exposure maps for both observing templates measured with GISMO. The dashed squares show the edges of the region covered by the central pixel along the lissajous curve, i.e. $1.5' \times 1.5'$ for the Compact Source and $4' \times 4'$ for the Large Map.

The **integration time per beam** is derived from the total integration time of the observation $t_{int}$ (excluding overheads), the effective field-of-view (FoV) of the camera, and the area A covered by the observation. If the scanning pattern covers a rectangular area of sides $\Delta_x$ and $\Delta_y$, then the integration time per beam is expressed as:

$$t_{beam} = \frac{\mathrm{FoV}}{\mathrm{A}} \cdot t_{int}, \tag{2}$$

where $\mathrm{A} \sim \Delta_x \cdot \Delta_y + \mathrm{FoV}$, and the ratio FoV/A represents the average fractional coverage[1] of the map. The effective field-of-view of the camera is given by the number of functional pixels $N_p$ and the area of a single pixel such that $\mathrm{FoV} = N_p \times S_p^2$.

The **data filtering scheme** implemented in Crush[2] to reduce GISMO data is designed to filter out correlated and uncorrelated instrumental noises, as well as atmospheric noise. The user can select filtering presets in the Crush command to suit the type of data to be processed. For observations of point sources, or faint extended emission structures, we have $f_{filter}$ in the range 1 to 1.4 depending on the amount of spatial filtering applied to the reconstructed map. The factor $f_{filter}$ is in general close to 1 for optimized point source photometry, but at the expense of a degraded spatial resolution of up to 40%. In addition, a dedicated filtering preset in Crush allows to preserve bright extended emission structures up to spatial scales of $\sim 4'$. This is however at the expense of a significant sensitivity loss with $f_{filter} \sim 4$ depending on the stability of the atmosphere. Note that the value of $f_{filter}$ is independent of the instrument performances, and that the sensitivity penalty to pay for recovering large spatial scales are only due to the post-processing. We recommend that the observer reads the Crush documentation[3] for a detailed description of the filtering scheme.

Concerning the data reduction pipeline for NIKA, we are still in the process of developing and finalizing the adequate tools. At this early stage we do not have firm numbers for this $f_{filter}$ factor yet. However we expect that the sensitivity penalty for retrieving extended emission in NIKA data will lead to similar values, i.e. $f_{filter} \lesssim 4$ with $f_{filter} \sim 1$ for point sources.

Putting the above information together, we obtain the following general formula that describes the total observing time $t_{total}$ required to reach a given flux uncertainty of $\sigma$:

$$\boxed{t_{total} = \left( \frac{\mathrm{NEFD} \cdot e^{\tau/\sin(el)}}{\sigma} \cdot f_{filter} \right)^2 \cdot \left( 1 + \frac{\Delta_x \cdot \Delta_y}{N_p \cdot S_p^2} \right) \cdot f_{overhead},} \tag{3}$$

where the $f_{overhead}$ factor accounts for telescope/observing overheads which include the usual calibration, pointing and focus observations. Based on our experience from the last GISMO observing run, this overhead factor depends strongly on the observing project. For instance deep integrations on a single source lead to small overheads ($f_{overhead} \sim 1.6$) while short integrations on multiple sources spread over the sky lead to significantly larger overheads ($f_{overhead} \sim 2.6$) due to the increased telescope slew time. Table 1 summarizes the parameter values for each GISMO and NIKA band, along with the zenith opacities for good, average, and poor winter conditions, i.e. for 2 mm, 4 mm, and 7 mm of precipitable water vapor (pwv), respectively.

[1] Note that the approximation $\mathrm{A} \sim \Delta_x \cdot \Delta_y + \mathrm{FoV}$ overestimates the covered area if the source stays on-array during the observation, in which case $t_{beam} \sim t_{int}$.

[2] Crush is the official software provided by Attila Kovács to reduce GISMO observations. More information on Crush at `http://www.submm.caltech.edu/~sharc/crush/`.

[3] documentation available at `http://www.submm.caltech.edu/~sharc/crush/document.html`

Table 1: NIKA and GISMO parameters for time estimates.

| Parameter | NIKA | | GISMO |
|---|---|---|---|
| Band | 1.2 mm | 2 mm | 2 mm |
| Central Freq. [GHz] | 255 | 145 | 150 |
| NEFD [$\mathrm{mJy} \cdot \sqrt{\mathrm{s}}$] | 35 | 14 | 14 |
| $\tau_{pwv=2mm}$ | 0.22 | 0.06 | 0.06 |
| $\tau_{pwv=4mm}$ | 0.36 | 0.11 | 0.11 |
| $\tau_{pwv=7mm}$ | 0.57 | 0.19 | 0.19 |
| $\Delta_x$ or $\Delta_y$ [$''$] | | $\gtrsim 60$ | |
| $N_p$ | 190 | 125 | 100 |
| $S_p$ [$''$] | 6.8 | 9.8 | 13.75 |
| $f_{filter}$ | | $1 \lesssim f_{filter} \lesssim 4$ | |
| $f_{overhead}$ | | $1.6 \lesssim f_{overhead} \lesssim 2.6$ | |
| $\sigma$ [mJy/beam] | | user defined | |
| $t_{total}$ [second] | | cf eq. 3 | |

# 4 Test Cases

- To observe a single point source of flux 1 mJy with GISMO, we choose the Compact Source observing template described in section 2 with $\Delta_x = \Delta_y = 90''$, and the most aggressive filtering scheme for Crush with $f_{filter} = 1$, which is optimized for point source photometry. For a 5-$\sigma$ detection of this source, one requires a flux uncertainty $\sigma = 0.2$ mJy. Assuming 4 mm of precipitable water vapor (pwv), i.e. an opacity $\tau \sim 0.11$ at 2 mm, and a typical source elevation of 50 degrees, equation 3 gives a total observing time of 4.1 hours, including overheads ($f_{overhead} \sim 1.6$). Note that in practice we would split this long observation into smaller observing blocks to allow for interlaced pointing and calibration measurements.

- To observe a point source of 10 mJy at 1 mm with NIKA at 30 degrees elevation and a pwv of 4 mm, we would execute a lissajous pattern with $\Delta_x = \Delta_y = 60''$, and a post-processing filtering appropriate for point sources with $f_{filter} = 1$. The telescope time required to reach a 5-$\sigma$ detection would be ∼50 minutes. The noise in the 2 mm band would then be 0.5 mJy. For a pwv of 2 mm, the execution time would be reduced to 28 minutes.

- To observe a bright star forming region that spans a $4' \times 8'$ field with multiple cores and filaments, we would execute an on-the-fly zig-zag pattern with $\Delta_x = 240'$ and $\Delta_y = 480''$. In order to preserve the extended emission from the filaments we would apply a mild filtering to the detectors timelines, at the expense of a higher noise in the final map, i.e. $f_{filter} = 4$. For a target at 60 degrees elevation, good weather conditions (pwv∼2 mm), and a 1 hour integration time (including overheads, $f_{overhead} \sim 2$), equation 3 gives a flux uncertainty of 16 mJy at 1 mm and 4.6 mJy at 2 mm with NIKA, and 3.7 mJy at 2 mm with GISMO. The better noise figure obtained with GISMO is due to its larger field-of-view.

# References


[1] Instrument performance of GISMO, a 2 millimeter TES bolometer camera used at the IRAM 30 m Telescope. Staguhn et al., Proc. of SPIE, Vol. 7020, 2008.

[2] Report on GISMO performance based on the pool run in April-2012. Bruni et al. 2012, available on the `GISMO wikipage`.

[3] Report on GISMO performance based on the pool run in April-2013. Hermelo et al. 2013, available on the `GISMO wikipage`.

[4] Improved mm-wave photometry for kinetic inductance detectors. Calvo et al., A&A, 551, L12, 2013.