Guidelines for GISMO observing time estimates
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N. Billot, G. Quintana-Lacaci, A. Kovács & C. Kramer

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1 What is 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 8×16 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., Proc. of SPIE, Vol. 7020 (2008), or at

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

2 Observing with GISMO

In the standard observing mode, data are taken continuously while the telescope follows Lissajous curves without switching the secondary mirror. This approach was chosen to provide a good coverage with a high spatial redundancy necessary to filter out noise in the map-making process, while it also minimizes telescope overheads. We describe below two observing templates that were heavily used during the last test run of GISMO in April 2011, and which gave satisfying performances.

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 GISMO follows a lissajous trajectory contained into a $1.5' \times 1.5'$ square (cf left panel 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.

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 this observing template, the central pixel of GISMO follows a Lissajous trajectory contained into a $4' \times 4'$ square (cf right panel of figure 1). This produces a map with a nearly uniform coverage over a $4' \times 4'$ field.

Although these two templates are in principle sufficient to cover most scientific cases, we will likely offer more flexibility in the choice of observing mode settings to accommodate special constraints, e.g. a rectangular on-the-fly scanning pattern might be considered a better scanning strategy for very large maps. Specific guidelines concerning the preparation of GISMO observations will be given at a later stage.

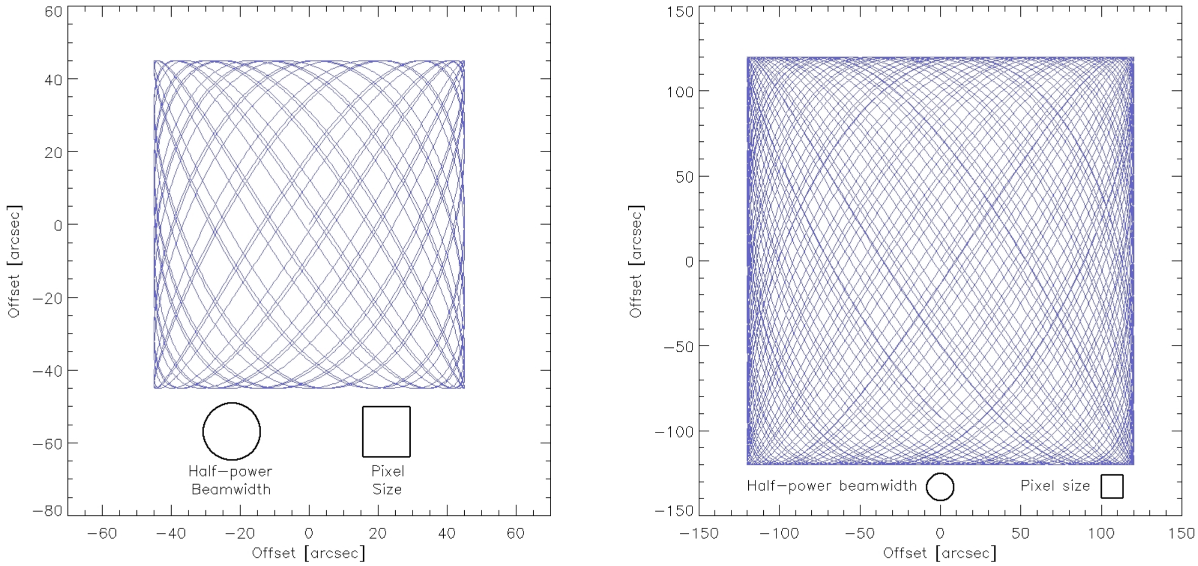

Figure 1: Lissajous trajectories of the GISMO array center for the Compact Source (left) and Large Map (right) observing templates.

3 GISMO Observing Time Estimate

The expected flux uncertainty of a GISMO map is given by:

$$\sigma = \frac{\mathrm{NEFD}}{\sqrt{t_{beam}}} \cdot f_{filter}, \tag{1}$$

where σ is expressed in mJy/beam, NEFD is the Noise Equivalent Flux Density in mJy$\cdot\sqrt{\mathrm{s}}$, t_{beam} is the integration time per beam in seconds, and f_{filter} is a dimensionless factor that accounts for post-processing noise filtering.

The typical **NEFD** was measured to be 16 mJy$\cdot\sqrt{\mathrm{s}}$, under almost all weather conditions, assuming an aggressive filtering scheme and a degraded spatial resolution of $\sim 23''$ (see details below).

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 GISMO, and the area A covered by the observation. If the scanning pattern covers a rectangular area of sides Δ_x and Δ_y, then the integration time per beam is expressed as:

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

where A $\sim \Delta_x \cdot \Delta_y + \mathrm{FoV}$, and the ratio FoV/A represents the average fractional coverage of the map. The effective field-of-view of GISMO is given by the number of functional pixels N_p and the area of a single pixel such that FoV $= N_p \times S_p^2$, where $N = 95$, as measured during the last test run, and the pixel size is $S_p = 13.75''$.

The **data filtering scheme** implemented in Crush[1] 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

[1]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/ .

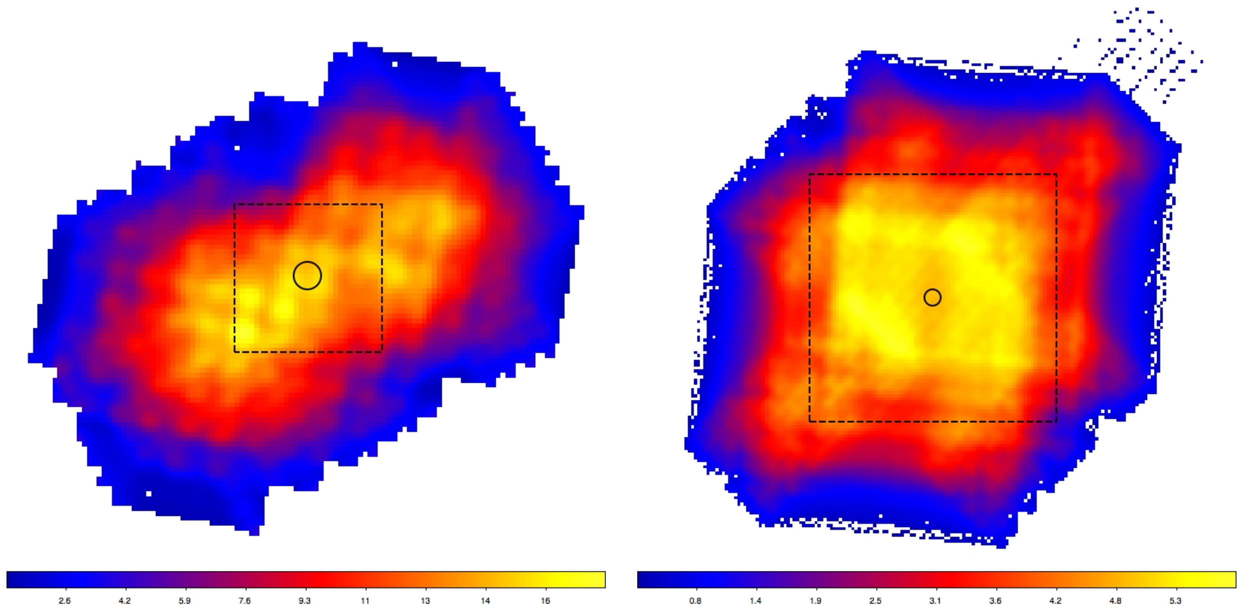

Figure 2: Typical exposure maps for the Compact Source (left) and Large Map (right) observing templates. The color scale is linear in units of second per map-pixel ($3'' \times 3''$ in this case). The circles at the center of each map indicate the half-power beamwidths scaled to the map size. The squares show the edges of the region covered by the central pixel of GISMO along the lissajous curve described in figure 1, i.e. $1.5' \times 1.5'$ for the Compact Source and $4' \times 4'$ for the Large Map.

to suit the type of data to be processed. For observations of point sources, or extended emission structures with spatial scales up to $2'$, we have f_{filter} in the range 1 to 6 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 beam widening of 40%. In case no spatial filtering is applied, the spatial resolution of the map is close to the diffraction limit of $\sim 17''$, but the factor f_{filter} then reaches a value of 6. In addition, a dedicated filtering preset in Crush allows to preserve extended emission structures up to spatial scales of $4'$. This is however at the expense of a significant sensitivity loss with f_{filter} in the range 15-20 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[2] for a detailed description of the filtering scheme.

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 σ:

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

where the $f_{overhead}$ factor accounts for telescope/observing overheads. Note that, although IRAM and the GISMO team will provide support at the telescope to carry out efficient observations, we still recommend to include generous overheads in the time estimates to allow for the usual calibration, pointing, and focus observations, as well as the unexpected setbacks inherent to operating a new instrument. We therefore recommend to take $f_{overhead} = 2$. A summary of the parameter values and their units are given in table 1.

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

Table 1: Summary of parameters for GISMO time estimates.

Parameter	Value	Unit
NEFD	16	mJy$\cdot\sqrt{s}$
Δ_x or Δ_y	> 60	arcsecond
N_p	95	N/A
S_p	13.75	arcsecond
f_{filter}	1 .. 20	N/A
$f_{overhead}$	2	N/A
σ	user defined	mJy/beam
t_{total}	cf eq. 3	second

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-σ detection of this source, one requires a flux uncertainty $\sigma = 0.2$ mJy. Plugging these numbers into equation 3 gives a total observing time of 5.2 hours. 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 $3' \times 7'$ field containing several 5 mJy point sources for which we require 5-σ detections, we choose the Large Map observing template described in section 2 with $\Delta_x = \Delta_y = 240''$, and the most aggressive filtering scheme for Crush, i.e. $f_{filter} = 1$. We need a couple of tiles to cover the entire field. Note that we prefer executing a mosaic of smaller maps rather than a larger map at once because of practical constraints set on the maximum size of a Lissajous map[3]. Equation 3 gives an execution time of 36 minutes per tile, for a total observing time of 1.2 hours.

- To observe a bright star forming region that spans an $8' \times 8'$ field with multiple cores and filaments, we choose the Large Map observing template with $\Delta_x = \Delta_y = 240''$, and a loose filtering to preserve the extended emission from the filaments, i.e. $f_{filter} = 15$, assuming a stable atmosphere. We cover the $8' \times 8'$ area with a mosaic of four $4' \times 4'$ maps. Equation 3 gives a flux uncertainty of $10\,mJy$ for an observing time of 1.35 hours per tiles, i.e. the total time of 5.4 hours. Note that a rectangular on-the-fly map, combined with an orthogonal cross-scan, would give a similar sensitivity and a slightly more homogeneous coverage.

[3] Above $4'$ a side, Lissajous maps do not offer efficient mapping due to the higher coverage at the edges of the maps compared to the central region where the sources are supposed to be. Rectangular on-the-fly maps are then recommended

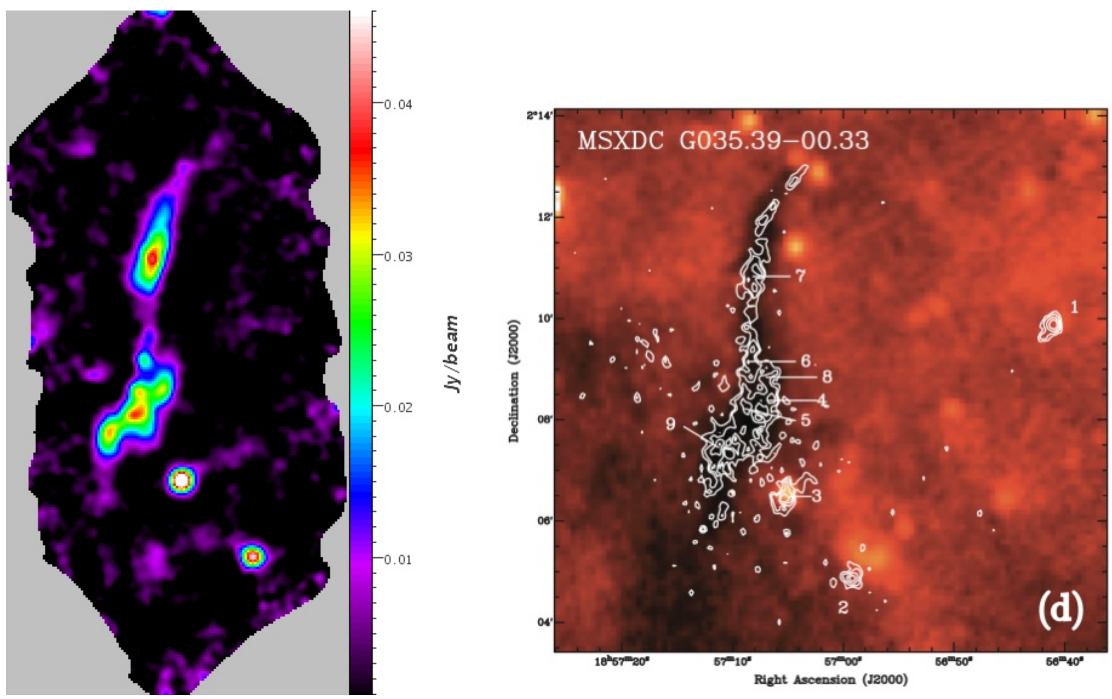

Figure 3: The left panel shows the GISMO map of a couple of millimeter-bright infrared-dark clouds. The map is made up of three $4' \times 4'$ maps, and it covers a $8' \times 14'$ area. The right panel shows the 1.2 mm contours of the same objects observed with MAMBO II, as published in Rathborne et al. 2006, which looks strikingly similar.