# IRAM NOEMA interferometer

## Observing Capabilities and current status

Jan Martin Winters

March 15, 2016

This document is updated twice a year to reflect the new capabilities of the interferometer at the time of the Call for Proposals publication. Non-trivial changes with respect to the previous version are marked in red. Note that this document contains active links marked with a different font for an easy access to documentation, e.g. on the `IRAM web pages`.

# 1 Progress of NOEMA

## 1.1 Correlator upgrades

The IF processor has been extended to feed the signals of up to eight antennas to the wide-band correlator WideX, and the corresponding real-time software was adapted accordingly. The narrow-band correlator, being a separate system, remains able to process the signals of up to six antennas.
To provide optimum flexibility for high spectral resolution studies with the narrow-band correlator, a software upgrade was implemented that allows to select any subset of six antennas in the array to be connected to the high spectral resolution units (39kHz - 2.5MHz). In particular, mapping projects on Galactic spectral lines profit from this flexibility.

## 1.2 Receiver upgrades

At the end of the summer semester 2015 new 2SB receivers (temporarily operated in SSB mode) were installed in antennas 1 and 2. This upgrade includes receivers for two orthogonal polarizations in band 1, 2, and 3; band 4 will be suspended for the time being. Each of the two polarizations delivers a bandwidth of 8 GHz, but only up to 3.6 GHz can be processed by the current correlators. Commissioning of the receivers confirmed that the new systems are performing to expectations. This April, i.e. before the start of the summer semester, also antenna 3 will be equipped with this type of new receivers. From now on, receiver tuning will preferentially be done on a fixed LO frequency grid of 500 MHz step width, on which the receiver performance is optimized.

## 1.3 Antenna construction

During the last months assembly of the reflector back structure of antenna 8 was finished and the reflector was equipped with aluminum panels. The subreflector is put in place, and the receiver will be installed in the cabin, cooled down, and aligned with the optical axis in the coming months. Commissioning of antenna 8 is planned to start in April 2016 and the antenna will possibly be integrated in the array during the summer semester.
Construction of antenna 9 started in October 2015, at the end of the antenna maintenance period, in parallel to completing antenna 8 construction.

# 2 Weather conditions and observing during the winter semester

The interferometer entered into the current winter semester with the antennas arranged in the seven-antenna C configuration. Weather conditions were very good to excellent during the second half of December. In order to work off a number of detection projects requesting high frequencies, the interferometer was moved on December 15 into the compact D-configuration. The switch to the seven-antenna A configuration took place on January 24. The array will be kept in the A configuration at least until end of February when we plan to move back into the second most extended configuration B. We currently anticipate to switch to the C configuration by end of March and to schedule the compact D configuration again in late April. Global VLBI observations, which include the array in the 3 mm phased-array mode, are scheduled from May 19 to 21, 2016.
As far as A-rated projects are concerned, we strive to bring most of them to completion before the end of the current winter semester. B-rated projects are likely to be observed only if they fall in a favorable

LST range. We remind users of the interferometer that B-rated proposals and time-filler projects which are not started before the end of the winter semester have to be resubmitted.
Investigators, who wish to check the status of their project may consult the `interferometer schedule` on the Web. This page is updated daily.

# 3 Conditions for the next summer period

Major ground work is foreseen between May and August to build new bypass tracks that will greatly facilitate moving antennas to the hall in the future, when more antennas will become available. This will however reduce our ability to observe in the standard configurations during the first three months of the summer semester.
We plan an antenna maintenance period starting around mid of May and to schedule essentially the 6-antenna 7D6 configuration (see Tab. 1) between June and October. At the end of the summer semester, antenna 8 might join the array.
Due to the large investment in technical time necessary in the current extension phase of the NOEMA project, *Large Programs* will not be accepted for the interferometer under the current *Call for Proposals*. For the same reason, and contrary to summer 2015, an extended configuration is not planned to be scheduled in the upcoming summer semester.
We strongly encourage observers to submit proposals that can be executed during summer operating conditions. To keep the procedure as simple as possible, we ask you to put emphasis on:

- observations requesting the use of the 3 mm and 2 mm receivers
- circumpolar sources or sources transiting at night between June and September,
- observations that qualify for the 7D6, 7C, and 7C6 configurations (see Tab. 1 below).

## 3.1 General Proposal Considerations

Please give high importance to the quality of your proposal. The NOEMA interferometer is a powerful, but complex instrument, and proposal preparation requires special care. In particular, your proposal should not only justify the scientific interest, but also the need for NOEMA. Proposers should also note in their application whether the same or a similar proposal was or is intended to be submitted to ALMA, in which case a special justification is required why IRAM interferometer time is needed.

Don't hesitate to contact the NOEMA Science Operations Group (sog@iram.fr) in case of doubts and for questions related to the preparation of a proposal.

## 3.2 Proposal category

Proposals should be submitted through the `Proposal Management System PMS` for one of the three categories:

STANDARD: Proposals that ask for a total of less than 100 h of observing time and to use the interferometer within its guaranteed capabilities (see the following sections and the documentation `An Introduction to the IRAM NOEMA interferometer`).

TIME FILLER: Proposals that have to be considered as background projects to fill in periods where the atmospheric conditions do not allow mapping, or to fill scheduling gaps. These proposals will be carried out on a "best effort" basis.

SPECIAL: Exploratory proposals, whose scientific interest justifies the attempt to use the array beyond its guaranteed capabilities. This category includes for example non-standard frequencies for which the tuning cannot be guaranteed, non-standard configurations and more generally all non-standard observations. These proposals will be carried out on a "best effort" basis.

The proposal category will have to be specified on the `PMS` web form and should be carefully considered by proposers.

Within each of these categories, observations in one or several of the following frequency bands can be requested:

BAND 1: Proposals that ask for 3 mm data (80 to 116 GHz).

BAND 2: Proposals that ask for 2 mm data (130 to 177 GHz). Band 1 receivers can be used for pointing and calibration purposes, but cannot provide any imaging.

BAND 3: Proposals that ask for 1.3 mm data (202 to 267 GHz). Band 1 receivers can be used for pointing and calibration purposes, but cannot provide any imaging. During the summer semester, proposals requesting the higher 1 mm tuning range (240-267 GHz) will be carried out on a "best effort" basis only.

**Short spacing observations** on the 30m telescope should directly be requested on the interferometer proposal web form through `PMS`. A separate proposal for the 30m telescope is not required. The interferometer proposal form contains a box, labeled "Request for 30m short spacings" which should then be checked. The user will automatically be prompted to fill in an additional paragraph in which the need for the short spacings should be justified. It is essential to give here all observational details, including size and type of map, rms noise, spectral resolution, receiver, and time requested.

### 3.3 Configurations

Configurations planned for the summer period are given in Table 1 below.

Part of the projects will be scheduled at the end of the summer period when the eight-element array might be operational. Please note however that studies using the narrow-band correlator are restricted to six antennas. Therefore, 6-antenna subsets of each of the 7-antenna configurations have been defined for high spectral resolution work (see table below). Projects observed with a subset of the regular array will be adjusted in uv-coverage and observing time. Please note that the uv-coverage using the narrow-band correlator (6 antennas) will differ from the uv-coverage obtained with WideX (up to 8 antennas).

The following configuration sets are available:

- `D` is best suited for deep integration and coarse mapping experiments (resolution $\sim$ 4.5″ at 100 GHz). This configuration provides both the highest sensitivity and the lowest atmospheric phase noise.
- `CD` (i.e. the combination of C **and** D configuration) is well adapted for low angular resolution studies ($\sim$3.5″ at 100 GHz).
- `C` is appropriate for mapping, snapshot, and size measurements and for detection experiments at low declination. It provides a spatial resolution of $\sim$ 2″ at 100 GHz.

Finally, enter ANY in the proposal form if your project doesn't need a particular configuration.
Please consult the documentation
`An Introduction to the IRAM NOEMA interferometer`
for further details.

### 3.4 Receivers

All antennas are equipped with dual polarization receivers for the 3 mm, 2 mm, and 1.3 mm atmospheric windows. The frequency ranges are 80 GHz to 116 GHz for band 1, 130 GHz to 177 GHz for band 2, and 202 to 267 GHz for band 3 (see table below). Each band is dual-polarization with the two RF channels, one per polarization, observing at the same frequency. The three bands are not co-aligned in the focal plane (and therefore are not aligned on the sky). Due to the pointing offsets between the three frequency bands, only one band can be observed at any time. Time-shared observations between band 1 and one of the other frequency bands (band 2 or 3) are possible in well justified cases, they are however not very efficient. Please contact the NOEMA Science Operations Group (sog@iram.fr) to discuss the feasibility in case you are interested in using this mode.

### 3.5 Signal to Noise

The rms noise can be computed from

$$\sigma = \frac{J_{\rm pK} T_{\rm sys}}{\eta \sqrt{N_{\rm a}(N_{\rm a}-1) T_{\rm ON} B}} \frac{1}{\sqrt{N_{\rm pol}}} \qquad (1)$$

where

- $J_{\rm pK}$ is the conversion factor from Kelvin to Jansky: 22 Jy/K in band 1, 29 Jy/K in band 2, and 35 Jy/K in band 3. These factors were determined for stable atmospheric conditions.
- $\eta$ is an additional efficiency factor due to atmospheric phase noise: $\eta = 0.9$ in band 1, 0.8 in band 2, and 0.6 in band 3. These factors take into account average phase stability in typical summer conditions.
- $T_{\rm sys}$ is the system temperature: $T_{\rm sys} = 100$ K below 110 GHz, increasing to 185 K between 110 and 116 GHz, 150 K in band 2 below 150 GHz, and increasing to 200 K between 150 GHz and 177 GHz, and $T_{\rm sys} = 250$ K in band 3 for sources at $\delta \geq 20°$ and for typical summer conditions.
- $N_{\rm a}$ is the number of antennas: 6 antennas will be available for the summer semester.
- $T_{\rm ON}$ is the on-source integration time in seconds (2 to 8 hours, depending on source declination). Because of various calibration overheads, the total observing time is typically 1.6 $T_{\rm ON}$.
- $B$ is the spectral bandwidth in Hz: 40 kHz to 2.5 MHz for spectral line observations using the narrow-band correlator, and from 2 MHz

Table 1: configurations planned this summer

| Conf | Stations | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 7D6 | W08 | W05 | E04 | N11 | N07 | N02 | — | |
| 7C | W12 | W09 | E18 | E12 | E04 | N17 | N11 | |
| 7C6 | W12 | W09 | — | E12 | E04 | N17 | N11 | |

| | Band 1 | Band 2 | Band 3 |
|---|---|---|---|
| RF range*/[GHz] | 80–116 | 130–177 | 202–267 |
| $T_{rec}$/[K] LSB | 40–55 | 30–50 | 40–60 |
| $T_{rec}$/[K] USB | 40–55 | 40–80 | 50–70 |
| $G_{im}$/[dB] | -10 | -12 ... -10 | -12 ... -8 |
| RF LSB/[GHz] | 80–102 | 132–164 | 202–262 |
| RF USB/[GHz] | 102–116 | 164–177 | 262–267 |

* center of the 4.2-7.8 GHz IF band

for line projects up to 3.6 GHz for continuum projects using WideX.

- $N_{pol}$ is the number of polarizations: 1 for single polarization and 2 for dual polarization (see section *Correlators* for details).

Investigators have to specify in the "technical justification" and on the Technical Sheet the 1 sigma point source sensitivity which is necessary to achieve each individual goal of a proposal, and particularly for projects aiming at deep integrations. In case of mapping projects, PMS asks for the on-source time requested and calculates the resulting point-source sensitivities using Eq. (1). Please verify that your numbers match throughout the proposal.

## 3.6 Correlators

### 3.6.1 Wide-Band correlator (WideX)

At any given time, only one frequency band can be observed, but with the two orthogonal polarizations available. Each polarization delivers a 3.6 GHz bandwidth (from IF=4.2 to 7.8 GHz). The two 3.6-GHz bandwidths coincide in the sky frequency scale. The wide-band correlator WideX gives access to the two 3.6 GHz wide IF bands simultaneously. WideX provides a fixed spectral resolution of 2 MHz over the full bandwidth and is available in parallel to the narrow-band correlator. WideX is capable of correlating the signals of up to 8 antennas.

### 3.6.2 Narrow-Band Correlator

The narrow-band correlator accepts as input two signals of 1 GHz bandwidth, that must be selected within the 3.6 GHz delivered by the receiver. In practice, the IF processor splits the two input 4.2–7.8 GHz bands in four 1 GHz wide "quarters", labeled *Q1...Q4*. Two of these quarters must be selected as narrow-band correlator inputs. Up to six antennas can be processed with the narrow-band correlator. The system allows the following choices:

- first correlator entry can only be Q1 HOR, or Q2 HOR, or Q3 VER, or Q4 VER
- second correlator entry can only be Q1 VER, or Q2 VER, or Q3 HOR, or Q4 HOR

where HOR and VER refer to the two polarizations:

| Quarter<br>IF1 [GHz] | Q1<br>4.2-5.2 | Q2<br>5.0-6.0 | Q3<br>6.0-7.0 | Q4<br>6.8-7.8 |
|---|---|---|---|---|
| input 1 | HOR | HOR | VER | VER |
| input 2 | VER | VER | HOR | HOR |

Note, that the combination VER VER is not allowed.

*How to observe two polarizations with the NB correlator?* To observe simultaneously two polarizations at the same sky frequency, one must select the same quarter (Q1 or Q2 or Q3 or Q4) for the two narrow-band correlator entries. This will necessarily result in each entry seeing a different polarization. The system thus gives access to 1 GHz × 2 polarizations.

*How to use the full 2 GHz bandwidth?* If two different quarters are selected (any combination except VER VER is possible), a bandwidth of 2 GHz can be analyzed by the narrow-band correlator. Only one polarization per quarter is available in that case;

this may or may not be the same polarization for the two chunks of 1 GHz.

*Is there any overlap between the four quarters?* In fact, the four available quarters are 1 GHz wide each, but with a small overlap between some of them: Q1 is 4.2 to 5.2 GHz, Q2 is 5.0 to 6.0 GHz, Q3 is 6.0 to 7.0 GHz, and Q4 is 6.8 to 7.8 GHz. This results from the combination of filters and LOs used in the IF processor.

*Is the 2 GHz bandwidth necessarily continuous?* No: any combination (except VER VER) of two quarters can be selected. Adjacent quarters will result in a (quasi) continuous 1.8 or 2 GHz band. Non-adjacent quarters will result in two separate 1 GHz bands.

*Where is the selected sky frequency in the IF band?* It would be natural to tune the receivers such that the selected sky frequency corresponds to the center of the IF bandwidth, i.e. 6.0 GHz. However, this corresponds to the limit between Q2 and Q3. If your project depends on the narrow-band correlator, it is therefore highly recommended to center a line in one of the quarters (see Section "ASTRO" below). In all bands, the receivers offer best performance in terms of receiver noise and sideband rejection in Q3 (i.e. the line will usually be centered at an IF1 frequency around 6500 MHz). ASTRO will propose a frequency that corresponds to a fixed grid of LO frequencies on which the receiver performance is optimized (see below).

### 3.6.3 Spectral units of the narrow-band correlator

The narrow-band correlator has 8 independent units, which can be placed anywhere in the 100–1100 MHz band seen by the NB correlator (1 GHz bandwidth, see Section ASTRO for more details). 7 different modes of configuration are available, characterized in the following by couples of total bandwidth/number of channels. In the 3 DSB modes (320MHz/128, 160MHz/256, 80MHz/512 – see Table) the two central channels may be perturbed by the Gibbs phenomenon if the observed source has a strong continuum. When using these modes, it is recommended to avoid centering the most important part of the lines in the middle of the band of the correlator unit. In the remaining SSB modes (160MHz/128, 80MHz/256, 40MHz/512, 20MHz/512) the two central channels are not affected by the Gibbs phenomenon and, therefore, these modes may be preferable for some spectroscopic studies.

| Spacing (MHz) | Channels | Bandwidth (MHz) | Mode |
|---|---|---|---|
| 0.039 | $1 \times 512$ | 20 | SSB |
| 0.078 | $1 \times 512$ | 40 | SSB |
| 0.156 | $2 \times 256$ | 80 | DSB |
| 0.312 | $1 \times 256$ | 80 | SSB |
| 0.625 | $2 \times 128$ | 160 | DSB |
| 1.250 | $1 \times 128$ | 160 | SSB |
| 2.500 | $2 \times 64$ | 320 | DSB |

Note that 5% of the passband are lost at both ends of each subband. The 8 units can be independently connected to the first or the second correlator entry, as selected by the IF processor (see above). Please note that the center frequency is expressed in the frequency range seen by the narrow-band correlator, i.e. 100 to 1100 MHz. The correspondence to the sky frequency depends on the quarters of the 3.6 GHz bandwidth which have been selected as correlator inputs and on the selected receiver side band (LSB or USB).

### 3.6.4 ASTRO

The software ASTRO can be used to simulate the receiver/correlator configuration.

The previous `LINE` command has been replaced by several new commands (see internal help). The behavior of the `LINE` command can be changed by the `SELECT BURE 1995|2000|2006|2013|2015` command, default is 2015, currently equivalent to the new `SELECT NOEMA` command.

- `LINE`: receiver tuning
- `NARROW`: selection of the two narrow-band correlator inputs
- `SPECTRAL`: spectral setup of the NB correlator
- `PLOT`: control of the plot parameters.

Starting from end 2015, receiver tuning will preferentially be done on a fixed grid of LO frequencies, spaced by 500 MHz throughout each receiver band, on which the receiver performance is optimized. This is taken into account in the latest ASTRO version for the 2015 state of BURE. For details see the internal help for the LINE command.

A typical session would be:

```
! choice of receiver tuning
line xyz 93.200 lsb /ongrid

! choice of the correlator windows
```

```
narrow Q3 Q3

! correlator unit #1, on entry 1
spectral 1  20 600 /narrow 1

! correlator unit #2, on entry 1
spectral 2  20 735 /narrow 1

! correlator unit #3, on entry 1
spectral 3 320 300 /narrow 1

! correlator unit #4, on entry 2
spectral 4 320 666 /narrow 2
...
```

The first step above:

```
! choice of receiver tuning
line xyz 93.200 lsb /ongrid
```

would produce a plot showing the full 3.6 GHz bandwidth delivered by the receivers that is accessible to WideX in dual polarization. The LINE command checks that the LO frequency is located on the 500 MHz-spaced tuning grid. If this is not the case, the command proposes a new IF center frequency that matches the grid. The option /FIXED_FREQ can be used to ignore the tuning grid. See the internal help for the LINE command for details.
Astronomers are advised to download the most recent version of `GILDAS` to prepare their proposals.

## 3.7 Source coordinates and Velocities

The interferometer operates in the equatorial J2000.0 coordinate system. Please do not forget to specify either LSR velocities or redshifts for the sources. The source list must contain all the sources (and only those sources) for which observing time is requested. The list must adhere to the standard sexagesimal notation.
**Any later request for a swap of targets has to be submitted for approval to the IRAM director and to be justified by new evidence or exceptional circumstances.**

## 3.8 Sun Avoidance

For safety reasons, a sun avoidance circle is enforced at a distance of 32 degrees from the sun. In the long term we aim to further reduce this sun avoidance limit.

## 3.9 Mosaics

NOEMA has mosaicing capabilities, but the pointing accuracy may be a limiting factor at the highest frequencies. Please contact the Science Operations Group (sog@iram.fr) in case of doubts.

## 3.10 Technical pre-screening

All proposals will be reviewed for technical feasibility in parallel to being made available to the members of the program committee. Please help in this task by submitting technically precise proposals. Note that your proposal must be complete and exact: the source position and velocity, as well as the requested frequency setup must be correctly given.

## 3.11 Non-standard observations

If you plan to execute a non-standard program, please contact the Interferometer Science Operations Group (sog@iram.fr) to discuss the feasibility.

## 3.12 Documentation

Documentation for the IRAM Interferometer can be retrieved from the `NOEMA Documentation web pages`. Detailed information is given in the description of the `Current NOEMA capabilities` (this document), in the `Introduction to the IRAM NOEMA Interferometer`, and in the `Calibration CookBook`.

## 3.13 Local Contact

A local contact will be assigned to every A or B rated proposal which does not involve an in-house collaborator. He/she will assist you in the preparation of the observing procedures and provide help to reduce the data. Assistance (write to sog@iram.fr) is also provided before a deadline to help in the preparation of a proposal. Depending on the program complexity, IRAM may require an in-house collaborator instead of the normal local contact.

## 3.14 Data reduction

Proposers should take the following into account with respect to reduction of their data:

- We recommend that proposers reduce their data in Grenoble. For experienced users, remote data reduction can also be offered with some restrictions enforced on the VISITOR accounts. Please contact your local contact if you're interested in this possibility.
- We keep the data reduction schedule very flexible, but wish to avoid the presence of more than 2 groups at the same time in Grenoble.

Please consult the `visitor schedule` before fixing your travel dates. Data reduction will be carried out on dedicated computers at IRAM. Please contact us in advance.

- In certain cases, proposers can be provided with updates as their observations progress. This service does not replace a careful data reduction after completion of the project. Please contact your local contact or NOEMA's Science Operations Group (sog@iram.fr) if you are interested in observational updates.

- Observers who wish to finish data reduction at their home institute should obtain the most recent version of CLIC. Because differences between CLIC versions may potentially result in errors if new data are reduced with an old package, we advise observers having a copy of CLIC to take special care in maintaining it up-to-date. The newer versions are downward compatible with the previous releases.