

IRAM NOEMA interferometer

Observing Capabilities and current status

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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

Commissioning of antenna 7 was successfully completed during the last months and the new antenna joined the array for regular observing at the beginning of the current summer semester. For the upcoming winter semester 2015/2016, **seven antennas will therefore be available for regular observing**.

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, will remain 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 (39 kHz - 2.5 MHz). In particular, mapping projects on Galactic spectral lines should profit from this flexibility.

1.2 Antenna construction

Construction of the second NOEMA antenna, antenna 8, is currently under way. The receiver cabin was mounted on the pedestal, the azimuth and elevation axes are aligned, and assembly of the reflector back structure is foreseen to start this September. In the following months, the subreflector will be put in

place and the reflector will be equipped with panels. According to current plans, antenna 8 will leave the hangar for commissioning at the end of the winter semester.

Construction of antenna 9 will start in October, at the end of the current antenna maintenance period, in parallel to completing antenna 8 construction.

2 Weather conditions and observing during the last months

Due to the commissioning of antenna 7, the move from the compact D configuration to the second-most extended (B) configuration was delayed until February 20, and A configuration was scheduled for 10 days only, starting on March 9. The interferometer was then moved back into a special 7B configuration for another 3 weeks. A seven antenna C configuration was scheduled from April 10 onward, i.e. about 3 weeks later than in previous years. Finally we moved back to the 6 antenna D configuration on May 8, when antenna 5 entered the hall for maintenance. The maintenance period is foreseen to end at the beginning of October.

Observing conditions this spring were reasonably good in terms of atmospheric opacity and stability during April and May, and allowed for useful 1 mm observations until mid of May. Acceptable 3 mm and occasionally fair 2 mm observing conditions are currently met during the second part of the night and typically lasting until around noon.

NOEMA participated in the global spring 3 mm VLBI session, scheduled from May 14 to 17, and performed with about 35% observing efficiency; the rest was lost due to adverse weather conditions. For this fall, global 3 mm VLBI observations are planned during 3 hours between September 24 and 28.

The interferometer was shut down for two weeks on

June 15 for extensive refurbishment of the correlator room to prepare for the arrival of the NOEMA antennas and the new correlator.

Because of the commissioning of antenna 7 and the limited time that the interferometer spent in A-configuration, several projects requesting the A-configuration could not be completed this year. The A-rated projects will be carried over for observations in the extended configurations to the next winter semester.

B-rated projects are likely to be observed only if they fall in a favorable LST range. We remind users of the NOEMA interferometer that B-rated proposals as well as time-filler programs, which are not started before the proposal deadline, have to be re-submitted.

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 winter session

At the end of the summer semester we plan to install new 2SB receivers (operated in SSB mode) 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. A bandwidth of 8 GHz will be delivered for each of the two polarizations, but only up to 3.6GHz will be processed by the current correlators.

During the winter semester we will try to work off the already accepted A-rated projects that request band 4; new proposals requesting band 4 observations will not be accepted.

Due to the large investment in technical time necessary in the current extension phase of the NOEMA project, *Large Programs* can not be accepted for the interferometer under the current *Call for Proposals*.

A preliminary configuration schedule for the winter period is outlined below. Adjustments to this provisional configuration planning will be made according to commissioning requirements in the frame of NOEMA, proposal pressure, weather conditions, and other contingencies. The configuration schedule given below should be taken as a rough guideline, in particular when the requested astronomical targets cannot be observed during the entire winter period because of sun avoidance constraints.

Conf	Scheduling Priority Winter 2015/16
C	December
(D	December – January)
A	January – February
B	February – March
C	March – April
D	April – May

Although the winter semester is preferred for high frequency observations, we encourage proposers to submit proposals also for observations at 3 mm. When the atmospheric conditions are not good enough at 1.3 mm or at 2 mm, 3 mm projects will be observed: in a typical winter, 20-30% of the time used for observations is found to be poor at 1.3 mm, but excellent at 3 mm.

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, to fill scheduling gaps, or even to fill in periods when only a subset of the standard antenna configurations will be available. 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 (129 to 177 GHz). Band 1 receivers may be used for pointing and calibration purposes, but cannot provide any imaging in parallel.

BAND 3: Proposals that ask for 1.3 mm data (201 to 267 GHz). Band 1 receivers may be used for pointing and calibration purposes, but cannot provide any imaging in parallel.

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 of the seven-antenna array

Four new configurations have been designed for the seven antenna array. Since the narrow-band correlator can process the signals from 6 antennas only, corresponding subsets of the new 7 antenna configurations will be fed to the NB correlator:

Name	Stations						
7A	W27	W10	E68	E24	E12	N46	N29
7A6	W27	W10	E68	E24	—	N46	N29
7B	W23	W05	E24	E18	E04	N46	N20
7B6	W23	—	E24	E18	E04	N46	N20
7C	W12	W09	E18	E12	E04	N17	N11
7C6	W12	W09	—	E12	E04	N17	N11
7D	W08	W05	E10	E04	N11	N07	N02
7D6	W08	W05	—	E04	N11	N07	N02

The general properties of these configurations are:

- A alone is well suited for mapping or size measurements of compact, strong sources. It provides a resolution of $0.88''$ at 100 GHz, $\sim 0.38''$ at 230 GHz.
- B alone yields $\sim 1.3''$ at 100 GHz and, in combination with A provides a $\sim 1.0''$ beam at 100 GHz with very low sidelobe levels. It is mainly used for relatively strong sources.
- C provides a fairly complete coverage of the uv-plane (low sidelobe level) and is well adapted to combine with D for low angular resolution studies ($\sim 3.2''$ at 100 GHz, $\sim 1.4''$ at 230 GHz) and with B for higher resolution ($\sim 1.75''$ at 100 GHz, $\sim 0.76''$ at 230 GHz). C alone ($\sim 2.5''$ at 100 GHz, $\sim 1.0''$ at 230 GHz) is also well suited for snapshot and size measurements, and for detection experiments at low declination.
- D alone is best suited for deep integration and coarse mapping experiments (resolution $\sim 4.5''$ at 100 GHz and $\sim 2''$ at 230 GHz). This configuration provides both the highest sensitivity to extended structures and the lowest atmospheric phase noise.

The four configurations can be used in different combinations to achieve complementary sampling of the uv-plane, and to improve on angular resolution and sensitivity. Mosaicing is usually done with D or CD, but the combination BCD can also be requested for high resolution mosaics. Check the ANY bullet in the proposal form if the scientific goals can be reached with any of the four configurations or their subsets. There is a possibility on the web form to restrict the choice of configurations, e.g., to C or D, if your project qualifies for ANY of the compact configurations.

Please consult the documentation **An Introduction to the IRAM NOEMA interferometer** for further details.

	Band 1	Band 2	Band 3
RF range*/[GHz]	80–116	129–177	201–267
$T_{\text{rec}}/[K]$ LSB	40–55	30–50	40–60
$T_{\text{rec}}/[K]$ USB	40–55	40–80	50–70
$G_{\text{im}}/[dB]$	-10	-12 ... -10	-12 ... -8
RF LSB/[GHz]	80–102	129–164	201–262
RF USB/[GHz]	102–116	164–177	262–267

* center of the 4.2-7.8 GHz IF band

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, 129 GHz to 177 GHz for band 2, and 201 GHz to 267 GHz for band 3.

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 co-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 Interferometer 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

$$\sigma = \frac{J_{\text{pK}} T_{\text{sys}}}{\eta \sqrt{N_a(N_a - 1)} T_{\text{ON}} B} \frac{1}{\sqrt{N_{\text{pol}}}} \quad (1)$$

where

- J_{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).
- η is an additional efficiency factor due to atmospheric phase noise: $\eta = 0.9$ in band 1, 0.85 in band 2, and 0.8 in band 3. These factors take into account average phase stability in typical winter conditions.
- T_{sys} is the system temperature: $T_{\text{sys}} = 100$ K below 110 GHz, increasing to 185 K between 110 and 116 GHz, 130 K in band 2 below 150 GHz, and increasing to 170 K between 150 GHz and 177 GHz, and $T_{\text{sys}} = 200$ K in band 3 for sources at $\delta \geq 20^\circ$ and for typical winter conditions.

- N_a is the number of antennas: currently 7 when using WideX but $N_a = 6$ for spectral resolutions better than 2 MHz.
- T_{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_{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 about 2 MHz 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 for uv-coverage 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 1.95 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. Only 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	Q1	Q2	Q3	Q4
IF1 [GHz]	4.2-5.2	5.0-6.0	6.0-7.0	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 $1 \text{ GHz} \times 2$ 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 middle of the IF bandwidth, i.e. 6.0 GHz. However, this corresponds to the limit between Q2 and Q3. It is therefore highly recommended to center a line at the center of a quarter (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 of 6500 MHz).

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 (1 GHz bandwidth). 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	1×512	20	SSB
0.078	1×512	40	SSB
0.156	2×256	80	DSB
0.312	1×256	80	SSB
0.625	2×128	160	DSB
1.250	1×128	160	SSB
2.500	2×64	320	DSB

Note that 5% of the passband is 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 command, default is 2013, currently equivalent to the new SELECT NOEMA command.

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

A typical session would be:

```
! choice of receiver tuning
line xyz 93.200 lsb 6500

! 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 6500
```

would produce a plot showing the full 3.6 GHz bandwidth delivered by the receivers that is accessible to WideX in dual polarization.

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 that was recently reduced to 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. 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.