IRAM NOEMA interferometer

Observing Capabilities and Current Status

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This document is updated twice a year to reflect the 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 8 was successfully completed during the last months. The new antenna joined the array for regular observing during the current summer semester. For the upcoming winter semester 2016/2017, eight antennas will therefore be available for science observations.

1.1 Correlator upgrades

The IF processor has been extended to feed the signals of eight antennas to the wide-band correlator WideX. The narrow-band correlator, operated in parallel to WideX, will remain able to process the signals of up to six antennas. Six-antenna subsets of the full array have therefore been selected to provide good sampling of the uv plane. These subsets will be connected to the high spectral resolution units of the narrow-band correlator.

The new NOEMA correlator *Polyfix* is scheduled to be installed on Plateau de Bure in Spring 2017. The installation and commissioning of Polyfix representing a major milestone in the construction of NOEMA, it is planned to shut down regular science operations for about 3 months. While this work will not affect the scheduling of the extended A configuration, it is anticipated that the commissioning of the new correlator and of NOEMA antenna 9 will significantly impact the observatory's ability to keep on science observations toward the end of the winter semester.

1.2 Receiver upgrades

By the end of the summer semester 2016, all NOEMA antennas will be equipped with the new 2SB receivers (temporarily operated in SSB mode), providing reduced noise temperatures. The receivers can be tuned USB or LSB throughout most of the accessible frequency range. Details are given in Table 2. The upgrade includes receivers for two orthogonal linear polarizations in band 1, 2, and 3. Each of the two polarizations delivers a bandwidth of 7.8 GHz, but only up to 3.6 GHz can be processed by the current correlators. The sky frequency ranges that can currently be covered are 74.7 GHz to 117.8 GHz for band 1, 128.2 GHz to 179.8 GHz for band 2, and 200.2 to 275.8 GHz for band 3. Proposals requesting band 4 will not be accepted for the winter semester 2016/2017.

The wide-band correlator WideX gives access to two 3.6 GHz wide IF bands simultaneously (one in each polarization) providing a fixed spectral resolution of 1.95 MHz over the full bandwidth for the eight available antennas. The narrow-band correlator accepts two signals of 1 GHz bandwidth that must be selected within the two 3.6 GHz IF bands. Spectral resolutions range from 40 kHz to 2.5 MHz in eight independent spectral units. The narrow-band correlator can process the signals of six antennas and is operated in parallel to WideX.

Receiver tuning will preferentially be done on a fixed LO frequency grid of 500 MHz step width, four times denser than before, on which the receiver performance is optimized.

1.3 Antenna construction

Construction of NOEMA antenna 9 is progressing well. The receiver cabin was mounted on the pedestal, the azimuth and elevation axes were

aligned, and the assembly of the reflector back structure is underway. In the following months, the subreflector will be put in place and the main reflector equipped with aluminum panels. According to current plans, antenna 9 will leave the hangar in March 2017 for commissioning and science verification work.
Construction of antenna 10 started at the end of July 2016.

2 Conditions for the next winter session

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*.

During the course of the winter semester, we plan to schedule all three configurations of the eight antenna array. 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.

8-Ant Conf	Scheduling Priority Winter 2016/17
C	December
D	December – January
A	January – February
C	February – March
(D	March – May)

The winter semester is preferred for high frequency (1.3 mm) observations. Nevertheless, 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. We especially encourage proposals that use the 8 antenna array, i.e. whose science goals can be reached with a spectral resolution of 2 MHz or lower.
Investigators who wish to check the status of their project may consult the `interferometer schedule` on the IRAM website. This page is updated daily.

2.1 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 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.

2.2 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).

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 are 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 (76.5 to 116 GHz).

BAND 2: Proposals that ask for 2 mm data (130 to 178 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 (202 to 274 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 short spacing data 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.

2.3 (New) Configurations of the eight-antenna array

Three new configurations have been designed for the eight-antenna array. Since the narrow-band correlator can process the signals from 6 antennas only, corresponding subsets of the eight antenna configurations will be fed to the narrow-band correlator (see Table 1). These have been designed to provide optimum coverage of the uv-plane.

The general properties of these configurations (numbers refer to a source at 20° declination) are:

- `A` alone is well suited for mapping or size measurements of compact, strong sources. It provides a resolution of 1.0″ at 100 GHz, ∼0.43″ at 230 GHz.
- `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 (∼2.6″ at 100 GHz, ∼1.1″ at 230 GHz) and with A for higher resolution (∼1.4″ at 100 GHz, ∼0.6″ at 230 GHz). C alone (∼1.9″ at 100 GHz, ∼0.85″ at 230 GHz) is also well suited for snapshot and size measurements, and for detection experiments at low source declination.
- `D` alone is best suited for deep integration and coarse mapping experiments (resolution ∼ 3.7″ at 100 GHz and ∼ 1.6″ at 230 GHz). This configuration provides both the highest sensitivity to extended structures and the lowest atmospheric phase noise.

The three 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 ACD 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 three configurations or their subsets. There is a possibility on the PMS web form to restrict the choice of configurations, e.g., to C or D, if your project qualifies for ANY of the more compact configurations.
Please consult the documentation
`An Introduction to the IRAM NOEMA interferometer` for further details.

2.4 Receivers

All antennas are equipped with dual polarization, low noise, 2SB receivers (currently operated in SSB mode) for the 3 mm, 2 mm, and 1.3 mm atmospheric windows. The sky frequency ranges that can be covered are 74.7 GHz to 117.8 GHz for band 1, 128.2 GHz to 179.8 GHz for band 2, and 200.2 GHz to 275.8 GHz for band 3. The receivers can be tuned LSB or USB throughout most of the accessible frequency range. Details are given in Table 2.
Each band is dual-polarization with the two RF channels, one per polarization, observing at the same frequency. 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.

2.5 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

Table 1: Configurations of the eight-antenna array and their six-antenna subsets

Name	Stations							
8A	W27	W09	E68	E23	E12	N46	N29	N20
8A6	W27	W09	E68	E23	—	N46	N29	—
8C	W23	W20	W05	E23	E16	E04	N20	N13
8C6	–	W20	W05	E23	E16	—	N20	N13
8D	W12	W08	W05	E10	E04	N13	N09	N02
8D6	W12	W08	—	—	E04	N13	N09	N02

Table 2: Receiver characteristics

	Band 1	Band 2	Band 3
F_{sky} range*/[GHz]	76.5–116	130–178	202–274
T_{rec}/[K] LSB	25–35	25–50	25–60
T_{rec}/[K] USB	25–35	25–50	30–60
G_{im}/[dB]	-10	-12 ... -10	-12 ... -8
RF LSB/[GHz]	76.5–104	130–166	202–262
RF USB/[GHz]	88.5–116	142–178	214–274

* The *sky frequency* range F_{sky} refers to the center of the 4.2-7.8 GHz IF band

35 Jy/K in band 3). These factors were determined for stable atmospheric conditions.

- 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. For typical winter conditions: $T_{sys} = 90$ K below 110 GHz, increasing to 175 K between 110 and 116 GHz, $T_{sys} = 130$ K in band 2 below 150 GHz, and increasing to 170 K between 150 GHz and 178 GHz, and $T_{sys} = 200$ K in band 3. These values apply for sources at $\delta \geq 20°$.
- N_a is the number of antennas: currently 8 when using WideX but $N_a = 6$ for spectral resolutions better than 2 MHz with the narrow-band correlator.
- 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 1.25 MHz for spectral line observations using the narrow-band correlator, and from 2 MHz up to 3.6 GHz when 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.

2.6 Correlators

2.6.1 Wide-Band correlator (WideX)

At any given time, only one frequency band can be observed, but with the two orthogonal polarizations available.
In each of the two linear polarizations a bandwidth of up to 3.6 GHz (from IF=4.2 to 7.8 GHz) can be processed by the current correlators. 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 8 antennas.

2.6.2 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 wide bands. 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 IF1 [GHz]	Q1 4.2-5.2	Q2 5.0-6.0	Q3 6.0-7.0	Q4 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.

2.6.3 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).

2.6.4 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, 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.

Starting from end 2015, receiver tuning is now preferentially 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 provided by the IF processor 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.

2.7 Source coordinates and Velocities

The interferometer operates in the equatorial J2000.0 coordinate system. Please do not forget to specify the exact coordinates and 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. Source coordinates and velocities must be correct: Wrong or incomplete source coordinates are a potential cause for proposal rejection.
A later swap of targets is not foreseen for regular projects.

2.8 Sun Avoidance

For safety reasons, a sun avoidance circle is enforced at 32 degrees from the sun.

2.9 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.

2.10 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.

2.11 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`.

2.12 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.

2.13 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.