An Introduction to the IRAM NOEMA interferometer

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This document introduces IRAM's interferometer called NOEMA to potential users. It contains general information about its capabilities and performance.

Related information is available in:

- `GILDAS: Grenoble Image and Line Data Analysis Software`
- `ASTRO: Astronomical Software To pRepare Observations`
- `CLIC: Continuum and Line Interferometric Calibration`
- `NOEMA: Calibration Cookbook`
- `NOEMA: Mapping Cookbook`

Revision 6.0: NOEMA Antenna 9,10, PolyFiX
Revision 5.1: NOEMA Antenna 8, NOEMA 2SB receivers (SSB mode)
Revision 5.0: NOEMA Antenna 7
Revision 4.2: Band 4
Revision 4.1: WideX
Revision 4.0: NGR system and extended array configurations

Contents

1 Description

The NOrthern Extended Millimeter Array (NOEMA) is located in the South of the French Alps, near St Etienne en Dévoluy in the Département Hautes Alpes. The interferometer's altitude is 2560 m at the intersection of the Azimuth and Elevation axes of the telescopes, and its longitude and latitude are 05:54:28.5 E and 44:38:02.0 N at the array phase center. The interferometer currently comprises

- ten antennas of 15 m diameter,
- baselines ranging up to 760 m
- a high-performance wide-band correlator named *PolyFiX*
- dual polarization receivers covering the 3 mm, 2 mm and 1.3 mm wavelength bands

The ten antennas of the interferometer can be positioned on 32 stations layed out along a "T" shaped track (see Figure 1). The north-south arm is 368 m long, and the east-west oriented arm extends 216 m west and 544 m east of the intersection. The angle between the arms is 75°. The station names are taken from the arm orientation and a two digit code indicating the distance from the track intersection (station W00) in 8 m units.

Until 2021, two more antennas will join NOEMA and the baselines will be extended up to almost 1700 m on the East-West arms, bringing NOEMA close to its full capabilities.

Each antenna is a 15 m diameter Cassegrain telescope constructed largely of carbon fiber. The primary mirrors have a surface accuracy below 50 μm rms. The antenna mounts incorporate self propelled transporters for moving the antennas along the tracks between stations.

The antennas are equipped with three receiver bands, observing in dual polarization and two sidebands in the 3 mm, 2 mm, and 1.3 mm atmospheric windows, respectively. The 3 mm receiver band covers sky frequencies between ∼71 and 119 GHz, the 2 mm receiver band covers sky frequencies between ∼127 to 182 GHz, and the 1.3 mm receiver band covers sky frequencies between ∼197 and 276 GHz. Typical receiver noise temperatures range from 25 K to 45 K, at 3 mm, from 35 K to 55 K at 2 mm, and from 40 K to 70 K at 1.3 mm. More details about the receivers are given in Sect. 2.2, a comprehensive summary can be found in Table 2.

The dual polar, 2SB receivers deliver four IF outputs (one per polarization and one per sideband), each 7.744 GHz wide. These are transmitted by optical fibers to the central building. An IF processor further splits each of the four IF outputs into two 3.872 GHz wide basebands per sideband and polarisation which are called outer and inner basebands. These eight basebands are then fed into the correlator (see also Figure 2).

The wide-band correlator PolyFiX, in its low spectral resolution mode with a 2 MHz channel spacing, can process a total instantaneous bandwidth of ∼31GHz for up to twelve antennas (see Sect. 2.3 for more details). The 31 GHz are thereby split up over the two sidebands and polarisations. In addition, a high spectral resolution mode with a channel spacing of 62.5 kHz is also available for a large number of spectral windows that can be placed in both sidebands and polarisations. Further modes will become available in the future.

A 64-bit Linux computer and several embedded processors control the interferometer and acquire the data. The user interface, OBS , is a variant of PaKo, familiar to most users of the IRAM 30 m telescope.

Each interferometer configuration, i.e. the placement of the 10 antennas on predefined stations within the array, provides 45 baselines simultaneously. For each configuration, a list of projects is

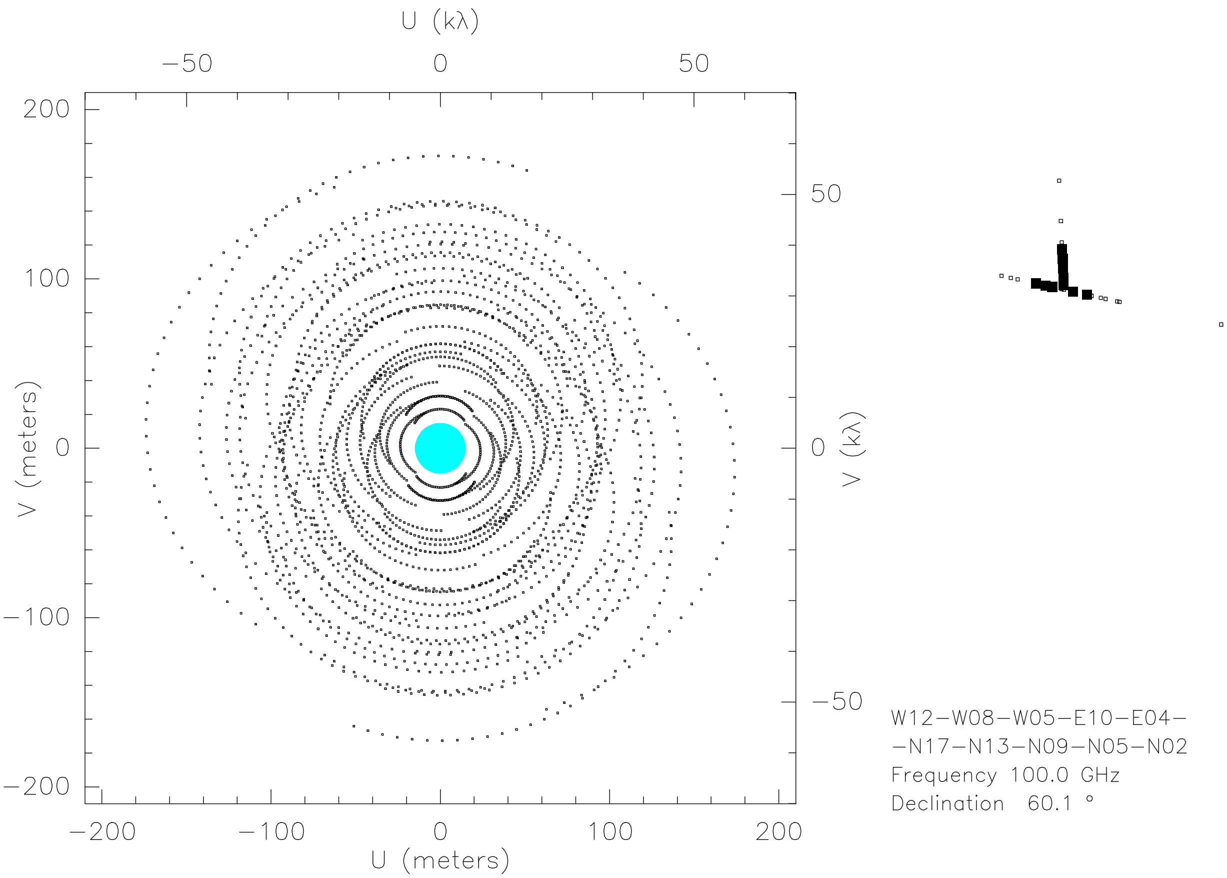

Figure 1: Example of uv-coverage (left) and interferometer station layout (right) for the 10D configuration, as produced by the ASTRO UV_TRACK command. The shaded circle at the center of the uv-plane shows the short spacing region that cannot be observed with the array.

provided to the on-site operator and the astronomer on duty, allowing for a flexible scheduling of the observations well adapted to the actual meteorological conditions. Depending on the weather and on the season, configurations are changed every two to six months, so a project that requires two configurations will on average take about four months to be completed.

2 Capabilities

2.1 Spatial Resolution

Three primary 10 antenna configurations (see Table 1) are available that can be combined to produce maps with different angular resolution. All three configurations are usually scheduled during the course of a year (see Table 1). During the summer period (May until September) each antenna undergoes a thorough maintenance and the interferometer is operated in a 9 antenna D configuration.

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

- **D** – the compact configuration with just the D array for maximum sensitivity. This configuration is best suited for detection experiments and coarse mapping (resolution $\sim 3.9''$ at

Table 1: Configurations of the ten-antenna array

Name	Stations									
10A	W27	W23	W08	E68	E24	E16	E03	N46	N29	N20
10C	W23	W20	W09	E23	E18	E10	E03	N20	N17	N11
10D	W12	W08	W05	E10	E04	N17	N13	N09	N05	N02
9D	W12	W09	W05	E10	E04	–	N13	N09	N05	N02

100 GHz and $\sim 1.7''$ at 230 GHz). This configuration provides the lowest phase noise and highest sensitivity.

- **C** – the intermediate configuration 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$2.6$''$ at 100 GHz, $\sim$1.1$''$ at 230 GHz) and with A for higher resolution ($\sim$1.4$''$ at 100 GHz, $\sim$0.6$''$ at 230 GHz). C alone ($\sim$2$''$ at 100 GHz, $\sim$0.9$''$ at 230 GHz) is also well suited for snapshot and size measurements, and for detection experiments at low source declination.

- **A** – the most extended configuration alone is well suited for mapping or size measurements of compact, strong sources. It provides a resolution of 1.0$''$ at 100 GHz, $\sim$0.4$''$ at 230 GHz.

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. The combinations AC, ACD, and CD are well suited for all declinations above 0° . For lower source declinations, the beam becomes increasingly elliptical. Sources lower than -25° declination cannot reasonably be observed from Plateau de Bure. Mosaicing is usually done with D or CD, but the combination ACD can also be requested for high resolution mosaics.

The antenna half-power beam size is 50$''$ at 100 GHz and the shortest possible antenna spacing is 24 m to avoid collisions between two antennas. Even taking into account projection effects that shorten the effective baseline, sources larger than about 15$''$ are already heavily resolved at 100 GHz. In these cases, additional short-spacing observations should be acquired by observing a raster- or OTF- (On-The-Fly) map using the IRAM 30 m telescope[1]. The short-spacing information can then easily be added to the uv-tables obtained from the interferometer by means of the GILDAS MAPPING software. (see also Section3.2.1).

[1] see also the `IRAM memo 2008-2`: *Single-dish observation and processing to produce the short-spacing information for a millimeter interferometer* by N.J. Rodríguez-Fernández, J. Pety & F. Gueth

Table 2: Receiver specifications.

	Band 1	Band 2	Band 3
F_{LO1} range/[GHz]*	82.000–108.256	138.616–171.256	207.744–264.384
F_{sky} range/[GHz]*	70.384–119.872	127.000–182.872	196.128–276.000
T_{rec}/[K]**	25–45	35–55	40–70
G_{im}/[dB]	-15-...-10	-15...-10	-15 ... -10

* Guaranteed LO1 frequency ranges per offered band. The LO1 frequency is the center frequency between the USB and LSB that can both be simultaneously observed in one tuning (see Fig 2). The center frequency of the USB (LSB) is separated by +(−)7.744 GHz from the LO1 frequency. With an effective width of 7.744 GHz per sideband the lowest and highest sky frequencies that can be covered per tuning are therefore $F_{sky}=F_{LO1}\pm11.616$ GHz. The lowest and highest LO1 frequencies per band define the F_{sky} ranges that are currently guaranteed.
** for LSB and USB.

2.2 Receivers

All NOEMA antennas are equipped with 2SB receivers, providing low noise performance and excellent long-term stability. The receivers provide two orthogonal linear polarizations in all three bands. Each of the two polarizations delivers a bandwidth of 7.744 GHz in the lower sideband (LSB) and upper sideband (USB) simultaneously. The sky frequency ranges that can be covered in each band and further characteristics are given in Table 2. Receiver tuning will preferentially be done on a fixed frequency grid of 500 MHz step width, on which the receiver performance is optimized (see Sect. 3.3 for more details).

2.3 The Wideband Correlator PolyFiX

The wide-band correlator PolyFiX can process a total instantaneous bandwidth of $\sim$ 31 GHz for up to twelve antennas that is split into two polarisations in each of the two available sidebands (the *upper* and *lower* sideband). The centers of the two 7.744 GHz wide sidebands are separated by 15.488 GHz. Each sideband is composed of two adjacent *basebands* of $\sim$3.9 GHz width, called *inner* and *outer* baseband (see Fig. 1). In total, there are thus eight basebands which are fed into the correlator. The channel spacing is 2 MHz[2] throughout the 15.488 GHz effective bandwidth per polarization. Additionally, up to sixteen high-resolution *chunks* can be selected in each of the eight basebands (i.e. up to 128 chunks in total). Each of these has a width of 64 MHz and, in the current implementation step of PolyFiX, a fixed channel spacing of 62.5 kHz. A number of contiguous chunks defines one spectral window (SPW).

Please note that there is a "non-exploitable, 20 MHz wide frequency area" ($\equiv$ LO2 zone) around the center of each sideband, i.e., in between the inner and outer basebands. Due to the filter response of the correlator, the noise level is also increased by up to a factor of two within a width of ±50 MHz around the center in each sideband. Important lines should therefore not be placed in this region (see also pages 19 and 20 in `this PolyFiX tutorial`).

Subsection3.3 explains how to configure the correlator using the GILDAS package ASTRO.

[2]due to default signal apodization with a sinc^2 function, the effective spectral resolution is 1.772 times the channel spacing

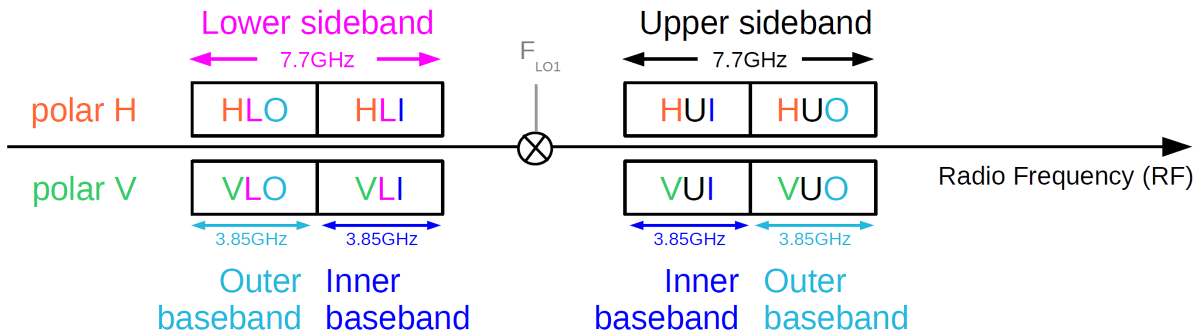

Figure 2: Basebands fed to the correlator

2.4 Sensitivity

The 1 sigma point source sensitivity (in Jy) can be derived with:

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

where

- J_{pK} is the antenna efficiency (Jy K^{-1}) i.e. $2k/(\eta_a A)$ with η_a the aperture efficiency, A the antenna collecting area, and k the Boltzmann constant.
- η is an additional efficiency factor due to atmospheric decorrelation. The short and long term atmospheric phase fluctuations depend on the baseline length, atmospheric stability and frequency.
- $T_{\rm sys}$ is the system temperature outside the atmosphere, i.e. corrected for atmospheric transmission.
- $N_{\rm a}$ is the number of antennas
- $T_{\rm ON}$ is the on-source integration time in seconds. Because of various calibration overheads, the total observing time is typically at least 1.6 $T_{\rm ON}$.
- B is the noise equivalent bandwidth of the correlator in Hz, equal to ∼1.8 times the channel separation; the effective channel width for standard apodization (using a Hanning time-lag window) is 1.772 times the channel separation.
- $N_{\rm pol}$ is the number of polarizations: 1 for single polarization and 2 for dual polarization

To provide the most realistic and up-to-date estimates of the sensitivity of NOEMA, NOEMA provides sophisticated sensitivity calculators via PMS (see Section 3.1) and via the GILDAS software package ASTRO (please use the most recent GILDAS version when preparing your proposals). Both softwares use the same calculations, based on equation (1) given above, and are regularly updated with the latest NOEMA characteristics.

The point source sensitivity obviously depends on the observing frequency and hence a so called representative frequency has to be choosen in order to calculate the sensitivity in ASTRO and PMS. In PMS, the representative frequency has to be within the frequency range and for high spectral resolution projects within one of the high resolution spectral windows that are selected in the respective technical sheet. The representative frequency does not have to be identical to the actual tuning frequency. Please note, that due to the large bandwidth and the dual-sideband mode, the noise can vary significantly with frequency in the available frequency range. Especially, if one of the sidebands is close to a receiver band edge, significant differences in the noise can occur within and between the sidebands. This should be taken into consideration when setting the representative frequency for each tuning. Please note that `PMS` and ASTRO take into account variations of the noise across the entire 15.488 GHz bandwidth to calculate the *continuum* sensitivity. Both tools also account for the declination of the source to estimate the rms noise levels. Longer telescope times are needed for sources at low declinations ($\delta < -10°$) to achieve the same point-source sensitivity.

3 Proposal Preparation

To exploit the full capabilities of NOEMA, proposals must be written with special care. It is of the utmost importance to provide the following parameters:

- A source list with accurate coordinates, velocities/redshifts
- Observing frequencies
- A source list with velocities and line width for spectral line observations
- Required spatial and spectral resolution, and estimate of required sensitivity
- For special cases: Required accuracy of the bandpass calibration (e.g., a weak line on a strong continuum, high precision relative astrometry)
- Dates to be avoided during scheduling, e.g., because of sun avoidance (a circle of 32 degree radius), phase stability requirements (daytime is often difficult in summer), or other reasons (specify)
- Any other stringent constraint (e.g. coordinated or triggered observations); please note that we currently guarantee a trigger response of three days

This information is absolutely required to decide about the feasibility of the program, a prerequisite before the program committee can consider the proposal.

3.1 The Proposal Management System (PMS)

Proposals must be submitted through the Proposal Management System (PMS) at URL: `http://pms.iram.fr`.

Proposal editors will have to create a `PMS` account to be able to login and prepare/submit their proposals. To do so, it is sufficient to click on the URL above and to follow the instructions on-screen that guide the proposal editor through the submission process. The submission procedure consists in filling in an on-line form with the details of the requested observations (source coordinates, receiver and correlator setups, array configuration, etc.), and to upload a single file in pdf format containing the scientific and technical justification. A LATEX template is provided from the `PMS` submission page. This file may be customized, but proposers should respect the following requirements: (1) a normal proposal may contain up to two pages of text describing the scientific aims and technical description (4 pages for a Large Program, see below) (2) you may add up to two pages of figures, tables, and references (but don't mix text with figures, tables, and references!), and (3) the font size must be 11pt or larger.

For a proposal to be complete, `PMS` requires that all authors validate their identity (e-mail and affiliation) and their participation to the proposal before the deadline. The editor of the proposal will have to send invitations to all authors through `PMS` by clicking an *invitation* button. We urge proposal editors to invite the authors through `PMS` well before the deadline to give them enough time to validate their identity before the deadline. Authors that fail to validate their participation will automatically be dropped from the proposal.

`PMS` will be opened for submission of new proposals about two to three weeks before the deadline[3]. Proposers may modify their proposals in `PMS` until the deadline, in which case the *submit* button must be activated again after modification of the proposal. Please avoid last minute submissions when the network could be congested. If you experience any difficulty with the submission process in `PMS`, please contact us at `pms-feedback@iram.fr` for help. You may also use this e–mail address for bug reports, general questions and comments.

3.2 Proposal Category

Proposals should be submitted through `PMS` for one of the four categories:

STANDARD: Proposals that ask for a total of less than 100 h of observing time and for the standard capabilities of NOEMA's current status (see the following sections).

TIME FILLER: Proposals that can be considered as backup 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, special needs with respect to calibration and more generally all non-standard observations. These proposals will be carried out on a "best effort" basis. PIs interested in special programs should contact the science operation group (sog@iram.fr) well before the deadline to discuss feasibility and observing strategies.

LARGE PROGRAM: A Large Program should require more than 100 hours of observing time, spread over a maximum of three years, i.e. 6 contiguous semesters, or longer for programs requesting more than 1000 hours and address strategic scientific issues (for more details see the `Large Program Policy` on the IRAM web site). The observing time request should currently be based on the availability and performance of **the ten-element array**. We might adjust it and/or review the observing strategy in response to PI needs and enhanced array's capabilities. In addition, less than the standard 50% of the total scheduled observing time will be reserved for *Large Programs* using NOEMA at this point. This restriction is necessary to account for the significant investment of technical time still needed to bring the NOEMA project to its full completion in the upcoming years.

[3]`PMS` remains open at all times for submission of Director Discretionary Time proposals.

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

Within each of these categories, observations in Band 1, 2, and 3 can be requested which are described in more detail in Section 2.2 and in Table 2.

3.2.1 Short spacing observations

Short spacing observations on the 30-meter telescope should be directly requested on the interferometer proposal web form through `PMS`. A separate proposal for the 30-meter telescope is not required. The interferometer proposal form contains a box, labeled "Request for 30-meter 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. The following documents may help to prepare your short spacing observations: `this Presentation` (especially page 23 for a brief summary) given at the 10th Interferometry School and `this Technical Report`. For further assistance, please contact the Science Operations Group (sog@iram.fr).

3.2.2 Track-Sharing Mode

Each technical sheet, i.e. frequency tuning, can be connected to several sources in `PMS`. In case that sources, sharing the same tuning, are located reasonably close to each other in the sky and need reasonably short integration times, `PMS` allows the PI to specify a track-sharing mode (please check the track-sharing box in the technical sheet in `PMS`), which will result in a lower overall telescope time due to reduced overheads. Please note that `PMS` will issue a warning should the maximum distance between the track-shared sources exceed the recommended 15 degrees and/or should the number of track-shared sources be larger than 15. These limitations have been chosen, among other reasons, to allow for gain calibrators that can still be reasonably close to all sources, and to reduce observing overheads due to slewing and calibration needs. The feasibility of track-sharing is, however, not guaranteed even if no warning is given by `PMS`. In particular, Doppler tracking will be done by default on the mean LSR velocity of the targets (requests for other tracking modes should be justified). Users should check that the spectral lines of the two targets with the highest velocity difference to the mean velocity will not move out of the selected frequency range, which is especially important with respect to the frequency coverage of selected high spectral resolution chunks. Therefore, special care has to be applied when configuring the spectral setup.

3.3 Configuring PolyFiX with ASTRO for PMS

The software ASTRO should be used to set up the receiver and correlator configuration. A description of the PolyFiX correlator and of the commands provided in ASTRO to prepare the correlator configuration can be found in `this PolyFiX tutorial`. Please use the `latest` version of GILDAS.

The essential ASTRO commands are:

- `TUNING`: receiver tuning
- `BASEBAND`: selection of baseband(s)
- `SPW`: selection of chunks to define high resolution spectral windows
- `PROPOSAL`: exports a script that needs to be uploaded to `PMS`

Receiver tuning is done on a fixed grid of LO frequencies, spaced by 500 MHz throughout each receiver band, on which the receiver performance is optimized. For a correct receiver tuning, either the source LSR velocity or the redshift is needed, or the (red)shifted frequencies should be used directly. In the latter case, the LSR velocity (or redshift) has to be set to zero in the source command. Also, the frequencies of molecular lines from the standard line catalogue in ASTRO that can be plotted over the spectrum (by setting **`set lines on`** in ASTRO) have to be redshifted by hand, i.e., a revised molecular catalogue needs to be uploaded in ASTRO (with `catalogue myfile.lin /LINE`). For more details see the internal help for the different ASTRO commands and `this PolyFiX tutorial`.

A typical session in ASTRO would be:

```
! Define a source with LSR velocity
SOURCE TOTO EQ 2000 09:11:39.786 -
                    30:53:29.257 LSR 7.0

! choice of receiver tuning
TUNING 232.686 LSB 7500
! ASTRO will shift the IF centering by
! 180.6MHz to match the tuning grid

TUNING 232.686 LSB 7319.4 /ZOOM
! Plots the selected receiver band only

BASEBAND
! select all 8 basebands

! define and display high resolution
! spectral windows (central frequency
! and width specified)
SPW /FREQUENCY 244.9 0.2
SPW /FREQUENCY 245.6 0.2
SPW /FREQUENCY 232.686 0.03
SPW /FREQUENCY 230.538 0.08
SPW /FREQUENCY 231.15 0.3
...
PROPOSAL /FILE MyFile.astro
! write the series of commands
! to set up the instrument;
! THE MyFile.astro NEEDS TO BE
! UPLOADED TO PMS
```

The TUNING command produces a plot showing the full 15.488 GHz bandwidth covered with both sidebands. The TUNING command checks that the LO frequency is located on the 500 MHz-spaced tuning grid. If this is not the case, the command moves the tuned frequency to a neighboring IF center frequency that matches the grid. The option /FIXED_FREQ can be used to ignore the tuning grid (e.g., if using the tuning grid does not cover all desired lines with the proposed tuning or if a contiguous spectral scan is requested).

PMS will only accept to load ASTRO scripts created with the PROPOSAL command (which uses the NOEMA OFFLINE syntax). This will allow PMS to show spectral coverages in a consistent way for any kind of projects (including line markers at the correct rest frequency for redshifted sources for instance).

Old NOEMA ONLINE language scripts, i.e. those created by the SETUP command (e.g., from the W17 semester) can be converted by typing in ASTRO:

```
OBSERVATORY NOEMA ONLINE
@ MyOnLineScript.astro
PROPOSAL /FILE MyOfflineScript.astro
```

4 Observing Procedures

After a proposal has been accepted, observing procedures will have to be prepared. All choices have to be finalized. This implies some additional work with your `local contact`. Non standard observations may require an in-house collaborator.

The following procedure is a standard one, which can be used for "normal" projects (full scale mapping on one object).

4.1 Setup Procedure

The standard setup defines the target source(s), configures the spectral correlator, selects the observing frequency, and leaves the system ready for receiver tuning.

```
!-----------------------------------------------------------------------
!
! PR:SETUP-zzzzzzzz.OBS ! Setup procedure for project "zzzzzzzz"
!
!    - Date:          01-Jun-2019
!    - Author:
!    - PI:
!    - Local contact:
!    - Project ID:    zzzzzzzz
!    - Verified by:   person (date)
!
!    - Rating:                        A or B
!    - Number of telescopes assumed: 10
!    - Observing mode:                mapping/detection/moving body,track-sharing/mosaic
!    - Time:                          [A,B,C,D,any] Any = CD (specify 'Any' if not ABCD)
!      (total hr os/configuration [A,B,C,D,Any] all sources/fields combined)
!
!    - Requested on-source time (h): sumt(Time)
!    - Time per source:               Fraction of time spent per source in case of track
!                                     sharing
!
!    - Requested sensitivity:        2mJy/20MHz   (e.g., rms at the given representative
```

```
!                                                   frequency)
!    - Additional sensitivity:       0.1mJy/16GHz (e.g., continuum sensitivity)
!    - rms for one mosaic pointing:  RMS_PER_POINTING
!
!    - Requested minimum S/N:      REQUESTED_SIGNAL_NOISE
!    - Representative Frequency:     REPRESENTATIVE_FREQUENCY in GHz
!
!    - Water limit:                  REQUESTED_WATER_LIMIT
!    - Obs date constraint:      OBS_DATE_CONSTRAINT
!
!    - Sun avoidance:                SUN_AVOIDANCE
!
!    - Other comments:               SETUP_COMMENT
!
!------------------------------------------------------------------------
! Do not edit directly, but copy first then
!
!        All lines marked !**! must be customized.
!            lines marked !* ! can be modified.
!
!------------------------------------------------------------------------
SET\END                           ! Finish previous observation
@ PR:defaults                     ! Restore defaults parameters
!
SET\PROJECT zzzzzzzz              !**! Specify project number for further
!
SYMBOL GO "@ PR:bserve-all zzzzzzzz" !* ! data processing
CATA SOU INTER_BASE:iram.sou         !* !
CATA PHA INTER_BASE:phase-pdb.sou    !* !
LET RECEIVER 1                       !**! Choose observing receiver: receiver 1 @ 3mm
!                                                                 receiver 2 @ 2mm
!                                                                 receiver 3 @ 1mm
!
LET LOW_LIMIT %LOW_LIMIT%                 !* ! Low elevation limit 15 degrees
SAY "Project 'PROJECT' starting"
!
SYMBOL NAME "NNNN EQ 2000 00:00:00.00 00:00:00.00 LSR 0.0"  !**! Source
!
LET N_SUBSCANS 45                 !* ! Scan length (in seconds)
LET N_SCANS 30                    !* ! Number of scans on SOURCE (22.5 minutes = 30*45sec)
LET N_SOURCES 1                   !* ! use SYMBOL NAME if N_SOURCES.EQ.1
IF (N_SOURCES.GT.1) THEN
  LET NAME_SOURCE[1:N_SOURCES]   ".." ".."  !* Enter list of sources (maximum 30)
  LET N_SCANS_SOURCE[1:N_SOURCES] ..   ..   !* Enter time per source (in scans)
ENDIF
!
LET CALIBRATOR_1 "......."        !**! 1st CALIBRATOR
LET CALIBRATOR_2 "......."        !**! 2nd CALIBRATOR
LET CALIBRATOR_3 "......."        !* ! 3rd CALIBRATOR
LET N_CALIBRATORS 2               !* ! Use 2 phase calibrators every N_SCANS
LET N_SUBS_CAL  45                !* ! Scan length on calibrator (in seconds)
LET N_SCANS_CAL  3                !* ! Nb scans on each calibrator (3 scans)

LET FSWI_CAL  .FALSE.             !* ! No fast-switching by default

LET N_MOSAIC 0                    !* ! No mosaic mode
IF (N_MOSAIC.NE.0) THEN
   DEFINE REAL X_MOSAIC[N_MOSAIC] Y_MOSAIC[N_MOSAIC] T_MOSAIC[N_MOSAIC] /GLOBAL
   LET X_MOSAIC .. ..            !* ! offsets in arcsec
```

```
   LET Y_MOSAIC .. ..           !* ! offsets in arcsec
   LET T_MOSAIC .. ..           !* ! in units of N_SUBSCANS
ENDIF
!
LET SOLVE_POINT YES
LET SOLVE_FOCUS YES
!
LET FOCUS_RECEIVER 'RECEIVER'     !* ! Focusing on observing receiver
LET POINT_RECEIVER 'RECEIVER'     !* ! Pointing on observing receiver
!
LET POINT_SOURCE_1 "......."      !**! 1st pointing source
LET POINT_SOURCE_2 "......."      !* ! 2nd pointing source
LET FOCUS_SOURCE_1 "......."      !**! 1st focusing source
LET FOCUS_SOURCE_2 "......."      !* ! 2nd focusing source
!
SET\UNLOCK
!
LINE MYLIN 90.0000 LSB 6000.000 /RECEIVER 1
BASEBAND HLO 1 /RECEIVER 1
BASEBAND HLI 1 /RECEIVER 1
BASEBAND HUI 1 /RECEIVER 1
BASEBAND HUO 1 /RECEIVER 1
BASEBAND VLO 1 /RECEIVER 1
BASEBAND VLI 1 /RECEIVER 1
BASEBAND VUI 1 /RECEIVER 1
BASEBAND VUO 1 /RECEIVER 1
!
! PLUS high spetcral resolution chunks
SPW /CHUNK 20 to 36 /BASEBAND HLO /RECEIVER 1
SPW /CHUNK 20 to 36 /BASEBAND VLO /RECEIVER 1
SPW /CHUNK 10 to 26 /BASEBAND HLI /RECEIVER 1
SPW /CHUNK 10 to 26 /BASEBAND VLI /RECEIVER 1
SPW /CHUNK 20 to 36 /BASEBAND HUO /RECEIVER 1
SPW /CHUNK 20 to 36 /BASEBAND VUO /RECEIVER 1
SPW /CHUNK 10 to 26 /BASEBAND HUI /RECEIVER 1
SPW /CHUNK 10 to 26 /BASEBAND VUI /RECEIVER 1
!
!
IF (N_SOURCES.GT.1) THEN
  SOURCE 'NAME_SOURCE[1]' /TYPE OBJ
 ELSE
  SOURCE 'NAME' /TYPE OBJ
ENDIF
!
SET\RECE 'RECEIVER' ! Choose receiver band for the observation
!
SET\OBS
!
LOAD /FREQUENCY                          ! Load frequency, but don't move antenna now
!
! Make sure any changes in the spectral configuration will be detected:
SET\LOCK
!
LET CHANGE_SPECTRAL .FALSE.                 !* ! .TRUE. if need to switch to broad_band
!                                              !(not needed with PolyFiX)
IF (CHANGE_SPECTRAL) THEN
   SPECTRAL /BROAD
ENDIF
!
```

```
SET SHOW OFF
!
TYPE PR:clean.obs
SAY "Project zzzzzzzz   Type: TYPE /  Category: CATEGORY" !**!
SAY " "
SAY "        Tuning Receiver "'RECEIVER'":            1          " !**!
SAY " "
!
! Insert here any other instructions to the operator/astronomer
!
SAY "Frequency sent, receivers may be tuned"
SAY "Execute all observations by typing GO"
SAY " "
SAY "Type END when project is finished"
SAY " "
SYMBOL PROCEED /INQUIRE "Type RETURN to remove this page: "
SET SHOW ON
SET SHOW ON
```

All information appearing on lines marked `!**!` must have been supplied in the observing proposal, lines marked `!* !` will use default values if not specified. The remaining part of the procedure will be defined by IRAM personal (your `local contact`, usually). The project number (zzzzzzzz in this example) is assigned by IRAM when observing proposals are received. After final checking by IRAM staff, this file will be given to the `operators` and `Astronomers on Duty`, together with a copy of the proposal and any accompanying information the `PI` may find useful. The `on-duty astronomer` will fill in a `NOTE file` that summarizes the individual conditions and particular problems encountered during each track observed. The `NOTE file` will provide some suggestions in cases where the data calibration is not straight-forward. A copy of it will be given to the `PI` when he/she visits Grenoble for data reduction after the project is completed.

4.2 Phase Calibrator List

The current `list of phase calibrators` used at NOEMA includes over 3000 objects. Flux densities at 85 GHz are indicated in Jy. The flux density is followed by the spectral index if measured, or 0 if no measurement is available. The last column gives the date, at which the flux has been measured. Be careful: most if not all sources are variable (both flux and spectral index vary). All coordinates are equatorial J2000.0.

5 Array Operation

Since projects are typically spread over several months, the presence of visiting astronomers when their observations are scheduled is practically impossible. In the course of observations and data processing, four "people" will play a role: the `proposal PI (PI)`, i.e. any member of the team that proposed the observations, the `local contact`, the `on-duty astronomer`, i.e. an IRAM staff member present on the site, and the array `operator`. The `local contact` is an IRAM astronomer assigned to each project that does not have an in-house collaborator. His/her role is to help the `PI` in preparing the observations and in properly calibrating the data. In case of any problem, question, or doubt, the `PI` should contact his `local contact`. The `PI` can monitor the progress of his project on the web: `http://www.iram.fr/IRAMFR/PDB/ongoing-last.html`; this page is updated three times per day. Note that checking results obtained in a given configuration, making intermediate data reductions, etc. is not the responsibility of the `local contact`. In certain cases, and upon request, remote login to a VISITORS account on the Grenoble computers can be granted to the `PI` to help him/her in this task.

The array is regularly operated by one `operator` and one `on-duty astronomer`. The `operator` has responsibility for conducting all observations, following pre-established observing procedures or under the supervision of the `on-duty astronomer` in case of unanticipated events. `Operators` have also full authority for all safety measures. Receiver tuning is done by the `operator`. The `on-duty astronomer` must assess the data quality during the observations by monitoring the array performance on standard calibrators. The `PI` usually will not be present on the site, but is expected to come to Grenoble for data calibration, once the project is finished.

5.1 Observations

The PI must specify all aspects of his/her program in an observing procedure. Standard observations can be made using general, parametric procedures. An example is given in Sect. 4.

The operator will execute the observing procedure, and the on-duty astronomer will monitor the data quality by examining the observations of phase calibration sources. In the case of peculiar observing conditions (high or exceptionally low phase drifts, calibrators too weak, etc.), the on-duty astronomer has full authority to modify the parameters of the observing procedures. He/She will, of course, try to consult with the `PI` or `local contact`.

Non-standard observations may require a specific arrangement with the `local contact` or `on-duty astronomer`, or may even require an in-house collaborator.

5.2 Data Handling

Raw data, corresponding to individual dumps of the correlator buffers, are not stored. Instead, a real-time software applies automatic calibrations (clipping corrections, atmospheric model, etc.) before writing on disk. This pre-calibrated data is archived daily, and sorted on a project by project basis.

Except for specific experiments, `PIs` will only have access to the sorted data, which contain the source data and all the calibration measurements acquired by the observing procedure. `PIs` will have exclusive access to their data for a three year proprietary period (counting from the end of the last semester of observations of the project), but no exclusive rights over the calibration data, which are duplicated in special data files to monitor a posteriori the performance of the interferometer.

Off-line calibration (RF bandpass, phase, flux, and secondary amplitude calibration) is the `PI`'s responsibility. It is possible to recalibrate the data for atmospheric transmission and receiver temperature. Recalibrating the IF bandpass is not possible.

6 Documentation and Help

NOEMA is a complex instrument. Previous knowledge of interferometry is necessary to use it correctly, and reading a standard textbook for this field is highly recommended (e.g., Thompson A.R., Moran J.M., and Swenson G.W., 2001 *Interferometry and Synthesis in Radio Astronomy. Second Edition*, John Wiley & Sons, Eds.). Information specific to the IRAM Northern Extended Millimeter Array (NOEMA) is available on the `NOEMA documentation web pages` and in the following documents:

- NOEMA ASTRO Users Guide:
  ASTRO is a graphic program to help planning observations. It is particularly useful for

complex observing programs such as series of snapshots on many sources or complex line setups

- NOEMA `Calibration Cookbook:`
  A guide to calibrating NOEMA data with CLIC
- NOEMA `CLIC Users Manual:`
  Detailed documentation of the off-line calibration program. It assumes the user has previous knowledge of interferometry
- NOEMA `Mapping Cookbook:`
  A guide to produce and analyze images from NOEMA with the GILDAS software
- GILDAS `Users Manual:`
  Documentation of the mapping and display software. GILDAS is an image processing system with many capabilities, and the documentation assumes the user has a basic knowledge of image processing

Although these manuals are updated relatively frequently, only the on-line help within the programs has the latest revisions.

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