# Status of the IRAM observatories

*Roberto* Neri[1,*] and *Miguel* Sánchez-Portal[2,**]

[1]IRAM, 300 rue de la Piscine, 38406 Saint-Martin d'Hères, France
[2]IRAM, Avenida Divina Pastora 7, 18102 Granada, Spain

**Abstract.** The NOEMA interferometer and the IRAM 30-meter telescope offer a range of outstanding capabilities that will continue to be expanded as part of IRAM's long-term development strategy.

## 1 Introduction

NOEMA and the IRAM 30-meter telescope were designed and built to provide world-class observing capabilities for thousands of researchers across the world. The two observatories together, provide a unique combination of cutting-edge technology to help researchers address key astronomical questions such as those related to the molecular complexity of star- and planet-formation processes in the Milky Way, structure formation and galaxy evolution in the Universe, and along the way helping researchers to understand the link between the formation of complex organic molecules in space and the emergence of life on Earth.

## 2 NOEMA

NOEMA is in a constant cycle of expanding its capabilities and opening new avenues to exploring the Universe. Among the most notable improvements the observatory has seen in recent years are the doubling of the number of antennas from 6 to 12 and the implementation of the antenna phasing-up capability for very long baseline interferometry (VLBI) in support of the Event Horizon Telescope (EHT, 230 and 345 GHz) and Global mm-VLBI array (GMVA, 86 GHz) campaigns. Current capabilities and those expected in the near future are presented here.

### 2.1 Current Capabilities

The receivers are equipped with dual-polarization sideband-separating mixing blocks, covering a nominal bandpass of 7.744 GHz in each polarization and sideband, and operate in the four atmospheric windows 70-116 GHz (Band 1), 127-179 GHz (Band 2), 200-276 GHz (Band 3), and 275-373 GHz (Band 4). While NOEMA currently only allows observations in the lower three frequency bands, science operations in the highest frequency band are expected to resume in 2024.

*e-mail: neri@iram.fr
**e-mail: msanchez@iram.es

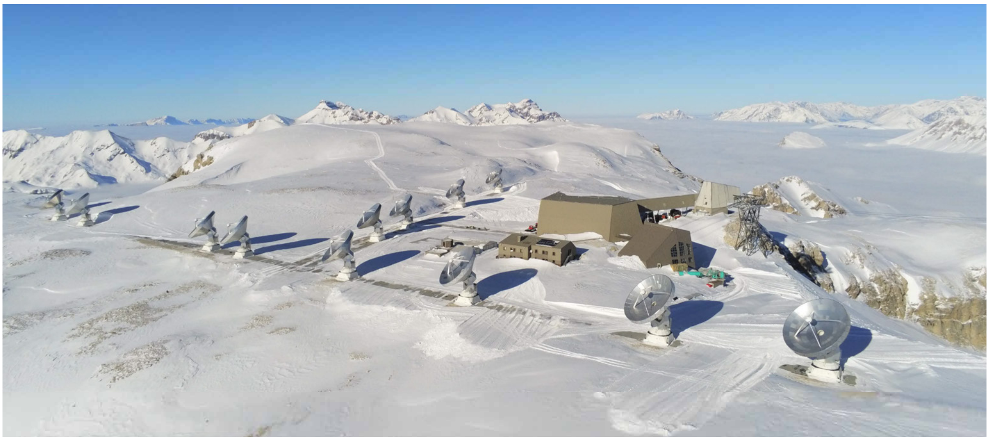

**Figure 1.** View of the NOEMA observatory as seen from the southeast. The antennas are arranged in the most compact configuration. The observatory is located in the French Alps at an altitude of 2550 m above sea level. NOEMA is operated by IRAM, an international research institute supported by the CNRS (France), MPG (Germany) and IGN (Spain). Photo by J. Boissier.

The PolyFiX correlator is able to process a 7.744 GHz bandwidth for each receiver in each sideband and polarization, for a total of 31 GHz bandwidth. The correlator, which incorporates FPGA technology to take advantage of flexible correlator configurations provides NOEMA with three basic operating modes. One mode allows observations with a channel spacing of 2 MHz over the entire 31 GHz bandwidth, with up to 128 high-resolution windows in parallel, each 64 MHz wide and with a channel spacing of 62.5 kHz. Another mode, recently commissioned (Q2/2022) and offered in the 2022 summer semester as a shared-risk opportunity, allows observations with a channel spacing of 250 kHz over the entire correlation bandwidth (Fig. 2). A third correlator mode is available that phases up the NOEMA antennas for VLBI observations.

## 2.2 Future upgrades

To ensure that NOEMA remains a major pathfinder in the development of instrumentation for millimeter- and submillimeter-wave research, developments are underway that will further expand its capabilities. These are presented below in the order in which they will be deployed in the near future.

### *2.2.1 New Configurations*

By the end of the year (Q4/2022), the interferometer is expected to offer a very extended configuration (A) with an east-west baseline of 1.7 km for observations up to 276 GHz, along with a new set of intermediate and compact configurations for optimal coverage of the uv-plane. With an angular resolution as high as 0.19", 12 antennas, and sidelobe levels of 13 dB below the synthesized beam, NOEMA will offer much improved imaging capabilities. At the lowest available observing frequency (70 GHz), NOEMA will enable the mapping of large-scale emission from regions up to 25" in extent and resolve details down to an angular resolution of 0.6".

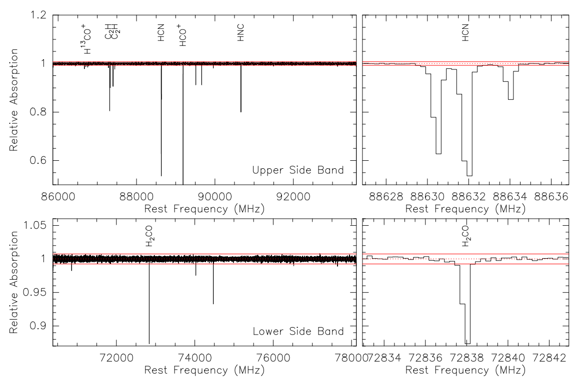


**Figure 2.** First science observations with the PolyFiX correlator operating in the 250 kHz mode. Narrow absorption lines towards the continuum of the BL Lac quasar reveal the presence of foreground Galactic clouds. The upper and lower left panels show the upper and lower sidebands, , the right panels zoom in on the HCN and $H_2CO$ absorption lines. The red lines are at 5× the noise level. Courtesy of H.Liszt, M.Gerin and J.Pety.

### *2.2.2 Spectral Scan Capabilities*

Since about 20% of the observing time is invested in spectral surveys, work is underway to offer contiguous spectral coverage over frequency ranges four times larger than the current 7.744 GHz wide IF bandwidth. Alternating between two LO frequencies separated by exactly one IF bandwidth after each calibration cycle will open the possibility of performing spectral sweeps over bandwidths of 31 GHz, under virtually identical observing conditions. This mode will be best suited to conduct NOEMA zGAL-like redshift searches [1] and ALMA PILS-like spectral surveys [2] with uniform uv-plane sampling and homogeneous sensitivity across the covered frequency window. In addition, it will help achieve higher calibration accuracy and a much improved ability to leverage spectral indices. While not yet fully commissioned, work is progressing towards offering this new capability in Q2/2023 for Band 1 observations.

### *2.2.3 Dual Band Receivers*

In the framework of the Dual Band Receiver (DBR) project, it is planned to equip all antennas with DBRs for simultaneous observations in Band 1 and Band 3 by the end of 2024. Concurrent operation in the two bands, coupled with the use of a second PolyFiX correlator to cover the entire 62 GHz bandwidth, will open a new era of unprecedented spectral coverage for NOEMA. Not only will this improve the observatory's scientific productivity by accelerating the completion of projects requiring observations in the two bands, but the DBRs will also allow for an overall improvement in data quality. They will pave the way for band-to-band phase referencing to improve the dynamic range of astronomical images, significantly reduce systematic calibration uncertainties, facilitate the completion of multiple transition line surveys, and last but not least, open up the possibility of observing transient and time-critical phenomena that evolve on short time scales.

### *2.2.4 Polarimetry and Band 4*

Work is underway to enable full-Stokes polarization observations with NOEMA. Current plans call for initial Band 1 science demonstration programs in Q3/2022, first polarimetric observations in 2023 as part of ECOGAL, an ERC Synergy 2020 funded project, and a possible opening to the general user community for regular Band 1 observations in 2024, and successively in other bands.

Last but not least, work is also underway to reinstate the ability to observe in NOEMA's highest frequency band. Under current plans, all antennas would need to be equipped with

Band 4 receivers and be operational by Q4/2024. Observations in Band 4 will open up new opportunities, including observations with an angular resolution down to 0.12", and provide new momentum for dust studies.

## 3 IRAM 30-meter

The IRAM 30-meter millimetre radio telescope in the Observatorio de Pico Veleta near Granada, Spain, is one of the most sensitive and powerful single-dish telescopes worldwide in the 73-350 GHz frequency range. In operation since 1984, it continues to be a leading facility thanks to: *(a)* a large primary reflector size (30 m), ensuring a high sensitivity and resolving power (11"/7" HPBW at 230/340 GHz); *(b)* a high mirror surface accuracy (around 60 $\mu$m r.m.s. at an elevation of 50°) that makes the telescope very efficient; *(c)* a panoply of state-of-the-art instruments (see section 3.1); *(d)* a high-altitude (2850 m above sea level), low-latitude (37°N) site that allows observations at frequencies up to 350 GHz and the best possible access to the Galactic Center from continental Europe. In addition, the excellent thermal control of the back-up structure (BUS), yoke and quadrupod, along with an efficient de-icing system, ensures continuous operation around the clock in all seasons, and rapid recovery of operations after snow storms. The IRAM 30-meter has been recognized as one of the facilities in the Spanish Map of Unique Scientific and Technical Infrastructures (ICTS).

### 3.1 Current Capabilities

The IRAM 30-meter is currently offering two instruments to the community: the Eight-MIxer Receiver (EMIR), a very efficient single-pixel heterodyne receiver with four bands at 90, 150, 230 and 330 GHz and two orthogonal polarizations, and the New IRAM KID Array 2 (NIKA2), a novel 1.2 and 2 mm continuum camera based on Kinetic Inductance Detector (KID) technology, with polarimetric capabilities at 1.2 mm. The status of the instruments is kept up to date in the documentation available for each call for proposals[1] [3]. The main innovation in EMIR is the change of the folding oscillator for the outer bands, which allows observation of the $DCO^+$ line at 72.039 GHz with the FTS backend at 50 kHz resolution and continuous coverage of a 32 GHz bandwidth at 200 kHz resolution with two tunings. For NIKA2, the commissioning of the polarimetric mode at 1.2 mm was completed by the end of 2021, and first observations of B-FUN, a Large Program aimed at probing the magnetic field in star-forming regions, were started in the winter semester of 2021/2022. The next updates will include a new, improved dichroic filter, planned for late 2022, and the adaptation of the PIIC data reduction software for polarimetry. In the longer term, new KID arrays with higher sensitivity and higher pixel yield will be installed.

The pointing and tracking capabilities of the IRAM 30-meter are outstanding [3], although improvements are underway (see section 3.2). In particular, the maximum tracking speed, which is 150"/s due to limitations in the control system, limits the maximum observable elevation to 83°. The tracking accuracy is excellent at low wind speeds (~0.2"), but decreases at wind speeds above ~10 m/s.

### 3.2 Telescope Upgrades

IRAM is currently carrying out an ambitious upgrade of the telescope to keep it at the forefront of research for the years to come. The planned refurbishment includes a new servo control system for the mount and subreflector, as well as improvements to the surface of the primary reflector. These measures are partially funded by the European Regional Development Fund (ERDF) program and will be briefly described in this section.

[1] https://www.iram-institute.org/EN/content-page-57-7-57-0-0-0.html

### 3.2.1 Servo Control System

The new servo control system aims to: *(i)* prolong the operational telescope lifetime by replacing obsolete components; *(ii)* improve the tracking accuracy at high wind speeds; and, *(iii)* allow faster slews and maximum tracking speeds, which will reduce overheads and extend the operating range near the zenith. In addition, it will be possible to design new scanning patterns. The new control system is being implemented by OHB Digital Connect GmbH in Mainz, Germany. It features state-of-the-art electronics, including ACU, amplifiers, motors and most of the safety sensors, and a control loop that runs at much higher rates than the current system. The bandwidth of the control loop will be extended to improve the tracking performance by 30% in high wind conditions. The system also implements a fully renewed servo control of the subreflector, including the six spindle drives of the hexapod and the wobbler control amplifiers. In addition, we are taking the opportunity to update and streamline parts of the control software. An overhaul of the telescope gear boxes is also planned in parallel. The Factory Acceptance Test (FAT) was recently performed in the contractor's premises, but the on-site deployment of the system, originally scheduled for summer 2022, has been postponed due to the delay in the provision of some critical hardware components. The updated plan is to start on-site activities in late February or early March 2023.

### 3.2.2 Surface Quality

The 30-meter telescope has an outstanding, although yet improvable, surface quality. The telescope primary mirror was initially covered with a $50\,\mu$m $TiO_2$ paint layer that degraded over the years. In some places, the paint layer is as thin as $\sim 10\,\mu$m, exposing the dark primer. This leads to a deterioration of the thermal behaviour in day time that manifests itself in mirror deformations and buckling of panels, which is especially critical for the imaging instrument NIKA2. In addition, the uneven paint layer contributes to the RMS error budget of the surface by at least $30\,\mu$m. Hence, the renewal of the paint layer is likely the most important and urgent action to be taken to improve the imaging quality of the telescope. In addition, the point source sensitivity is strongly dependent on elevation, decreasing by about 25% above $80^\circ$ and below $20^\circ$. Therefore, the following targets were defined: *(i)* improve the thermal behaviour of the surface and reduce the surface RMS due to optical path differences; *(ii)* improve the surface RMS error to $50\,\mu$m at any elevation, with a goal of $40\,\mu$m which would correspond to a 1.5 to 2-fold improvement in efficiency at high frequencies; and, *(iii)* reduce the dependence of mirror efficiency on elevation, so that the contribution to the RMS error due to gravity-only effects should be less than $30\,\mu$m over the entire elevation range from $20^\circ$ to $80^\circ$. On-going studies are considering a number of strategies, with "conservative" and "aggressive" approaches. In the "conservative" strategy, all actions are performed in-situ without dismounting the panels from the BUS. The main action would be to clean and repaint the panels with very stringent accuracy requirements to greatly improve the thermal behaviour of the telescope and reduce the error induced by the optical path. This measure will be likely implemented in summer 2023 if the tests currently on-going are successful. In addition, it would be possible to reinforce some structures to improve the dish gravitational deformation at low and high elevations. The "aggressive" approach implies dismounting the panels with their sub-frames from the BUS, repaint and realign the panels within the sub-frames at a carefully chosen elevation, install a number of actuators at the corners of the sub-frames using predefined lookup tables to improve the gain-elevation curve, and finally remount the panels in the BUS. The final study report is due in fall 2022, and consolidated strategies will emerge from its outcome.

### 3.3 Future Instruments

Future instrumental developments are geared towards multi-beam (MB) heterodyne receivers and their associated backends. The pioneering HERA instrument, a $3 \times 3$ MB SSB receiver at 1 mm, with 1 GHz bandwidth per pixel and polarization, will have two successors, both using SIS 2SB mixers and dual polarizations: the SHERA instrument with $7 \times 7$ pixels at 1 mm and the 3 mm MB, with $5 \times 5$ pixels. Both instruments will produce 32 GHz of bandwith per pixel. Hence, new backends will be required to handle the huge amount of data. These instruments are in the preliminary design phase, but a prototype MB instrument at 3 mm, using HEMT LNA technology, with $3 \times 3$ pixels and dual polarization is being developed in collaboration with the IAF, INAF and MPIfR institutes in the framework of the AETHRA/RadioNet project. This receiver, equipped with a test array of $1 \times 3$ pixels was tested at the telescope in April 2022 (Figure 3).

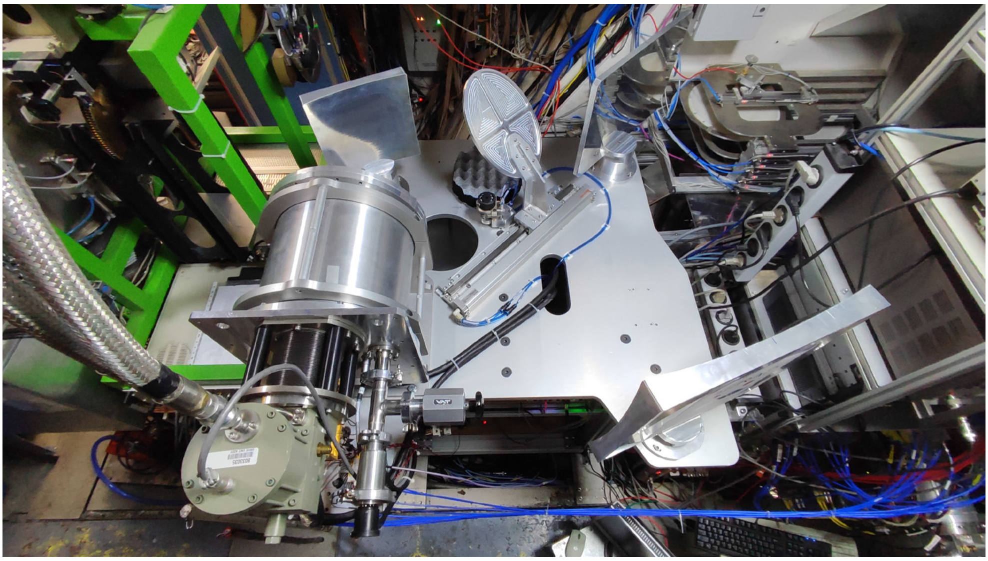

**Figure 3.** The 3 mm AETHRA prototype installed in the receiver cabin of the 30-meter telescope in April 2022. The cryostat (currently housing a $1 \times 3$ pixel array), warm optics and calibration unit can be easily identified in the optical bench. Picture courtesy S. Navarro.

## References

[1] Cox P. et al., Multi-line Diagnostics of the Interstellar Medium, Nice Proceedings (2022)
[2] Jørgensen J.K. et al., A&A, 595, A117 (2016)
[3] Kramer, C. and Sánchez-Portal, M., IRAM 30-meter Telescope: Observing Capabilities and Organisation (2022). http://www.iram.fr/GENERAL/calls/s22/30mCapabilities-delta-s22.pdf