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Introduction to the IRAM 30-meter telescope capabilities and recent upgrades

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Abstract

The IRAM 30-meter millimetre radio telescope (MRT) is located in the Observatorio de Pico Veleta in Granada, Spain and has been continuously operating since its inauguration in 1984. It is still one of the most sensitive and powerful telescopes worldwide in its frequency range. This contribution presents a brief description of the characteristics and performance of the MRT and the recent upgrades performed.

1 Introduction

The *Institut de Radioastronomie Millimétrique* (IRAM) is a French (CNRS)-German (MPG)-Spanish (IGN) institute, founded in 1979. The headquarters are located in Grenoble (France) with offices in Granada (Spain). IRAM operates two observatories, namely NOEMA (Northern Extended Millimetre Array) and the 30-meter Millimetre Radio Telescope (MRT;[1]). NOEMA is a millimetre interferometric array comprising $12 \times 15\,\mathrm{m}$ antennae, located at 2550m in the Plateau de Bure in French Alps. The MRT is sitting at 2850m in the Loma de Dílar in Sierra Nevada, in Granada, Southern Spain. Since its inauguration in 1984, the MRT has been a leading facility in the class of millimeter-wave (73–375 GHz) single-dish telescopes, thanks to the combination of a large primary reflector size, high mirror surface accuracy, a panoply of state-of-the-art instruments and a high-altitude site with a low average opacity at a relatively low latitude in South Spain.

The MRT continues being one of the most powerful facilities worldwide in the millimetre/sub-millimetre range. It has been recognised as one of the facilities within the Spanish Map of Singular Scientific and Technical Infrastructures (ICTS). In order to keep it in the forefront of scientific research, a number of upgrades have been implemented (and others are undergoing). This contribution aims at briefly describing the main characteristics and performance of the MRT, the operation and conditions at the observatory and finally, the upgrades recently finished.

2 Telescope main characteristics

The MRT has a parabolic primary reflector of 30 m diametre that provides a high angular resolving power (10.7/7.5 arcsec HBPW at 230/340 GHz). It consists of 420 aluminum panels with a very small global surface error, around 60 μm r.m.s. at an elevation of 50°. The optical configuration is a classical Cassegrain/Nasmyth station, with a hyperboloidal secondary of 2 m ⌀. The effective focal ratio is 9.73 and the unvigneted field-of-view is 6.5 arcmin ⌀. The mount is alt-azimuth type with a range of movement of 90° in elevation and 400° in azimuth. The telescope has a quasi-homologous structural design (see [1] and references therein) that allows a perfect control of the paraboloid surface with varying elevation. The telescope is almost entirely built on steel, with a moving mass of some 800 t. The operating range of frequency allowed by the current instruments is 73–375 GHz.

The MRT is equipped with an efficient thermal control, using both passive (diffusive paint, insulation, closed back structure) and active methods (ventilation and heating of the back-up structure, quadripod, yoke and counter-weights). A large number of temperature sensors (160), distributed across the telescope structure, continuously monitor the temperature. The goal is to maintain a uniform temperature across the whole controlled volume within 1° C of the reference temperature. This ensures having a very accurate telescope shape in both day and night (thus allowing observing 24h/day) and minimizes the astigmatism. The de-icing system consists of a large set of resistors installed on the panel rear side, the reflector rear cladding, yoke surfaces, quadripod, and sub-reflector, to prevent icing when it is raining/snowing at freezing temperatures. It takes about 6 hours to recover a thermally stable state after using this system.

The antenna is moved by two groups in elevation (El) and one group in azimuth (Az). Each group has two gearboxes (1/2 motors per gearbox in El/Az), with one pushing and the other pulling for backslash compensation. The current performances of the control system are given under Sect. 5 below. The secondary mirror, or sub-reflector, is equipped with an hexapod structure with 6 motors that allow shifting and tilting it in the X, Y and Z axes. This way, focus and homology correction can be applied. In addition, a seventh motor permits a bulk rotation of the hexapod. Furthermore, the sub-reflector is equipped with a "wobbler", a system that allows performing a fast tilt of the mirror between the source and the reference position, crucial for background subtraction. The maximum amplitude of the throw is ±110 arcsec with a maximum beating frequency of 2 Hz.

3 Instruments

The instrumentation of the MRT is described in details elsewhere in this workshop. Here, a very brief outline is provided. The instrumentation has been continuously updated since the beginning of operation, and we are now running the fifth generation of instruments. Currently, we operate two powerful receivers, EMIR and NIKA2.

The Eight MIxer Receiver (EMIR; [2]) is a true "workhorse" of the MRT. It is a heterodyne receiver consisting of four bands at 3, 2, 1.3 and 0.8 mm (90, 150, 230 and 330 GHz). Each

Figure 1: The MRT in late summer 2024. Notice the new paint layer in the main dish. The auxiliary observatory building is shown to the left. The Pico Veleta summit is visible to the right (credits M. Castillo).

band provides two very well aligned orthogonal polarisations at the same frequency. The detectors are dual side-band (2SB) mixers. Each band has 8 GHz of bandwidth per side-band and polarisation, i.e. 32 GHz total. Two bands can be used simultaneously by means of dichroics. The instrument has its own calibration system with ambient and cold loads.

There are three spectrometers that can be used in combination with the heterodyne receivers. The Fast Fourier Transform Spectrometer (FTS) is the main general-use backend at the MRT. It can be configured with two spectral resolutions, 200 and 50 kHz. It provides 32 GHz instantaneous bandwidth at 200 kHz with the current setup of 24 FTS units. The Wideband Autocorrelator (WILMA) provides a spectral resolution of 2 MHz with a instantaneous bandwith of 16 GHz and exquisite baseline cosmetics. Finally, the VErsatile Spectrometric and Polarimetric Array (VESPA) is a very flexible backend, with spectral resolution ranging from 3.3 kHz to 1.25 MHz, with instantaneous bandwidths from 10 to 512 MHz. This backend provides both autocorrelation and cross-correlation of orthogonal polarisations for polarimetry purposes. In addition to the spectrometers, the MRT has two sets of continuum backends: the Broad-Band (BBC) and Narrow-Band (NBC) continuum detectors have a bandwidth of 8 and 1 GHz, respectively. These are mostly used for calibration observations (pointing and focus), but also for some science applications (e.g. quasar flux and pulsar monitoring).

The New IRAM KID Array 2 (NIKA2; [3]), is a a novel kilopixel broad-band continuum camera based on the technology of kinetic inductance detectors (KID), working simultaneously in two bands at 2 and 1.15 mm. The instantaneous field-of-view is 6.5 arcmin. It offers two modes of operation, namely total power and polarimetry (the 1.15 mm band has two arrays for gathering the two linear orthogonal polarisations). The detectors are cooled at 150 mK by means of a ^{3}He/^{4}He dilution refrigerator.

4 Site conditions and observatory operation

The MRT site, close to Pico Veleta, at a latitude of $\simeq 37°$N makes it vantage place in Continental Europe to observe the Galactic Center. Its altitude, 2850 m above the sea level, allows high-frequency observations ($\gtrsim 350$ GHz). The observatory is equipped with a radiometer at 225 GHz to perform continuous measures of the atmosphere opacity. The database comprises measures since 2012 to present. The distribution of precipitable water vapour (PWV) shows stability across the years. Table 1 shows the quartiles of the cummulative distribution of PWV along the period 2020–2023. It reflects the high quality of the atmosphere at the observatory site, with median values of 3.8 and 7.0 mm for the Winter (December–May) and Summer (June–November) semester, respectively.

Table 1: Cummulative Precipitable Water Vapour (PWV) quartiles, 2020-2023 for the Summer and Winter semesters.

Season	PWV 25% mm	PWV 50% mm	PWV 75% mm
Winter	2.8	3.8	5.9
Summer	5.0	7.0	10.1

Unlike the most modern observatories, that are service, queue-oriented facilities, the IRAM 30m MRT is a "traditional" observatory, supporting three main modes of operation: *(a)* visitor mode, either on-site or remote (the visiting observers connects from remote locations through a VNC viewer); *(b)* "pool operation" mode: the observers at the pool blocks (usually of one week) observe the projects in the pool list according to their visibility, required atmospheric conditions and priority; and *(c)* service mode, carried out by IRAM atronomers; reserved for short ($<$ 8h) observations.

A vast amount of the available observing time is offered to the community in open, competitive calls for proposals issued each semester (Summer and Winter). Typically, two-thirds of the projects are devoted to galactic topics (interestellar medium, astrochemistry, star formation and evolution, circumstellar discs, cores, solar system) and one-third to extra-galactic topics (nearby galaxies, AGNs, and high-z sources). The time distribution between EMIR and NIKA2 is usually around 80 and 20%, respectively.

The observational efficiency is commonly in the range 60%-70%. Technical down-time is typically low, around 5% for maintenance and technical observations, and 1% due to technical problems. The fraction of time lost due to weather conditions is generally around 25-30%

5 Recent upgrades

To ensure a continued operation of the MRT as a benchmark facility, two aspects were identified as critical: on the one hand, even though the existing telescope servo control system was performing well, most of the hardware components were very old (from the early 80's) and therefore obsolete and difficult to maintain. Furthermore, the system showed some limitations, e.g. limited tracking speed and reduced operational range. And, on the other hand, the paint surface of the primary mirror had deteriorated significantly after almost fourty years exposed to the harsh environment of the observatory. In order to overcome this limitation, IRAM embarked into an ambitious program to upgrade the telescope. After a long period of concept definition, the activities formally started in 2021. The on-site servo control system upgrade works started in March 2023 (Fig. 2) and prolonged until February 2024. The surface upgrade activities were carried out in the period June-September 2024. Both activities are briefly described below.

Figure 2: Hexapod disassembly procedures during the servo System upgrade.

The new servo control system was built by the company OHB Digital Connect GmbH in Mainz, Germany. It features state-of-the art hardware and software components. All key components, including both mount and sub-reflector, were replaced, comprising motors, amplifiers (for drives and wobbler), control computer, safety computer and many sensors. A powerful Beckhoff industrial computer implements the Antenna Control Unit (ACU) controlling the axes and sub-reflector hexapod spindles and wobbler. The IRAM computing team at Granada developed a software component to interface the existing, high-level telescope control software with the low-level software running in the new ACU. At present, all previously existing observing modes are enabled and running correctly. Now the telescope is able to track correctly at elevation close to 89° (limited in the previous system to 83°). The mapping speed has been greatly increased. Current tests indicate the possibility of mapping at 40–50 arcsec/sec at an elevation of 88° (that corresponds to a maximum azimuth speed of ∼1500–1800 arcsec/sec). The tracking accuracy is similar to that of the previous control system (0.2 arcsec r.m.s. with low wind conditions) and is still improving.

The surface upgrade involved a comprehensive restoration, resulting in a significant enhancement of the operational efficiency of the MRT. A detailed study, completed in March 2023, outlined the procedures for cleaning, painting, and validating the primary reflector surface. The restoration utilized Goldstone 7 paint from Triangle Inc., a specialized coating that had demonstrated excellent performance in laboratory tests. Prior to its application, the panels required cleaning through laser ablation to remove the old paint (Fig. 3) . The paint was then applied with a precise thickness specification of $50\,\mu\text{m} \pm 8\,\mu\text{m}$. A follow-up validation campaign ensured that the paint's thickness and uniformity met the stringent specifications. Current measures indicate an average thickness of $52.4\,\mu$m with a dispersion of $4.6\,\mu$m r.m.s. We are currently measuring the telescope efficiency and surface roughness, day and night time beam shape and other figures of merit. Preliminary results indicate a great improvement of the telescope behaviour in day time, as expected.

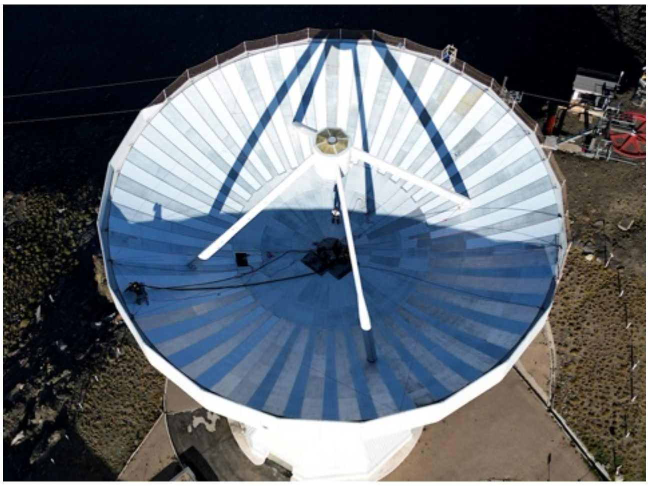

Figure 3: Laser ablation cleaning and repainting of the main reflector surface.

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