The IRAM-30m telescope: Recent and future developments

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Overview

- The IRAM-30m MRT telescope in a nutshell
- Recent developments:
  - 2021-2023: servo control upgrade
  - 2024: primary mirror surface upgrade
  - 2025: NIKA2 continuum instrument upgrade
- Current developments
- Future developments: the ALHAMBRA multibeam instrument
- Lessons learned

The IRAM-30m MRT in a nutshell

- The "Instituto de Radioastronomía Milimétrica" (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 MRT telescope.
- Inaugurated in 1984, the 30-meter MRT is sitting at 2850m in the Loma de Dílar in Sierra Nevada, in Granada, Southern Spain.

The IRAM-30m MRT in a nutshell

- Nowadays, continues to be a leading facility in the class of millimeter-wave (73-350 GHz) single-dish telescopes; main assets include:
  - **Large aperture (30m)** ensuring high sensitivity and high resolving power (11/7.5 arcsec HPBW at 230/340 GHz). Excellent imaging quality.
  - **High mirror accuracy** (around 60 μm) making it very efficient
  - **Excellent thermal control** of the backup structure (BUS), yoke and quadrupod
  - **Efficient de-icing**, ensuring quick recovery after snow storms.
  - **The telescope operates day and night, 24/7** (but for a short weekly maintenance slot). Some 5,000-6,000h are dedicated every year to science observations.
  - **State-of-the-art instrumentation**: EMIR, a very efficient single-pixel multi-band heterodyne receiver, and NIKA2, a novel, KID technology-based continuum camera with two channels at 1.2 and 2mm and polarimetry capabilities
  - **Relatively high-altitude (2850 m)** allows observing around or beyond 350 GHz (slready within the sub-mm range)
  - **Low-latitude (37^{o} N)** within continental Europe permits easy access to the Galactic Centre.
  - Every year, **nearly 200 visiting astronomers** make use of the facility. Research topics range from Solar System to Cosmology.
- The 30-meter is one of the facilities within the Map of ICTS, integrated in the Spanish Network of Astronomy Infrastructures (RIA).

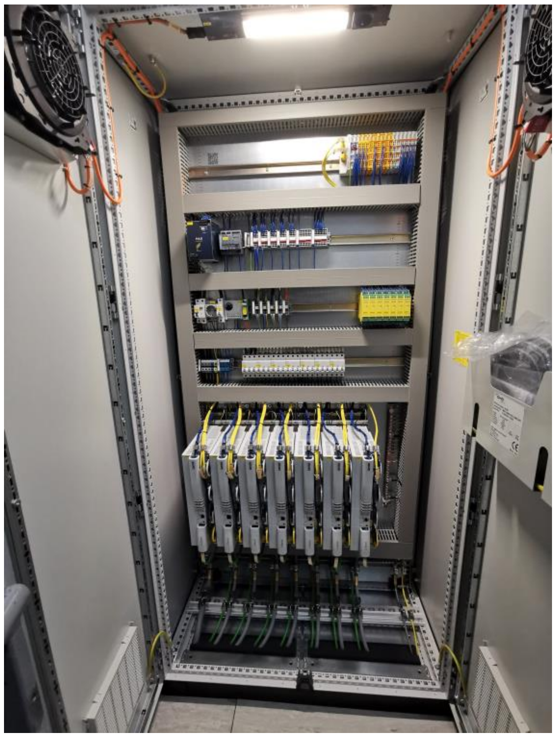
Telescope servo-control upgrade (2021-2023)

- Goals of the project:
  - Implement a new servo system featuring state-of-the-art electronics with a control loop running at significantly higher rates than the current system.
  - Increasing the control loop bandwidth (goal 1 Hz) to improve the response to disturbance torques.
  - Renew the servo control system of the sub-reflector, including the hexapod (with 6 spindle motors) and wobbler control amplifiers, to facilitate future maintenance.
  - Update and streamline the control software.
- Timeline:
  - The project formally started in September 2021 with the contractor company OHB Digital Connect GmbH (ODC, Mainz, Germany). Initially it was intended to be completed by the end of summer 2022.
  - Due to unforeseen delays in the availability of hardware components, the onset of on-site works was postponed to spring 2023.
  - On-site servo upgrade works started by the 1st March 2023.
  - The telescope was stopped from March to December 2023.
  - Commissioning was completed in January 2024.

The project was supported by the Instituto Geográfico Nacional (IGN) and partially financed by the European Union through the European Regional Development Funds (ERDF) programme.

UNIÓN EUROPEA
Fondo Europeo de Desarrollo Regional

New Servo Control System Deployment

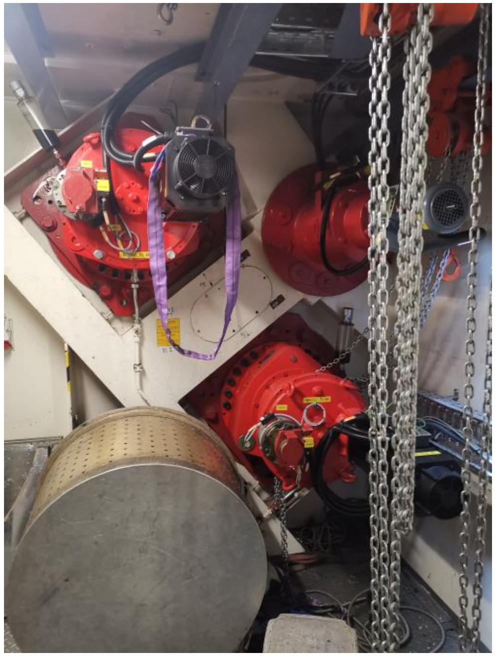


Hexapod amplifiers cabinet

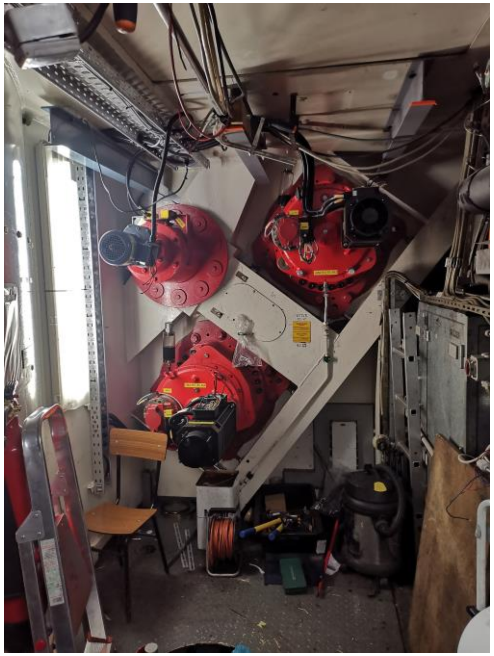
AZ & EL amplifiers cabinet

Main Control Cabinet with the Beckohff ACU display.

New Servo Control System Deployment



Left Elevation Motors



Right Elevation Motors

Left Azimuth Motors

Azimuth Safety Encoder

Elevation Safety Encoder

New Servo Control System Deployment

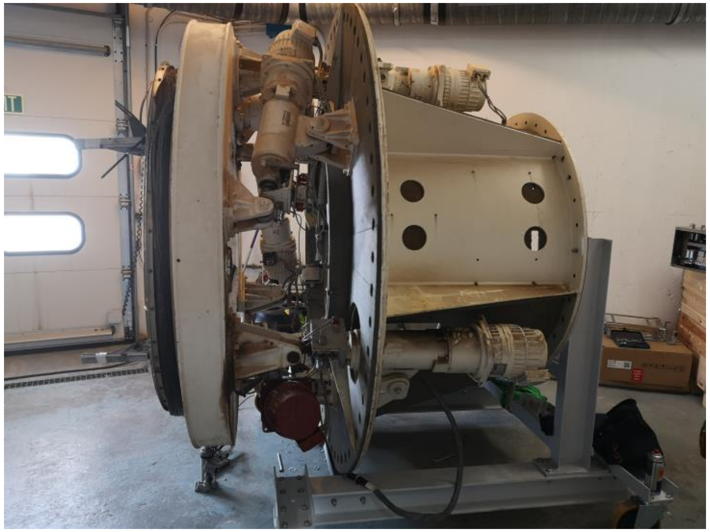
- The Secondary disassembly was done on May, 16th 2023.



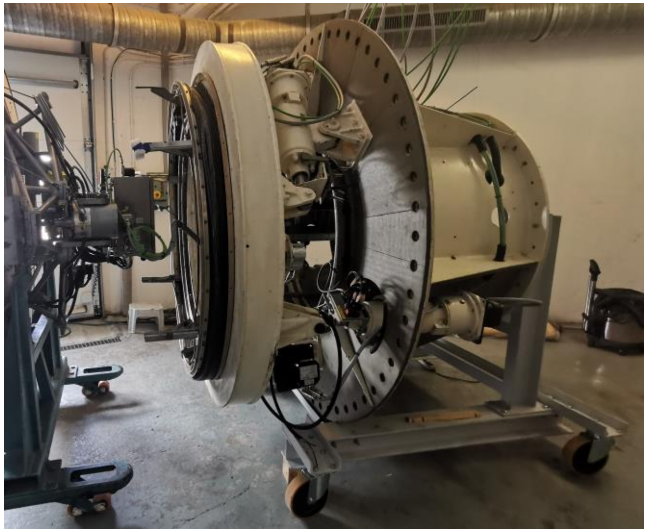



Hexapod refurbishment

- The design of the 30m hexapod/subreflector cage makes it very difficult to maintain the spindle motors or replace them in case of failure → Lesson learnt: the design of the telescope must be oriented towards maintainability, making key components easily serviceable.



2023-05-17



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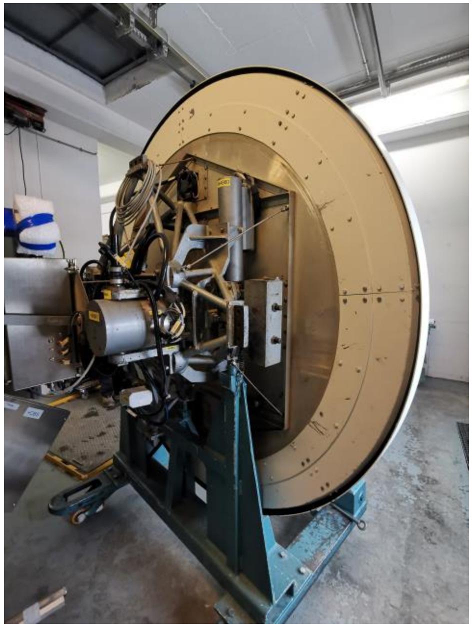
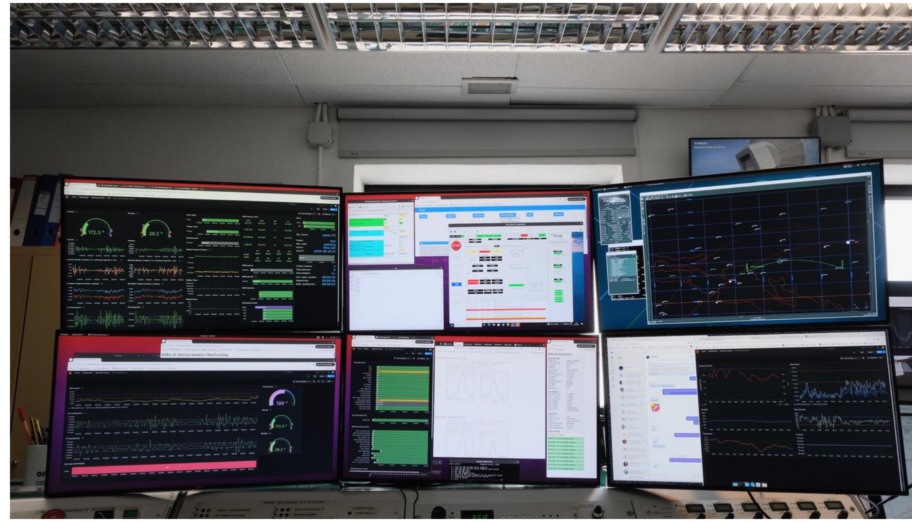
New Servo Control System Deployment

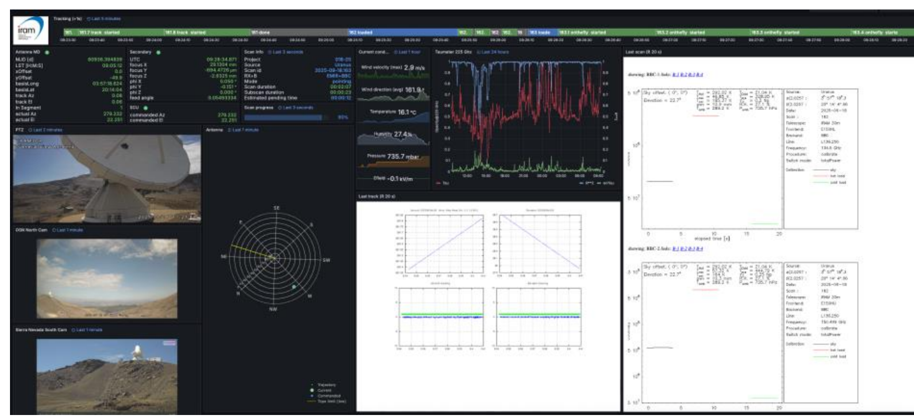
Subreflector and wobbler refurbishment



Telescope control status after the upgrade

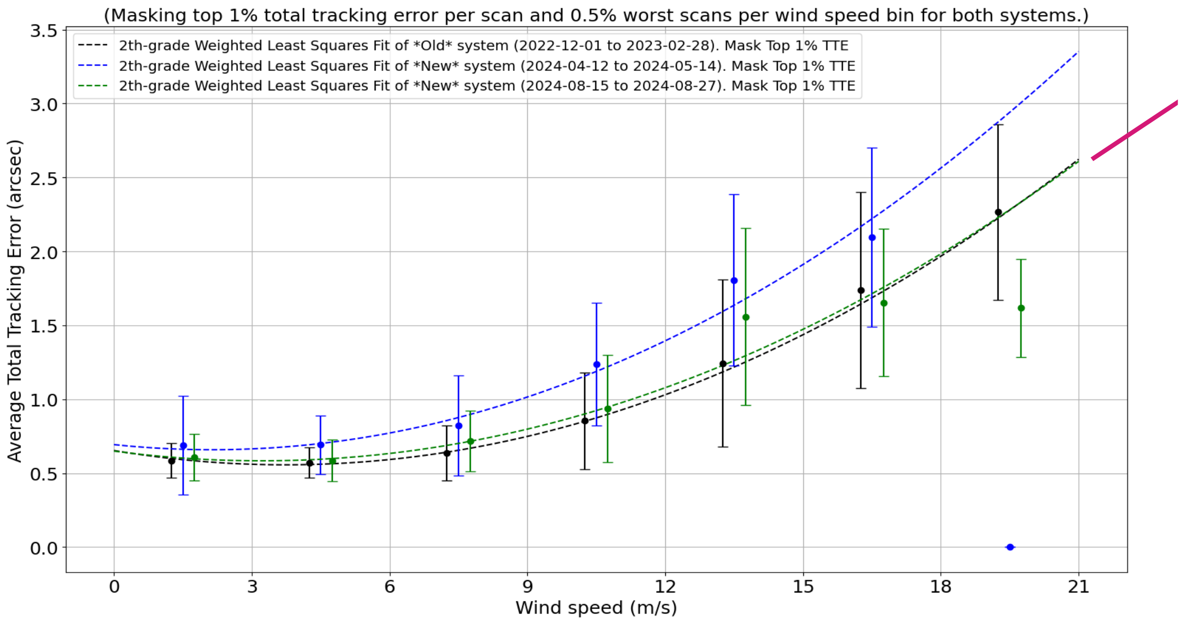
- The new control system is working well and the characterisation of its capabilities is still on-going:
  - ➢ All observing modes are enabled and working correctly.
  - ➢ The interface between the NCS and the new ACU is working flawlessly.
  - ➢ The telescope is now able to track correctly at elevation as high as 89º (although the vertex closes at 88.5º).
  - ➢ The mapping speed now can exceed 200”/sec up to elevations of > 80º.
  - ➢ Yet improving the tracking accuracy (see next slide).
  - ➢ The wobbling system is now working correctly, with same or better dead time performance as before the upgrade, although the maximum wobbling amplitude has been limited to 100” to avoid overloading the amplifiers.
  - ➢ Additional monitoring capabilities added (Zabbix agent, Grafana…).





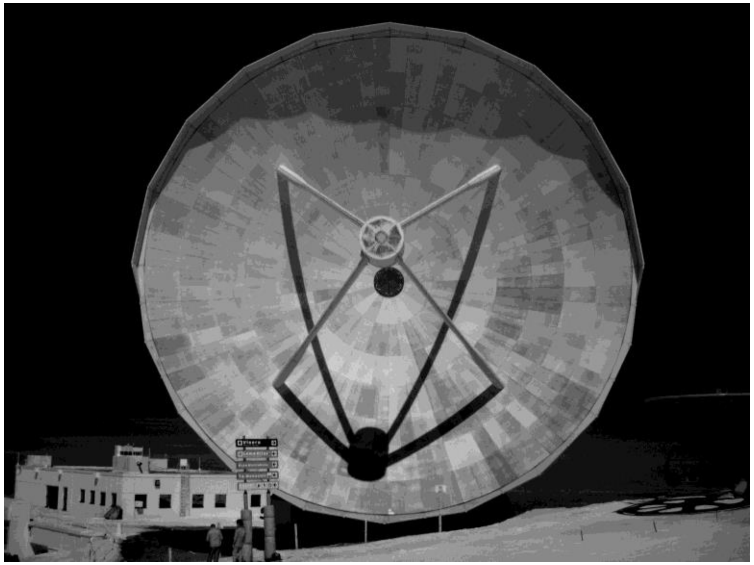
Telescope tracking accuracy

- ODC engineers have been attempting to improve the tracking accuracy in different wind conditions.
- The last parameter set was derived after computing the mount eigen-frequencies on 14th August 2024.
- Since then, we are compiling statistics. Conclusions so far:
  - ✓ With no wind, or mild wind conditions, old and new systems are similar.
  - ✓ With moderate wind conditions, the old system is still behaving marginally better than the new one.
  - ✓ But with high wind conditions (> 18 m/s) the new system seems to behave better. Highly dependent on the wind direction relative to boresight.
- Still under investigation. A possible cause could be related to the reading of our (old) position encoders → Lesson learned: ensure compatibility of new and old components!

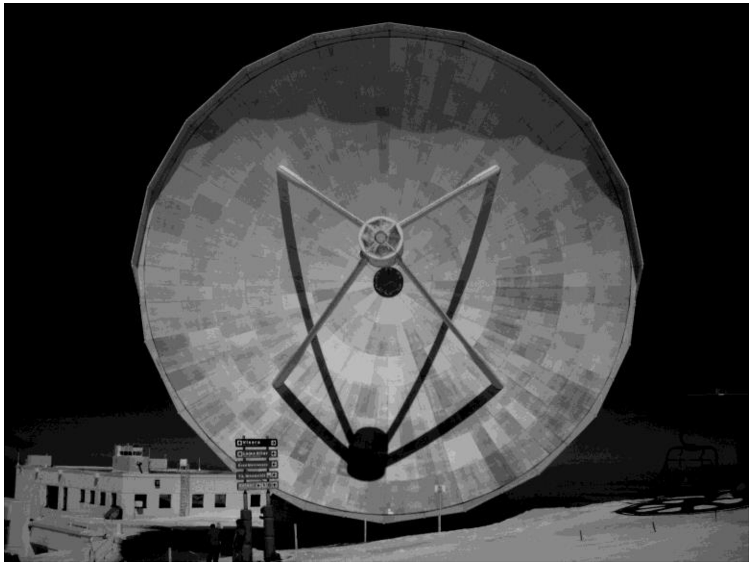


Telescope Surface Upgrade (2024)

VIS



NIR



March, 23rd 2021

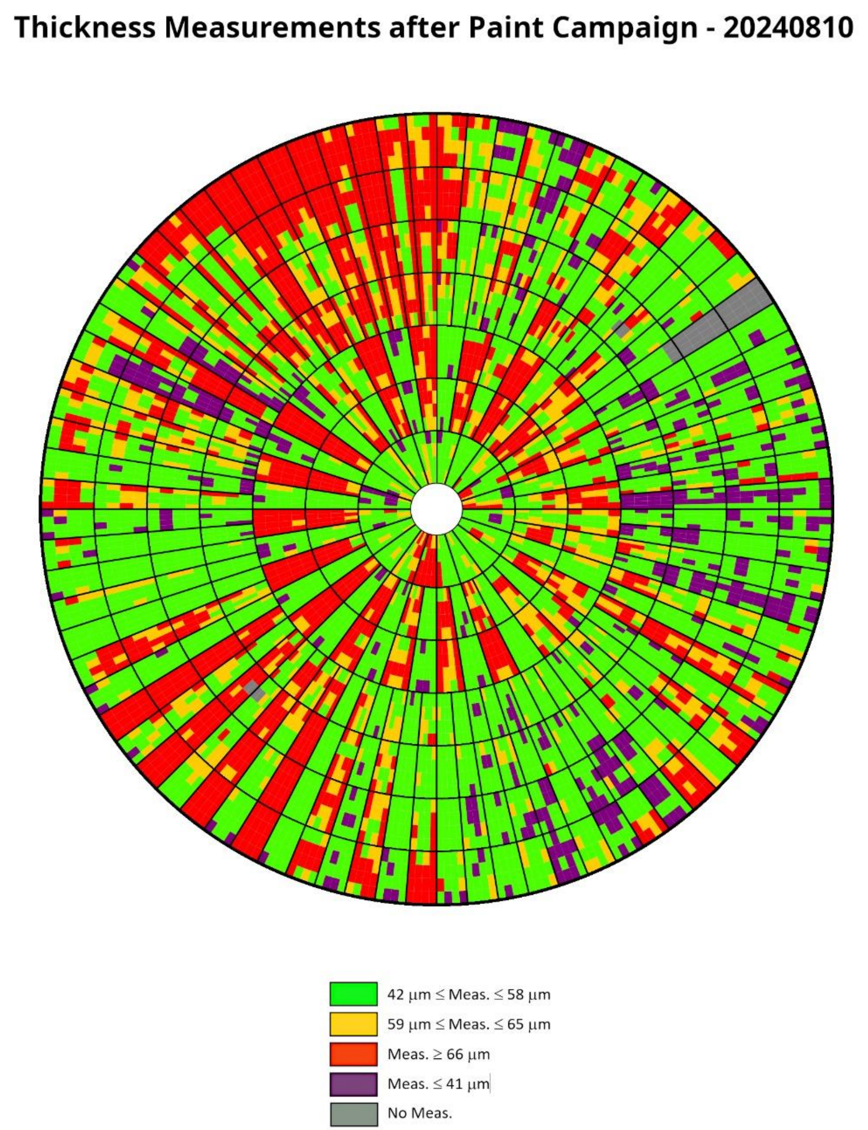
- Renewing the paint was an urgent action necessary to improve the 30-meter telescope.
- In 2022, an on-site paint test campaign was carried out (laser cleaning + painting of 3 panels from the external telescope ring) to analyze the challenges and requirements.
- A detailed study report was delivered by ODC in May 2023, outlining the procedures for surface painting (cleaning, painting, safety, measurement, validation), paint degradation tests, and an FE study of the telescope structure. This study was presented to SAC in 2023.
- Based on the study's conclusions, ODC proposed an execution project that was accepted by IRAM.
- Finally, the painting work started on June 3rd and was completed on September 17th, 2024.

Telescope Surface Upgrade

- The final paint selected was **Goldstone 7** from Triangle Inc (same used in NASA DSN antennas). It doesn't require primer and shows good laboratory performance.
- Nominal thickness requirement was 50 μm ±5μm peak-to-peak. The final thickness requirement considered for acceptance, including the error of the measurement device, is 50 μm ±8 μm.
- Works started on June 10th with the deployment of the safety system
- Effective Laser cleaning started on June 19th. Painting started one week after. All these works were completed on August 6th.
- Preliminary efficiency measurements were performed by IRAM staff from August 6th up to the first planned observations.
- A paint retouch campaign was performed between September 3rd to 17th to finally adjust the paint thickness to the requirements.
- IRAM team monitored all the phases of the works (laser cleaning, painting and retouch) measuring the thickness of all panels. It required around 100,000 measurements on the surface.

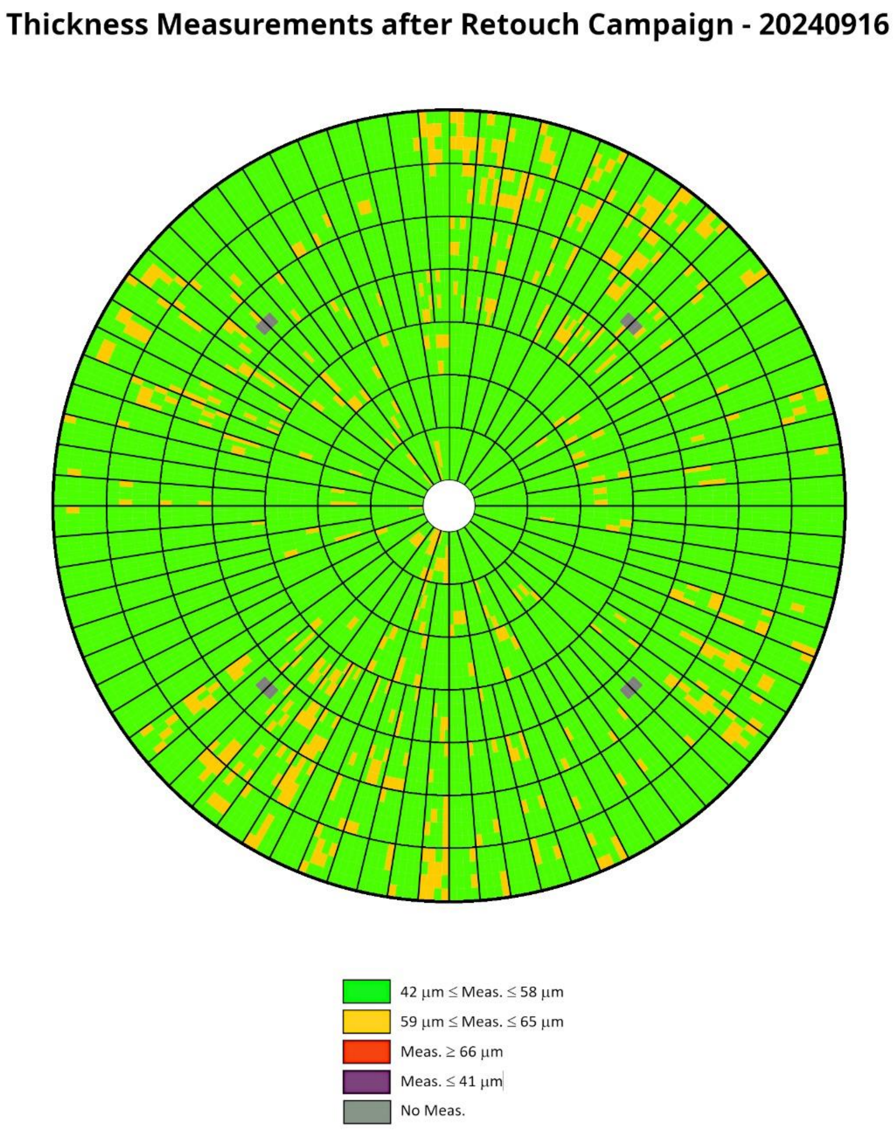
Telescope Surface Upgrade

Average thicknes: 57.5µm
r.m.s.: 13.6 µm

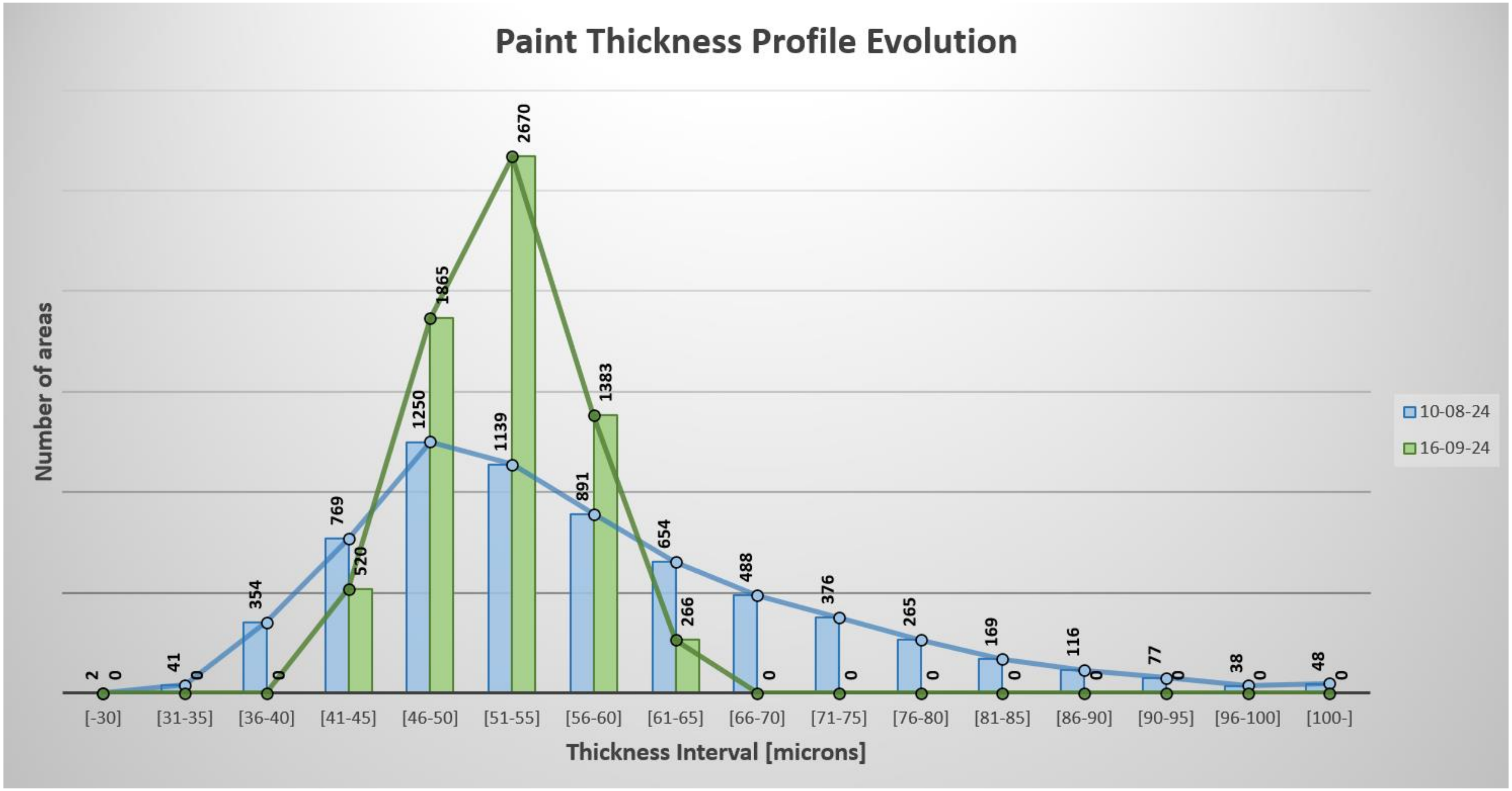


Telescope Surface Upgrade

Average thicknes: 52.4µm
r.m.s.: 4.6 µm



Telescope Surface Upgrade



Telescope Surface Upgrade

September, 16th 2024

NIKA2 upgrade (2025-2026)

- The NIKA2 instrument is a continuum camera consisting of two bands, with one array at 2 mm (150 GHz) and two arrays at 1.15 mm (260 GHz). The 1.15 mm band has polarimetry capabilities.
- The arrays consist in Kinetic Inductance Detectors (KID), with 616 and 1140 pixel at 2 and 1 mm, respectively.
- We have planned an ambitious upgrade of the instrument in two phases:

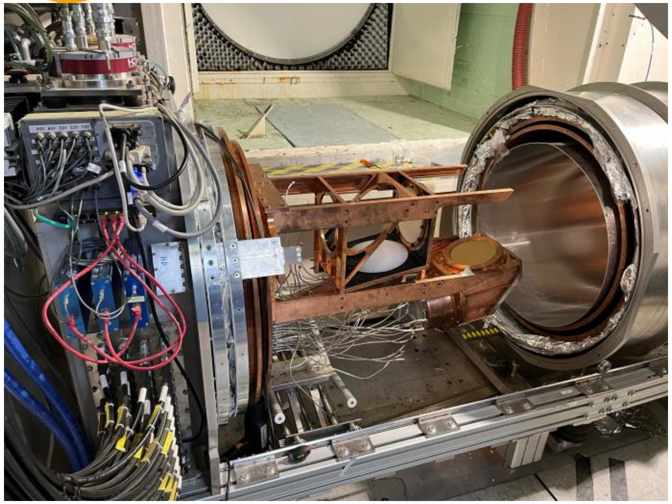
Phase 1 (performed in March, 2025)

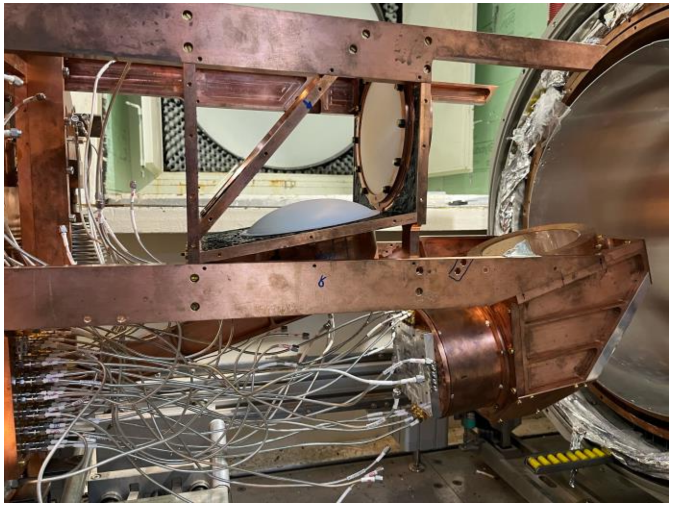
1. New dichroic, improving the efficiency at 1.15mm.
2. New IR cutting filters
3. HDPE lenses
4. New KID arrays @1.15mm (Array 1 & 3) replaced by higher sensitivity, larger bandwidth ones. Array 3 replaced in March 2026.

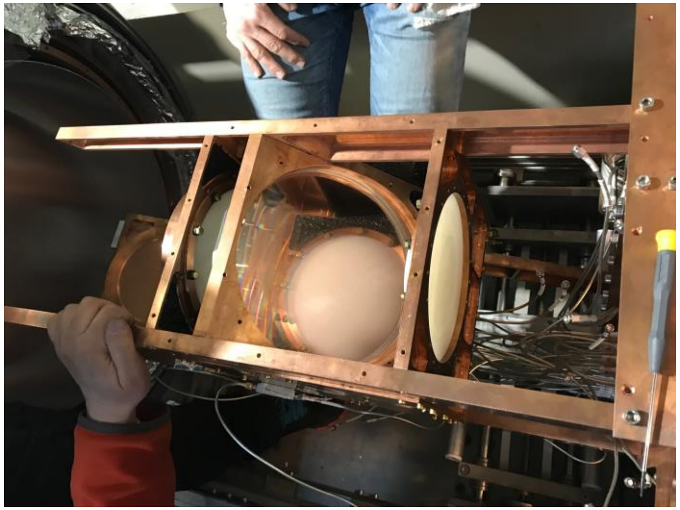
Phase 2 (date TBD)

1. New control electronics (replacing NIKEL boards)
2. Silicon lenses replacing HDPE ones (higher refraction index, thinner lenses)
3. New KID arrays.

NIKA2 upgrade (2025-2026)



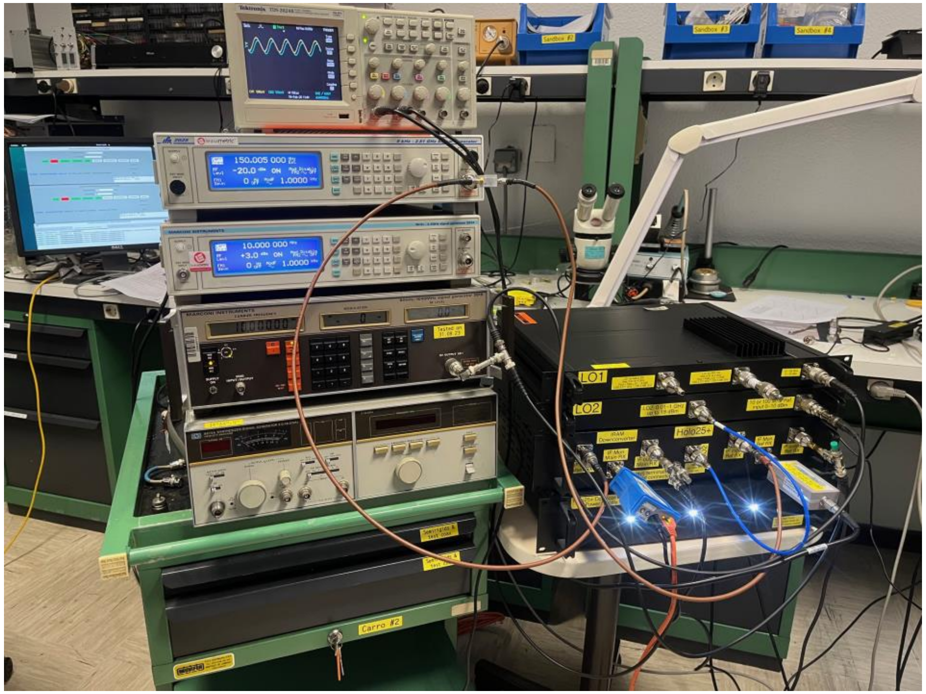




Current developments: Holo2025+

- The new Holo2025+ holography system will be consist of two receivers, one permanently placed at the sub-reflector housing and a second one very likely installed with a pick-up mount inside the vertex of the telescope between the sub-reflector (M2) and the M3 mirror.
- Procurement of components (receivers, down-converters, synthesizers) completed.
- The Holo2025+ system will work together with the new ASH backend.

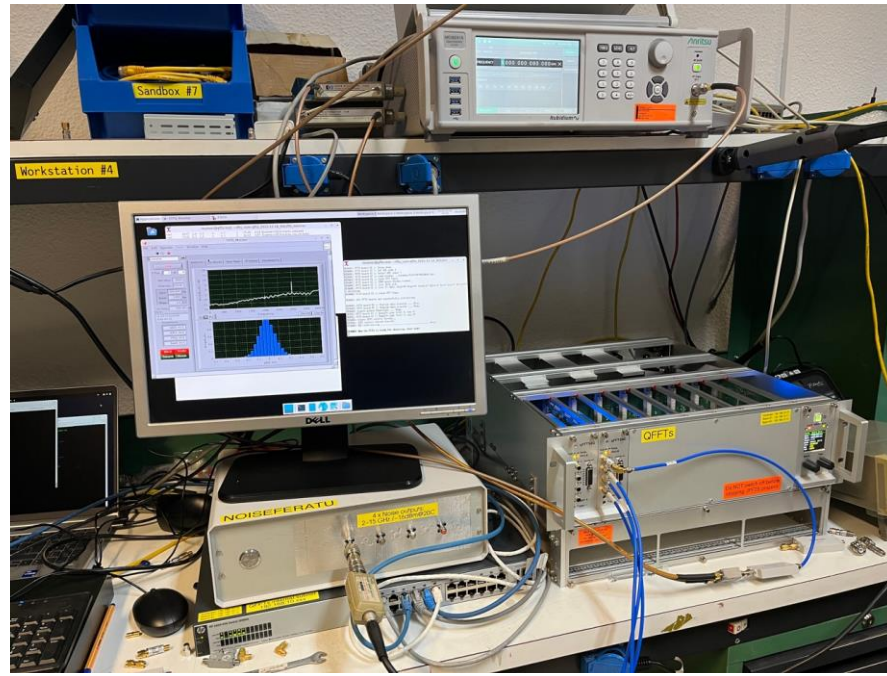
Lesson learned: holography is an important tool for improving the quality of the optical surface. Setting up the system should be quick and easy, allowing for iterations. Appropriate far-field sources should be secured.



Current developments: qFFTS (PoC for ALHAMBRA)

qFFTS4G – *quad-Fast Fourier Transform Spectrometer 4GHz*

- State-of-art, high-performance backend (received on-loan from MPIfR)
- To operate with EMIR as a PoC of the backends for the future multi-beam instrument ALHAMBRA
- The compact rack is equipped with two cards (up to 8), each capable of processing 4 channels of 4 GHz with 65,536 channels, i.e. up to 32 GHz with ~60 kHz resolution.
- Currently finishing tests at the Granada lab before being shipped to the telescope.
- To be installed in a rack placed in a rack at the Servo room directly under the receivers' cabin. Short coaxial cables will transport the IF from the EMIR instrument to the backend.
- The processed data with be carried by means of an optical fibre connection, thus avoiding the need of a large set of coaxial cables in the cable wrap.



Next development: ALHAMBRA

We have been studying and developing a concept for a dual color heterodyne 2SB dual-pol array(s) for **1mm (7x7) and 3mm (5x5)**

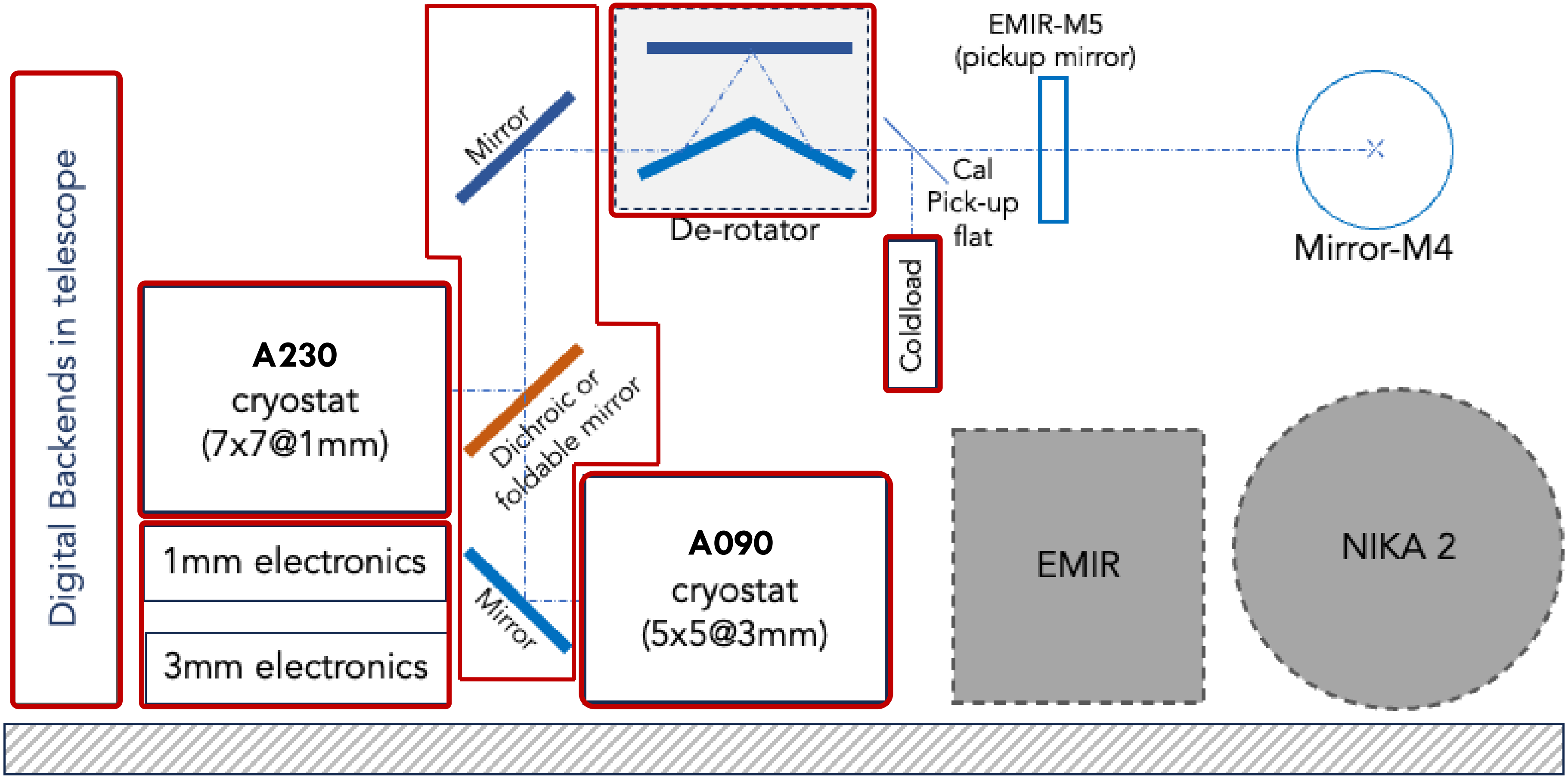
Alhambra

Advanced Large Heterodyne Array for Millimeter Band Radio Astronomy

- Very modular approach, to make it as flexible, scalable and **maintainable as possible**
- Proofs of concepts have been already developed or are under development
- Still, there are major technical challenges and open questions

ALHAMBRA layout

Major modules of ALHAMBRA

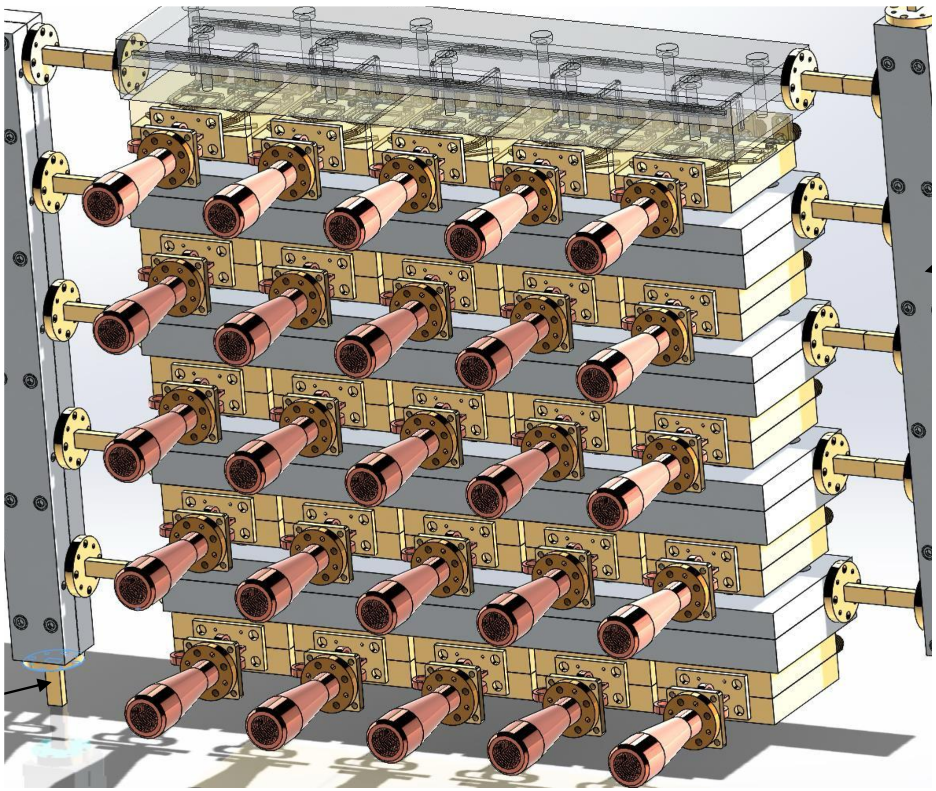


+ Telescope preparations (RX Control (SW), power, cooling, etc.)

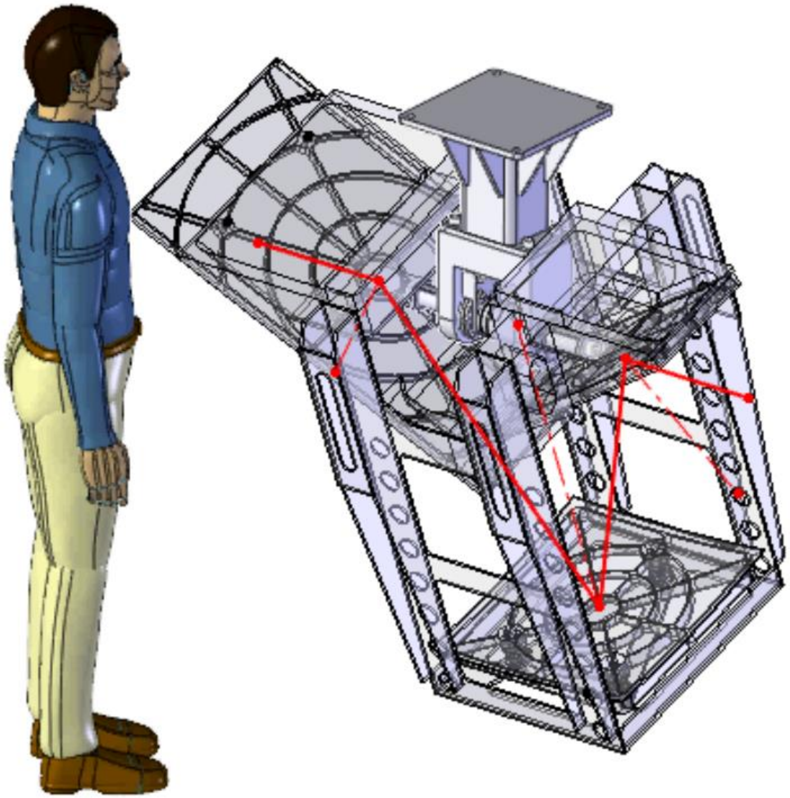
ALHAMBRA: Baselines and goals

Feature	A230 Goal	A230 Baseline	A230 unit	A090 Goal	A090 Baseline	A090 unit
Frequency range	**196 -- 280**	200 -- 276	GHz	**67 -- 117**	72 -- 116.5	GHz
LO range	**208 -- 268**	212 -- 264	GHz	**79 -- 105**	84 -- 104.5	GHz
IF range	**4 -- 12**	4 -- 12	GHz	**4 -- 12**	4 -- 12	GHz
Mixer topology	**2SB Dual Pol**			**2SB Dual Pol**		
TRX for 80% of the RF band		≤ 83	K (SSB)	**50**	50	K (SSB)
TRX at any frequency		≤ 138	K (SSB)	**≤ 60**	≤ 70	K (SSB)
Spread in Trec between pixels (%)	**≤ 10**	≤ 30	%	**≤ 15**	≤ 30	%
Sideband ratio	**< -20**	< -10	dB	**< -20**	< -10	dB
Spectroscopic stability with 1 MHz BW (Allan time)	**≥ 200**	≥ 100	s	**≥ 120**	≥ 100	s
Total power stability with 1 MHz BW (Allan time)	**≥ 20**	≥ 10	s	**≥ 20**	≥ 10	s
Total power stability for 4-12 GHz IF	**4x10-7 A.V. up tp 100s** **3x10-6 A.V. up tp 300s**			**4x10-7 A.V. up tp 100s** **3x10-6 A.V. up tp 300s**		
Backend resolution	**≥ 32**	≥ 64	KHz	**≥ 32**	≥ 64	KHz
Array layout	**7 x 7**			**5 x 5**		
Pixel separation (physical)		25	mm		44	mm
On-sky separation (@ lowest frequency)		> 2	HPBW		> 2	HPBW
HPBW beam size (high -- Low)	**9 -- 12**	9 -- 12	"	**21 --- 34**	21 --- 34	"
Edge taper	**14**	14	dB	**14**	14	dB
Alignment accuracy between pixels (on sky)	**≤ 0.5**	≤ 1	"	**≤ 0.5**	≤ 1	"
Co-alignment between sub-arrays for 7 pixels (on sky)	**≤ 1**	≤ 2	"	**≤ 1**	≤ 2	"
Co-alignment between sub-arrays for central pix (on sky)	**≤ 0.5**	≤ 1	"	**≤ 0.5**	≤ 1	"
Main beam efficiencies	**≥ 0.60**	≥ 0.53		**≥ 0.80**	≥ 0.75	
Aperture efficiency	**≥ 0.50**	≥ 0.41		**≥ 0.65**	≥ 0.60	
Forward efficiency	**≥ 0.95**	≥ 0.88		**≥ 0.98**	≥ 0.95	

ALHAMBRA design



3mm array design (5x5 pixel)



ALHAMBRA derotator – version XXL
Version XXL for fewer mirrors but very large structure
1st version about 350kg, now decreased to 270 kg.

World panorama of 1mm and 3mm arrays*

Institut de Radioastronomie Millimétrique

3 mm

		Npixels	Detectors	Mode	Trec SSB (K)	IF BW (GHz)
	SEQUOIA, LMT	16	HEMT	2SB	55-90	15
❂	CARUSO, SRT	2x16	HEMT	2SB	50 - 60 ?	2x8 (2x4)
❂	BEARS, Nobeyama	25	SIS	DSB		0.5
✷	SSAR-Delingha, CN	9	SIS	2SB	60	2x1
❂	FOREST, Nobeyama	4	SIS	2SB	30-70	2x4
	ARGUS, GBT	16	HEMT	2SB	40-80	2x1.5
	ARGUS-144, GBT	144	HEMT	2SB	-	-
	ALHAMBRA – 3mm	2x 5x5	SIS	2SB	-	2x8

1 mm

		Npixels	Detectors	Mode	Trec SSB (K)	IF BW (GHz)
✷	8-Beam NRAO	8	SIS	DSB	80-200	0.3
✷	HERA, 30m	2x9	SIS	SSB	150-300	1
	ALHAMBRA – 1.3mm	2x 7x7	SIS	2SB	60	2x8

✷ K-mirror
❂ Cryostat rotation

Dark grey: Not clear if still operational
Light grey: Decommissioned
Green: Under development

(*): Known to the authors

ALHAMBRA: current status and next steps

- The Phase A proposal is being finished, along with the science cases (white paper).
- If the project is eventually approved, will span 5+ years and several MEuro.
- A very challenging project: cryogenics, heat dissipation, IF transport, field de-rotation, data handling, etc.
- A completely new telescope control system will be required.
- Many parts will be outsourced/subcontracted (e.g. cryogenic systems, mechanics, amplifiers, backends…).
- Hence, there will be room for opportunity for the Spanish Science Industry!

Some lessons learned (takeaway points)

When designing a new facility, in order to simplify the immediate and future maintenance, incorporation new technologies and upgrades dealing with the obsolesce of materials and equipments, it would be helpful to consider the following good practices:

- Clean systems development and evolution: proper labelling, mapping and inventory of all (sub)system , removal of replaced elements (e.g. geological layering of undated unremoved cables and accumulation of residues).
- Maintainability should be kept in mind in the design: accessibility of critical serviceable elements, guarantee of the proper non-destructive dismount of elements (e.g. access to IRAM30m secondary motors, sealing of panels and inter-panels make impossible to dismount panels and the replacement of embedded sensors and deicing elements), ensure the availability and procurement of spare parts during the expected facility life span.
- Adaptation to new requirements: adaptability and scalability requires to implement modular solutions both for HW and SW (e.g. power, communications, data storage),
- Durability of materials in harsh environments: Material must be selected considering working environment (e.g. weathering of polymers due to UV and low temperatures),
- Obsolescence of the different (sub)systems: Lifespan and maintenance support must be considered during the design to reduce upgrade needs.

Some lessons learned (takeaway points)

When required to upgrade a (sub)system, by design or contingency:

- Follow the same recommendations proposed for the design in the upgrades to avoid repeating the same errors,
- Assessment of all interacting elements (e.g. sensors): Interacting elements compatibility must be ensured as far as possible to avoid surprises with the integration with new elements (e.g, our old Heidenhain encoders were not compatible with the proposed servo upgrade system).
- Careful selection of contractors is a must.
- Project timelines: contingencies should be properly handled (e.g. EU funded budgets doesn´t allow timeline flexibility)
- Upgrades must be carefully planned: limit the room for improvisation.
- Virtualisation: IT HW/SW elements are always evolving out of your control. Consider vitualisation to adapt to changes.

Thanks for your attention!