Yebes Observatory Report

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Abstract We present the observations carried out by the Yebes Observatory's legacy 40-meter and VGOS 13.2-meter radio telescopes during the 2023–2024 period as part of the IVS network, along with the current status of their instrumentation. Additionally, we highlight recent technical developments relevant to the IVS community, and we discuss upcoming initiatives at Yebes Observatory aimed at enhancing the capabilities and contributions of our stations within the global geodetic network.

1 General Information

The National Geographic Institute of Spain (IGN) operates two radio telescopes at Yebes Observatory, both actively contributing to the IVS observing program: the 40-m radio telescope and the 13.2-m VGOS-compatible antenna.

Yebes Observatory serves as the reference station for the Spanish GNSS network and hosts permanent facilities for gravimetry and seismology. In 2024, we completed the installation of a Satellite Laser Ranging (SLR) station. The integration of this station into the Global ILRS Network, alongside the VLBI and GNSS techniques, has established Yebes as the Spanish Geodetic Fundamental Station.

The YNART project, co-funded by the EU ERDF 2014–2020 program and supported by the former Spanish Ministry of Economy, Industry, and Competitiveness, included the design and implementation of the RAEGE software correlator. Since 2024, this correlator has been actively contributing to the correlation of VGOS observations. For details on the RAEGE project check `http://www.raege.net/`.

Yebes Observatory is also a Technology Development Center for the IVS, and the center's activities are detailed in another contribution to this Biennial Report. Additional information about the Observatory can be found on its website: `https://astronomia.ign.es/en_GB/web/guest/icts-yebes/acercade`.

1.1 Yebes Staff

The staff devoted to VLBI consists of two support astronomers, Victor Pérez-Díez and Cristina García-Miró; the VLBI technical friend, Javier González-García; one geodesist, Elena Martínez-Sánchez; one IGN fellow, Felipe Paredes; and the Observatory director, Pablo de Vicente. The VLBI group is also supported by a team of engineers and technicians who perform maintenance and development. In 2024, two colleagues left the Observatory, resulting in a reduction of human resources.

2 Yebes Activities during the Past Two Years

The following subsections review Yebes Observatory's IVS participation in legacy S/X observations with the

1. Yebes Observatory
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40-m radio telescope and VGOS observations with the 13.2-m antenna.

2.1 Yebes 40-m Radio Telescope Operations

Over the past two years, the 40-m participation has shifted from EOP to TRF and CRF sessions to better leverage its high sensitivity and to contribute to the enhancement of the Celestial Reference Frame at higher frequencies [1, 2]. Due to the high demand from our own observing programs, the number of scheduled observations per year has been reduced from 20 to 10 sessions.

In 2023, we participated in just three IVS sessions: two CRF-type and one T2-type sessions. This limited participation was due to the installation and commissioning of a new wobbler subreflector.

In 2024, our participation increased to a total of eight sessions, including five CRF sessions, two T2 sessions, and one T2P session. One scheduled session was canceled due to hardware problems, and another session was conducted for optical clock comparison.

During the summer of 2024, the antenna performance in S-band improved significantly following the overhaul of the S-band receiver and the installation of two High Temperature Superconductor (HTS) filters. The impact of RFI on the S-band channels has been drastically reduced (Figure 1). As a result, the SEFD and Tsys also showed improvement, with values decreasing from 1400 and 600 to less than 1000 and 400, respectively.

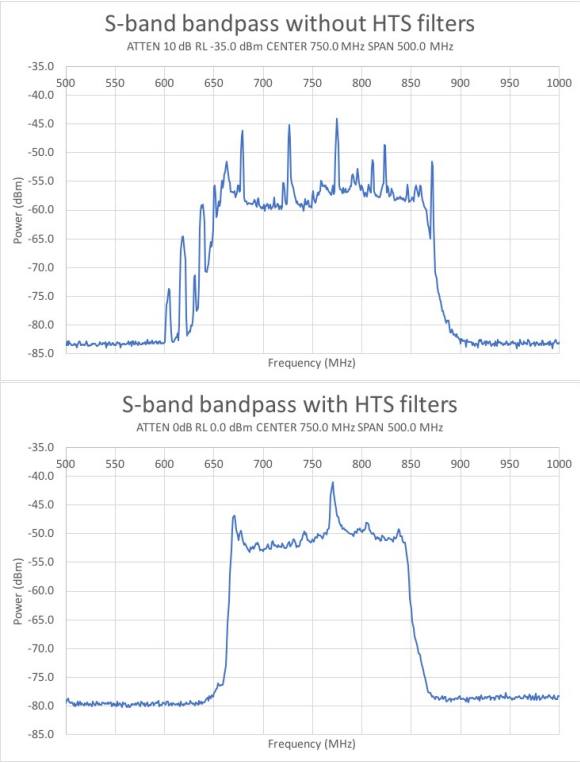

Fig. 1 The S-band bandpass before (top) and after (bottom) the installation of the HTS filters [5]. Most of the RFI is internally generated by the antenna servo electronics. While most of these interferences have been successfully filtered out, such as the three large RFI signals on the left edge caused by fixed external radio-links, a remaining radio-link persists around 2.3 GHz.

Table 1 Yebes 40-m participation in IVS legacy sessions.

YEBES40M (Ys)	2023	2024
IVS-T2	1	2
IVS-T2P	0	1
IVS-CRF	2	5
TOTAL	3	8

2.2 VGOS Operations

The year 2023 was highly successful, with 24 out of 27 sessions completed, along with the four scheduled VGOS-R&D experiments. Of the three failed sessions, two failed due to hardware issues, while the third was deselected by the analyst due to excessive noise in the solution. This year, we continued our participation in the VGOS-INT-Y program, proposed by L. Petrov, involving the RAEGYEB, RAEGSMAR, and GGAO (or MGO, depending on GGAO availability) stations.

At the beginning of 2023, the antenna control software was modified to properly stop the subreflector in the Z-axis while allowing movement in X and Y. Additionally, the vmux procedure was found to be losing bytes. To solve this issue, a small modification was made to the DQA program, implementing a lengthier but more reliable process to generate separate files for each of the four bands. Preventive maintenance was also performed on the two Mark 6 units to mitigate fire risks caused by overheating cables, following the procedure provided by Haystack.

The year 2024 proved to be challenging. In April, a falling object from the azimuth cabin caused a cable wrap failure, rendering the antenna inoperative (Figure 2). As a result, only eight VGOS-OPS sessions were completed. By the end of 2024, the contract for repairing the damaged hardware was awarded to the Spanish company Asturfeito. Several components of the winding chain, as well as the power and signal cables running through the winder, need to be replaced. To avoid further problems, an automatic system has been designed to detect anomalies in the reel's operation, utilizing optical sensors installed on the hanger arms.

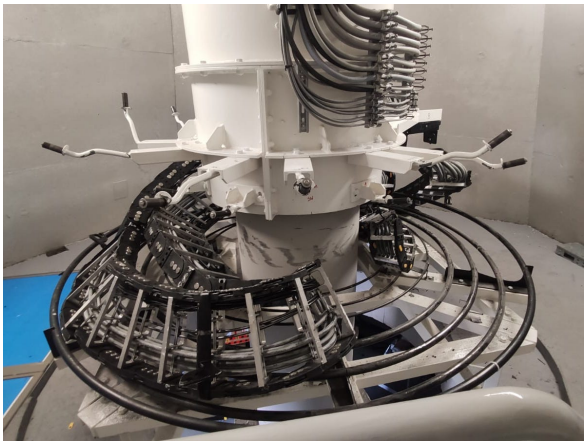

Fig. 2 Close-up view of the cable wrap failure.

During this period, no major system upgrades were carried out. However, the following repair works were completed:

- Replacement of the coaxial cable carrying the 80-Hz signal to trigger the noise calibration signal, as an intermittent connection prevented the telescope from performing amplitude calibration in certain directions.
- Performance of a complete cryogenic cycle to the VGOS receiver, including replacement of the absorber in the He compressor.
- Development of a buffering board for the 80-Hz signal after the optical link.

An interesting project related to the VGOS antenna operations was identifying and monitoring satellite RFI sources using a piggyback backend running in parallel during the VGOS sessions according to the same schedule. The study focused on the [10.7, 12.7] GHz band. Promising initial results were presented in [3], showing reliable detection of geostationary satellites.

Table 2 Yebes 13.2-m participation in IVS VGOS sessions.

RAEGYEB (Yj)	2023	2024
VGOS VO	24	8
VGOS VR&D	4	1
VGOS INT-Y	38	12
VGOS INT-G	0	9
TOTAL	66	30

2.3 Local Tie and Other Activities

The geodetic group at Yebes Observatory continues to contribute to the IERS/IAG Working Group on Site Surveys & Techniques. Recently, efforts were put towards expanding the geodetic network at Yebes Observatory to incorporate the new SLR station. This upgrade included the construction of five new concrete pillars in the NW area of the observatory (Figure 3). Furthermore, a collaboration has begun with colleagues from HartRAO to develop an automated system for calculating the local tie.

Fig. 3 A new geodetic pillar in front of the SLR station.

As part of other activities, some of our colleagues participated in a course organized by the Alicante University on the application of machine learning techniques for predicting geodetic parameters. In addition, V. Pérez-Díez's research group [4] developed

a pipeline for full-polarization imaging of calibrators in the four VGOS frequency bands, aiming to extract valuable astronomical information and to potentially improve the geodetic results (Figure 4).

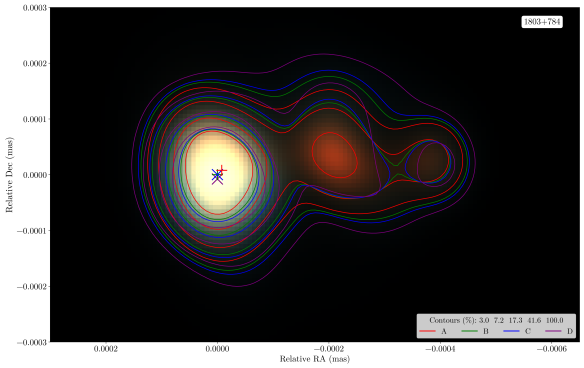

Fig. 4 Total intensity multi-frequency contour maps of 1803+784 from experiment VO2187 in the four VGOS bands, superposed to the optical image.

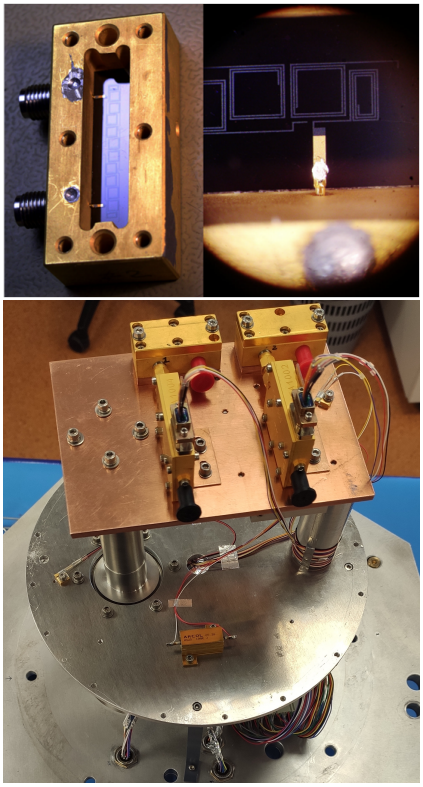

Fig. 5 Detail of the HTS filters (top, [5]) and interior of the S-band receiver after the upgrade (bottom), showing the new OFHC copper plate used for the cold stage, where both the filters and LNAs are installed, with improvement of their physical temperature from 18 K to approximately 10 K [7].

3 Current Status and Upgrades

In January 2023, the RedIRIS (Spanish NREN) PoP at the Observatory was upgraded to 100 Gbps connected to their backbone.

Recently, the observatory's secondary hydrogen maser was put on hold due to low hydrogen reserves. Administrative procedures for refilling it, along with the primary masers, have been initiated. In parallel, a request has been submitted for an electronics upgrade to ensure continued eligibility for maintenance services provided by Safran.

The 40-m radio telescope is equipped with simultaneous S/X receivers to routinely support the IVS. Following a cold head failure, the S-band cryogenic receiver was overhauled, including the installation of two HTS filters (Figure 5). The filters were developed in-house in collaboration with the University of Birmingham and INAF. They are tenth-order filters with insertion losses of less than 0.2 dB, and they provide attenuation of more than 50 dB for signals outside the band of interest [5].

Over the past two years, the Observatory designed and manufactured the ASTROREC K-band receiver, covering the 18 to 32 GHz range in linear dual-polarization [6]. The first VLBI fringes were successfully demonstrated within the EVN in October 2024 employing a quarter-wave plate to register circular polarization. In the near future, this receiver will also include phase calibration capability and a modulating noise diode. Additionally, another wideband receiver covering the 4 to 18 GHz range is currently being developed.

In addition to previous upgrades, several efforts have been made to enhance the sensitivity of the 40-m radio telescope for single-dish observations. This includes the installation of a wobbler subreflector, allowing on/off integrations without requiring movement of the primary mirror.

Among the previously reported backends and recorders used in VLBI, a DBBC3-6L-6H backend is currently being commissioned to enable triple-band

K-Q-W simultaneous recording for Frequency Phase Transfer (FPT) observations. Meanwhile, the four R2DBE systems installed in 2022, intended to replace the operational RDBEs, are still not fully functional. The multicast interface to the Field System has yet to be completed, preventing the recording of auxiliary data in the observation log file.

Regarding the VGOS antenna, a laser measurement system was installed in early January 2024 to monitor height variations of the azimuth cabin and characterize the Invariant Point. This project is on standby until the repair of the azimuth cable wrap is complete. The system will then be reinstalled and validated.

To support the RAEGE network, Yebes has designed and installed a DiFX software correlator, which can also contribute to the VGOS observing program enabling more frequent observations. In a nutshell, the correlator has 896 cores shared between storage and computing, 2 PB of NAS storage, and 100 Gbps connectivity through a link to RedIRIS. The commissioning of the HPC cluster running the DiFX correlator has been completed. The test results, both with real and simulated data, show that the design meets the required specifications, keeping the correlation factor below 1 for three VGOS stations (Figure 6). Since last year we have been running VGOS Intensive-type correlation for the VGOS-INT-G program in collaboration with the GSI and SHAO correlators.

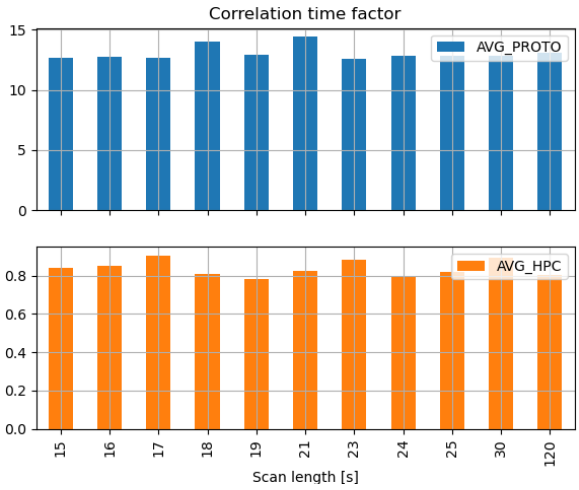

Fig. 6 Comparison of the correlation factor as the ratio of scan time to correlation time for the prototype (top, blue) and the HPC (bottom, orange) for a network of three stations and an acquisition rate of 16 Gbps.

4 Future Plans

In 2025, we plan to participate in the IVS correlator comparison campaign that has been started by MIT Haystack Observatory. After this campaign, we expect to validate our data and be involved in more sessions. A new post-graduate student has recently been incorporated into the correlation group, which currently consists of three people.

Future hardware upgrades will focus on improvements to the VGOS receiver, including:

- replacement of the noise diode with a more powerful unit,
- reduction of PCal tone spacing to 5 MHz,
- a new cryostat monitoring system,
- new room-temperature filters for 5G signal rejection.

Next spring, the entire geodetic network at Yebes will be recalculated, ensuring the SLR station is included in the local-tie calculations. At Santa María station field observations are also scheduled. In collaboration with a Spanish university, a new 3D scan survey and an Unmanned Aerial Vehicle (UAV) photogrammetry survey are also being planned.

References

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