Yebes Observatory Report

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Abstract We describe the observations performed by the 40-m radio telescope and the VGOS 13.2-m radio telescopes during the 2021–2022 period as part of the IVS network and the current status of the instrumentation for both telescopes. We also present recent technical developments relevant to the IVS community and future plans within Yebes Observatory to keep our stations as part of the most dynamic elements of the network.

1 General Information

The National Geographic Institute of Spain (Instituto Geográfico Nacional - IGN, Ministerio de Transportes, Movilidad y Agenda Urbana), has supported geodetic VLBI programs at Yebes Observatory since 1995 and currently operates two radio telescopes on the site that participate in the IVS observing program. The 40-m radio telescope, station code "Ys" (YEBES40M), has been operating regularly since 2008 within the S/X (now Legacy) network. The 13.2-m VGOS compatible antenna, inaugurated in 2014 with code "Yj" (RAEGYEB), has been observing bi-weekly in the VGOS 24-hour sessions. Detailed information about the RAEGE project is available on the web at `http://www.raege.net/`. IGN Yebes Observatory is also the reference station for the Spanish GNSS network, holds permanent facilities for gravimetry and seismology, and is currently installing a Satellite Laser Ranging (SLR) station.

Currently, the observatory also has small correlation capabilities, which consist of a DiFX software correlator running on an HPC cluster of three nodes that add up to a total of 28 cores. A modest storage capacity of 144 TB on a RAID-Z system is hosted on a single Supermicro server.

Since 2014, IGN Yebes Observatory has become a Technology Development Center for the IVS. Activities are described in the corresponding contribution in this Biennial Report. More information about the Observatory, including technical details of the radio telescopes, can be found on the website `https://astronomia.ign.es/en_GB/web/guest/icts-yebes/acercade`

1.1 Yebes Staff

Yebes Observatory staff dedicated to geodetic and astrometric VLBI activities is formed by two support astronomers, Victor Pérez-Díez and Cristina García-Miró, the VLBI technical friend, Javier González-García, one geodesist, Elena Martínez-Sánchez, the observatory software developer, Francisco Beltrán, one IGN fellow, Felipe Paredes, and the Observatory director, Pablo de Vicente.

1. Yebes Observatory
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Yebes Network Station

IVS 2021+2022 Biennial Report

2 Yebes Activities during the Past Two Years

The following subsections review Yebes' participation in Legacy IVS observations with the 40-m radio telescope and VGOS IVS observations with the 13.2-m antenna.

2.1 Yebes 40-m Radio Telescope Operations

In 2021, the 40-m radio telescope observed eighteen IVS experiments, of which seven were R4s, nine were R1s, and two were T2s. YEBES40M additionally participated in one RUA experiment and two experiments for optical clock comparison and remote clock distribution. Due to a major failure of the radio telescope as a result of an unusual severe snowstorm in central Spain, "Filomena", we were not able to participate in many observations during the first semester. Four more observations were impacted during June and July due to different problems with the antenna. Our participation increased to a total of 23 observations in 2022, with fifteen R4 sessions, seven R1s, and one T2. No major problems were experienced during last year.

Table 1 Yebes 40-m participation in IVS Legacy observations.

YEBES40M (Ys)	2021	2022
IVS R1	9	7
IVS R4	7	15
IVS T2	2	1
EURD	0	0
R&D	0	0
CRF	0	0
EINT	0	0
TOTAL	18	23

During the reported period, the antenna sensitivity has remained in its nominal values, with the usual RFI impact on the S-band channels.

2.2 VGOS Operations and Related Activities

The year 2021 turned out to be a fateful year in terms of performance of the VGOS-type radio telescope operated by the Yebes Observatory. Even in spite of the big snowstorm "Filomena", which prevented access to the facilities for almost a week due to the large amount of snow and ice accumulated, the radio telescope could be operated remotely, thanks to its high degree of automation. From January 7th to June 9th, the telescope performed 12 VO sessions of the VGOS project, all of them successfully completed. In addition, it performed two test experiments to validate modifications to the technical operating procedure within the framework of the EU-VGOS project. It also participated up to three times in fringe-test observations as a reference station to assist the RAEGE radio telescope located in Santa María, Azores.

Unfortunately in mid-June, the telescope suffered a mechanical failure that stopped the antenna completely until the end of the year (Figure 3). As later revealed by the investigations by the Observatory's own specialized personnel in conjunction with technicians belonging to the manufacturer, mechanical alterations of the system caused by normal usage produced a malfunction of the cable winding system, which in turn caused the rupture of two cable guide chains that compose it. This system is what keeps the cabling tidy during azimuth movements. Fortunately, there was no damage to the cables themselves, neither to the signal cables nor to the power cables. The shortage of raw materials, especially aluminum, significantly delayed the repair, which was initially scheduled for September but was repeatedly delayed until it was executed during the week of December 20th.

In turn, 2022 was a more productive year. Most of the observation time was devoted to 24-hour VGOS observations, both from the VO and VR projects. Within this framework 49 sessions were scheduled, of which 41 were completed successfully, two were aborted due to equipment failure at the station, two data sets were discarded at the correlator or analysis stage, and four were partially observed. In the spring of 2022, the VGYG observing project also began, consisting of one-hour Intensive sessions involving three VGOS stations: GGAO12M, RAEGYEB, and RAEGSMAR. The one-hour sessions are followed by a ten-minute test time to prove alternative observing configurations in the scheduling parameters. The VGYG is observed at 14:00 UT every Tuesday.

The following major system upgrades took place during this period:

- Replacement of the entire frontend. The old receiver was sent to Santa María to be installed in RAEGSMAR.
- Replacement of the broken reference cable carrying the 5 MHz from the CDMS-GU to the CDMS-AU.

Further details are given in Section 3.

Table 2 RAEGYEB 13.2-m participation in VGOS and VGYG observations.

RAEGYEB (Yj)	2021	2022
VO obs	12	47
VGYG obs	–	18

During these two years, calibration and deconvolution tasks of observations taken with the EU-VGOS subnetwork were carried out. These observations were used to develop ultra-wideband global fringe fitting (GFF) algorithms. Thanks to the use of a priori ionospheric information from GNSS data, higher quality results were achieved and in a significantly shorter calculation time than those obtained with the standard geodesy adjustment software, HOPS. These improvements were added to the PolConvert software [1]. Closure-based imaging algorithms were applied to these data, having obtained both brightness distribution and polarimetric images from various calibrator sources in the different VGOS bands (Figure 1). Thanks to the robustness of these algorithms, it was possible to obtain images of experiments with only four antennas and ten minutes of observation, which cannot be obtained with the classic CLEAN algorithm. These developments will allow a detailed analysis of the relativistic jets of the AGNs, including core shift, the relationship between the opacity and the morphological evolution of the jets, and the magnetic fields that surround them.

Additionally, since last year, a VGOS calibration server is being developed to properly extract the calibration information from the different observing logs, independently of the type of backend used. The server computes and plots the single dish system temperatures and produces the antabfs files to properly apply the PolConvert algorithm and calibrate the total brightness and polarimetric images.

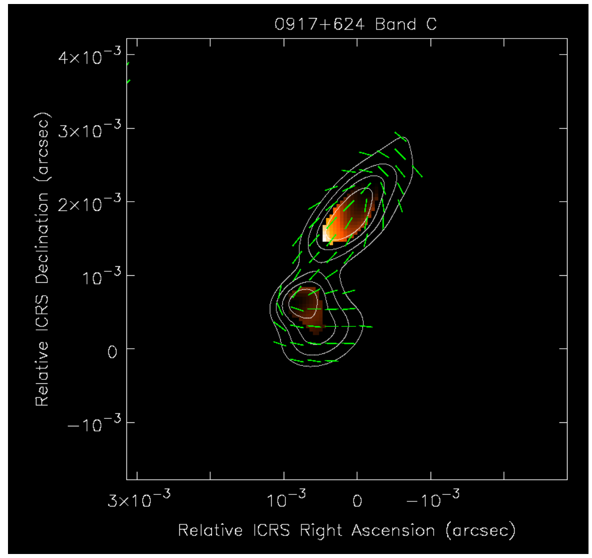

Fig. 1 Image of 0917+624 obtained from the EU-VGOS experiment EV9217 at Band C. The white contours show the brightness distribution of Stokes I. The orange raster plot shows the brightness distribution in linear polarization. The green vector map shows the EVPA.

2.3 Local Tie and Other Activities

Since December 2021, the Yebes Observatory has been part of IERS/IAG Working Group: Site Surveys & Techniques. During the regular meetings, this working group has presented best survey practices to perform the local-tie. Lately, this group has focused on antenna deformation. At Yebes, we have performed a 3D-scan survey and an Unmanned Aerial Vehicle (UAV) photogrammetry survey (Figure 2). Both produce accurate high-resolution orthophotos that can be used to obtain temperature and gravity deformation of the antenna, a very important parameter for calculating the local-tie.

In 2022, specialized Yebes staff traveled to Santa María island (Azores) to accomplish a survey for the construction of five pillars. Those pillars will be part of the RAEGE-AZ local network, which will be needed to perform the local-tie survey between the RAEGE VLBI and RAEGE GNSS techniques.

Fig. 2 Filtered dense point cloud at 65º elevation of the RT40-m main reflector, secondary mirror, and support legs.

3 Current Status

The Yebes Observatory runs two active Hydrogen masers from T4-Science that provide the frequency references (5, 10, and 100 MHz, and also the 1PPS TTL signal) for all the electronics involved in VLBI operations, in a master-backup scheme. This same setup is also used to secure the GPS time synchronization by means of two GPS receivers (CNS Clock II and Symmetricom XLi, now Microsemi).

The 40-m radio telescope is equipped with a simultaneous S/X receiver that routinely performs the observations that contribute to the IVS. A new wideband receiver that operates from 4.5 GHz to 9 GHz (C, M, and X bands) was designed and manufactured on-site and demonstrated its first VLBI fringes in December 2021. Within the last two years, the observatory also achieved another major upgrade to its astronomical capabilities, with the addition of a dichroic mirror to simultaneously observe in W band together with the K and Q receivers. To complete the triple band observing capacity, the DBBC3 backend was upgraded at Hat-Lab to incorporate four more processing units, becoming a DBBC3-6L-6H. All the receivers can record dual circular polarization except W and Q, which are linear, but lambda quarter plates are available for use in circular polarization mode. Continuous calibration is available in the S/X, C-X, and K receivers, using a noise diode driven by an 80 Hz signal generated in the backend. Q and W band observations can be calibrated with a hot-cold load system. A phase calibration signal is available in the S/X and also in the C-X receiver.

Since its first light, the 13.2-m VGOS-type telescope has been equipped with four RDBE-G backends connected to a single Mark 6 unit. The frontend signal chain consists of a cryo-temperature QRFH feed connected to Yebes' own broadband receiver that sends the full 3 to 12 GHz band through an optical fiber link to four UDCs, each of them adapting a 512 MHz band in Nyquist zone 2 to be digitized by an RDBE-G. The frontend has experienced several modifications in 2021 and 2022, mainly focused on reducing the receiver noise temperature across the 3 to 14 GHz range. These changes consisted of replacing the LNAs to install double LNAs per polarization in a balanced scheme (including cryo-hybrids), installing a FAP module (Filter-Amplifier module, at room temperature), using better high pass filters with 3 GHz cut off frequency and using power limiters to prevent the fiber optic transceiver from being destroyed by RFI. A new version of the QRFH, developed at Yebes (third generation), was also installed. But, although these modifications proved to decrease the system noise, we detected that the Cable Delay Measurement System (CDMS) failed to report accurate measurements from time to time. This problem was traced down to a faulty coaxial cable that ended up breaking at several points after being exposed to certain bending cycles. On September 30, 2022, this cable was replaced with a brand new LMR-400UF coaxial cable. No symptoms of CDMS failure have been observed since. Reference [2] is a publication on sensors that describes the system.

Due to the high pressure on YEBES40M from the radio astronomy community, specifically for Single-Dish projects, we have begun a process of withdrawing it from geodetic observations in the framework of the IVS. However, ten IVS sessions are scheduled for 2023, all of them devoted to CRF and TRF determination, as this antenna is actively participating in the enhancement of the K-band Celestial Reference Frame [3, 4]. At the same time, it is expected that RAEGYEB will overtake this duty, nowadays doing bi-weekly observations within the VGOS core network.

The meteo data is collected by a MET4 station from Paroscientific and the Vaisala WXT532 wind sensor. Both instruments are located on a meteorological tower

Fig. 3 Detail of the cable wrap structure breakage.

about ten meters tall, 150 m NW from the 13-m telescope and 270 m W from the 40 m. Time synchronization is provided by a CNS Clock II system, and a secondary GPS receiver from Microsemi is operated as a backup.

4 Future Plans

During the second half of 2022, we have installed and configured four R2DBE systems. They are meant to replace the current RDBE on duty, but there is still a missing step that prevents us from using them in VGOS operations. The multicast interface to the Field System has not been finished yet, so auxiliary data can not be recorded in the observation log file. This auxiliary information (system temperatures, pcal data, attenuator settings) plays an important role in the improvement of the geodetic measurements in the VGOS era; therefore to dispense with it, right now, would be a step backwards in the quality of the data provided by the station.

A complete overhaul of the HPC cluster running the DiFX correlator was designed with aid from the Spanish consultant company QUASAR to expand the correlation capabilities. The final setup will consist of 128 computing cores distributed across four nodes and almost 2 PB of available storage in a BeeGFS system for virtualization and redundancy. Infiniband technology will be used for network interconnection. After all the components have been purchased, we expect the last piece of equipment to be delivered by the end of April.

Finally, the Yebes Observatory, as part of the national high speed network for Investigation and Education (RedIRIS) in Spain, has just upgraded the networking equipment to support a new 100 Gbps connection to the RedIRIS backbone, in view of higher bit rates for data transfer of wide bandwidth observations (over 1 GHz).

References

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