RAEGE Santa Maria Station Report

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Abstract The RAEGE Station of Santa Maria (RAEGSMAR), situated in the Azores archipelago, Portugal, is one of four stations comprising the RAEGE network. This report outlines the observations conducted with the RAEGSMAR 13.2-m VGOS antenna as part of the IVS network. Key developments during this period include the installation of superconductive filters in the VGOS receiver, the construction of local-tie pillars, and ongoing enhancements to the signal chain. Additionally, the report provides an overview of the station's staff, equipment, and the activities carried out throughout 2023 and 2024.

1 General Information and Staff

The RAEGE network (Atlantic Network of Geodynamic and Space Stations) is a collaborative project between the National Geographic Institute of Spain (IGN Spain) and the Regional Government of the Azores [**?**] (see Fig. 1). This unique geodesy initiative focuses on the establishment and operation of four Fundamental Geodetic Stations: Yebes and Gran Canaria stations in Spain, and Flores and Santa Maria stations in the Azores, Portugal. In 2017, the Government of the Azores established the RAEGE-Azores Association (RAEGE-Az) to oversee the implementation of RAEGE's infrastructure in the Azores and manage its operations [**?**]. Santa Maria Station has a 13.2-m dish radio telescope (VGOS-like) equipped with a VGOS broadband receiver, covering 2 to 14 GHz with dual-linear polarization. Additionally, the facility hosts other instruments, including three GNSS stations, a GWR iGrav® superconducting gravimeter (installed in October 2022), a seismograph, and an accelerometer.

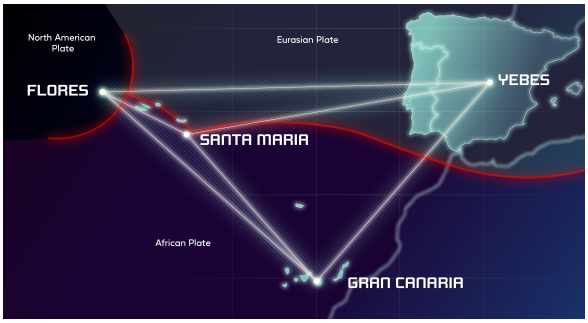

Fig. 1 Geographical distribution of the RAEGE network [**?**].

Table 1 outlines the RAEGE staff members for the period 2023–2024, highlighting their roles and tenure. The station's leadership transitioned in December 2023, with João Salmim Ferreira serving as Station Director until then, followed by Abel García-Castellano, who also leads R&D. The R&D team included Diogo Avelar, who contributed from January 2021 to June 2023, playing a key role in technical and development efforts. Mariana Moreira and Valente Cuambe remain active members of the team. The station also saw changes in outreach, marketing and communication department, with Raquel Ribeiro leading initiatives until December 2022. Additionally, administrative, IT, and maintenance staff, support the station's continued operation.

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Table 1 RAEGE Staff Members during 2023–2024.

Department	Name	Dates
Station Director	João Salmim Ferreira	Feb 2020 – Dec 2023
R&D / Station Director	Abel García-Castellano	Mar 2021 – present
R&D	Diogo Avelar	Jan 2021– Jun 2023
R&D	Mariana Moreira	Nov 2020 – present
R&D	Valente Cuambe	Oct 2021 – present
Outreach	Raquel Ribeiro	Jan 2021 – Dec 2022
Administrative	Elsa Melo	Oct 2021 – present
IT	Nuno Mata	Jan 2021 – present
Maintenance	Valério Pacheco	Jan 2019 – present
Maintenance	Sérgio Chaves	Jan 2021 – present

2 Activities in 2023 and 2024

2.1 VGOS and Intensives Operation

In 2023, Santa Maria station participated in five VGOS-OPS and four VGOS-RD sessions. The limited number of sessions observed that year was due to a strong RFI interference near the station. A high-pass COTS filter (2–4 GHz rejection) was installed in January 2023 to protect the receiver's LNAs. However, this resulted in the loss of VGOS Band-A data, delaying the station's acceptance into the VGOS network. To restore Band-A capabilities, a superconducting notch filter was developed at the Yebes Technology Development Center, and it was installed in September 2023. With these upgrades, Santa Maria was officially admitted to the VGOS network in October 2023 and could start its regular participation.

Additionally, the station participated in 66 of 70 scheduled VGOS-INT-Y sessions, a program proposed by L. Petrov, involving RAEGYEB, RAEGSMAR, and GGAO (or MGO, depending on availability).

In 2024, participation increased, with 29 of 41 VGOS sessions completed, including three of five VGOS-RD sessions and all five VGOS-VT sessions (details below). The high number of incomplete sessions resulted in Santa Maria station being out of operation from 24 May to 20 October 2024 due to several technical issues.

First, operations had to be canceled because it was discovered that the atomic clock was almost out of hydrogen; so for security reasons, it was set to standby mode. Due to administrative issues, the contract for the refill was only completed in August. Then, when operations resumed, a mechanical issue related to the elevation crown was discovered, triggering several error messages that stopped the antenna. Following the manufacturer's recommendations, the elevation speed was limited to 4°/s, and since then, the antenna has been operating in this manner.

Regarding Intensive sessions, 59 out of 62 VGOS-INT-Y sessions were held before the program ended in May 2024. Meanwhile, VGOS-INT-G sessions, which began in February 2024, saw 23 of 25 scheduled observations completed.

Figures 2 and 3 present statistics on the types of observations and the number of observations recorded during the period 2023–2024.

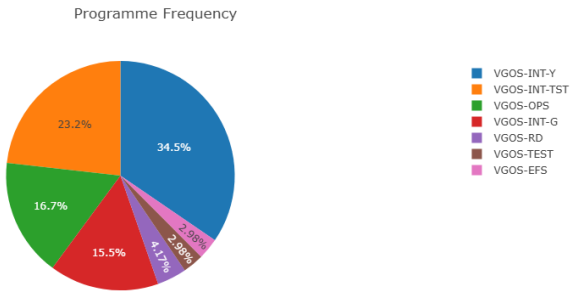

Fig. 2 Operation statistics 2023–2024 [**?**].

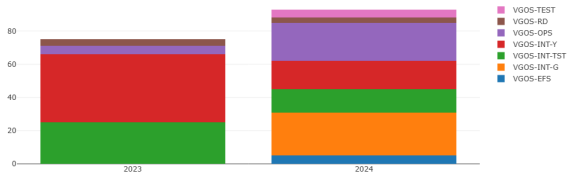

Fig. 3 Number of sessions during 2023–2024 [**?**].

The IVS VGOS Technical Committee (IVS VTC) is exploring improvements such as expanding bandwidth and extending the frequency range to 14 GHz. Fringe tests (VGOS-VT), conducted in late 2024 and February 2025, aim to assess these enhancements. The results are expected to help optimize VGOS frequency configurations and support their integration into ITU Radio Regulations. Santa Maria station is one the VGOS stations to participate in this endeavor. The preliminary results show that Santa Maria's PhaseCal signal at high frequencies has excellent stability.

VGOS-INT-G sessions were first formulated at the 26th EVGA meeting to address Radio Frequency In-

terference (RFI) affecting VLBI stations like RAEGE (Yj and Sa), SESHAN (S6), and ISHIOKA (Is). Major interference sources include radars, mobile networks (3G, 4G, 5G), and S-band radio links, severely impacting the 2–3 GHz band. This has led to a shift in VGOS operations to the 3–14 GHz range. Filtering challenges and 5G overlap in VGOS Band-A pose risks such as receiver gain compression and hardware damage. To mitigate these effects, the study proposes adjusting observation frequencies to 4–14 GHz and evaluating the impact of long East-West baselines on UT1 data.

The first phase of the proposed test is still ongoing. The network Sa-Yj-S6-Is observed simultaneously and with the same frequency plan as regular VGOS-INT-A (K2-Ws) sessions over the year 2024. These tests aim at enabling a direct comparison and consistency check between regular UT1 data from IVS and UT1 data obtained by the RAEGE Analysis Group from the proposed baselines.

2.2 Installation of Superconducting Filters

In 2022 a space debris radar started to operate at a distance of 1.75 km from the Santa Maria RAEGE station; the radar's frequency range is from 2.93 GHz to 2.97 GHz as shown in Fig. 4. According to the measurements, the total power at the input of the low-noise amplifiers of the receiver would be 3.34 dBm. This level was 30 dB above the 1 dB compression point and probably very close to the destruction level, so it was impossible to observe under these conditions.

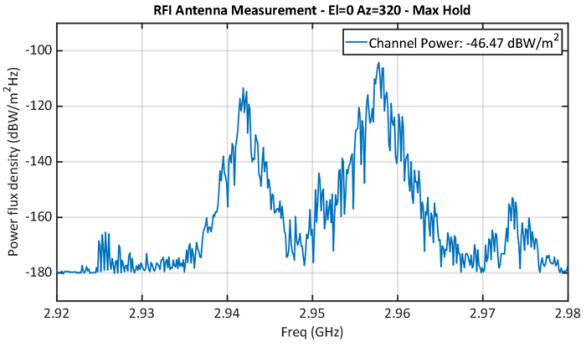

Fig. 4 Spectrum of the RFI signal taken with a portable measurement system.

As a first step towards operation, two COTS (Commercial Off-The-Shelf) filters were installed in January 2023 [**?**]. The rejection of the RFI signal was about 50 dB, but this resulted in the loss of VGOS Band-A.

During 2023, two HTS (High-Temperature Superconducting) filters were designed and constructed by Yebes Observatory [**?**]. The filters were installed in September 2023. Fig. 5 shows a photograph of the two filters already mounted in the cryostat.

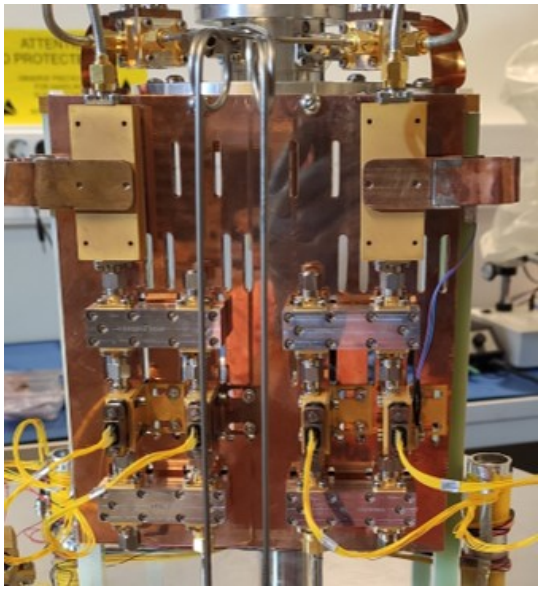

Fig. 5 Photograph of HTS filters mounted on RAEGSMAR VGOS receiver.

Unlike the COTS filters, these filters allowed the observation of VGOS Band-A, thus meeting the requirements defined by the IVS to participate regularly in 24-hour observations. Moreover, the low attenuation in the passband reduced the loss of sensitivity caused by the commercial filters (from 17% to 3%).

As a downside compared to the commercial filters, the attenuation of the radar signal is lower (33 dB versus 50 dB). Nevertheless, the received power levels at the input of the LNAs pointing to the radar direction (-47.2 and -55 dBm in horizontal and vertical polarization, respectively) were lower than expected, possibly due to the blocking effect of a hill that exists in the line of sight. More details can be found in [**?**].

On the 29 September 2023, first fringes at four VGOS bands were detected after a test observation with the RAEGE Yebes radio telescope.

2.3 Local Tie

In early October 2024, excavation began for six local-tie pillars. The reinforcement structure was assembled, followed by concreting and curing. Afterward, protective casings were installed, completing the work by late October. Fig. 6 shows one of the local-tie pillars constructed.

Fig. 6 Local-tie pillar installed at Santa Maria station.

2.4 RAEGE Analysis Group

The RAEGE Analysis Group, established in 2021, brings together researchers from IGN Spain, the Yebes and Santa Maria observatories, and the University of Alicante. The group aims to promote VLBI analysis activities within the RAEGE Project, expand research activities, and facilitate participation in international projects and interactions with other groups. The team works closely together, holding weekly meetings to track progress and align research goals.

During 2023–2024, the group focused on developing the necessary skills for comprehensive end-to-end VLBI data processing, particularly for VGOS-INT-G and VGOS-INT-Y sessions. They conducted simulations to assess the impact of higher VGOS frequencies on UT1 data quality and the effects of long East-West baselines. The group is also engaged in historical VLBI data consistency studies, developing machine learning models for EOP forecasting, and exploring new approaches to modeling Free Core Nutation (FCN).

This research continues to strengthen RAEGE's contributions to geodesy, astrometry, and VLBI, while promoting collaboration within the global scientific community.

2.5 Radio Astronomy Observations and Developments

One of the main goals of RAEGE-Az is to extend the applications of its radio telescope towards astronomy.

During the period 2023–2024, efforts have been made to carry out two main types of observations: spectral observations of methanol masers (Fig. **??**) and continuum observations of AGN (Active Galactic Nuclei). The latter are being performed in the context of the PhD project of Pedro Martins, under the supervision of Valente Cuambe, with the goal of establishing a monitoring program of AGN.

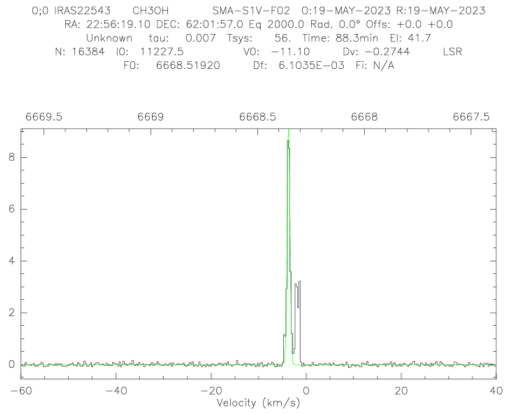

Fig. 7 Methanol maser emission towards IRAS22543+6145 at 6.7 GHz.

As the results came in, the stability of the telescope was evaluated by comparing the data from multiple observations, while also monitoring system and environmental conditions during each observation.

So far, for both observation types, the telescope has revealed remarkable results, being able to detect most of the objects observed, down to flux densities of 6 Jy in spectroscopic observations and 3 Jy in continuum observations.

However, we observed some instability in the measured fluxes, sometimes in successive observations. Several tests have been conducted to better understand the origin of these instabilities.

The main source of instability lies in the calibration system, which is used to calculate the system temperature. The low power of the noise diode makes the telescope sensitive to variations in the system temperature itself, resulting in a bad calibration. This can be mitigated by reducing the integration time of each individual observation and ignoring observations with bad calibration.

There are currently plans to carry out several modifications to the system in order to improve the results, such as the installation of a more powerful noise diode.

In this context, a master's thesis project, initiated in October 2024, is focused on developing a tunable up/down converter at the station by Pedro Soares, with the supervision of Abel García-Castellano.

This device is designed to convert the broadband frequencies of the VGOS receiver to baseband, offering four selectable bandwidth options: 100 MHz, 500 MHz, 1500 MHz, and 4 GHz.

3 Future Plans

Several modifications in the VGOS receiver are planned for the beginning of 2025 (most of them have already been made during the preparation of this report). They include:

- Installation of a new noise diode with higher power to improve single-dish calibrations.
- Installation of 5G notch filters to prevent saturation in the RF over fiber (RFoF) links.
- Installation of additional RFoF links to split the signal into low and high frequencies to prevent saturation in the RFoF links.

The last two points will enable the reduction of attenuation at the input of the RFoF transmitters, thereby reducing the noise temperature of the signal chain.

It is also planned to install a noise measurement system in the lab to carry out noise measurements in Santa Maria.

In 2025, the tunable down converter under development by Pedro Soares is planned to be assembled and tested at Yebes Observatory so that it can then be deployed at Santa Maria Station to improve radio astronomy observations while completing his master's degree.

A measuring campaign for local ties is planned for April or May 2025, aiming to assess the precision and stability of the newly constructed pillars.

There are several parts of the radio telescope that have high levels of corrosion, so they need to be repaired or substituted:

- Sub-reflector surface and protective cover for the servo system.
- Azimuth and Elevation cabin doors.
- Static discharge cables between azimuth and elevation cabins.
- Most of bolts and nuts of the back structure of the main reflector (Fig. **??**).

Fig. 8 Example of the status of the bolts in the back structure of the antenna.

Finally, it will be necessary to replace the UPS system and the batteries due to aging.

Acknowledgements

We sincerely appreciate the dedication and resilience of the RAEGE Santa Maria station team, who continue to persevere and rise to every challenge. Our gratitude

also goes to IGN Spain and the Yebes Observatory team for their unwavering support, whether through technical assistance, guidance, and their continuous efforts.

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