Hartebeesthoek Radio Astronomy Observatory (HartRAO)

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Abstract HartRAO is the only fiducial geodetic site on the African continent, and it participates in global networks for VLBI, GNSS, SLR, and DORIS. This report provides an overview of geodetic VLBI activities at HartRAO during 2023 and 2024, including the long anticipated first steps of the VGOS antenna as well as gravitational deformation surveys of the HartRAO 26-m and 15-m antennas.

1 Geodetic VLBI at HartRAO

The Hartebeesthoek Radio Astronomy Observatory (HartRAO) is a vital component of the South African Radio Astronomy Observatory (SARAO). Located 65 km northwest of Johannesburg and 32 km from the nearest town, Krugersdorp, HartRAO is nestled in a remote valley offering a measure of natural protection from terrestrial RFI. The observatory operates 26-m, 15-m, and 13.2-m radio telescopes.The VGOS antenna was initiated into the IVS network in October 2024 through tagalong sessions, which will continue as results are vetted and any issues are addressed. The telescopes are co-located with an ILRS SLR station (MOBLAS-6), a Russian satellite laser and radio ranging system «Sazhen-TM+OWS», two IGS GNSS stations (HRAO and HRAG00ZAF), a seismic vault, and an IDS DORIS station (HBMB) at the adjoining South African National Space Agency Earth Observation (SANSA EO) site. SARAO is also a full member of the European VLBI Network (EVN).

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HartRAO Network Station

IVS 2023+2024 Biennial Report

Fig. 1 The HartRAO 13.2-m VGOS antenna in tagalong mode with the 26-m and 15-m antennas holding down the fort in the background.

2 Technical Parameters of the 26-m, 15-m, and VGOS Telescopes at HartRAO

Table 1 outlines technical parameters for the HartRAO 26-m, 15-m, and 13.2-m antennas. Tables 2 and 3 present the technical parameters for the HartRAO 26-m and 15-m receivers, respectively, while Table 4 details the corresponding back-end components for these antennas. Additionally, a 462 TB Flexbuff recording system is available on the 26-m antenna for astronomical VLBI use. VDIF was first recorded to Flexbuff for geodesy (on the 26-m antenna) during the RD2305 session on 21 June 2023.

Table 1 Antennas and related parameters.

Parameter	Hart26	Hart15	HartVGOS
Owner and operating agency	NRF	NRF	NRF
Year of construction	1961	2007	2017
Mount type	Offset equatorial	Offset Az-El	Az-El
Receiving feed	Cassegrain	Prime focus	Ring-focus
Diameter of main reflector d	25.914 m	15 m	13.2 m
Focal length f	10.886 m	7.5 m	3.7 m
Focal ratio f/d	0.42	0.5	0.4
Surface error of reflector (RMS)	0.5 mm	1.6 mm	0.1894 mm
Short wavelength limit	1.3 cm	3 cm	3 mm
Pointing resolution	0.001°	0.001°	0.0001°
Pointing repeatability	0.004°	0.004°	(unknown)
Slew rate on each axis	HA: 2° s^{-1} Dec: 1° s^{-1}	Az: 0.5° s^{-1} El: 0.5° s^{-1}	Az: 12° s^{-1} El: 6° s^{-1}

Table 2 Parameters of the 26-m receiver (degraded performance due to dichroic reflector being used for simultaneous S/X VLBI).

Parameter	X-band	S-band
Feeds	dual CP conical	dual CP conical
Amplifier type	cryo HEMT	cryo HEMT
T_{sys} (K)	52	40
S_{SEFD} (Jy)	849	1190
PSS (Jy/K)	16.3	29.8
3 dB beamwidth (°)	0.096	0.418

Table 3 Parameters of the 15-m co-axial receiver.

Parameter	X-band	S-band
Feeds	stepped horn	wide-angle corrugated horn
Amplifier type	cryo HEMT	cryo HEMT
T_{sys} (K)	40	42
S_{SEFD} (Jy)	1400	1050
PSS (Jy/K)	35	25
3 dB beamwidth (°)	0.16	0.57

Table 4 Parameters of the 26-m and 15-m back-ends.

Parameter	Hart26	Hart15
Terminal	DBBC2	DBBC2
Recorder	256 TB Flexbuff	306 TB Flexbuff

Currently, the iMaser 72 hydrogen maser is used for VLBI on the 26-m, 15-m, and 13.2-m antennas. In late 2024, the heater controller of the EFOS-28 hydrogen maser was replaced, and it now serves as the backup maser. The older EFOS-6 hydrogen maser was decommissioned in mid-2023 due to faulty power supply circuitry and is no longer considered cost-effective to repair.

3 Current Status

In 2023 and 2024, the 15-m antenna participated in 186 and 170 IVS sessions, respectively (Figure 2), while the 26-m antenna was involved in 28 and 26 sessions each year (Figure 3). The two antennas observed together only during the T2P sessions over this period.

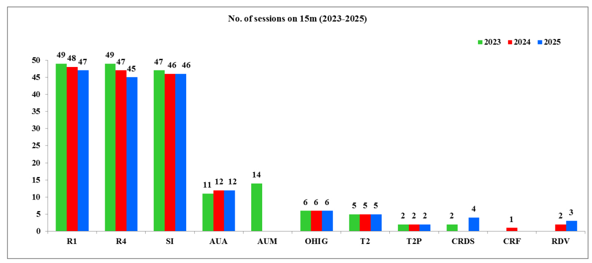

Fig. 2 HartRAO 15-m IVS sessions observed during 2023 and 2024, as well as sessions planned for 2025.

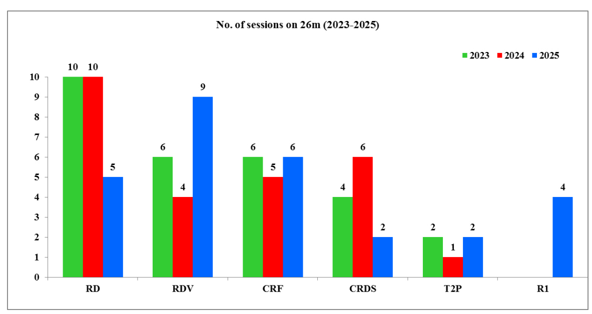

Fig. 3 HartRAO 26-m IVS sessions observed during 2023 and 2024, as well as sessions planned for 2025.

The 15-m antenna continued its participation in the weekly hour-long Southern Intensive (SI) sessions alongside the Hobart 12-m antenna, with the Yarragadee 12-m antenna rejoining from February 2024 onward. The AUSTRAL mixed-mode (AUM) observing sessions came to an end in December 2023. The 15-m antenna also took part in two CRDS sessions in

2023 and in one CRF and two RDV sessions in 2024—normally reserved for the more sensitive 26-m antenna.

Although the Hobart 26-m antenna was unavailable for HARTRAO-HOBART26 single-baseline observations during 2023 and 2024, the HartRAO 26-m antenna remained integral to astrometric CRF observations at K-band (24 GHz), collaborating with the Yebes 40-m antenna in Spain, the KVN 22-m and Sejong 20-m antennas in Korea, and the Mopra 22-m antenna in Australia (under KASI/KVN contract).

In 2023 and 2024, all sessions for the HartRAO 15-m and 26-m antennas continued to be operated remotely, with VLBI data from all sessions e-transferred to the correlators as before. The VGOS teething sessions at the end of 2024 were conducted in person.

The 15-m antenna operated reliably throughout 2023 and 2024, with only minor issues related to faulty cables and connectors. The 26-m antenna required more attention, particularly due to sub-reflector problems. The focus chain failed early in 2023, and the replacement chain frequently dismounted, causing pointing inaccuracies. These issues were resolved by the end of 2023 through realignment of the leadscrews and adjustment of the tension. In 2024, the primary iMaser 72 unexpectedly lost lock twice, necessitating a switch to the EFOS-28 backup maser for several sessions. To improve response times for such issues, changes have been implemented to log sensor data from both the iMaser 72 and EFOS-28, enabling continuous monitoring and automatic alerts.

4 Personnel

Table 5 lists the HartRAO station staff involved in geodetic VLBI. Jonathan Quick (VLBI friend) handles all local telescope scheduling issues and provides technical support for the Field System as well as support for hardware problems.

Operations astronomer Aletha de Witt provides support for astrometric VLBI. In 2024, Alet was appointed president of the IAU Astrometry Commission A1. Starting from 2024, she also serves on the GGOS GB and as IAG representative on the IVS DB. At the beginning of 2024, she transitioned from HartRAO to become Director of Radio Astronomy at the Department of Science, Technology and Innovation (DSTI). Because Geodesy falls under Astronomy within South Africa's framework, Alet remains involved with HartRAO.

Table 5 Staff supporting geodetic VLBI at HartRAO.

Name	Function	Program
J. Quick	Hardware/ Software	Astronomy
A. de Witt	Operations/ Scheduling	Fundamental Astronomy
S. Blose	Electronics	Engineering
R. Botha	Logistics/ Operations	Geodesy
P. Mey	Drive systems	Engineering
M. Nickola	Logistics/ Operations	Geodesy
R. Nombembe	Receivers	Engineering
P. Stronkhorst	Cryogenics	Engineering

5 New Developments

On 13 February 2024, IGN engineers and technicians José Antonio ("Pepe") López Pérez, Adrián Alonso, Joaquín Fernández, and Gabriel Gómez arrived at HartRAO to install and commission the much anticipated Yebes Observatory broadband cryogenic VGOS receiver. The receiver was successfully installed on the HartRAO 13.2-m VGOS antenna on 16 February 2024. As HartVGS is a non-vetted station, it started tagging along in select VGOS sessions from October 2024 onwards. On 14 November 2024, we received our first official correlator feedback from Bonn for fringe test FT5, with Simone congratulating HVGS on detection of the first fringes, on the Hv-Sa baseline. Teething issues, including hexapod motor and control problems, along with correlator reports of "significant delay residual differences between adjacent scans and highly variable phasecal amplitudes" have been keeping Jon and our Engineering team on their toes.

The IGN Engineering/Receiver team was joined by Elena Martinez Sánchez, Geographical Engineer at Yebes Observatory, who contributed her expertise in site tie measurements, particularly methods for determining the antenna IVP using a Total Station. During a follow-up visit to Yebes Observatory in Spain in 2024, Elena conducted a hands-on demonstration of the process for determining the Yebes VGOS antenna's IVP, and she shared various techniques and software for processing and analyzing local tie data. At HartRAO, some data analysis software has been developed using MATLAB, with further development ongoing.

A new MET4 unit has been installed at the same height as the current barometer to enable an initial comparative study. Once sufficient data have been collected, the MET4's height will be adjusted to the reference height of the 15-m antenna. A Paroscientific barometer has been installed in the VGOS antenna's elevation cabin at the VGOS reference height.

Gravitational deformation surveys of the HartRAO 26-m and 15-m antennas, initiated by John Gipson and led by Axel Nothnagel, were conducted in late April 2024 in collaboration with TU München and TU Wien. At HartRAO, Terrestrial Laser Scanner (TLS) measurements were overseen by Christoph Holst, with Theresa Pfaffinger and Marco Ortiz from TU München carrying out the scans. The polar mount of the 26-m antenna makes its deformation model more complex, as it depends on both HA and Dec. Additionally, laser sensors were used to measure distance variations between the 26-m antenna's vertex and sub-reflector. Preliminary results will be presented at the EVGA, IAG, and JISDM meetings in 2025.

The first EVN astrometric K-band CRF observations aimed at reference frames began at the end of 2024 and are scheduled to continue until the end of 2027. In 2024, the KOSMIC (K-band VLBI Observations with Improved Scheduling and Ionospheric Corrections) collaboration, led by Benedikt Soja and Aletha de Witt and involving ETH Zürich, SARAO, and TU Wien, focused on optimizing scheduling through an enhanced source selection strategy and improving ionospheric corrections with a machine learning-based model to predict VTEC. Presentations on KOSMIC were given at the IAU GA in Cape Town, South Africa, in August 2024.

6 Future Plans

Of the 202 geodetic VLBI sessions scheduled for 2025, 170 sessions (including 46 SI sessions) are allocated to the 15-m antenna and 28 sessions to the 26-m antenna. Two T2P sessions will be run on both antennas simultaneously, along with four R1 sessions to ensure historical continuity.

The main goal for 2025 is to complete the commissioning of the VGOS antenna. Funding for replacing the 26-m antenna's declination shaft bearings has not yet been secured. Due to the antenna's age, along with the associated costs and risks, SARAO management has not yet committed to supporting this initiative. Meanwhile, the axial shift is being closely monitored for further degradation, and an upgrade to the 26-m antenna's hour angle encoder is underway, with lab testing currently in progress. Increased issues with the sub-reflector, stemming from the current chain and leadscrew system, have prompted a shift toward exploring alternative solutions, including plans to replace the system with a more robust linear actuator. Additionally, we have begun migrating all sensor data to InfluxDB, using Grafana as the front-end for continuous monitoring and alerting.

Prism installations for all antennas and initial site tie measurements are planned for 2025. Efforts are underway to collaborate on re-coding legacy Yebes software for IVP determination into MATLAB and Python. Additionally, a barometer is to be installed on the 26-m antenna, positioned as close as possible to its reference height.

An opportunity to establish GGOS Africa emerged during a geodesy session titled *Africa Rising: Shaping Our Common Future Through Geodesy*, held at the UN GA Science Summit in New York in September 2024. The session was convened by the DSTI and SARAO, in collaboration with key partners such as the UN-GGCE, IAG, GGOS, and others.

Acknowledgements

HartRAO forms part of SARAO, which is a national facility operating under the auspices of the National Research Foundation (NRF), South Africa. The Space Geodesy Programme is an integrated program, combining VLBI, SLR, and GNSS, and it is active in several collaborative projects with NASA's GSFC and JPL, the ILRS, «Roscosmos», DLR, ESA, and the UN-GGCE, as well as numerous local institutes. General information as well as news and progress on geodesy and related activities can be found at `http://geodesy.hartrao.ac.za/`.

Fig. 4 The VGOS receiver has arrived!

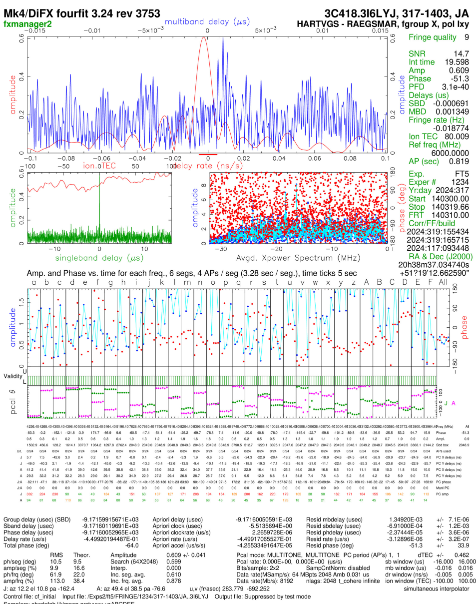

Fig. 5 First HartVGS fringes on the baseline with Santa Maria.

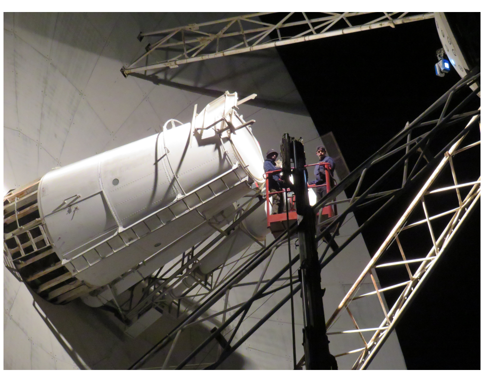

Fig. 6 TLS installation for gravitational deformation survey of the 26-m antenna.

Fig. 7 Yebes VGOS Receiver and Local Tie Hit Squad (from the left: Gabriel, Elena, Joaquín, Adrián, and Pepe).

Fig. 8 VGOS pressure sensor installed in the elevation cabin at its reference height.

Fig. 9 Marco and Theresa scanning the 15-m dish with Pieter providing assistance.