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 2021 and 2022, including progress with the VGOS antenna and an update on the 26-m antenna's failing west declination shaft bearing.

1 Geodetic VLBI at HartRAO

The Hartebeesthoek Radio Astronomy Observatory (HartRAO) forms part of the larger South African Radio Astronomy Observatory (SARAO). The Hartebeesthoek site is located 65 km northwest of Johannesburg, just inside the provincial boundary of Gauteng, South Africa. HartRAO is located 32 km away from the nearest town, Krugersdorp. The telescopes are situated in an isolated valley which affords some protection from terrestrial radio frequency interference. HartRAO currently operates 13.2-m, 15-m, and 26-m radio telescopes. The 13.2-m VGOS radio telescope is still not fully operational, but a broadband VGOS receiver is under construction at Yebes, and a matching DBBC3 backend and Mark 6 recorder are now available. It should hopefully achieve operational status in the first half of 2024. The 26 m is an equatorially mounted Cassegrain radio telescope built by Blaw Knox in 1961. The telescope was part of the NASA deep space tracking network until 1974 when the facility was converted to an astronomical observatory. The 15 m is an az-el radio telescope built as a Square Kilometer Array (SKA) prototype during 2007 and converted to an operational geodetic VLBI antenna during 2012. 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).

Fig. 1 The HartRAO 26-m and 15-m antennas currently participating in IVS sessions.

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

Table 1 contains the technical parameters of the HartRAO 15-m, 26-m, and VGOS antennas, while Table 2 and Table 3 contain technical parameters of

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the HartRAO 15-m and 26-m receivers, respectively. The current data acquisition systems consist of a DBBC terminal and a 432 TB Flexbuf recorder for the 15-m antenna and a Mark 5B+ recorder for the 26-m antenna. Spare Mark 5B, Mark 5B+, and Mark 5C recorders are used for e-transfer of data and conditioning and testing of disk packs. Both DBBC2s have recently had an internal power-wiring upgrade installed. A 258 TB Flexbuf recording system is also available on the 26-m antenna for astronomical VLBI use.

Currently, the hydrogen maser iMaser 72 is being used for VLBI on both the 15-m and 26-m antennas. The EFOS-28 hydrogen maser, previously employed for VLBI on the 15-m antenna, developed an internal heater fault and was taken out of service. It is not reliable but still usable. A heater controller replacement on EFOS-28 is also pending, which should correct the problem once installed. The older EFOS-6 hydrogen maser is completely down at the moment, and attempts to restart it have failed thus far.

Table 1 Antenna parameters.

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

3 Current Status

During 2021 and 2022, the 15-m antenna participated in 131 and 169 geodetic/astrometric IVS sessions respectively (see Figure 2). The 26-m antenna participated in 29 and 30 sessions during 2021 and 2022 respectively (see Figure 3). Only during the T2P sessions did the antennas have an opportunity to observe together in 2021 and 2022. The 15-m antenna continued its participation in the hour-long Southern Intensive (SI) test sessions, observing together with the Hobart and Yarragadee 12-m antennas in 35 sessions in 2021. The SI sessions were officially added to the 2022 Master Intensive Schedule with observations scheduled for Mondays at 06:30 UT to overlap with the INT-3 sessions. From June 2022 onwards, the three-station network was reduced to the single HartRAO15–Hobart12 baseline. During 2021 and the first part of 2022, the 15-m antenna also joined in the AUSTRAL mixed-mode (AUM) observing sessions which aimed to provide the Hobart and Katherine 12-m antennas with uninterrupted position time series before they transitioned to full VGOS wideband operations. The HartRAO 26-m also contributes to astrometric celestial reference frame (CRF) observations conducted at K-band (24 GHz). Regular single-baseline observations between the HartRAO and Hobart 26-m antennas provide valuable data for the southern K-band CRF. Unfortunately, from March 2021 onwards, a bearing failure on the Hobart 26-m antenna prevented any further single-baseline VLBI sessions between the HartRAO and Hobart 26-m antennas from being observed. These astrometry experiments, towards the improvement of the K-band CRF in the South, will resume in 2023.

Table 2 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 3 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

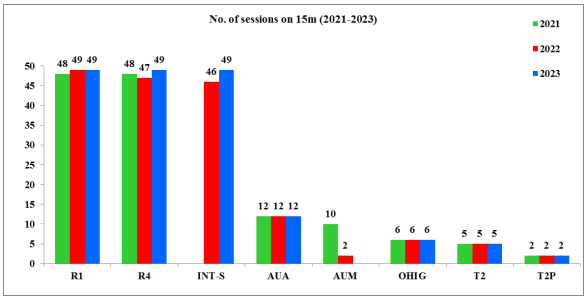

Fig. 2 HartRAO 15-m IVS sessions observed during 2021 and 2022, as well as planned for 2023.

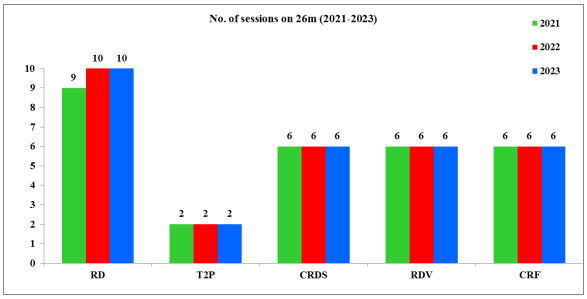

Fig. 3 HartRAO 26-m IVS sessions observed during 2021 and 2022, as well as planned for 2023.

All sessions in 2021 and 2022 continued to be run under remote control whilst the COVID-19 situation slowly returned to normal. VLBI data for all sessions were e-transferred to the correlators as before.

Despite the continued use of remote attendance, the 15-m antenna's reliability was markedly improved during 2021–2022. This was in part due to a long overdue servicing of the dewar o-rings. In 2021, the S/X receiver on the 15 m was brought down to fix the vacuum leaks. It was possible to fix these leaks without removing the heat shield or any components, and therefore it was unnecessary to do a full calibration of the receiver before reinstalling. The main reason for the 15-m antenna's improvement, however, was the introduction of a far more reliable Flexbuf recording system. The most data loss was due to factors beyond our control, such as bad weather and/or external power supply issues. Currently, our biggest challenge to observing is the electricity supply. Although we have backup generators in place, there are occasions where the antennas are interrupted, thus losing some observation time.

Unfortunately, the same cannot be said about the 26-m antenna's reliability over the same period. Various drive, power supply, and interlock failures plus control system hardware issues resulted in not unplanned downtime. We also ran into at least two disk pack failures. Fortunately, this antenna is less sensitive to external power supply events and usually recovers automatically.

One of the 26-m antenna's BEI encoders failed on November 16, 2022. It was replaced by a similarly aged encoder, dating from 1995, which also did not operate reliably. On November 23, 2022, the BEI was replaced with a 26-bit Heidenhain ROC226 encoder. This is an interim solution, as the west declination shaft bearing is still in need of replacement, thereby delaying the installation of new higher resolution Heidenhain absolute encoders. The performance of the new encoder in relation to the old encoder still needs to be ascertained; however, the 26 m is back to normal operation.

The feedcone cover on the 26-m antenna was replaced on October 10, 2022. The previous cover was already 20+ years old, and its seam ran through the middle and across some of the receivers. Although watertight, the seam allowed water to pocket and possibly affect the receiver temperature at K-band. The replacement cover is wide enough to cover the feedcone without any seams (see Figure 4).

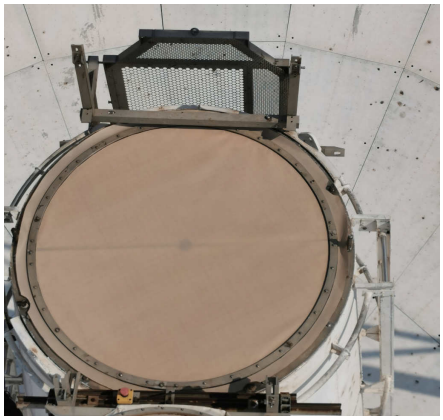

Fig. 4 A brand new cover for the 26-m antenna's feedcone.

4 Personnel

Table 4 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. During the COVID-19 lockdown, from March 19, 2020 onwards, Jon has been running all geodetic VLBI sessions remotely.

Operations astronomer Aletha de Witt provides support for astrometric VLBI. Alet is the principal investigator for CRF and CRDS IVS astrometric VLBI sessions, as well as for the K-band CRF project. In 2021, Alet was elected as vice president of the IAU Astrometry Commission A1. She is also the chair of the IVS CRF Committee. Alet continued to serve as an at large member on the IVS Directing Board during 2021–2022.

Table 4 Staff supporting geodetic VLBI at HartRAO.

Name	Function	Program
A. de Witt	Operations/ Scheduling	Fundamental Astronomy
J. Quick	Hardware/ Software	Astronomy
S. Blose	Operator	Engineering
P. Mey	Operator	Engineering
R. Myataza	Operator	Engineering
M. Nickola	Logistics/ Operations	Fundamental Astronomy
P. Stronkhorst	Operator	Engineering

5 New Developments

A fully VGOS-capable DBBC3 terminal from Hat-Lab was delivered in early 2021 but was only commissioned in mid-2022 once staff returned to work on site more regularly. Although Yebes Observatory was also appointed to build a complete wide-band VGOS receiver system to match in early 2020, long pandemic-related delays in sourcing the necessary components has pushed out the delivery of the latter, now expected in late 2023.

During 2019 and 2020, plans were put in place and preparation started to improve the performance and enhance the reliability of the 15-m and 26-m antenna systems. There was only limited progress on this refurbishment, mainly due to limited staff availability on site.

Although bids for possible replacement of the 26-m declination shaft bearings, which would probably involve some significant period of downtime, were solicited in 2020, we have as yet been unable to secure funding for this, as it does not have the support of SARAO management. We are hopeful of convincing our funding agencies of the critical importance of the 26 m's continued participation in IVS activities, given that it is one of only a very few antennas in the south and one of only two in Africa forming part of the IVS network (the other being the 15 m). Continuous monitoring of the axial shift on the 26 m is being performed pending a decision. Work will also continue to upgrade the hour angle encoder on the 26-m antenna with a higher accuracy Heidenhain encoder.

To address the increased load-shedding in South Africa, a generator control unit is being tested to start and run the generator before any planned electricity outages. The UPS for the control room and main building will also be upgraded to a solar power system with additional battery capacity.

In August 2021, the VLBA stations Mauna Kea and St. Croix were added to the CRDS network, followed by the addition of the Kunming 40-m antenna in October 2021. Single-baseline astrometric VLBI observations between the HartRAO 26-m and Yebes 40-m antennas were introduced in May 2022, towards increasing the number of north-south baseline observations needed to further improve and maintain the K-band CRF. During 2021 and 2022, emphasis was placed on observing ICRF-3 defining sources in IVS CRDS and CRF sessions. VLBA CRF SX observations taken between April and June 2021 were combined with near-simultaneous CRF observations at K- and Q-band and used to compare images and astrometry for the SX-, K-, and Q-bands in order to study the astrophysical differences and determine the optimal frequency band for CRF observations.

Support for the tracking of arbitrary ephemeris tables by way of cubic spline interpolation was added to the local Field System antenna interface to facilitate the use of the 26-m antenna for spacecraft tracking — a return to its original role some 50 years later! The 26 m was tested for use in a few space missions in collaboration with the South African National Space Agency (SANSA). Due to the 26 m's sensitivity, it is possible for SANSA to transmit a signal to the satellites using their smaller 12-m antennas and receive the response via a fiber optic link connected to our 26-m antenna.

The power and communication system for a new permanent meteorological system was installed next to the Stevenson screen. Once the comparative study with the current (old) sensors has been completed, the height will be adjusted to measure the barometric pressure at the reference height of the 15-m antenna. We have procured two Paroscientific Model 6000-16B barometers, which are to be mounted at the reference heights of the 26-m and VGOS antennas. To calibrate these multiple barometers (and our off-site GNSS MET4 barometers), we also procured a Paroscientific Model 765-16B Field Barometric Standard.

Progress with the automated site tie continued to be slow due to software issues. We've made some headway with standardizing the reference pier construction as well as the surveying accessories (reference plate, levelling plate, and z-coaxial prism holders—see Figure 5) and can now proceed with initial measurements towards automation.

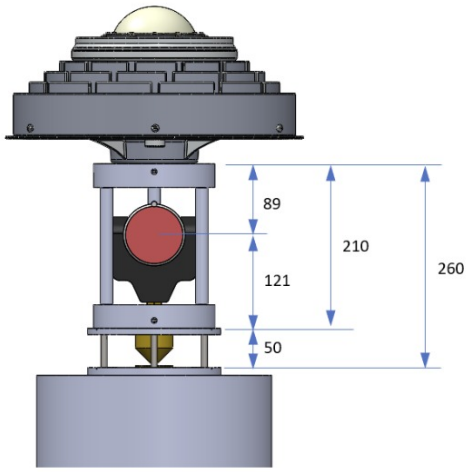

Fig. 5 Automated site tie—typical assembly of a levelling plate and z-coaxial prism holder (Leica GPH1P) with a GNSS antenna (Leica AR25).

6 Future Plans

Of the 202 geodetic VLBI sessions scheduled for 2023, 170 sessions (including 49 Southern Intensive sessions) are allocated to the 15-m antenna, 28 sessions are allocated to the 26-m antenna, and two T2P sessions will be run on both antennas.

Work is still under way to equip the VGOS antenna with an in-house cryogenic receiver that will be used to test and resolve possible interface/control issues before arrival of the broadband VGOS receiver. Preliminary participation in VGOS observations is only expected to begin in early 2024.

Depending on the state of the 26-m antenna declination bearing and the continued monitoring thereof, the utilization of this antenna may have to be decreased to ensure a longer lifespan. A gravitational deformation survey of the 26-m equatorially mounted antenna, initiated by John Gipson and led by Axel Nothnagel in collaboration with Christoph Holst and Agnes Weinhuber from the Technical University of Munich, is planned for 2023.

Plans to further expand the CRDS network, as well as for a SARAO geodetic correlator facility, are under way. A data paper with details and results of the CRDS observations is to be submitted for publication in 2023. Time was also granted for K-band CRF observations between the Korean VLBI Network (KVN) and the HartRAO and Hobart 26-m antennas for the first semester of 2023. And finally, the IAU Astrometry Commission A1 is planning an Astrometry Focus Meeting at the next IAU General Assembly to be held in Cape Town in 2024.

Acknowledgments

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 DLR, ESA, GFZ (Potsdam), GSFC, ILRS, JPL, and «Roscosmos», 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/`.