# 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 2015 and 2016, including progress with the VGOS project.

## 1 Geodetic VLBI at HartRAO

Hartebeesthoek 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 protection from terrestrial radio frequency interference. HartRAO currently operates both a 15-m and a 26-m radio telescope. A new 13.2-m VGOS radio telescope is under construction. 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 Kilometre 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 new Russian satellite laser and radio ranging system ≪Sazhen-TM+OWS≫ (not fully operational yet), an IGS GNSS station (HRAO), a seismic vault, and an IDS DORIS station (HBMB) at the adjoining South African National Space Agency Earth Observation (SANSA EO) site. HartRAO is also a full member of the EVN.

HartRAO

HartRAO Network Station

IVS 2015+2016 Biennial Report

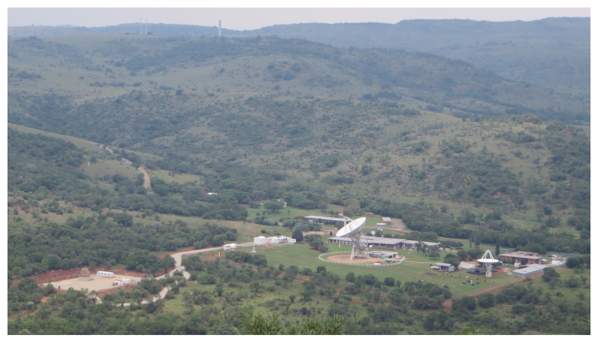

**Fig. 1** New additions at fundamental site HartRAO: VGOS installation bottom left with, to its right, the ≪Sazhen-TM+OWS≫ (GNSS one-way station, Sazhen-TM quantum-optical station and control room).

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

Table 1 contains the technical parameters of the HartRAO 15-m and 26-m radio telescopes, while Table 2 and Table 3 contain technical parameters of the HartRAO 15-m and 26-m receivers, respectively. The current data acquisition systems consist of a DBBC terminal and a Mark 5B+ recorder for both the 15-m and the 26-m antennas. A Mark 5C recorder is used for e-transfer of data and conditioning and testing of disk packs. A 102-TB Flexbuf reading system is also available for astronomical VLBI use. Three hydrogen masers are available—the EFOS-28, which is currently employed for VLBI on the 15-m antenna, the iMaser 72, currently employed on the 26-m antenna, and the resuscitated EFOS-6.

**Table 1** Antenna parameters.

| Parameter | Hart15M | HartRAO |
|---|---|---|
| Owner and operating agency | HartRAO | HartRAO |
| Year of construction | 2007 | 1961 |
| Radio telescope mount | Offset az-el | Offset equatorial |
| Receiving feed | Prime focus | Cassegrain |
| Diameter of main reflector $d$ | 15 m | 25.914 m |
| Focal length $f$ | 7.5 m | 10.886 m |
| Focal ratio $f/d$ | 0.5 | 0.42 |
| Surface error of reflector (RMS) | 1.6 mm | 0.5 mm |
| Short wavelength limit | 3 cm | 1.3 cm |
| Pointing resolution | 0.001° | 0.001° |
| Pointing repeatability | 0.004° | 0.004° |
| Slew rate on each axis | Az: 2° $s^{-1}$ | HA: 0.5° $s^{-1}$ |
| | El: 1° $s^{-1}$ | Dec: 0.5° $s^{-1}$ |

**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 |

## 3 Current Status

Telescope time allocation for geodetic VLBI consisted of 29 sessions on the 26-m antenna during 2015 and 33 sessions during 2016. The 15-m antenna participated in 153 sessions in 2015 and in 37 sessions in 2016 (Table 4). The 15-m antenna could not participate in a further 73 sessions scheduled from the 8th of February to the 11th of October 2016 due to a major antenna azimuth drive failure just before the start of the R1726 session. The azimuth motor-gearbox assembly was severely damaged during an electrical storm preceding the session. The rotor of the drive motor had disintegrated, and the gearbox was also damaged. A custom-built replacement motor-gearbox assembly had to be procured from Germany but got lost between the factory and the observatory, delaying the 15-m antenna's return to action by several weeks, with its first session after repairs, R4761 on the 13th of October 2016, being run in tag-along mode. Before this session, the 15-m antenna's S/X receiver was refurbished. Further extensive maintenance and refurbishment took place while the 15-m antenna was not operational. A reflector surface repair process was initiated in order to repair dry patches on the 15-m antenna's surface causing water ingress (see Figure 3).

Intermittent phase-cal and LO instability, during March–May 2015, pointed at possible damage to the 15-m antenna's cables through the wraps. New cables were installed in the azimuth wrap before the R4695 session on the 9th of July 2015. During August 2016, the 26-m antenna also displayed intermittent phase-cal and cable-cal values due to a loose connection in the cable between the antenna and the ground units.

During February and June 2015, the 15-m antenna participated in two AUSTRAL-CONT campaigns. Five experiments with both the 15-m and 26-m antennas observing—three R1s and two T2s—were performed during 2015, whilst only a single dual R1 session was possible during 2016. The 15-m antenna partcipated in one Chinese Lunar Lander Chang'E-3 RD/OCEL session during 2015 while the 26-m antenna observed in three such sessions in 2015 and four OCEL sessions in 2016. Geodetic VLBI data for all sessions were e-transferred to the correlators.

HartRAO has also been running astrometric single-baseline VLBI sessions in collaboration with Hobart (UTAS) to help to improve the S/X- and K-band reference frames in the South and its contribution to the ICRF-3. The 26-m antenna's sensitivity at 22 GHz has been improved by a factor of five with the installation of a cooled K-band receiver. The efficiency was doubled with a recent first-ever K-band session in the South at 2 Gbps. The combined upgrades enable the instrument to be used effectively at 22 GHz, tripling the resolution of the instrument over previous work at 8.4 GHz.

**Table 4** Geodetic VLBI experiments in which HartRAO participated during 2015 and 2016.

| Experiment | No. of sessions on 15 m | | No. of sessions on 26 m | |
|---|---|---|---|---|
| | 2015 | 2016 | 2015 | 2016 |
| R1 | 49 | 15 | 3 | 6 |
| R4 | 49 | 16 | 0 | 0 |
| AUST15 | 30 | 0 | 0 | 0 |
| AUST | 12 | 1 | 0 | 0 |
| RD | 1 | 0 | 9 | 12 |
| T2 | 6 | 2 | 2 | 1 |
| CRDS | 0 | 0 | 6 | 6 |
| OHIG | 6 | 3 | 0 | 0 |
| RDV | 0 | 0 | 6 | 5 |
| CRF | 0 | 0 | 3 | 3 |
| Total | 153 | 37 | 29 | 33 |

## 4 Personnel

Table 5 lists the HartRAO station staff involved in geodetic VLBI. Jonathan Quick (VLBI friend) provides technical support for the Field System as well as support for hardware problems. Operations astronomer, Alet de Witt, provides support for astrometric VLBI and is a member of the ICRF-3 Working Group. Astronomy student, Sayan Basu, joined the geodetic VLBI team as a trainee operator at the start of 2015.

## 5 New Developments

At the end of 2015, MT Mechatronics was appointed as supplier for the new 13.2-m VGOS antenna at HartRAO. Design reviews were undertaken during March 2016. The antenna is currently being manu-

**Table 5** Staff supporting geodetic VLBI at HartRAO.

| Name | Function | Program |
|---|---|---|
| L. Combrinck | Program Leader | Geodesy |
| J. Quick | Hardware/ Software | Astronomy |
| S. Basu | Operator | Student |
| R. Botha | Operator | Geodesy |
| J. Grobler | Operator | Technical |
| P. Mey | Operator | Geodesy |
| R. Myataza | Operator | Technical |
| M. Nickola | Logistics/ Operations | Geodesy |
| P. Stronkhorst | Operator | Technical |
| C. Zondi (2015) | Operator | Technical |

factured. Alliance Construction was appointed as the civil works contractor and started site preparations in September 2016. The first steps taken during civil works concerned the site layout—surveying the site perimeter, clearing the site and surrounds, and establishing a slight slope for rainwater to run away from buildings. Water and electricity have been connected to the site, and the site has been fenced off to control access. The anchorage ring was the first part to arrive on site and has been positioned and cast in place (see Figure 4). Live footage of the construction process is being captured by a webcam and can be accessed at:
http://geodesy.hartrao.ac.za/site/en/geodesy-equipment/vgos-telescope/150-vgos-videos.html

The HartRAO engineering team is designing a new automated dichroic mirror system for the 26-m antenna. The current design, with the dichroic mirror located in the X-band beam and reflecting the S-band beam, is to be replaced by a design with a reversed configuration, with the S-band beam reflecting the X-band. The new setup will be much smaller than the current one and will be automated to move in and out of the beam with actuators.

A local automated site tie system is being installed at HartRAO (see Figure 5). It uses a Leica MS50 Multistation that is mounted on a reference pier, which has line-of-sight to all of the major geodetic systems on-site. This system will perform frequent automated measurements to determine daily ties at the mm-level.

HartRAO is now hosting a Russian satellite laser and radio ranging system ≪Sazhen-TM+OWS≫. Full functionality was achieved on 16 December 2016.

HartRAO is continuing with its project to install GeoStations in the southern African regions as well as in the rest of Africa. These GeoStations consist of a GNSS reference station, seismometer, Met4 unit, and other equipment as required. HartRAO, Matjiesfontein, and the Nelson Mandela Metropolitan University (see Figure 6) already have such installations. A seismometer has been installed on Marion Island.

HartRAO in collaboration with the Namibian Port Authority, Namport, has installed GNSS reference stations at Lüderitz (see Figure 7) and Walvis Bay in Namibia on behalf of the University of Luxembourg. These installations are co-located with the tide gauges that were already operating there.

As part of the development of the new Lunar Laser Ranger, a new model of a timing reference system was developed by Microsemi according to our specifications. HartRAO has obtained the first such unit. It was characterized, and we are satisfied that it meets our system design requirements.

## 6 Future Plans

Of the 159 geodetic VLBI sessions scheduled for 2017, 127 sessions are allocated to the 15-m antenna with the remaining 32 sessions to be run on the 26-m antenna. The 15-m antenna will participate in several astrometric AUSTRAL sessions as well as in the CONT17 campaign taking place during November and December 2017.

Regarding VGOS activities, network and maser connections should be in place by February 2017. The last concrete pour is scheduled for 23 January 2017 with the last outstanding items being completed by the end of February 2017. Factory Acceptance Tests (FATs) for the VGOS antenna's steel top structure, i.e., everything from the azimuth cabin to the subreflector, are scheduled for mid-January 2017 at the CETC 54 facilities in China. The FAT for the hexapod and servo cabinets will follow in February 2017. After the FAT, the antenna will be shipped to HartRAO. Assembly is foreseen to start in April/May 2017 with final commissioning to take place around September 2017.

The total station should be operational by mid-2017. ≪Sazhen-TM+OWS≫ should also achieve full operational status by mid-2017.

The following GeoStation installations are to occur during 2017: at the Gamsberg in Namibia, Kutunse in Ghana, Necsa near HartRAO, and Klerefontein near the SKA core in South Africa. Stations are also planned for the Stellenbosch area in South Africa and Zambia.

During 2017, integration of all LLR hardware via a software system will be pursued. It is also endeavoured to procure the last few outstanding specialized hardware items for the LLR, such as the photon detection system.

## Acknowledgements

HartRAO 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 GSFC, JPL, GFZ (Potsdam), and ≪Roscosmos≫ as well as numerous local institutes. Collaboration also includes OCA/NASA and the ILRS community in a Lunar Laser Ranger (LLR) project with local support from the University of Pretoria, amongst others. General information as well as news and progress on geodesy and related activities can be found at http://geodesy.hartrao.ac.za/.


**Fig. 2** Thanking organizers and participants alike for making the 9th IVS GM hosted by HartRAO in March 2016 a great success!

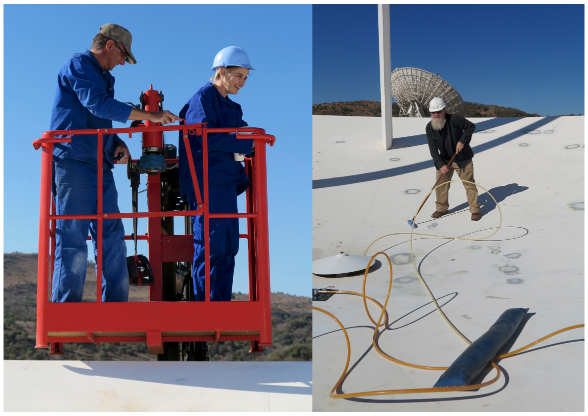

**Fig. 3** The surface of the 15-m antenna under repair: vacuum and fiberglass curing in progress. Visiting scientists beware—you will be put to work!

**Fig. 4** VGOS site, 15 December 2016; last concrete pour of antenna tower is scheduled for the end of January 2017.

**Fig. 5** The local automated site tie system is nearly ready to start operations.

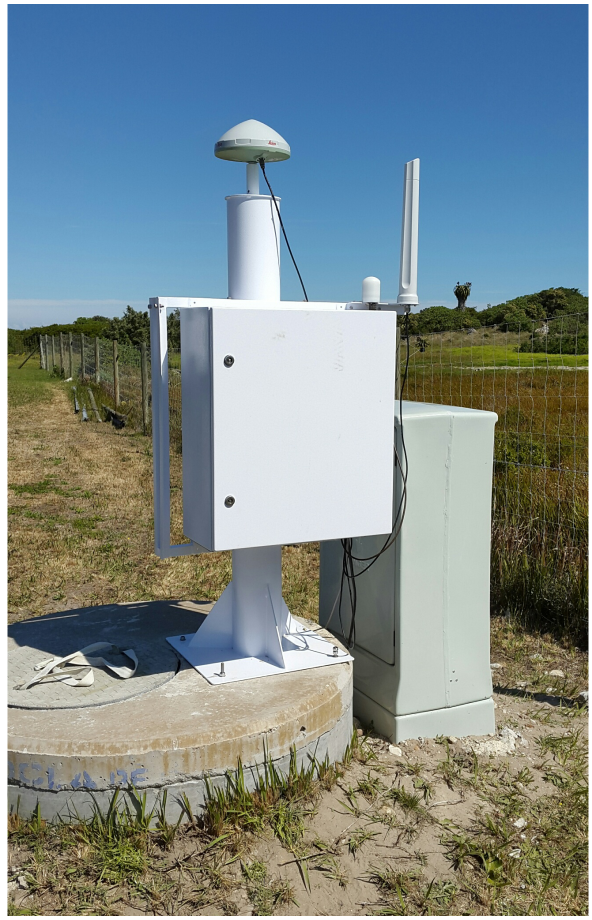

**Fig. 6** NMMU GeoStation installation, Port Elizabeth, South Africa.

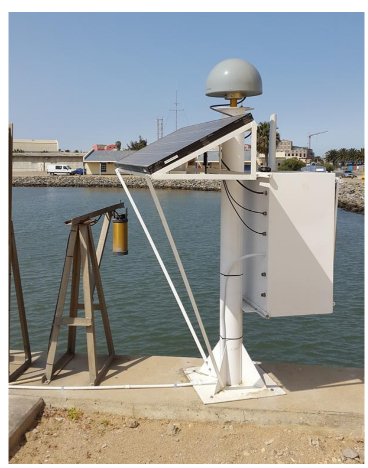

**Fig. 7** GNSS reference station and tide gauge at Lüderitz in Namibia.