AuScope VLBI Array and Hobart 26-m Antenna

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Abstract This is a report on the activities carried out at the University of Tasmania in support of the three AuScope VLBI observatories and the Hobart 26-m antenna in 2021 and 2022. Our current and completed research programs are outlined, as are our planned developments of the array.

1 General Information

The Australian AuScope VLBI array consists of 12-m VLBI telescopes located in Hobart, Tasmania (Hb); Katherine, Northern Territory (Ke); and Yarragadee, Western Australia (Yg). Those three telescopes are in the transition to VGOS sites, with the existing legacy S/X telescopes being equipped with new VGOS receivers and backends. This contribution also covers the Hobart 26-m telescope (Ho). While the telescopes are owned and operated by the University of Tasmania, the Australian IVS observations are contracted through Geoscience Australia. This is done within the *AuScope VLBI Project*, funded through *Positioning Australia*, an initiative of the Australian Government. Funding is secured on five-year cycles, with a renewal of the contract scheduled for the end of 2023.

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UTAS, AuScope, Hb, Ho, Ke, Yg, Network Stations

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2 Component Description

The AuScope VLBI array was initially designed as three identical telescopes with the technical specifications for legacy operations detailed in [2]. Today, Hb and Ke were upgraded to VGOS sites, while Yg remains in legacy S/X configuration with the upgrade planned for 2023. Ho experienced a major structural damage in August 2021, but has recently rejoined some IVS legacy observations.

2.1 Yarragadee 12-m

Yarragadee has continued observing as part of the S/X network throughout 2021–2022, although its upgrade to a VGOS station is planned for early 2023. The system is essentially unchanged, except that the phase calibration unit was decommissioned in early 2021 after an investigation into apparent clock breaks affecting the data. This appears to have been linked to a lack of temperature stabilization in the phase calibration unit, leading to step changes in its performance around sunrise and sunset. With COVID travel restrictions in place, the decision was made to shut it down rather than attempt a repair remotely. The observing system at Yarragadee consists of the legacy S/X receiver with a DBBC2 as sampler, recording to a Mark5B+ unit. Data transfer is via post, with modules or USB-HDDs with a copy of the data being sent to Hobart for further e-transfer. The Internet connection is sufficient for basic remote operations and suitable for high-latency transfers of small test data. Peak rates are approximately 10 Mbps.

2.2 VGOS Stations Hobart12 and Katherine

Late in 2021, the first upgraded 8-input DBBC3 was received at Hobart and put into use to enable the full VGOS mode. Prior to this, we lacked the ability to observe both the A- and B-bands simultaneously. Previous test observations had used a subset of bands to demonstrate fringes, but no useful observations could be made in this configuration. The first full-band VGOS observation occurred in late 2021 which revealed some issues in the phase calibration system causing spurious harmonics.

A major overhaul of the calibration (noise diode and phase cal) systems was undertaken in early 2022 which has greatly improved the performance. In the previous implementation, there were extreme differences in the amplitude with respect to frequency, with low frequencies dominating. The noise diode circuit now includes some gain equalization and the 10-MHz input to the phase cal unit was filtered, improving the pulse sharpness. There is still a variation in strength with frequency, but at a manageable level. Over the course of 2022, tag-along experiments were performed and Hobart12 joined the IVS VO observing program at the end of 2022.

Katherine's upgraded DBBC3 was delivered in September 2022, enabling participation in full VGOS observations. The first tag-along experiment was scheduled for the end of 2022 and we are currently waiting on results, although local baseline fringe tests appear very promising.

The observing system at both Hobart12 and Katherine consists of a dual-linear polarization wideband receiver (2.2–14 GHz), connected to an 8-input DBBC3 and recording to a 36-disk Flexbuff system. Frequencies below 3 GHz are sent over coaxial cable using pre-existing S-band local oscillator for downconversion, while the 3–14 GHz RF is transmitted using RF-over-fiber links to the control room. The output is bandpass filtered to provide three 4 GHz input bands to the DBBC3 sampler (3–7 GHz, 6–10 GHz, and 9.5–13.5 GHz). The 3–7 GHz band goes through an additional splitter, with the additional input enabling the IVS VGOS mode. There are two Flexbuffs in use at Hobart and one at Katherine, each with approximately 288 TB storage capacity. A new, higher capacity Flexbuff is planned for each site in preparation for the increasing needs of VGOS experiments. In Hobart, data is e-transferred from the site, using a 10-Gbps link to the University and then over a shared multi-Gbps link to the Australian Research Network (AARNet) on the mainland and wider Internet. While variable, typical performances are on the order of hundreds to thousands Mbps, both inwards and outwards.

2.2.1 Mixed-mode Configuration

As mentioned above, the S-band from the receivers is made available in the control room through the previous S/X system's downconverter. These IF signals (at 300–400 MHz) are connected to the DBBC3 inputs through a remotely controllable RF switch. This allows us to swap between either the 3–7 GHz band or the downconverted S-band as the input to the first two modules of the DBBC3. This system was first implemented at Katherine following the failure of the DBBC2 but was adopted for Hobart12 soon afterwards. This system is considerably easier to monitor and control than the previous implementation, where the S-band was recorded using a separate DBBC2. The DBBC3 in use now supports the DDC_U firmware and the flexible bandwidth selection this supports. As such, we are now able to observe in the typical R1/R4 modes with only the lack of the LSB channels, and a doubling of the recorded data volume due to the dual-polarization.

2.3 Hobart26

The Hobart 26-m telescope was largely out of service during 2021–2022, following a failure of the X-axis bearing in July 2021. Carrying out the repairs proved to be a considerable challenge but were successfully completed in November 2022. Unfortunately, several other components of the receiver and backend systems suffered during the prolonged outage and we have seen some issues with sensitivity and stability affecting data from late 2022. We hope to be able to restore the Hobart26 to its previous performance early in 2023 and for it to continue its contributions to the IVS observing program. The recording system consists of the original RCP-only S/X receiver, sampled through a DBBC2 and recorded by a Mark5B+ recorder. Data

Table 1 Staff and their responsibilities.

Name	Role	Topics
Jamie McCallum	AuScope array manager	Operations & Development
Warren Hankey	Technical support	Technical support and data transfers
Brett Reid	Observatory manager	Maintenance, repairs, and implementation of new systems
Eric Baynes	Technical support	Electronics specialist, part-time
Peter McCulloch	Technical support	VGOS RF-design, part-time
Lucia McCallum	AuScope scientist	research, AOV secretary, part-time
Guifré Molera Calvés	Post-doc	systems development, until 01/2022
Tiege McCarthy	Post-doc	project work, correlation
Boye Zhou	Post-doc	research, since 07/2022
Lim Chin Chuan	PhD student	research, dynamic observing
Ahmad Jaradat	PhD student	research, VGOS
David Schunck	PhD student	research, satellite VLBI
AuScope observers		about 12 regular observers

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3 Staff

Routine operations, maintenance, and development are undertaken by a few staff members, while experiment monitoring is usually carried out by PhD students. All staff are affiliated with the University of Tasmania in Hobart, where we have also established a small research group. Table 1 summarizes the current staff and their responsibilities.

4 Current Status and Activities

During 2021 the AuScope array participated in 168 IVS-scheduled 24-hour sessions, with the number increasing to 190 in 2022. Yarragadee was supporting the bulk of these experiments with regular particpation in all R1 and R4 sessions except during the Christmas–New-Year shutdown period.

4.1 VGOS Upgrade

The Hobart wide-band receiver was permanently installed in 2017, with Katherine following in late 2019. A fully VGOS-compatible system was finally established in early 2020 after the first 4-input DBBC3 system arrived at Hobart and put into service. After the phase calibration system was redesigned in early 2022, commissioning observations were carried out for Hobart12 and commenced for Katherine in late 2022. Yarragadee's upgrade is still pending, but is planned for the second quarter of 2023, following the arrival of the final upgraded DBBC3.

4.2 VGOS Observations

We are also carrying out our own Hobart12–Katherine fringe tests and experiments to both test the systems and investigate the potential of alternative frequency sequences. As the phase calibration system was unfit for use at Katherine until late in 2022, these observations have used a manual phase calibration approach where the single-band delay per sampler is calibrated prior to the wideband fit. Additionally, a priori dTEC information is needed which we have taken from global TEC maps. The results appear stable and accurate, looking at baseline length repeatabilites. Over the course of 2022, these sessions were enhanced with the participation of the Ishioka telescope and now use the phase calibration system.

4.3 Mixed-mode Observing

Mixed-mode sessions were a high priority during the past two years. The major aim was to bring Hb and Ke back into the IVS (legacy S/X) network, with regular routine operation. In Australia, we understand mixed-mode as such, that Hb and Ke essentially mimic the S/X mode, with the only difference that they are recording dual-linear polarization signals instead of the right-hand circular polarization used in legacy S/X IVS observing. Further details are given in [3], following an extensive mixed-mode series as part of the AUSTRAL observing program.

4.4 AUSTRAL Sessions

AUSTRAL sessions [4] are an important part of the AuScope project. On the one hand, organizing these sessions ensures to maintain knowledge and capabilities of all stages of VLBI (*from scheduling through analysis*), and on the other hand we believe that by increasing our observing cadence we have a better chance to make improvements in automation, data volume, storage and processing etc., that are needed for VGOS. While the Australian mixed-mode sessions (AUM) represented the majority of the AUSTRAL sessions over the past two years, AUA sessions are also ongoing at a monthly cadence. The AUSTRAL program is kindly supported by the stations in HartRAO and Warkworth, as well as DACH for some of the scheduling. All AUSTRAL sessions are part of the IVS program with the data made available through standard channels.

4.5 Southern Intensives

Since 2021, the Southern Intensive sessions [1] have been operationally observed on the Hart15M–Hobart12 baseline. These *Intensive*-style sessions are of one-hour duration, and processed and submitted with low latency. A good data connection between Hobart and HartRAO as well as achievements in automation typically allow for the data to be fully transferred from HartRAO in an hour or so. Correlation and post-processing was typically performed during office hours the next day, for a turnaround time of less than 24 hours.

4.6 Dynamic Observing

The *Dynamic Observing* project covers work on automating the AuScope operation and observing procedures to increase the session throughput and improve the observing efficiency. The automation is realized through the fully developed tool *Dynob*. The performance of the AuScope telescopes in most AUM sessions was monitored, together with the flux density for all observed sources. New AUM sessions are expected to be scheduled with the monitored antenna sensitivity and source flux densities for improved a priori signal-to-noise ratio prediction. Continuous observation is still needed to yield more data and identify room for improvement. The *Dynob* tool has now been tested with our weekly southern Intensive sessions to improve the turn-around time. The processing of these sessions until Level-1 vgosDB is now achievable with one click after all data have arrived from Hartebeesthoek. The processing latency is about one hour. *Dynob* fully supports legacy S/X, mixed-mode, and VGOS observations at flexible frequency ranges.

4.7 Correlation

As of early 2022, UTAS has secured additional funding, through Geoscience Australia (GA) as part of the Positioning Australia project, to establish an Australian VLBI Correlation Center. This Correlation Center will initially aim to service the VLBI correlation needs of Australia and the Asia-Pacific region; however, the ultimate goal is to become recognized by the IVS as an official international Correlation Center. The backbone of this center is Gadi, a high performance computing (HPC) system hosted by the National Computational Infrastructure (NCI) in Canberra, Australia.

Initial testing show that this HPC can readily handle geodetic VLBI correlation workloads, with exceptional compute and data I/O performance. The primary challenge of this project is data logistics and transport, particularly for VGOS data volumes, due to the facility not being directly run by UTAS (unlike our current cor-

relation infrastructure). The fact that it is not a UTAS run facility has created two issues: the first is that shipping data directly to the HPC is not feasible (due to lack of staff and/or data ingest infrastructure), and the second is that nominally transferring data to Gadi is restricted to approved NCI accounts that are members of the project. To accommodate for e-transfer to the center, we have created a dedicated e-transfer virtual machine using the NCI Nirin cloud infrastructure. The virtual machine allows us to configure our own security rules, allowing for incoming UDP and TCP from IP addresses that we approve, and lets us mount the same storage allocation that is accessible to Gadi. This allows data to be e-transferred to the center by external partners that can be directly managed by UTAS geodesy staff. As not all stations are currently capable of e-transfer to Correlation Centers, including our remote stations in Katherine and Yarragadee, we are working on a data relay station based out of Geoscience Australia's headquarters in Canberra. This relay station will allow data disk packs to be shipped in, where they will be subsequently e-transferred over onto our Gadi storage allocation. Ideally, this solution will become less necessary moving into the future as e-transfer capability is expanded; however, currently it is necessary to begin production correlation at this center in the near future. Once this relay station is implemented, larger scale testing and validation of the whole correlation pipeline can be undertaken.

4.8 VLBI Satellite Tracking

Funded by the Australian Research Council (ARC), at UTAS we investigate VLBI observations to satellites, aiming for improved space ties. Current work covers the technical realization of such observations (*pipeline from scheduling to analysis*) as well as simulation studies.

5 Future Plans

The next priority for the AuScope project is the VGOS upgrade of Yg, planned for the first part of 2023. In terms of observations, our in-house AUV VGOS program will be extended and we have also started AUJ sessions with participation of the Ishioka telescope.

5.1 High-speed Data Connections

The transition to the VGOS backend has emphasized the current limitations of our data transport via shipping, and highlighted the need for better e-transfer capabilities. Funding has been sought to install 10-Gbps fiber optic connections to both the Katherine and Yarragadee sites and prospects are good that this will go ahead in 2023, with both links operational by the end of 2024. Having access to high speed data transfer should greatly reduce the latencies involved in data transport and improve their reliability.

Acknowledgements

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