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 2019 and 2020. Our current and completed research programs are outlined as well as 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). In addition, this contribution covers the Hobart 26-m telescope (Ho). While owned and operated by the University of Tasmania, AuScope VLBI observations are contracted through Geoscience Australia. Thanks to the Australian Government *Positioning Australia* initiative, operations and staff are now on medium-term funding cycles allowing improved planning into the future.

2 Component Description

The AuScope VLBI array was initially designed as three identical telescopes with the technical specifications for legacy operations detailed in [1]. Since then, several improvements as well as the gradual VGOS upgrade has resulted in slightly unequal technical situations at the three sites, which are summarized below:

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

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2.1 Hobart 12-m Antenna

A Callisto wide-band feed has been installed since August 2017, operating across the 2.2–14 GHz frequency range. Frequencies below 3 GHz are sent over coaxial cable using a 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 existing DBBC2 is used to sample the S-band signal in mixed-mode configuration. A phasecal unit is installed, operating with a 10-MHz spacing together with a noise diode for Tsys calibration. Recording is carried out by a 36-disk Flexbuff system, populated with 8-TB drives for a total data volume of 288 TB. The observatory is connected via 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 Katherine 12-m Antenna

A Callisto wide-band feed was installed in August 2019 using the same RF configuration as at Hobart. Until the end of 2020, the existing DBBC2 was used to sample the S-band signals in mixed-mode configuration until it suffered an equipment failure. A new arrangement has been developed where the DBBC3 is used for the S-band data through recabling. A phasecal unit is installed, operating with a 10-MHz spacing together with a noise diode for Tsys calibration. The recording is carried out using a 36-disk Flexbuff system typically populated with 8-TB drives for a total data volume of 288 TB. The Internet connection is sufficient for basic remote operations and suitable for high-latency transfers of small test data. Peak traffic rates are approximately 10 Mbps.

2.3 Yarragadee 12-m Antenna

Largely unchanged. A new cable wrap system and an air conditioning unit in the hub were installed in early 2019. In late 2019, a Fila10G was installed in the DBBC2 together with a 36-Disk Flexbuff unit as an alternative recording system. 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.

2.4 Hobart 26-m Antenna

The Mark IV rack has been officially decommissioned and all recordings are now using the DBBC2 and Mark 5B+ system, previously in use for the Hobart 12-m. The phasecal unit previously used on the Hb 12-m is planned to be restored to the 26-m telescope. There have been a number of ongoing issues with front-end electronics and cryogenic systems which have affected the reliability and sensitivity of this telescope throughout the period. In 2019–2020, the Hobart 26-m increased its participation in the IVS observing program, partly to compensate for the removal of the Hobart 12-m from S/X operations. However, the telescope is currently also experiencing increased demand from other projects.

3 Staff

Routine operations, maintenance, and development are undertaken by a few staff at the University of Tasmania, while experiment monitoring is usually carried out by PhD students. Table 1 summarizes the current staff and their responsibilities.

4 Current Status and Activities

The AuScope array of telescopes has been participating in the regular IVS experiments, aiming to observe whenever it is possible and useful to do so. In 2019 and 2020 the AuScope and Hobart 26-m antennas participated in 158 and 151 IVS sessions, respectively. The slight decrease from $\sim$170 in 2017–2018 is largely due to the removal of Katherine from the S/X network.

The main activities in 2019 and 2020 were efforts into maintaining current operations, planning, managing, and implementing the VGOS upgrades. While at the start of this reporting period we were very low on staffing, we have worked on recruiting and training towards a critical number of staff for sustainable operations and critical research. For the first time, we have a geodetic VLBI research group at the University of Tasmania, with regular meetings and 5+ members.

A brief discussion of significant projects undertaken over the last two years is given below.

- **VGOS upgrade:** Early in 2018 the final adjustments were made to the Hobart 12-m optical arrangements which considerably improved the performance of the system. With the design finalized and the arrival of the DBBC3s, it was possible to undertake the upgrade of the Katherine telescope in mid-2019. The upgrade to the Yarragadee station is contingent on the ability of the array to contribute to global VLBI and thus on the performance of the Hobart12 and Katherine stations. Unfortunately, we have not been able to carry out fully compatible observations with the existing VGOS network. With our current design having three bandpasses (and corresponding DBBC3 samplers) we are currently limited to observing three out of four bands at a time (using eight BBCs).
  While it would be possible to observe a wider subset of the lower bands through mixed USB/LSB channels, this would require some additional configuration of the correlator, together with non-trivial modifications to the post-processing system. Some test observations with Ishioka (correlated in Hobart) resulted in fringes but have

Table 1 Staff

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
Amirsadra Falahati	Technical Assistant	Maintenance and repairs, part-time
Eric Baynes	Technical support	Electronics specialist, part-time
Peter McCulloch	Technical support	VGOS RF-design, part-time
Jim Lovell		Project work, casual
David Horsley		Project work, casual
Lucia McCallum	Post-doc	research, part-time / extended leave periods
Guifré Molera Calvés	Post-doc	systems development, AOV secretary
Tiege McCarthy	Post-doc	project work, feed-back system
Simin Salarpour	PhD student	research, source structure
Lim Chin Chuan	PhD student	research, dynamic observing
Ahmad Jaradat	PhD student	research, AuScope VGOS
AuScope observers		about 10 regular observers

not been fully post-processed. An upgrade of the DBBC3 to support the latest firmware, which can generate up to 16 BBC per IF and should make it possible to carry out fully compatible ovservations, is being carried out in stages, with the first unit currently being in Bonn. We hope that all three DBBC systems will be available by the end of 2021 and that we will be able to join the global VGOS observations with Hobart12 and Katherine somewhat earlier.

- **AUM sessions:** With the upgrade of the Hobart12 telescope to the wideband backend in 2017, it became unavailable as an S/X station. With the difficulties in the beginning VGOS operations, we investigated the potential for "mixed-mode" (VGOS–Legacy) observations. After some initial tests, a short series of experiments was carried out in mid-2018 using the Hobart 12-m as a VGOS station, together with Katherine and Yarragadee as S/X stations. After correlation and fringe-fitting, the results appeared promising and Hobart12 joined the ongoing AUSTRAL experiment series. With the upgrade of the Katherine telescope in mid-2019, the network now had a VGOS–VGOS baseline and a new AUM experiment series was begun to investigate the technique's application on this baseline. Observations made in 2020 with the participation of Warkworth are currently under analysis.
- **AUV sessions:** With Katherine's upgrade to a wideband receiver and recording system in mid-2019, it became possible to carry out single baseline observations using a wideband observing mode. With the limitations of the current system, observations made using a subset of the "standard" VGOS bands were unlikely to yield useful data due to ambiguity issues with dTEC and delay resolution. Instead, a new frequency sequence was designed around the capabilities of the DBBC3-equipped stations which utilized the wide input bandwidths available. Test observations were made in 2020 with promising results, but a full 24-hour session is yet to be successfully observed. The fringe-fitting is carried out using fourfit, following the normal VGOS procedures. This does require some modifications of the processing scripts.
- **AUA sessions:** The AUSTRAL-Astrometry experiment series in 2019 was based around the SOuthern Astrometry Project (SOAP), but has reverted to standard geodetic observations in 2020. The scheduling for the geodetic sessions has been carried out by Matthias Schartner (TUW/ETHZ), with correlation carried out by TUW during this period.
- **Southern Intensives:** Organized by TUW, a series of "Intensive"-style experiments were carried out during 2020, using the Hart15–Yarragadee baseline. Additionally, the Hobart12 joined in a number of these sessions as a way to both investigate the performance of the station in mixed-mode and hopefully as a comparison with the Hart15–Yarragadee baseline. Over 30 sessions were observed and correlated in Vienna. An analysis of the results is pending.

- **Data transfers:** As part of the upgrade to the wideband observing system, the Mark 5B systems were decommissioned for Hobart12 and Katherine. Without a high-speed network link available at Katherine, it was necessary to develop a method for transferring the large data volumes generated in mixed-mode or VGOS-style observations. The solution has been to use the removable drive caddies from the flexbuff chassis, shipping these as needed. For local correlation, the correlator nodes have matching interfaces and can directly mount the drives. Alternatively, the nodes can act as temporary storage for data transfers to overseas correlators.
- **Station upgrades:** We have conducted several upgrades on the instrumentation and computation infrastructure in order to keep up-to-date and modernize the Auscope VLBI array. New NASA Field System (FS) computers were built and installed with the latest version of the FSL 10.0.0. The new FS machines were installed and tested successfully at the three geodetic locations of Yarragadee, Katherine, and Hobart. We can now operate the antenna, the recorder, and both DBBC3 and DBBC2 from the FS without any external scripts.

  During these two years we also have worked on adapting the DBBC3 to the needs of the AuScope sessions. At the moment, Katherine and Hobart operate with the DBBC3 for broadband sessions and a combination of DBBC2 and DBBC3 for the mixed-mode sessions. Yg still uses the DBBC2 with its S/X receiver.

  In 2020 we also redesigned the monitoring and analytics platform to supervise the correct functioning of the array with Grafana. We set up the system as suggested in the NASA VLBI Station Monitoring and Archival System (MAS) Guide. All data are collected from the nodes using Telegraf and transferred to the Web server. Data are collected and archived using the influxdB database. Finally, the metrics stored in the database is displayed using Grafana and it can be accessed via our Web site by operators and observers. The development is a work in progress (as seen in Figure 1).
- **Feedback loop:** An automated system for processing correlation and analysis reports to monitor the performance on the UTAS operated telescopes was developed in 2020 and is currently in operation. The aim is to ensure better performance from the array.
- **Dynamic observing:** This research focuses on improving the efficiency of the three 12-meter AuScope VLBI telescopes by streamlining the operational processes through more dynamism and automation. This work also includes the improvement of the agreement between the actual and scheduled signal-to-noise ratio through improved source selection and better determined antenna sensitivities. A discrepancy between the source flux on the global network with the Australian network is also under investigation.
- **Source structure:** As part of a PhD project, source structure and its effects on VLBI observations is an active research topic at UTAS: We have studied different structure index (SI) characteristics in a statistical sense on a large sample. We have investigated SI time series of 8,000 images (186 sources) over a 25-year period and the impact of different X-band observing modes on these values. We have also compared the median structure delay calculated in different VGOS observing networks with nominal SI. In another investigation, we have constructed source models for a group of quasars (176 sources) by fitting two/multiple Gaussian components to their available X-band images at various epochs using an automated script. We have applied these models to generate simulated broad bandwidth observations with the Vienna VLBI Software (VieVS). Using this approach and simulated VGOS networks, we aim to quantify the number of observations that may be affected by variable source structure.
- **Satellite observations:** Funded by the Australian Research Council (ARC), we continue investigations of VLBI observations to satellites, aiming for improved space ties. In a benchmarking study [2], we designed an observing setup to use VLBI radio telescopes as bright reflectors for InSAR satellite imagery. With regular observations ongoing, the aim is to use these observations for improved georeferencing of the InSAR images. Alternatively, precise information about relative height-changes of the radio telescope may be useful for VLBI local ties.
- **AuScope VLBI performance:** In late 2020, a new PhD project was commenced with the aims to quantify the recent performance of the AuScope VLBI

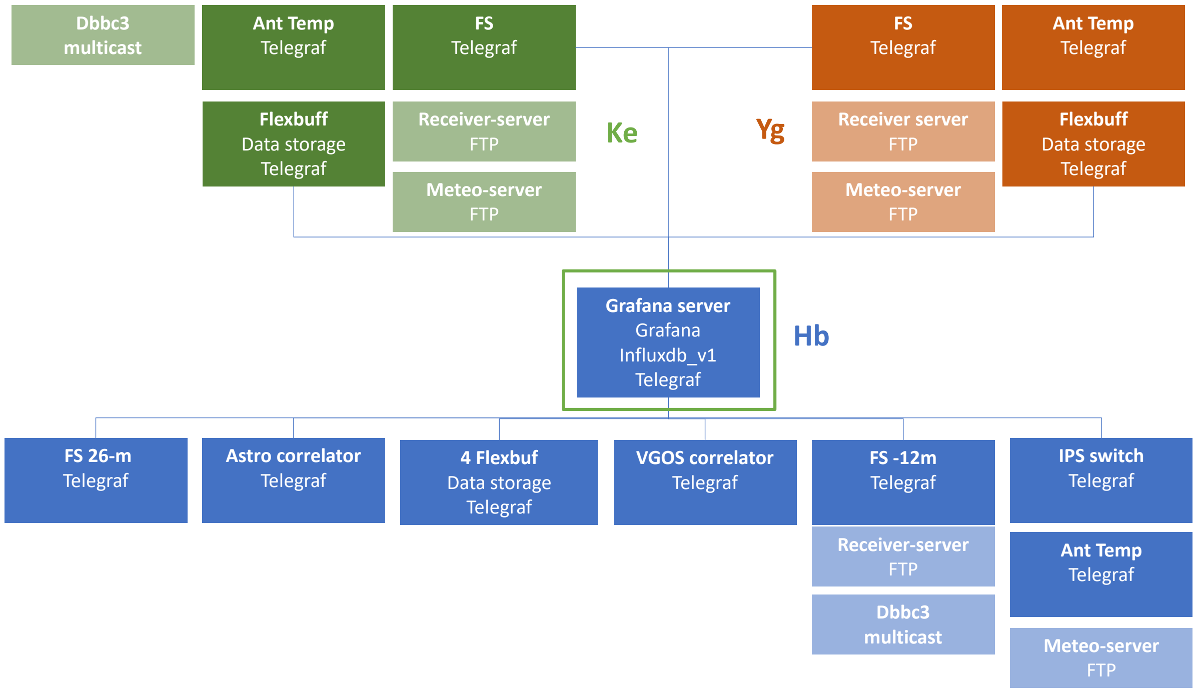

Fig. 1 Newly implemented Grafana setup.

array and to design observations in order to create useful AuScope VLBI VGOS results.

5 Future Plans

We are currently looking forward to being able to make use of the upgraded DBBC3s and to begin the process of joining the global VGOS experiment. With the continued importance of the S/X program, we aim to continue our mixed-mode campaign and the associated observing programs.

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