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The AuScope VLBI Array

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Abstract

The AuScope VLBI array, consisting of three new 12-m radio telescopes in Australia dedicated to geodesy, has now commenced operations. The telescopes at Hobart (Tasmania), Katherine (Northern Territory), and Yarragadee (Western Australia) are co-located with other space geodetic techniques including GNSS, gravity, and SLR. This new facility is making significant contributions to improving the densification of the International Celestial Reference Frame in the southern hemisphere, to improving the International Terrestrial Reference Frame in the region, and in measurement of intraplate deformation of the Australian tectonic plate. We present an overview of the current status of the VLBI facility and its current performance. We also highlight some of the geodetic research projects currently underway that are taking advantage of this new facility.

1. Introduction

In 2006 the National Cooperative Research Infrastructure Strategy (NCRIS) initiated program 5.13,"Structure and Evolution of the Australian Continent", which is funded by the Department of Innovation, Industry, Science, and Research (DIISR) and managed by AuScope Ltd. (`http://www.auscope.org.au`). A major component of this project was the establishment of a national geospatial framework to provide an integrated spatial positioning system spanning the whole continent. Total federal funding for this undertaking is AUD$15.8M, together with AUD$21M from universities, state governments, and Geoscience Australia. The infrastructure that was funded to achieve this improvement to the geospatial framework included: three 12-meter radio telescopes and a computer cluster for a software correlator; about 100 GNSS receivers; upgrade of existing SLR facilities; an absolute gravimeter and three tidal gravimeters; and improved computing facilities.

As part of this effort, the University of Tasmania (UTAS) has constructed three new radio telescopes, located near Hobart (Tasmania), Yarragadee (Western Australia), and Katherine (Northern Territory). UTAS is responsible for construction and operation of the three new VLBI sites (Figure 1). A software correlator facility has been developed at Curtin University.

The new telescopes double the number of IVS stations in the Southern Hemisphere. They allow the extension of astrometric VLBI solutions to radio sources south of declination −40 deg, an area of the sky that has been severely under-sampled by the existing array because so few telescopes were available in the south. The AuScope telescopes closely follow the International VLBI Service VLBI2010 specification for the next generation of telescopes for geodesy [4] or provide an upgrade path to meet the specification where it is not currently possible to do so.

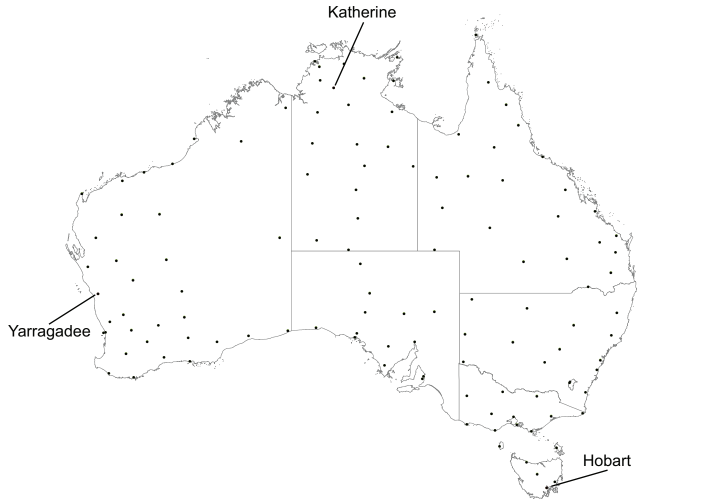

Figure 1. The geographical distribution of VLBI and GNSS infrastructure for AuScope. The locations of the new 12-m telescopes are labelled, and the new GNSS sites are indicated by filled dots.

2. Infrastructure

Each AuScope VLBI observatory is equipped with a 12.1-m diameter main reflector designed and constructed by COBHAM Satcom, Patriot Products division. The telescope specifications include: 0.3 mm of surface precision (RMS), fast slewing rates (5 deg/s in azimuth and 1.25 deg/s in elevation), and acceleration (1.3 deg/s/s). All three sites are equipped with dual polarization S and X-band feeds from COBHAM with room temperature receivers, developed at UTAS by Prof. Peter McCulloch. The receiver systems cover 2.2 to 2.4 GHz at S-band and 8.1 to 9.1 GHz at X-band. System Equivalent Flux Densities (SEFDs) are 3500 Jy in both bands. Data digitization and formatting is managed by the Digital Base Band Converter (DBBC) system from HAT-Lab, and data are recorded using the Conduant Mark 5B+ system. Each site is equipped with VCH-1005A Hydrogen maser time and frequency standards from Vremya-CH.

Observatory sites were selected to satisfy two main criteria: good geographical coverage over the Australian continent and co-location with existing geodetic techniques. The new Hobart telescope is co-located with the existing 26-m telescope to preserve the more than 20 year VLBI time series at the site. Midway between the 26-m and 12-m telescopes is the HOB2 GNSS installation which has been a core site of the International GNSS Service (IGS) since its conception. A hut capable of housing a mobile gravimeter is also co-located on the site. The Yarragadee telescope provides a far western point on the continent and is co-located with multiple existing geodetic techniques including SLR, GNSS, DORIS, and gravity. The Katherine site is new and provides a central longitude, northern site. The telescope at Katherine is co-located with a new GNSS site that forms part of the AuScope GNSS network.

AuScope also includes funding for a software correlator, the Curtin University Parallel Processor for Astronomy (CUPPA) which is a 20 node beowulf compute cluster. Each node consists of a server class PC with dual quad-core processors, 8 GB of RAM, and 1 TB of internal hard disk storage. Additionally, the cluster incorporates external mass storage and a total disk pool of

100 TB is available to the cluster. CUPPA is networked internally with standard 1 GbE (two ports per node) and with a 10 GbE connection to iVEC, the eastern Australian state supercomputing center. In order to process AuScope data, three Mark 5B+ VLBI data recorder/playback units were acquired for CUPPA. For VLBI correlation, CUPPA runs the DiFX software correlator [1].

3. Project Status

Construction of the first AuScope telescope at Hobart was completed in 2009 and officially opened at the Sixth IVS General Meeting on 9 February 2010. Following a period of commissioning, testing, and debugging, the Hobart telescope made its first successful IVS observation in October 2010. Construction and commissioning at the other two sites continued in parallel. Yarragadee made its first successful IVS observation in May 2011. Following a successful full-network fringe check on 8 June 2011, correlated at CUPPA, all three telescopes participated in an IVS observation for the first time on 16 June 2011.

All three observatories were designed and constructed to be remotely controlled and monitored to keep operating costs at a minimum. Operation of the AuScope VLBI array is being carried out from a dedicated operations room on the Sandy Bay campus of the University of Tasmania.

Presently, the AuScope VLBI facility has sufficient operational funds for ∼70 observing days per year, usually consisting of two AuScope telescopes observing as part of the IVS network. Unfortunately operational funds are not presently sufficient to support correlation at CUPPA.

3.1. Antenna Positions

Global VLBI measurements made as part of the IVS observations were used to construct antenna position time series. OCCAM 6.3 software [5] was used for analysis. Each 24-hour IVS session was analyzed individually. In all, 51 sessions between February and October 2011 were used to determine the position of the Hobart 12-m antenna; 7 sessions were used for Yarragadee, and 9 sessions were used for Katherine. Station positions derived from these observations are presented in Table 1. In each case, the inner uncertainties represent the average rms of individual measurements while the outer uncertainties denote scatter in best-estimates (i.e., weighted rms about the trend line for the whole time series). In other words, the first number corresponds to formal uncertainty given by an OCCAM solution for a typical 24-hour session. The second number indicates how repeatable the station position estimate is from one session to the next.

While there is only limited data for the Yarragadee and Katherine antennas, a time series can be constructed for the Hobart AuScope antenna. In Figure 2 we show the evolution of the Hobart 26-m (Ho) and Hobart 12-m (Hb) baselines to station Kokee Park, Hawaii (Kk). Inclusion of AuScope antennas is expected to improve both the formal errors and repeatability (wrms) of the Hobart-26-m–Kokee baseline. Taking a similar number of observations (33), we obtain (σ,wrms) = (0.014,0.017) m for the period 2009–2010 when no AuScope antennas were involved; and (0.014,0.029) m in 2011, when AuScope antennas are included. The larger baseline errors when AuScope antennas are included are consistent with results for individual antenna positions. This, in turn, is due to "teething problems" at the stations, such as frequent clock discontinuities. It is encouraging though to see a decrease in scatter between Hb-Kk baseline solutions with time as the observing system improved. A more subtle effect is network geometry. AuScope antennas observe in more Southern Hemisphere-dominated networks than Hobart 26-m. Scarcity of short baselines (affecting the quality of atmospheric solutions) and smaller number of quasars that do not exhibit structure therefore degrade the solutions involving AuScope antennas.

Table 1. Calculated positions for the three AuScope VLBI antennas at epoch 2011.50, ITRF2005 datum. Inner uncertainties represent the average rms of individual measurements, while the outer uncertainties denote the scatter in best-estimates.

Hobart		
Latitude	−42 48 20.06380	(±0.0004, 0.0004)
Longitude	147 26 17.3055	(±0.0005, 0.0008)
Height	40.971	(±0.011, 0.012)
Katherine		
Latitude	−14 22 31.66897	(±0.00024, 0.00033)
Longitude	132 09 08.5430	(±0.00044, 0.0005)
Height	189.257	(±0.013, 0.013)
Yarragadee		
Latitude	−29 02 49.72375	(±0.00044, 0.0004)
Longitude	115 20 44.2564	(±0.0009, 0.00054)
Height	248.239	(±0.014, 0.012)

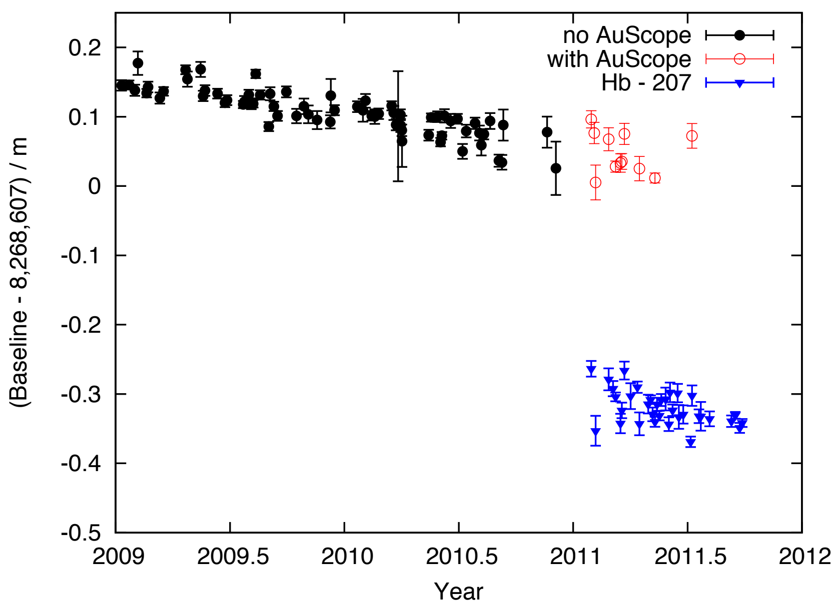

Figure 2. Time series for the baselines Hobart-26-m–Kokee (Ho–Kk) and Hobart-12-m–Kokee (Hb–Kk). Black filled circles represent data for the Ho–Kk baseline before construction of the AuScope antennas. Red open circles show the Ho–Kk baseline with at least one AuScope station included. Blue filled triangles show the Hb–Kk baseline, offset by 207 meters. With the construction and operation of the AuScope array, Hobart 26-m has only been observing once per month on average in 2011.

As expected for two antennas located on the same bedrock, the measured baseline length between Hobart 12-m and 26-m is stable at 295.92 m, with (σ,wrms) = (0.007,0.020) m. These residuals are due to effects such as thermal and gravitational deformation of the antennas, clock stability, and structure of quasars making up the ICRF. This is in perfect agreement with the results of the Mt. Pleasant local tie survey [3] of 295.918 ± 0.001 m.

4. Geodetic Research Program

Space geodetic tools including Global Navigation Satellite Systems (GNSS), Satellite Laser Ranging (SLR), and Very Long Baseline Interferometry (VLBI) are key to the realization of modern celestial and terrestrial reference frames that underpin the study of both astronomical and Earth based phenomena. "Environmental space geodesy", or the use of space geodetic tools applied to global climate change and sea level studies, crustal strain and seismic deformation, and surface expression of hydrologic loading, is an active theme area of research at UTAS between the School of Maths and Physics and the School of Geography and Environmental Studies. With the completion of the AuScope telescope array, a high priority for research and development within this theme area is geodetic VLBI and its contribution to improving the reference frame. A specific focus of this theme area includes the investigation of systematic errors that currently limit individual space geodetic techniques and therefore their combination in the process of realizing the terrestrial reference frame. A specific outcome of the new AuScope telescope array will therefore be the further characterization and mitigation of systematic error sources within geodetic VLBI and GNSS data analyses.

Areas of activity include automated monitoring of the 26-m and 12-m telescopes to better understand thermally induced deformation, source structure and motion studies, and from a GNSS perspective, investigations into the mitigation of spurious energy at harmonics of the GPS draconitic year in coordinate time series. These are some of a number of sources of systematic errors that bias the ITRF and hence limit geophysical interpretation from space geodetic data.

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