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# THE LONG BASELINE ARRAY

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## ABSTRACT

The Long Baseline Array is an array of radio telescopes using the technique of Very Long Baseline Interferometry to achieve milli-arcsecond–scale angular resolution. The core telescopes are located in Australia, with telescopes in New Zealand and South Africa also participating regularly. In this paper the capabilities of the Long Baseline Array are described, and examples of the science undertaken with the array are given.

*Key words:* techniques: interferometric

## 1. INTRODUCTION

Astronomical observations using the Very Long Baseline Interferometry technique in the southern hemisphere are conducted with the Long Baseline Array (LBA). The core elements of the LBA are the Australia Telescope National Facility's Parkes 64 m telescope, Mopra 22 m telescope, and the Australia Telescope Compact Array, and the University of Tasmania's Hobart 26 m and Ceduna 30 m telescopes. Other telescopes also participate, including the Tidbinbilla 70 m or 34 m telescopes, the Hartebeesthoek (South Africa) 26 m telescope, and the Warkworth (New Zealand) 12 m telescope,

The LBA can operate in the standard radioastronomy bands at 1.4, 1.6, 2.3, 4.8, 6.7, 8.4 and 22 GHz, although not all telescopes can support all bands. Observations with a three-element subset of the array at 32 GHz are also being made. However, operational constraints on the number of receiver changes at Parkes (a prime focus instrument) have resulted in very few observations at 2.3 or 4.8 GHz in recent years.

The LBA operates for a total of ∼25 days per year, concentrated in 3 or 4 observing sessions, with additional out-of-session support for RadioAstron observations and occasional time-critical observations. In this paper we describe the capabilities of the LBA and give examples of recent scientific results from the array.

## 2. A BRIEF HISTORY

Telescopes in Australia participated in early VLBI observations in the late 1960s and early 1970s (e.g., Kellermann et al., 1971; Gubbay et al., 1972), but routine VLBI observing did not commence until the development in the 1980s of SHEVE, the Southern Hemisphere VLBI Experiment (see, e.g., Jauncey, 1991).

By the mid-1990s, this had grown into the Long Baseline Array, based on the Canadian S2 tape-based recording system, and with hydrogen maser frequency standards at most sites. Tape-based recorded ended in the mid-2000s when disk-based recording was introduced.

## 3. THE TELESCOPES

The location and approximate System Equivalent Flux Density of elements of the LBA are given in Table 1. An on-line sensitivity calculator, developed by Adam Deller, is available at http://www.atnf.csiro.au/vlbi/calculator/ .

The addition of a 20 cm capability to Ceduna via a tertiary reflector is a noteworthy recent improvement to the LBA's capability. A single 12 m ASKAP dish (with a single-pixel feed) also participates on occasions in 20 cm or 3 cm band observations.

LBA blocks are scheduled when the ATCA is in one of its more compact array configurations, in an effort to minimise the effetcs of phase fluctations on the "tied array" output. It is for this reason that CA06, typically located ∼4.5 km from the rest of the array, is not used as part of the tied array. When phase stability is poor (typically at the higher frequencies), the ATCA must either "phase-up" on a bright calibrator more regularly, or drop one or more antennas from the tied array.

One of the Tidbinbilla 34 m antennas has a 32 GHz receiver, and so observations between Tindbinbilla, Mopra and ATCA can be made at this band. Mopra and the ATCA have a 7 mm band which covers the 30–50 GHz range, and recently fringes were obtained from test observations in this band between the ATCA and elements of the Korean VLBI Network. Mopra and the ATCA also have 3 mm receivers, with fringes obtained in tests, but no scientific observations yet conducted.

The University of Tasmania operates the Hobart and

Table 1
LOCATION AND SYSTEM EQUIVALENT FLUX DENSITIES OF LBA ELEMENTS

| Telescope | Lat. | Long. | 20 cm | 13 cm | 6 cm | 3 cm | 1.5 cm | 7 mm |
|---|---|---|---|---|---|---|---|---|
| ATCA (5 x 22 m) | 150 E | 30 S | 40 Jy | 40 Jy | 36 Jy | 39 Jy | 106 Jy | 180 Jy |
| ASKAP (1 x 12 m) | 117 E | 26 S | 6000 Jy | — | — | 3500 Jy | — | — |
| Ceduna (30 m) | 134 E | 32 S | 1500 Jy | 400 Jy | 450 Jy | 600 Jy | 2500 Jy | — |
| Hobart (26 m) | 147 E | 43 S | 450 Jy | 650 Jy | 650 Jy | 560 Jy | 1800 Jy | — |
| Hartebeesthoek (26 m) | 28 E | 26 S | 200 Jy | 210 Jy | 290 Jy | 340 Jy | 1320 Jy | — |
| Mopra (22 m) | 149 E | 31 S | 340 Jy | 530 Jy | 350 Jy | 430 Jy | 675 Jy | 900 Jy |
| Parkes (64 m) | 148 E | 33 S | 40 Jy | 30 Jy | 110 Jy | 43 Jy | 810 Jy | — |
| Tidbinbilla (70 m) | 149 E | 35 S | 23 Jy | 16 Jy | — | 25 Jy | 60 Jy | — |
| Tidbinbilla (34 m) | 149 E | 35 S | — | 165 Jy | — | 90 Jy | — | 180 Jy |
| Warkworth (12 m) | 175 E | 37 S | 7000 Jy | 3500 Jy | — | — | 3500 Jy | — |

Ceduna telescopes, and has operated these as a single-baseline array for rapid-response VLBI observations (Blanchard et al., 2012). The University of Tasmania also operates the AuScope geodetic array of three 12 m telescopes (Lovell et al., 2013). On occasions, elements of the AuScope array have participated in LBA observations at 8.4 GHz.

## 4. DATA RECORDING

Disk-based recording systems are now used at all telescopes. The Australian stations use the LBA Data Recorder (Phillips et al., 2009). A bit rate of 256 Mbps (2x16 MHz bandwidth in 2 polarisations, with 2 bit digitisation and Nyquist sampling) can be sustained at all LBA telescopes and is the standard observing mode. Higher bit rates, up to 1 Gbps, can be achieved but are not supported at all telescopes. Raw voltages are recorded in a local format but tools exist to translate this into Mark5B or VDIF (Phillips et al., 2009) formats, improving the compatibility between Australian VLBI antennas and international antennas using other disk-based recording systems. The ASKAP antenna uses a recorder developed at Curtin University from off-the-shelf based equipment, including a PCI-based sampler card.

From most stations data are transferred over the internet to the correlator, however for Ceduna it is still necessary to physically ship the disks from the telescope to the correlator.

## 5. CORRELATION

The ATNF hardware correlator was used to correlate data recorded on the S2 recorders, however with the move to disk-based recording correlation was moved to the DiFX software correlator Deller et al. (2007, 2011). The software correlator is capable of correlating the high data rate observations at high spectral resolution with arbitrary correlator integration times. This was initially performed on a computer cluster at Swinburne University of Technology, and more recently on a cluster at Curtin University.

## 6. eVLBI

Real-time e-VLBI observations are also possible, using the ATNF antennas connected together via high-speed network links and the DiFX software correlator running either on a cluster based the ATCA or at Curtin University. Data-rates for e-VLBI observations of 1 Gbps from Parkes, ATCA and Mopra antenna are available. Real-time eVLBI capabilities to the Hobart, ASKAP and Warkworth antennas are also now available at 512 Mbps. Neither Ceduna nor Tidbinbilla are able to participate in e-VLBI observations. e-VLBI observations have been undertaken both on Australian arrays (e.g., Hancock et al., 2009) and also with Australian telescopes participating in international e-VLBI networks (e.g., Giroletti et al., 2011). This includes sending data from Australia to the JIVE VLBI correlator in the Netherlands as well as sending data from China, Japan, Korea and South Africa (as well as Australian telescopes) to be correlated in Australia. The results of an e-VLBI demonstration with an Australasian network of telescopes are described by Moin et al. (in preparation).

## 7. SPACE VLBI

The angular resolution at a fixed frequency is inversely proportional to baseline length, and the Earth's diameter imposes a natural limit on the maximum baseline achievable. This can be surmounted, however, by launching a radio-telescope into Earth orbit – "space VLBI". Elements of the LBA were active participants in the VLBI Space Observatory Program, VSOP (Hirabayashi et al., 1998), which ran from 1997 to 2003, and are currently participating in space VLBI observations with the RadioAstron spacecraft (Kardashev et al., 2013).

## 8. SCIENCE

The frequency coverage of the LBA has enabled observations with a variety of scientific goals, including pulsar proper motions and parallaxes (e.g., Deller et al., 2008), OH masers (e.g., Caswell et al., 2011), methanol masers (e.g., Dodson et al., 2004), water masers (e.g., Greenhill et al., 2003), geodesy and astrometry (e.g., Petrov et al., 2009), monitoring structural changes in galactic sources (e.g., Tingay et al., 1995; Fomalont et al., 2001) and active galactic nuclei (e.g., Tingay et al., 2002; Ojha et al., 2010), and a SETI experiment (Rampadarath et al., 2012).

## 9. CONCLUSION

The Long Baseline Array has evolved over the last 20 years in line with technological advances over the same period, and continues to be a productive astronomical instrument for probing the milli-arcsecond–scale structure of southern hemisphere radio sources.

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