Radio astronomy and VLBI in New Zealand

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Abstract

New Zealand's location and geophysical attributes carry unique opportunities for radio astronomy and VLBI: a compact cluster of 12-m and 30-m antennas at the Warkworth Radio Astronomical Observatory can provide a vital element of the global and regional VLBI networks, both astronomical and geodetic. The radio telescopes' characteristics and the observatory basic equipment specifications are outlined. Recent developments in radio astronomy, VLBI and eVLBI capabilities for astrophysics, astrometry and geodesy are presented. IRASR development towards SKA, as well as involvement in educational activities is summarized.

1. Introduction

New Zealand's first radio interferometry was successfully conducted in 1948 when John Bolton and Gordon Stanley used high cliffs in Leigh and Piha for sea (cliff) interferometry of bright "radio stars" [1]. This observation led to the first ever identification of radio sources with known astronomical objects – radio galaxies and supernova remnants. By virtue of its geographic position, New Zealand's participation in VLBI has been sought since the 1970s. Coverage of radio telescopes is very sparse but highly desirable in the southern hemisphere – only a few of the world's 150 radio telescopes are situated south of the equator. As the only landmass in a largely oceanic region in the Southern Pacific, New Zealand is able to make a uniquely valuable contribution to the science of radio astronomy.

A new (VLBI) period in New Zealand radio astronomy started in 2004 when the Institute (initially Centre) for Radio Astronomy and Space Research (IRASR) was formed at the Auckland University of Technology (AUT). The mission of the IRASR has been considered as follows:

- to establish the Radio Astronomical Observatory, fully equip it with world class modern equipment, and sustainably develop it towards the status of a National Facility;
- to conduct world class research in radio astronomy, astrophysics, geodesy and space science;
- to establish and sustain fruitful international collaboration in radio astronomy, including development of a Trans-Tasman (New Zealand – Australia) VLBI network and active participation in Asia-Pacific, Asia-Oceania, East Asian, European and global radio astronomical and geodetic research projects and networks;
- to prepare a solid foundation for New Zealand, together with Australia, to host the Square Kilometre Array.

The first successful VLBI experiment between Australia and New Zealand was made in 2005 with a 6-m radio telescope near Auckland (Karaka) and the Australia Telescope Compact Array (ATCA) [2, 3]. In 2008 AUT commissioned a new 12-m antenna at Warkworth – New Zealand's first research capable radio telescope [4].

2. Radio Astronomical Observatory at Warkworth, New Zealand

The IRASR operates the AUT's Warkworth Radio Astronomical Observatory located in a radio quiet zone near the township of Warkworth, 60 km north of Auckland. The observatory has two radio telescopes (12m and 30m) located 200 m apart (Figure 1). The observatory is equipped with a Symmetricom Hydrogen maser clock and connected to the world with a 1-Gbps fibre optic data link through KAREN (Kiwi Advanced Research and Education Network).

AUT's 12-m radio telescope is a modern fully steerable fast slewing antenna of Cassegrain design. It was built by Patriot Antennas (USA) and commissioned in 2008. The radio telescope operates in L, S and X bands. It is equipped

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with all necessary elements allowing contribution to modern international VLBI and eVLBI research and service, such as digital baseband converter (DBBC), Haystack MIT Mk5B+ and Mk5C data recorders.

The 30-m antenna was built by NEC in 1984 and used by Telecom New Zealand for telecommunication purposes until 2010 when it was made available to IRASR for radio astronomy research. The antenna is designed as a wheel-on-track construction with 30.48m reflector and a beam-waveguide feed. The antenna was originally designed and used for telecommunication in C band. After upgrade of motors, cables and the control system, the antenna is planned to be initially used for observations in C band: in continuum for VLBI study of AGNs and in spectral lines for study of star formation complexes (methanol maser emission at 6.7 GHz and radio recombination lines of hydrogen, helium and carbon). Extension to S and X bands is planned to make the antenna available for geodetic VLBI. Suitability of the antenna for observations in higher frequencies is currently under investigation.

Figure 1. Shows 12-m (left) and 30-m radio telescopes of the AUT's Warkworth Radio Astronomical Observatory.

3. VLBI and eVLBI observations with LBA and ASKAP

In February 2011 AUT's Warkworth 12-m radio telescope officially became a part of the Australian Long Baseline Array (LBA). The first VLBI observations between the New Zealand 12-m antenna, LBA telescopes, and the first antenna of the Australian SKA Pathfinder (ASKAP) were conducted in April-May 2010. Figure 2 shows the location of radio telescopes and the baselines they form. The additional capability gained by adding radio telescopes in Western Australia and New Zealand to the LBA is substantial, increasing the angular resolution of the Australasian LBA by a factor of approximately four. The central parsec areas of Centaurus A and PKS 1934-638 were mapped in 1.4 GHz resulting in the first scientific outcomes for both the new antenna in New Zealand and the first ASKAP antenna [5]. A compact double radio source PKS 1934−638, the archetypal Gigahertz Peaked Spectrum radio galaxy, has been monitored over a period of 40 years. These combined New Zealand – ASKAP – LBA observations provided the latest datum, eight years after the previous observation, to aid in the study of the long-term evolution of the source structure. The relatively low frequency of 1.4 GHz allowed examination of the effects of optical depth on the structure of the radio source. It was shown that the evidence for expansion of the radio source over 40 years was weak and previous estimates for the age of the radio source had to be reconsidered.

Real-time eVLBI experiments between Australia and New Zealand were conducted in February 2011. On 8 February, Australian and New Zealand radio telescopes were operated remotely via KAREN and AARNet networks from AUT's Warkworth radio astronomical observatory. A range of celestial objects was observed – from one of the strongest compact radio sources in the southern sky (quasar PKS 1921-293) to a relatively weak (~0.3 Jy) compact radio source.

4. Space VLBI and spacecraft tracking

The AUT radio telescope has the capability to provide ground tracking services for a variety of proposed Space VLBI missions, discussions with both VSOP-2 and Radio Astron programmes have taken place. In September 2010

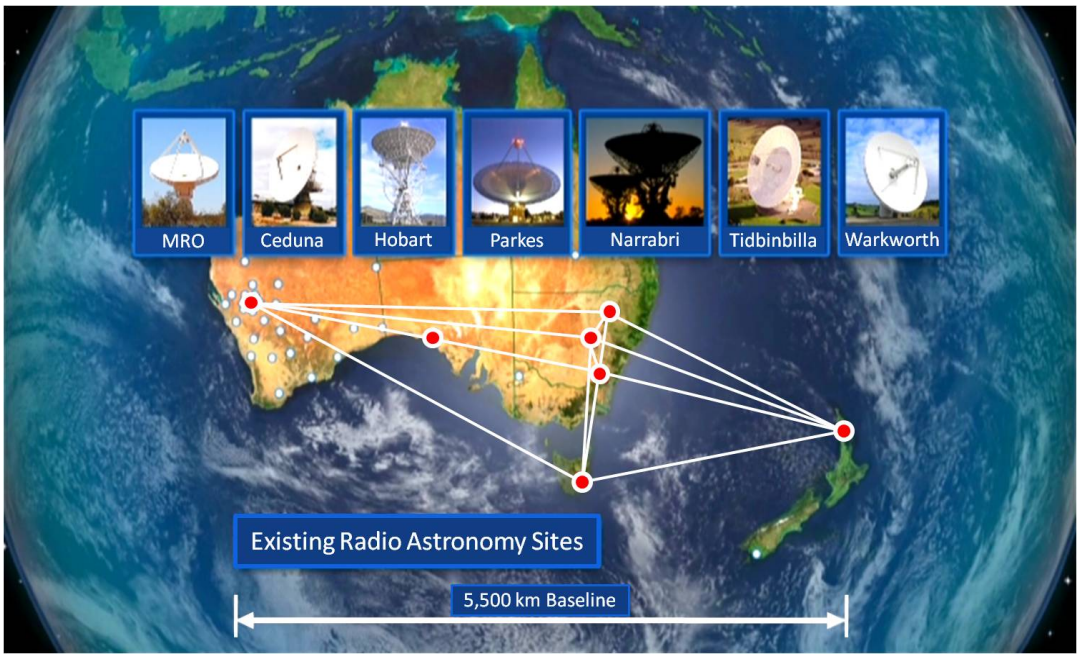

Figure 2. Upgraded Long Baseline Array (LBA). LBA sites (red marks) and baselines are shown. White marks show possible locations for SKA remote stations. Credit: Brian Boyle/CSIRO/IRASR

a signal from ESA's Mars Express satellite explorer was successfully detected. Using a PCEVN recorder and a modified receiver backend a 32 MHz band of data was collected for analysis. All data was transferred by network directly to Metsahovi, Finland using the international connections of the Kiwi Advanced Academic Research and Education Network (KAREN). On the 8th September 2010 data was successfully streamed direct from the AUT recorder to Metsahovi using the Tsunami protocol. A Memorandum of Understanding between AUT and JIVE was signed and joint work in NEXPReS and PRIDE projects has started.

5. Geodetic VLBI, astrometry and the Earth Science

Development of a New Zealand VLBI service for geodesy, astrometry and Earth science is one of the central tasks of the IRASR. This direction includes:

- Participation in the regular IVS observations as one of IVS network stations;
- Integration of VLBI into New Zealand space geodesy research and development of a New Zealand geospatial link between VLBI and GNSS techniques for definition and maintenance of the New Zealand Geodetic Datum;
- Integration into the AuScope (Australia) programme to jointly study the structure and evolution of the Australian Tectonic Plate.
- Microarcsecond astrometry of quasars including study of collective apparent proper motion pattern due to a galactocentric acceleration of the sun (secular aberration drift) and determination of large-scale dynamic parameters of our Galaxy, the Milky Way.

A successful 7 hour 1.4 GHz geodetic VLBI experiment was conducted in May 2010 using Warkworth 12-m radio telescope. It was linked to LBA antennas and the new station, ASKAP-29 located in Western Australia. This was the first geodetic VLBI observing session with the participation of the New Zealand and ASKAP antennas.

This VLBI session resulted in determination of geocentric coordinates for the Warkworth 12-m antenna centre [6]. The differences in position estimates of the New Zealand 12-m antenna from VLBI and from GPS surveys (VLBI–GPS), are 1.66 m for the vertical component, 0.49 m for the east component, and −0.48 m for the north component. The

difference in the vertical component can be explained by the effect of the ionosphere, but the difference in the horizontal components cannot be. New VLBI observations and GPS surveys will be conducted in the near future aimed to refine both VLBI and GPS coordinates of the antenna centre and study the reasons for the differences in coordinates determined with these two space geodesy methods.

On 14 February 2011 the New Zealand 12-m radio telescope participated in its first successful IVS session along with radio telescopes in Asia, Europe, North and South America.

6. The Square Kilometre Array

The IRASR has been engaged in Australasian SKA development since 2004 and continues a strong research focus on SKA capabilities. It includes:

- RFI study in potential SKA locations in New Zealand;
- Development of the image synthesis methods and software;
- Investigation of heterogeneous computing architecture for streaming and processing large amounts of data with IBM InfoSphere Streams and IBM Blade Centre platform;
- Development of real-time e-VLBI – a basic technique for the SKA;
- SKA simulation and modelling.

7. Education and public outreach

IRASR develops and offers, together with School of Computing and Mathematical Sciences, an Astronomy Major program as part of the Bachelor of Science qualification. IRASR engages with teachers in the secondary and primary sectors to promote radio astronomy in schools, and networks with amateur astronomers through national astronomical societies.

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