SKANZ 2012
CONFERENCE
Auckland, New Zealand

InterTronic Antennas
CSIRO
SKA
AUT UNIVERSITY
anzska

INSTITUTE FOR
RADIO ASTRONOMY & SPACE RESEARCH
AN INSTITUTE OF AUT UNIVERSITY
Australasian VLBI: SKA and NZ Agenda

Sergei Gulyaev
AUT University
SKA Common Framework

- **70 MHz**
- **300 MHz**
- **700 MHz**
- **2 GHz**
- **5 GHz**
- **10 GHz**

- **AA-Lo**
- **AA-Hi**
- **Dish-Lo PAF**
- **Dish-Hi WBSPF**

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Credit: R. Schilizzi
ASKAP--LBA--NZ VLBI, April-May 2010

Existing Radio Astronomy Sites

5,500 km Baseline

Credit: Brian Boyle/CSIRO/ANZSKA
Memo 135

Very High Angular Resolution Science with the SKA

L. Godfrey
H. Bignall
S. Tingay

International Centre for Radio Astronomy Research,
Curtin University, Bentley, WA, Australia

May 2011
Very High Angular Resolution Science with the Square Kilometre Array

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Abstract:
Preliminary specifications for the Square Kilometre Array (SKA) call for 25% of the total collecting area of the dish array to be located at distances greater than 180 km from the core, with a maximum baseline of at least 3000 km. The array will provide angular resolution $\theta \lesssim 40 - 2$ mas at 0.5 – 10 GHz with image sensitivity reaching $\lesssim 50$ nJy/beam in an 8 hour integration with 500 MHz bandwidth. Given these specifications, the high angular resolution component of the SKA will be capable of detecting...
1 Summary

2 Introduction

3 High Angular Resolution Science Case
   3.1 Key Science Project: Strong Field Tests of Gravity
      3.1.1 Enabling strong field tests of gravity with precise parallax distance measurements to compact, relativistic pulsar binaries
   3.2 Key Science Project: Cosmic Magnetism
      3.2.1 Enabling tomographic modelling of the Galactic magnetic field with pulsar parallax distance measurements
   3.3 Key Science Project: The Cradle of Life
      3.3.1 Imaging proto-planetary disks at centimetre wavelengths
   3.4 Key Science Project: Galaxy Evolution, Cosmology, and Dark Energy
      3.4.1 Resolving AGN and Star Formation in Galaxies
      3.4.2 HI absorption against AGN
   3.5 Key Science Project: Probing the Dark Ages and the Epoch of Reionization
      3.5.1 Finding the first generation of AGN jets, and radio/CO studies
   3.6 Exploration of the Unknown
      3.6.1 Transients
   3.7 Binary Supermassive Black Holes
   3.8 X-ray binary systems and relativistic jets
   3.9 Small-scale structure and evolution in AGN Jets
   3.10 Strong gravitational lensing
3.5.1 Finding the first generation of AGN jets, and radio/OH studies

3.6 Exploration of the Unknown

3.6.1 Transients

3.7 Binary Supermassive Black Holes

3.8 X-ray binary systems and relativistic jets

3.9 Small-scale structure and evolution in AGN Jets

3.10 Strong gravitational lensing

3.11 Absolute Astrometry and Geodesy

3.12 Relative Astrometry: Parallax and Proper Motions

3.13 Galactic Masers

3.14 Mapping high mass star formation in nearby galaxies

3.15 Stellar winds/outflows

3.16 Stellar Atmospheres

3.16.1 Imaging stellar atmospheres

3.16.2 Resolving stellar radio flares

3.17 Spatial and temporal changes in the fundamental constants

3.18 Ultra High Energy Particle Astronomy at $\gtrsim 2$ degree angular resolution via the Cerenkov technique

3.19 Scattering

3.19.1 Probing the Intergalactic Medium via Angular Broadening

3.19.2 Resolving AU-scale structure in the ISM via diffractive scintillation

3.19.3 Extreme scattering events

3.20 Spacecraft tracking
<table>
<thead>
<tr>
<th>Project</th>
<th>KSP</th>
<th>Frequencies [GHz]</th>
<th>Band</th>
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<tbody>
<tr>
<td>Pulsar Astrometry to enable projects including:</td>
<td>Strong field tests of gravity</td>
<td>1.4 -- 8</td>
<td>&gt; 300 MHz (ionosphere correction)</td>
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<tr>
<td>- Strong field tests of gravity</td>
<td>Cosmic Magnetism</td>
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<td>- Tomographic Mapping of the Galactic magnetic field</td>
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<td>- Mapping the ionized ISM</td>
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<tr>
<td>Imaging Proto-planetary disks (continuum)</td>
<td>Cradle of Life</td>
<td>5 -- 10</td>
<td>&gt; 500 MHz (sensitivity)</td>
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<tr>
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<td>Galaxy Evolution, Cosmology and Dark Energy</td>
<td>0.5 -- 8</td>
<td>1 GHz</td>
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<td>The first supermassive black holes</td>
<td>Probing the dark ages and the epoch of re-ionization</td>
<td>1.4</td>
<td>~ 300 MHz would be sufficient</td>
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<tr>
<td>Binary Supermassive Black Holes</td>
<td></td>
<td>5 -- 10</td>
<td>TBD</td>
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<tr>
<td>Project</td>
<td>Bandwidth</td>
<td>Max Baseline Length</td>
<td>Image Sensitivity</td>
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<td>Pulsar Astrometry to enable projects including:</td>
<td>&gt; 3000 km</td>
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<td>- Strong field tests of gravity</td>
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<td>- Mapping the ionized ISM</td>
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</tr>
<tr>
<td>Imaging Proto-planetary disks (continuum)</td>
<td>&gt; 1000 km</td>
<td>&lt; 0.1 μJy/beam</td>
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<tr>
<td>Resolving AGN and star formation in galaxies</td>
<td>&gt; 3000 km</td>
<td>&lt; 6 μJy/beam</td>
<td>1000 m^4 K^{-2} deg^{-2}</td>
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<td>The first supermassive black holes</td>
<td>&gt; 4000 km</td>
<td>&gt; 10 μJy/beam</td>
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<tr>
<td>Binary Supermassive Black Holes</td>
<td>&gt; 5000 km</td>
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<td>&gt; 50,000 sources in the order of a few months</td>
</tr>
<tr>
<td>Project</td>
<td>Field of View</td>
<td>Num. of Beams (FoV sampling)</td>
<td>Dynamic Range</td>
</tr>
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<tr>
<td>Pulsar Astrometry to enable projects including:</td>
<td>&gt; 4 beams (phase referencing)</td>
<td>&gt; 1000</td>
<td>Yes</td>
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<tr>
<td>- Strong field tests of gravity</td>
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<tr>
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</tr>
<tr>
<td>Imaging Proto-planetary disks (continuum)</td>
<td>~ 4 beams (phase referencing)</td>
<td>Moderate to high dynamic range - complex source structure</td>
<td>Yes</td>
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<tr>
<td>Resolving AGN and star formation in galaxies</td>
<td>---</td>
<td>&lt; 10,000</td>
<td>Yes</td>
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<td>~ 4 beams (phase referencing)</td>
<td>10,000 would be sufficient</td>
<td>Yes</td>
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<tr>
<td>Binary Supermassive Black Holes</td>
<td>~ 4 beams (phase referencing)</td>
<td>TBD</td>
<td>Yes</td>
</tr>
</tbody>
</table>
C. Carilli & S. Rawlings, 2004

The range of baselines and flux densities needed to probe high brightness temperature components of AGN. It shows baselines needed to allow sources with certain flux densities to be identified unambiguously with AGN.
Australasian Interferometry
The Cosmic Noise Expedition

From this site in August 1948, two pioneering radio astronomers, John Bolton and Gordon Stanley, from the Council for Scientific and Industrial Research in Sydney, determined for the first time the source of radio waves from outside our solar system. The astronomical world was astonished by this surprising opening of a new window on the universe.

The expedition gathered data at Pakiri on the east coast, then moved to this World War II Radar Station. Success was ensured because of a reliable electricity supply for their trailer-mounted sea-cliff interferometer (used at 100 MHz) and a west-facing horizon from the high cliffs.

Bolton and Stanley identified radio signals from three 'radio stars' - Taurus A, Centaurus-A and Virgo-A. Taurus-A is the remnant of the famous Crab Nebula, a supernova which exploded in 1054 AD. The other two sources of 'cosmic noise' are associated with galaxies outside the Milky Way.

Modern radio astronomy made a big leap forward with this discovery at Piha and this is acknowledged with this marker unveiled on 28th January 2011 by Auckland Council.
Graph: A beam mgwng
from Pakini Hill
July 15th, 1948
BART -6
Karaka, South Auckland
2005
6m L-band RT used in the first Trans-Tasman (New Zealand–Australia) VLBI observations in 2005.
Taurus: First Fringes
14m + 26m in Hobart
25 August 2005

CORREL FN (Product Numbers.)

Tim Natusch
Brett Reed
Steve Tingay

FEBaynes
The first fringe and the image of PSK1921-231 obtained from Australia—New Zealand VLBI.

(Credit: Adam Deller and Steven Tingay)
- Diameter: 12.1 m
- Manufacturer: Patriot/Cobham
- Shaped Cassegrain
- Slewing: 5 deg/s Az
  1 deg/s El
- Surface: 0.35 mm (rms)
- Bands: S/X dual polarisation;
  L-band (InterTronics)
- H-maser (Symmetricom, US)
- Mk5B+, Mk5C: 
  9 chassis x 8 disks x 1 TB
- DBBC (Gino)
- 1 Gbps International Connectivity
- Controlled remotely
ASKAP--LBA--NZ VLBI, April-May 2010

Existing Radio Astronomy Sites

Credit: Brian Boyle/CSIRO/ANZSKA
The 1\textsuperscript{st} real-time eVLBI
ASKAP—LBA—NZ
June 2011
KAREN – Kiwi Advanced Research and Education Network

WRK – The end node to the Warkworth Radio Astronomical Observatory
IRASR collaborates with a number of international partners

S. Weston et al, 2011
NZ development towards eVLBI

Image: Blue Marble Next Generation. Courtesy: NASA Visible Earth
North Shore (NSH) to Warkworth (WRK): Last Year

North Shore (NSH) to Warkworth (WRK) - maximum total throughput

- North Shore (NSH) -> Warkworth (WRK) Max: 48,662,088,600 bits/s
- Warkworth (WRK) -> North Shore (NSH) Max: 98,665,789,000 bits/s
Network connectivity

• Southern Cross Cables:
  - NZ – Australia: 2 Tbps
  - NZ – USA: 2 Tbps

• KAREN: Kiwi Advanced Research and Education Network
  - Inside NZ: 10 Gbps
  - NZ – Australia: 1 Gbps
  - NZ – USA: 1 Gbps

• Warkworth Observatory GigaPoP: connection to KAREN at 1 Gbps
KAREN connectivity

Professor John Raine, Chair of KAREN:
“SKA-like real-time observations are a great achievement by New Zealand and Australian researchers. KAREN which provides the data network for New Zealand’s research institutions intends to be an anchor tenant on a new international cable that, if built, will provide international connectivity of 40 Gbps by 2014, scaling through 80Gbps in 2017 to 160 Gbps by 2022 – more than enough to link the New Zealand and Australian parts of SKA.”

• 2012: 10 Gbps
• 2014: 40 Gbps
• 2017: 80 Gbps
• 2022: 160 Gbps
Radio galaxy Centaurus A

ASKAP antenna

NZ radio telescope

Image credit – Whole galaxy: I. Feain, T. Cornwell & R. Ekers (CSIRO/ATNF); ATCA northern middle lobe pointing courtesy R. Morganti (ASTRON); Parkes data courtesy N. Junkes (MPIfR). Inner radio lobes: NRAO / AUI / NSF. Core: S. Tingay (ICRAR) / ICRAR, CSIRO and AUT.
The 1st real-time eVLBI
ASKAP—LBA—Warkworth
June 2011

Quasar PKS 0637-752
Image credit: S.Tingay et al.
EVOLUTION OF THE PARSEC-SCALE STRUCTURE OF PKS 1934—638 REVISITED: 
FIRST SCIENCE WITH THE ASKAP AND NEW ZEALAND TELESCOPES

A. K. Tzioumis1, S. J. Tingay2, B. Stansby2, J. E. Reynolds1, C. J. Phillips1, S. W. Amy1, P. G. Edwards1, 
M. A. Bowen1, M. R. Leach1, M. J. Kesteven1, Y. Chung1, J. Stevens1, A. R. Forsyth1, 
A. Hotan2, C. Hotan2, L. Godfrey2, S. Ellingsen4, J. Dickey4, J. Blanchard4, and J. E. J. Lovell4

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2 International Centre for Radio Astronomy Research, Curtin University of Technology GPO Box U1987, Perth, Western Australia 6102, Australia 
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Received 2010 June 8; accepted 2010 September 7; published 2010 October 15

ABSTRACT

We have studied the archetypal Gigahertz Peaked Spectrum radio galaxy, PKS 1934—638, using the Australian Long Baseline Array augmented with two new telescopes that greatly improve the angular resolution of the array. These very long baseline interferometry observations represent the first scientific results from a new antenna in New Zealand and the first antenna of the Australian SKA Pathfinder. A compact double radio source, PKS 1934—638 has been monitored over a period of 40 years and the observation described here provides the latest datum, eight years after the previous observation, to aid in the study of the long-term evolution of the source structure. We take advantage of these new long baselines to probe PKS 1934—638 at the relatively low frequency of 1.4 GHz in order to examine the effects of optical depth on the structure of the radio source. Optical depth effects, resulting in the observation of frequency-dependent structure, may have previously been interpreted in terms of an expansion of the source as a function of time. Expansion and frequency-dependent effects are important to disentangle in order to estimate the age of PKS 1934—638. We show that frequency-dependent structure effects are likely to be important in PKS 1934—638 and present a simple two-dimensional synchrotron source model in which opacity effects due to synchrotron self-absorption are taken into account. Evidence for expansion of the radio source over 40 years is therefore weak with consequences for the estimated age of the radio source.
ASKAP & NZ VLBI of 1934-638

Normal LBA at 1.4 GHz

LBA with NZ and ASKAP

Image credit: Steven Tingay
(see also Tzioumis et al. AJ, 140, 2010)
• A two-dimensional synchrotron source model takes into account opacity (optical depth) effects associated with synchrotron self-absorption

$$\rho(x, z) = \begin{cases} 
\rho_0 \exp \left[ -\frac{(|x|-x_0)^2+z^2}{r_0^2} \right], & |x| < x_0, \\
0, & \text{otherwise},
\end{cases}$$

• A “cutoff” Gaussian profile represents the shock front at the jet working surface and the corresponding backflow from the shock region
First geodetic observations using new VLBI stations ASKAP-29 and WARK12M

Leonid Petrov\textsuperscript{A,G}, Chris Phillips\textsuperscript{B}, Tasso Tzioumis\textsuperscript{B}, Bruce Stansby\textsuperscript{C}, Cormac Reynolds\textsuperscript{C}, Hayley E Bignall\textsuperscript{C}, Sergei Gulyaev\textsuperscript{D}, Tim Natusch\textsuperscript{D}, Neville Palmer\textsuperscript{E}, David Collett\textsuperscript{F}, John E Reynolds\textsuperscript{B}, Shaun W Amy\textsuperscript{B}, Randall Wayth\textsuperscript{C}, Steven J Tingay\textsuperscript{C}

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\textsuperscript{B} CSIRO Astronomy and Space Science, PO Box 76, Epping, NSW 1710, Australia
\textsuperscript{C} International Centre for Radio Astronomy Research, Curtin University, Bentley, Western Australia, 6102, Australia
\textsuperscript{D} Institute for Radio Astronomy and Space Research, Auckland University of Technology, Private Bag 92006, Auckland 1142, New Zealand
\textsuperscript{E} GNS Science, PO Box 30368, Lower Hutt 5040, New Zealand
\textsuperscript{F} Land Information New Zealand, 160 Lambton Quay, PO Box 5501, Wellington 6145, New Zealand
\textsuperscript{G} Corresponding author: E-mail: Leonid.Petrov@lpetrov.net

Received December 20, 2010, accepted February 22, 2011 published June 16, 2011
Australian-NZ observations in 2010-11 demonstrated that

- NZ has a strong observational basis for VLBI and e-VLBI
- NZ is capable of electronically transferring large amounts of data in real-time
- NZ has excellent radio-quiet zones
RFI in Western Australia desert (ASKAP)

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<th>Mp</th>
<th>Ww</th>
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RFI in Warkworth radio quiet zone

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</table>
LBA meeting in February 2011
NZ joining LBA
AuScope

Study of Australian Tectonic Plate deformation
- Warkworth (WARK12M) is one of IVS network stations.
- Regular IVS observations started in February 2011
Session t2074

Start: 2011-02-01 17:30:00
End: 2011-02-02 17:30:01
Intensive: No

Sources (68)
0003-066, 0059+581, 0106+013, 0119+115, 0133+476, 0208-512, 0235+164, 0316+413, 0336-019, 0355+508, 0454-234, 0528+282, 0718+792, 0727-115, 0851+202, 0923+392, 0955+476, 1034-293, ...

Stations (15)
Aira, Chichijima, Crimea Simeiz, DSS13, Hartebeesthoek, Hobart 12m, Hobart 26m, Ishigakijima (VERA), Kokee Park, Mizusawa

Warkworth (New Zealand)
Coordinates:
-36°26′05.31″ N ; 174°39′47.72″ E
Elevation: 91 m
Diameter: 12.1m
Website: Link
 Webcam:
Plate boundaries & earthquakes

- NZ
- Japan

22 February, 2011

11 March, 2011
Space Geodesy

- NZ
    - ITRF96, 2000.0
    - Semi-dynamic system

- Japan
    - ITRF94, 1997.0
    - Static system
      + Semi-dynamic correction
        (referred NZ)
AuScope

Study of Australian Tectonic Plate deformation
The Square Kilometre Array
THANK YOU !
Acknowledgements

• IRASR team
• CSIRO Astronomy and Space Science
• ICRAR team
• Curtin University group
• UWA group
• UTas radio astronomy group
• Swinburne University team