Current New Zealand Activities in Radio Astronomy: Building Capacity in Engineering & Science for the Square Kilometre Array

M.Johnston-Hollitt[⋆], V. Kitaev[†], C.P. Hollitt[‡], N. Jones[§], T.C. Molteno[¶]

[⋆]School of Chemical & Physical Sciences, Victoria University of Wellington
Box 600, Wellington, NEW ZEALAND.
Email: Melanie.Johnston-Hollitt@vuw.ac.nz

[†]School of Engineering, Auckland University of Technology
Private Bag 92006, Auckland, NEW ZEALAND.

[‡]School of Engineering & Computer Science, Victoria University of Wellington
Box 600, Wellington, NEW ZEALAND.

[§]Department of Physics, University of Otago
Box 56, Dunedin, NEW ZEALAND.

[¶]Department of Computer Science, University of Auckland
Private Bag 92019, Auckland, NEW ZEALAND.

Abstract: We present an update on the NZ-wide advances in the field of Radio Astronomy & Radio Engineering with a particular focus on contributions, not thus reported elsewhere, which hope to either directly or indirectly contribute to New Zealand's engagement with the international Square Kilometre Array (SKA) project. We discuss the status of the SKA project in New Zealand with particular reference to activities of the New Zealand Square Kilometre Array Research and Development Consortium.

Keywords: Radio Astronomy, Square Kilometre Array in New Zealand, Radio Engineering.

1 Introduction

The Square Kilometre Array[1] (SKA) is a billion dollar, multinational project which aims to construct the world's largest radio telescope[1, 2]. A consortium of 17 countries has pledged involvement in this mega-science project which aims which will collect more information on the radio sky in the first seven hours of operation than has been obtained in the first 70 years of radio astronomy. The SKA will be comprised of thousands of individual radio telescopes, with a total collecting area of one square kilometre. These telescopes will be arranged in stations of 20 - 45 antennas. The stations will stretch over thousands of kilometres in order to provide resolution of the order of milliarcseconds which will be comparable to the best optical and infrared instruments. The array will be sited in either Australasia or Southern Africa and bids to host the telescope are being coordinated by South Africa and Australia with both countries committed to building 'pathfinder' telescopes on the sites of the proposed SKA core in each country.

Realization of the truly paradigm-shifting nature of the SKA will require significant challenges in radio engineering, data transport & storage, signal processing and power generation to be overcome. Much progress has been made on many of these fronts but there is much still to do and even seemingly small communities can play a vital role in the project. In this paper we describe the current status of the project in New Zealand with particular emphasis on the research enagement from Aotearoa.

2 SKA in Australia

Australian researchers have been involved in the SKA project since its inception over a decade ago. Radio astronomy is the largest single discipline in Astrophysics in Australia accounting for over 30 per cent of the total astronomical research output in Australia [3]. Radio astronomy research groups currently exist in seven Australian universities in addition to the government funded CSIRO division of the Australia Telescope National Facility and radio astronomy accounted for nearly 40 per cent of all permanent jobs in Australian Astronomy in 2005 [3]. With the

[1]www.skatelescope.org

advances toward the SKA, this fraction is likely to expand significantly.

To date the Australian Federal Government has committed 125 million AUD for construction of their pathfinder telescope, the Australian Square Kilometre Array Pathfinder (ASKAP) and 80 million AUD for a High Performance Computing (HPC) facility in Perth[2]. In addition, the Western Australian Government has committed a further 20 million AUD to establish the International Centre for Radio Astronomy Research (ICRAR)[3] as a joint venture between the state and the University of Western Australia and Curtin University of Technology.

3 SKA in New Zealand

In August 2009 New Zealand and Australia signed an arrangement to collaborate on the bid to host the SKA [4]. This marked the first formal step of New Zealand's engagement with the project and will see a joint trans-Tasman effort to work together to co-host the telescope.

3.1 NZ SKA Project Office

The Ministry of Economic Development (MED) is the lead government agency for New Zealand's involvement in the SKA. A New Zealand SKA project office has been established as New Zealand's point of contact for SKA matters and is coordinating New Zealand's Government level programme for engagment in the SKA project. As part of the coordination effort the project office is working closely with the Australia-New Zealand SKA Coordinating Committee (ANZSCC) on which the NZ Government has a representative.

3.2 SKA Research & Development Consortium

In June 2009, just prior to the announcement of the formal arrangement with Australia, the New Zealand Square Kilometre Array Research & Development Consortium (SKARD) was formed[5]. The role of SKARD is to bring together professional researchers involved in SKA related research in NZ, to foster collaboration both within NZ and internationally and to liaise with industry, government and other groups to advance New Zealand's contribution to the SKA. Members are drawn from all of New Zealand's major research universities and have interests in antenna design, signal processing, imaging and inference, high performance computing and radio astronomy.

[2] www.ska.gov.au/news/Pages/MinisterCarrnamesPawseyHPCCentre.aspx

[3] www.icrar.org

[4] 'Arrangement between the Australian Government and the New Zealand Government on a Joint Bid to Secure the Siting of the Square Kilometre Array in Australia and New Zealand'

[5] www.ska.ac.nz

3.3 NZ SKA Industry Consortium

In addition to SKARD, the New Zealand SKA Industry Consortium (NZ SKAIC) has formed to achieve positive economic outcomes for New Zealand from involvement in the SKA project. The group consists of industry partners representing IT software, hardware, networks and services, the Ministry of Economic Development (MED) and New Zealand Trade and Enterprise (NZTE).

4 Research Engagement in New Zealand

Although SKARD acts as a coordination point for researchers engaged in SKA related research, research engagement at the individual level has been quite active over 2009 even before the formation of the consortium. Several groups from across the country have come together to form collaborative projects around radio astronomy and related engineering. Highlights of this collaborative work include efforts in radio astronomy, radio engineering and signal processing.

4.1 Radio Astronomy

Currently there are only two universities in which radio astronomy research is conducted in New Zealand. Consequently, direct involvement in pure radio astronomy research is limited [6], however where such engagement has occurred it has been well placed. In particular, NZ has good representation on forthcoming major science and associated technical research associated with the Australian SKA Pathfinder, pan-NZ capability building in radio astronomy, signal processing and engineering and an emerging interest in associated High Performance Computing (HPC).

4.1.1 ASKAP Surveys

Australia has committed to build a one per cent demonstrator for the SKA called the Australian Square Kilometre Array Pathfinder (ASKAP). ASKAP, which is in construction now and due for completion in 2012, will be a powerful new telescope in its own right. Located at the core of the Australian & New Zealand site for the SKA, the Murchison Radio Observatory in Western Australia, ASKAP will comprise 36 15 meter diameter radio dishes spread over a 6 km diameter area. The configuration is designed to optimize sensitivity on angular scales of 30 arcseconds, whilst still providing good low surface brightness sensitivity at lower resolutions [4]. ASKAP will operate over 700 - 1800 MHz with a one degree field of view and has

[6] Refereed research publications in radio astronomy for NZ based researchers in the last decade are confined to only two authors: Johnston-Hollitt & Budding.

been specifically designed as a survey instrument for redshifted observations of neutral hydrogen (HI) [5]. ASKAP will act as a survey instrument for approximately 75 per cent of the first five years of operation (2013 - 2018) and an open call for survey science proposals in late 2008 resulted in 38 expressions of interest from world-wide teams of researchers. An extensive, multi-stage process of international peer review to prioritize the science surveys has just concluded with eight science surveys and two strategic programs selected[6].

Several NZ-based researchers are involved in the successful surveys which were selected for ASKAP. Staff from the Victoria University of Wellington (VUW) are involved in three ASKAP proposals, the A ranked Evolutionary Map of the Universe (EMU)[7] and the A- ranked surveys "POSSUM"and "VAST". Staff from the Auckland University of Technology are part of the strategic project "The high resolution component of ASKAP: meeting the long baseline specifications for the SKA".

Within the commensally observed EMU and POSSUM projects, researchers at VUW will contribute to science related to clusters of galaxies. In particular, understanding the role of environment on the production of radio emission in clusters will be investigated. This will include: the detection and characterization of low surface brightness diffuse synchrotron emission associated with dynamical encounters [8], the use of tailed radio galaxies as barometers of "cluster weather" [9] and as probes of high density regions [10, 11], and an investigation into the properties of AGN and starforming galaxies in different cluster environments [12, 13, 14]. The latter two projects are relatively straightforward in terms of finding and identifying sources. Detection of diffuse, low surface brightness sources however will be a challenge and is likely to require new signal processing techniques. Consequently researchers from VUW are undertaking a broader program of research in signal processing for astronomical research to address the challenge (see [15]).

The particular interest of NZ members of the VAST team is investigating coherent emission from active stars and binary systems. Such observations will probe fundamental parameters of stellar magnetospheres such as magnetic field intensity and topology and electron energy distribution and provide vital information on the relation of this emission to the physical characteristics of the host stars.

4.1.2 Radio Telescopes in New Zealand

The have been a range of substantial low-frequency arrays and small higher frequency ($\nu \leq 3$ GHz) dishes in NZ over the last 50 years. In particular, there has been a long history of polytechnics associated with small dishes including a 10m dish at Hamilton built in 1985 by the Waikato Institute of Technology in association with

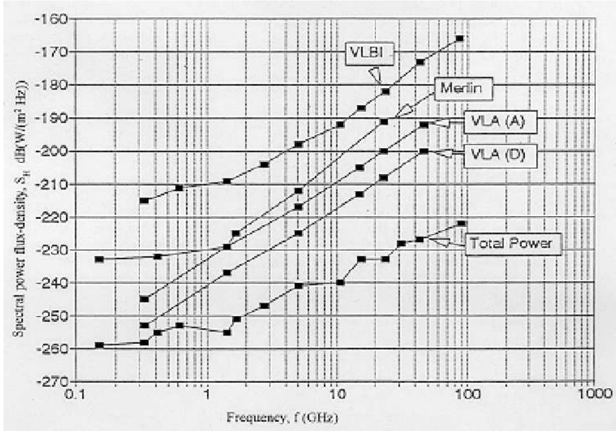

Figure 1: Interference thresholds as a function of frequency for continuum observations with several different configurations of radio telescopes. The line for total power describes the spectral power flux density (dB(W m$^{-2}Hz^{-1}$)) for a single dish radio telescope. Subsequent lines give the threshold for harmful interference for different configurations of interferometers going from more compact (VLA(D)) to least compact (Merlin) configurations. The least stringent requirements are the present recommendations for Very Long Baseline Interferometry (VLBI). Taken from the International Telecommunication Union Handbook on Radio Astronomy [19]. The outer stations of the SKA, such as those potentially in New Zealand, will be required to conform with VLBI levels [20, 21].

Waikato University[16] and a 5m dish constructed in 1998 by the Central Institute of Technology in Upper Hutt [17]. (See [16] and references therein for a full discussion of the history of small radio dishes in NZ.) The most recent in this long line of small dishes is the AUT 12m dish at Warkwork, located just north of Auckland [18]. Although this dish, which has been constructed but is currently still undergoing testing, will primarily undertake geodetic observations [18], it is hoped it will contribute to science observations of bright radio sources through the Australian Long Baseline Array (LBA).

Additionally, there are several low-frequency arrays operating in NZ for the purposes of undertaking upper atmospheric or meteor detection research, which are not connected to radio astronomy research.

4.1.3 Low Frequency Transient Network Development

Funding has recently been obtained to build a low frequency receiver network deployed across NZ to investigate properties of the transient radio sky. The project Transient Radio Emission Array Detector Prototype (TREAD-P) [22] will employ FPGA devices connected across the Kiwi Advanced Research and Education Network (KAREN) to test collection and storage of very high data rates and novel techniques for data processing using Bayesian inference with the hope of characterizing the low frequency radio sky. The core of the detector network will be the Digital Receiver Sensor (DRS) which is based around Field Programmable Gate Array (FPGA) technology, which is becoming increasingly important to radio astronomy. Depending on the configuration, each DRS will produce up to 10MB of data per second and the network of 10 devices will produce more than 8.6 Terabytes daily when running at maximum capacity.

Major international radio telescopes like the Low Frequency Array (LOFAR) [23] and ASKAP have identified characterization of the transient radio sky as a high science priority and proposed instruments like the Long Wavelength Array plan to conduct science specifically on the transient radio sky (20 - 80 MHz) in the next decade. Instruments like the DRS will provide vital information on the frequency of both artificial and naturally occurring radio signals which will be vital to the survey design of these large low-frequency telescopes.

In order to achieve this goal researchers from the Auckland University of Technology, University of Otago, Victoria University of Wellington, University of Auckland and the University of Canterbury and industry partners have agreed to contribute resources. It is expected this will provide opportunities for at least three research students at partner institutions across New Zealand in 2010.

4.2 HPC Facilities

New Zealand has capability in High Performance Computing, with dedicated facilities at the University of Canterbury (BlueFern) and computation clusters in several universities and government research labs. Many of these facilities are coordinated via its national grid initiative BeSTGRID led by the University of Auckland and seven other member institutions, which operates over a 10 Gb/s national research network the Kiwi Advanced Research and Education Network (KAREN), providing essential services for collaboration, computation, and data management.

NZ-based researchers are currently utilizing these tools to develop capability in relation to the SKA. As an example, the low frequency transient project (Section 4.1.3) involving researchers from five institutions has been recently funded to exploit this infrastructure to transport, store and process data at high rates from a network of GPS-synchronized low frequency antennas across NZ for radio astronomy research.

Additionally, researchers at three of NZs universities (Otago, Auckland and AUT) have established a collaboration developing new high performance computing techniques for processing radio astronomy data with a specific focus on reconfigurable computing. AUT, Otago and VUW maintain HPC clusters and in addition AUT and Otago have reconfigurable FPGA based systems (based in physics and engineering respectively) while BeSTGrid (Auckland) provides an ideal middleware platform to develop techniques for distributed computations which will be required for SKA research.

While this is a foundation, it should be noted however that host countries for the SKA will require significant upgrades to e-Infrastructure including a distributed high-speed fibre optic network between the stations and the science processing facility, mega-watt power for SKA stations and specialised hardware for the central digital signal processing facility. Depending on how the SKA is configured many of these resources may be located in NZ as part of the international project.

5 Discussion: Immediate goals

5.1 Station Locations

In partnering with Australia to host the SKA, New Zealand is hoping to contribute the outer stations of the array. At this stage this is likely to mean two stations of antennas in NZ, though arguments for more stations could be made in the future. In order to achieve the science goals of the SKA even the outer stations of the array will require low levels of radio frequency interference (RFI)[21]. Figure 1 shows the currently required levels specified for outer stations of the SKA in the low to mid frequency bands[20]. While there have been a couple of suggested locations put forward for SKA stations none of these meet the required specifications.

It is probably worth noting here that the vast majority of RFI is man-made and easiest way to achieve the radio quite levels required for the SKA is to place the antennas in regions of low population density. Figure 2 shows the current population density of NZ as determined from the 2006 national census[7] in addition to Telecom's current mobile phone coverage[8]. Regions of low population density and no mobile coverage exist in much of the South Island and there are some pockets in the North Island with similar characteristics.

At present, a comprehensive and independent site selection and survey process in close collaboration with Australia is currently being negotiated through the NZ SKA Project Office. As with all telescope site selection processes this will examine a range of metrics before finalising potential sites.

5.2 Research Engagement

With the signing of the arrangement with Australia and formation of SKARD and NZSKAIC, New Zealand is now

[7] http://en.wikipedia.org/wiki/File:NewZealandPopulationDensity.png
[8] www.telecom.co.nz

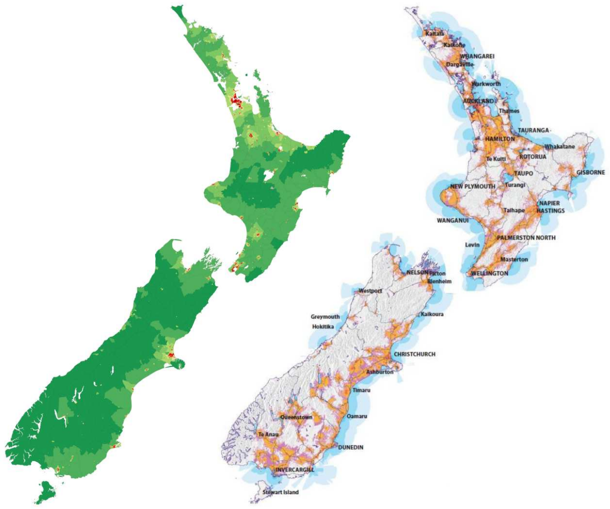

Figure 2: LHS: Population density of NZ from the 2006 Census[7]; RHS current mobile phone coverage for NZ[8]. To reduce the levels of RFI, potential SKA stations should ideally be located in regions of low population density with little mobile coverage.

on a firm footing for researchers from the private and public sector to engage in this project. As the final host nations for the array will not be decided until the early part of 2012 it is important for NZ to maximise benefit in the project via early engagement while simultaneously mitigating the risk that the project will go to Southern Africa. This means that it is important to identify niche opportunities which are independent of the ultimate location of the array. This can be achieved via expanding existing links between NZ and Australia in radio astronomy related areas via:
i) continued participation of NZ scientists in the science and design of the SKA,
ii) building expertise in NZ through the training of graduate students in radio astronomical research - a natural complement to NZ's existing strength in optical astronomy, and
iii) undertaking significant and ground breaking research which will be used for further enhancement of science with next generation radio telescopes.

The latter speaks directly to the identification and exploitation of niche research opportunities. Such niches have clearly emerged in NZ around science-driven post-processing via novel signal processing [15]. Work of this nature combines NZ's strengths in radio astronomy, signal processing, HPC & middleware. Additionally, capacity building exercises and pan-NZ collaborative work [22] which has commenced will be important to realize opportunities that will arise with hosting the telescope.

On the purely astronomical research front, in order to maximize the science outcomes of both ASKAP and eventually the SKA it is crucial that knowledge from existing instruments is examined and used to developed expertise vital for survey design on next generation instruments and the research teams thus far involved are well placed to make significant contributions.

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