An update on SKA activities in Australia

Phil Edwards | CSIRO SKA Project Scientist
14 February 2018
Outline

• Some history
• SKA Design Consortia
• SKA precursors
  • MWA
  • ASKAP
• SKA Science Working Groups
• SKA Operations
• Further information
"It's the telescope of the future. It can look back millions of years."

Bolton Symposium

• Held at Marsfield, last December
• The day included the launch of Peter Robertson’s biography of John Bolton
SKA Organisation: 10 countries, more to join

Australia (Dol&S)
Canada (NRC-HIA)
China (MOST)
India (DAE)
Italy (INAF)
Netherlands (NWO)
New Zealand (MED)
South Africa (DST)
Sweden (Chalmers)
UK (STFC)

Interested Countries:
- France
- Germany
- Japan
- Korea
- Malta
- Portugal
- Spain
- Switzerland
- USA

Contacts:
- Mexico
- Brazil
- Ireland
- Russia

Full members
- SKA Headquarters host country
- SKA Phase 1 and Phase 2 host countries

African partner countries
(non-member SKA Phase 2 host countries)

This map is intended for reference only and is not meant to represent legal borders

Exploring the Universe with the world's largest radio telescope
SKA history

“To my mind one goal stands out – a volume of the ‘Encyclopedia of the Universe’ is written in 21cm typescript. Unfortunately the printing is rather faint and we need a large ‘lens’ to read the text!”

– Peter Wilkinson 1991
SKA—Key Science Drivers: The history of the Universe

- Testing General Relativity (Strong Regime, Gravitational Waves)
- Cradle of Life (Planets, Molecules, SETI)
- Cosmic Magnetism (Origin, Evolution)
- Cosmic Dawn (First Stars and Galaxies)
- Galaxy Evolution (Normal Galaxies $z \sim 2-3$)
- Cosmology (Dark Energy, Large Scale Structure)
- Exploration of the Unknown

Extremely broad range of science!
Milestones

• 1991 – “The Hydrogen Array” Peter Wilkinson
• 1993 – URSI establishes Large Telescope Working Group
• 1997 – Eight institutions from 6 countries sign MoU
• 1999 – Taylor & Braun “Science with the Square Kilometer Array”
• 2000 – 11 countries establish International SKA Steering Committee
• 2004 – Carilli & Rawlings “Science with the Square Kilometre Array”
• 2006 – Site down-selected to Australia or South Africa
• 2012 – Site selection announced: Australia and South Africa
• 2015 – Outcome of rebaselining: SKA1-Survey deferred
• 2016/17 – Cost Control Project: Design & deployment baselines
SKA1 LOW - the SKA's low-frequency instrument

The Square Kilometre Array (SKA) will be the world's largest radio telescope, revolutionising our understanding of the Universe. The SKA will be built in two phases - SKA1 and SKA2 - starting in 2018, with SKA1 representing a fraction of the full SKA. SKA1 will include two instruments - SKA1 MID and SKA1 LOW - observing the Universe at different frequencies.

- **Frequency range:** 50 MHz to 350 MHz
- **Antennas:** ~130,000 antennas spread between 500 stations
- **Total collecting area:** 0.4 km²
- **Maximum distance between stations:** 65 km
- **Total raw data output:**
  - 157 terabytes per second
  - 4.9 zettabytes per year
SKA1 MID - the SKA's mid-frequency instrument

The Square Kilometre Array (SKA) will be the world's largest radio telescope, revolutionising our understanding of the Universe. The SKA will be built in two phases - SKA1 and SKA2 - starting in 2018, with SKA1 representing a fraction of the full SKA. SKA1 will include two instruments - SKA1 MID and SKA1 LOW - observing the Universe at different frequencies.

Location: South Africa

Frequency range: 350 MHz to 14 GHz

~200 dishes (including 84 MeerKAT dishes)

Total collecting area: 33,000 m²

or 126 tennis courts

Maximum distance between dishes: 150km

Total raw data output:
2 terabytes per second
62 exabytes per year
SKA work packages

- Assembly, Integration & Verification
- Science Data Processor
- Wide Band Single Pixel Feeds
- Telescope Manager
- Dish
- Signal and Data Transport
- Central Signal Processor
- Mid-Frequency Aperture Array
- Low-Frequency Aperture Array
- Infrastructure Australia
- Infrastructure South Africa
Work packages

The consortia responsible for each work package are:

• Assembly, Integration and Verification (AIV)  
  
  CSIRO +

• Central Signal Processor (CSP)  
  
  CSIRO, ICRAR, Swinburne +

• Infrastructure Australia and Africa (INFRA AU/INFRA SA)  
  
  Aurecon, CSIRO, Horizon Power +

• Low-Frequency Aperture Array (LFAA)  
  
  Curtin +

• Signal and Data Transport (SaDT)  
  
  CSIRO, AARNet, UWA +

• Science Data Processor (SDP)  
  
  CSIRO, UWA, iVEC +

• Telescope Manager (TM)  
  
  CSIRO +

• Dish (DSH)  

• Mid-Frequency Aperture Array (MFAA)  

• Wideband Single Pixel Feeds (WBSPF)  

See talks by Grant Hampson, JC Guzman and Drew Devereux later this week
The SKA Assembly, Integration and Verification (AIV) Consortium

Member organisations:

AIV is planning the roll out and integration of telescope products (Hardware, Firmware, Software, Computer Networks, Support Systems)

In construction AIV will be:

• Facilitating early product-to-product testing,
• Striking telescope baselines,
• Commissioning the telescope,
• Verifying the requirements,
• Supporting validating against end-user needs.

Exploring the Universe with the world's largest radio telescope
Australian RQZ WA (ARQZWA)

**Red small circles:** Likely SKA1-Low antenna station locations

**Yellow circle:**
70km radius for the ARQZWA Inner Zone – Applications for terrestrial radio-transmitters to be assessed as secondary to radio-astronomy (co-ordination zones out to 260km)

**Red line** – Current MRO boundary (to be expanded to the Boolardy Station perimeter)

**Key CSIRO activities:**
- Evaluation of proposed radio transmitter applications as they arise, mainly from mining activities, in accord with existing ARQZWA legislative and policy instruments
- Manage policies around self-generated interference to MRO radio-telescopes
- Provide the Commonwealth and WA State with input around ARQZWA legislation, regulatory and policy instruments as governed by the Australian Communications and Media Authority (ACMA) and the Dept. of Mines, Industry Regulation and Safety
SKA PAF Consortium

R&D for future SKA PAF

- PHAROS upgrade: 4 to 8 GHz Cryogenic PAF, 24 elements, 4 single-pol beams, digital backend.
- L-band Cryogenic PAF for Parkes (Rocket array)
- ASKAP Commissioning Reports
- PAF on Effelsberg – RFI mitigation, Pulsar, FRB, Wide-field Imaging
- FAST L-band Cryogenic PAF design, 19 element crossed dipole
- SKA2 PAF technology review & early concept development
- Requesting SKA SWG to review cases for PAFs on SKA - where can PAF capabilities enable new science?

Part of Advanced Instrumentation Programme

Much reduced spectral ripple
- Less reflection from feed; lower standing waves
Precursors

Australian SKA Pathfinder (ASKAP)
MeerKAT
Murchison Widefield Array (MWA)
Hydrogen Epoch of Reionization (HERA)

*These play a critical role in establishing infrastructure, gaining experience, identifying problems, bottlenecks, sticking points, frustrations...*
MRO movie

https://www.youtube.com/watch?v=k28zWHmHtTY&feature=youtu.be
Thanks to Randall Wayth for MWA slides
MRO (operated by CSIRO)

On site: data rate into central building ~60 Gbps

Off site: data rate into science archive ~3 Gbps

Pawsey Centre 20 PB storage for MWA

Geraldton

Perth

Population Density: 0.002 km$^{-2}$

41,000 sq. km = The Netherlands

~200 km
Phase I MWA: 128 tile system

Antenna tiles: 128
Operating frequency: 70-300 MHz
Array diameter: 3 km
Processed bandwidth: 30.72 MHz / 10 kHz
Field of view: 30 degs @ 150 MHz

Many small antennas -> huge field-of-view and excellent image fidelity (arcmin resolution)

2016-2017: MWA phase 2 upgrade. Doubles number of antennas and array diameter
Past, present, future

**Phase 1: 2013-2016**
- 128 antennas, 2.5 km max baseline

**Phase 2: 2016-2018**
- Expand with additional 128 antennas, comprised of
  - 72 closely spaced in 2x hexagonal grids approx 100m size
  - 56 new long baseline antennas to double max baseline to 5km
- Only 128 antennas used at any time: reconfigure for
  - ‘EoR array’ (existing core tiles plus new hexes)
  - ‘Long baseline array’ (existing non-core tiles + new long baseline tiles)
- Same correlator, receivers: reconfigure by manual re-plugging of tiles into receivers
MWA phase2 – long baselines

128 new tiles:
* 72 in two hex config arrays
* 56 forming new long baselines to 5km

1800 meters
Central Signal Processing:

- 128 dual pol tiles
- 30.72 MHz bandwidth, 10 kHz spectral resolution
- 8128 baselines

- Visibilities integrated to ~1s time resolution
Pawsey Supercomputing Centre in Perth

- Data archive & data portal for all users
- Galaxy supercomputer for:
  - Data quality & flagging
  - Calibration & imaging
  - High time resolution data processing

www.pawsey.org.au
MWA Key science

The Epoch of Reionisation

Transient & variable universe

Galactic & extragalactic astrophysics

Solar & heliospheric science

Bowman et al., 2013.
SKA-Low Precursor

MWA experience & expertise directly feeds back to SKA-Low (several recent publications and memos, + membership in working/consultation groups)

Engineering Development Array (EDA)
• Test & verification system aimed at MWA & SKA-Low prototyping
• Development for integration of external signals->MWA
AAVS (Aperture Array Verification System)
ASKAP (700—1800 MHz)
ASKAP

- First light with first antenna March 2010
  - Tzioumis et al. 2010 AJ 140, 1506
- All 36 antennas were assembled by June 2012
- The first six Phased Array Feeds installed by Oct 2013
- The BETA array enabled experience in using Mk I PAFs to be gained while the ADE process was carried out
  - Hotan et al. 2014 PASA 31, 41: McConnell et al. 2016 PASA 33, 42
- Galaxy computer available at Pawsey in Feb 2014
- BETA switched off in Feb 2016
- ASKAP Early Science (12 Mk II PAFs) started late 2016
- All 36 Mk II PAFs installed by Dec 2017
The Detection of an Extremely Bright Fast Radio Burst in a Phased Array Feed Survey

K. W. Bannister¹, R. M. Shannon¹,², J.-P. Macquart²,³, C. Flynn³,⁴, P. G. Edwards¹, M. O’Neill³,⁴, S. Osłowski⁴, M. Bailes⁴, B. Zackay⁵, N. Clarke², L. R. D’Addario⁶, R. Dodson⁷, P. J. Hall², A. Jameson⁴, D. Jones⁸, R. Navarro⁹, J. T. Trinh¹⁰, J. Allison¹, C. S. Anderson¹¹, M. Bell¹, A. P. Chippendale¹, J. D. Collier¹,¹², G. Heald¹¹, I. Heywood¹,¹³, A. W. Hotan¹, K. Lee-Waddell¹, J. P. Madrid¹, J. Marvil¹, D. McConnell¹, A. Popping³,⁷, M. A. Voronkov¹, M. T. Whiting¹, G. R. Allen¹, D. C.-J. Bock¹, D. P. Brodrick¹, F. Cooray¹⁴, D. R. DeBoer¹⁵, P. J. Diamond¹⁶, R. Ekers¹, R. G. Gough¹, G. A. Hampson¹, L. Harvey-Smith¹, S. G. Hay¹⁷, D. B. Hayman¹, C. A. Jackson², S. Johnston¹, B. S. Koribalski¹, N. M. McClure-Griffiths¹⁸, P. Mirtschin¹, A. Ng¹, R. P. Norris¹,¹², S. E. Pearce¹, C. J. Phillips¹, D. N. Roxby¹, E. R. Troup¹, and T. Westmeier⁷
Australian Scientists Are Massive Nerds (In The Best Possible Way)

Rae Johnston

May 23, 2017, 8:15am · Filed to: ASKAP

Credit: Kim Steele
GW170817

Abbott et al. ApJL

0.14% of author list CASS-affiliated!
SKA Science Working Groups

Science Working Groups were established to provide advice and guidance on the design and development of the SKA. Specific activities are likely to include:

- Providing advice on the science requirements for the SKA, such as the suite of expected measurements, processing approaches, and data products;
- Providing advice on the expected operation of the telescope;
- Making recommendations about potential improvements, particularly in response to emerging research topics; and
- Serving as liaisons to the broader community for SKA science, design and development progress through presentations at major astronomy meetings, universities and research institutions.
SWG Science Teams

Radio Transients
H I Galaxy Science
Our Galaxy
Extragalactic Continuum
Cosmic Magnetism
Epoch of Reionisation
Fundamental Physics with Pulsars
Cosmology
Cradle of Life/AstroBiology
Extragalactic Spectral Line
Solar & Heliospheric Physics
+ VLBI & High Energy Cosmic Particles focus groups
Table 2. List of highest priority SKA1 science objectives, grouped by SWG, but otherwise in arbitrary order.
SKA Operations

- Global Headquarters, Jodrell Bank, UK
- Site Entity
  - MRO land and infrastructure management
- SKA Operator
  - Site and engineering operations
- Science Processing Facilities
  - Pawsey Centre, for initial pipeline processing of data
- SKA Regional Centres
  - Data curation and heritage, computational resources for additional processing, including science analysis and visualisation
**Australia and New Zealand SKA project**

The Square Kilometre Array, or SKA, is a global next-generation radio telescope project involving institutions from over 20 countries. The SKA will be the largest and most capable radio telescope ever constructed. During its 50+ year lifetime, it will expand our understanding of the universe and drive technological development worldwide. Australia and southern Africa will each host different SKA components.

**Project Director’s Update**

December 2016

It’s been a busy few months with plenty of exciting new activity in the project. In November, we were proud to launch the Australian SKA Fellowships program. The program enables Australia-based scientists and engineers to spend up to four months in the UK contributing to SKA delivery at the SKA Headquarters. Congratulations to all four recipients of the first round of fellowships, the first two of which have already commenced work at the SKA HQ. More...

**Pia Wadjari school visit**

Schoolchildren from the Pia Wadjari school, located in Murchison, WA, near the site of the SKA, were in Canberra to celebrate National Aboriginal and Torres Strait Islander Children’s Day with local schoolchildren on 4 August 2016. More
ANZSCC Science Advisory Committee

Phil Edwards
Lisa Harvey-Smith
Andrew Hopkins
Naomi McClure-Griffiths
Elaine Sadler
Lister Staveley-Smith
Cath Trott
Willem van Straten
OzSKA

- The 4th OzSKA meeting will be held in 2018
- The aim of these meetings is to provide updated information to the Australian astronomical community about recent progress within the SKA project including:
  - the development of key science and working group activities,
  - progress towards the realisation of scientific operations on SKA1,
  - and the SKA in the context of multi-wavelength astronomy.
CASS Radio School 2017

2018 Radio School to be held in Western Australia.
Data reduction workshop to be held at Marsfield in 2018.
Summary

• The SKA is the telescope of the future: it will look back billions of years!
• As a host country, there is a lot of activity in Australia
• A lot of effort internationally in the design consortia
• Similar efforts in the Science Working Groups
• SKA precursors doing a lot of good science and establishing infrastructure and experience for SKA
• Plenty of scope for increased NZ involvement
We acknowledge the Wajarri Yamatji people as the traditional owners of the Murchison Radio-astronomy Observatory site.

Thanks to Randall Wayth, Steve Barker, Howard D’Costa and Adam Macleod for slides.

Thank you

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