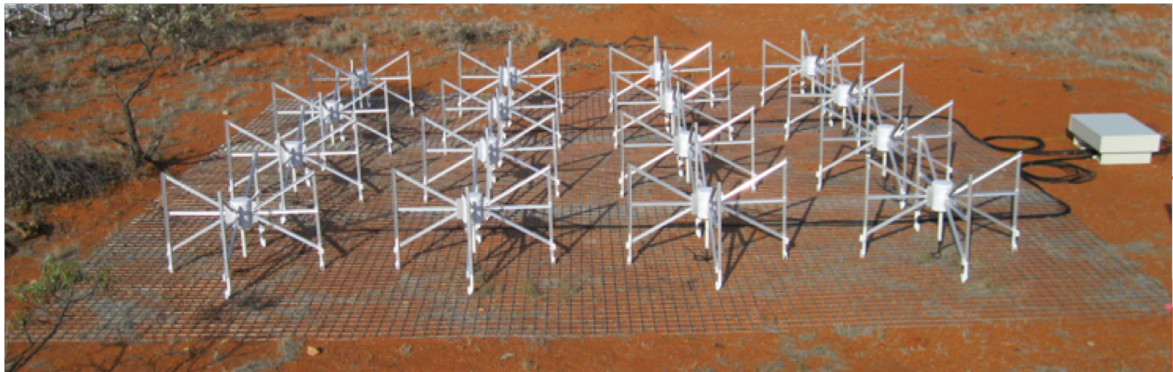
New Zealand's role in the Murchison Widefield Array

Prof. Melanie Johnston-Hollitt, MWA Director



MWA Overview

- The MWA is an international low-frequency radio telescope operated by Curtin University on behalf of a consortium of 21 institutions from Australia, China, Japan, Canada, New Zealand and the USA.
- The instrument operates from 70 – 300 MHz with a 30.72 MHz bandwidth that can be split into 4 x 7.5 MHz sub-bands.
- 30 x 30 degree field-of-view for rapid survey capability.
- The telescope achieved full practical completion in November 2012 and Phase I completed commissioning on 20 June 2013.
- In 2017 the array was substantially upgraded to double the number of antennas to 4096 and to increase the maximum baseline to ~5km, providing a resolution of ~1’ at 150 MHz.
- The expansion of the array, known as ‘Phase II’ included an expansion of the international collaboration with the addition of China, Japan and Canada.

Location

- The MWA is located at the Murchison Radio Observatory.
- The MRO is the future site of the SKA and currently hosts a number of radio telescopes including ASKAP, EDGES, BIGHORNS as well as demonstrators for the SKA like the EDA and AAVS instruments.
- The site is one of the best places on Earth for radio astronomy and is protected via Australian regulatory measures.

Gurlgamarnu

MWA
MURCHISON WIDEFIELD ARRAY

PARTNER INSTITUTIONS

Australian National University

BROWN

CSIRO

Curtin University

国立大学法人
鹿児島大学
KAGOSHIMA UNIVERSITY

Kumamoto University

THE UNIVERSITY OF MELBOURNE

NAGOYA UNIVERSITY

国立天文台
NAOJ
National Astronomical Observatory of Japan

Shanghai Astronomical Observatory, CAS

SWINBURNE UNIVERSITY OF TECHNOLOGY

TOHOKU UNIVERSITY

BERKELEY SETI RESEARCH CENTER

THE UNIVERSITY OF SYDNEY

東京大学
THE UNIVERSITY OF TOKYO

UNIVERSITY OF TORONTO

UNIVERSITY of WASHINGTON

THE UNIVERSITY OF WESTERN AUSTRALIA

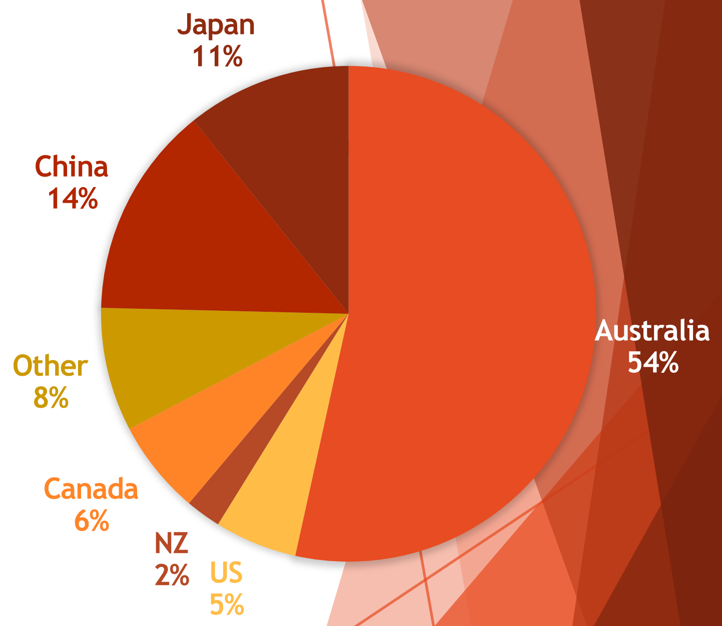
UNIVERSITY of WISCONSIN
UWMILWAUKEE

TE WHARE WĀNANGA O TE ŪPOKO O TE IKA A MĀUI
VICTORIA
UNIVERSITY OF WELLINGTON

WESTERN SYDNEY UNIVERSITY

Phase II MWA Partners

- MWA is an international radio telescope operated by Curtin University on behalf of a consortium of 21 institutions
- Shares in the MWA telescope are allocated nationally based on investment quanta. 1 quantum provides 1 board seat, membership for 25 individual members and access to MWA shared resources and data.
- As of Phase II the Board is comprised of 4 members from Australia, 2 from China, and 1 each from the US, NZ, Canada and Japan.
- At present there are 270 individual researchers who are members of the MWA Collaboration.

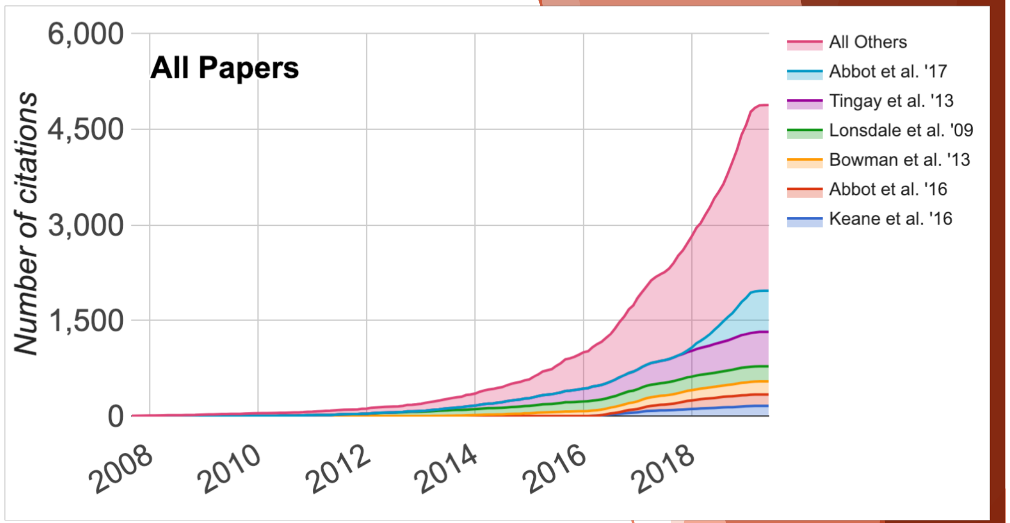


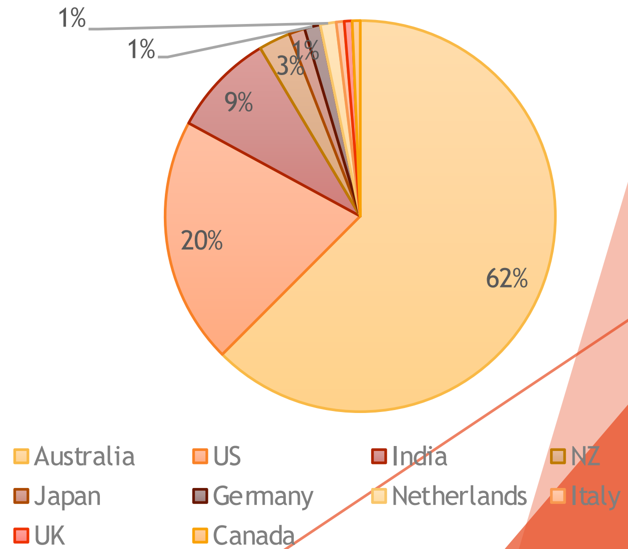
Phase II Collaboration Membership

Output

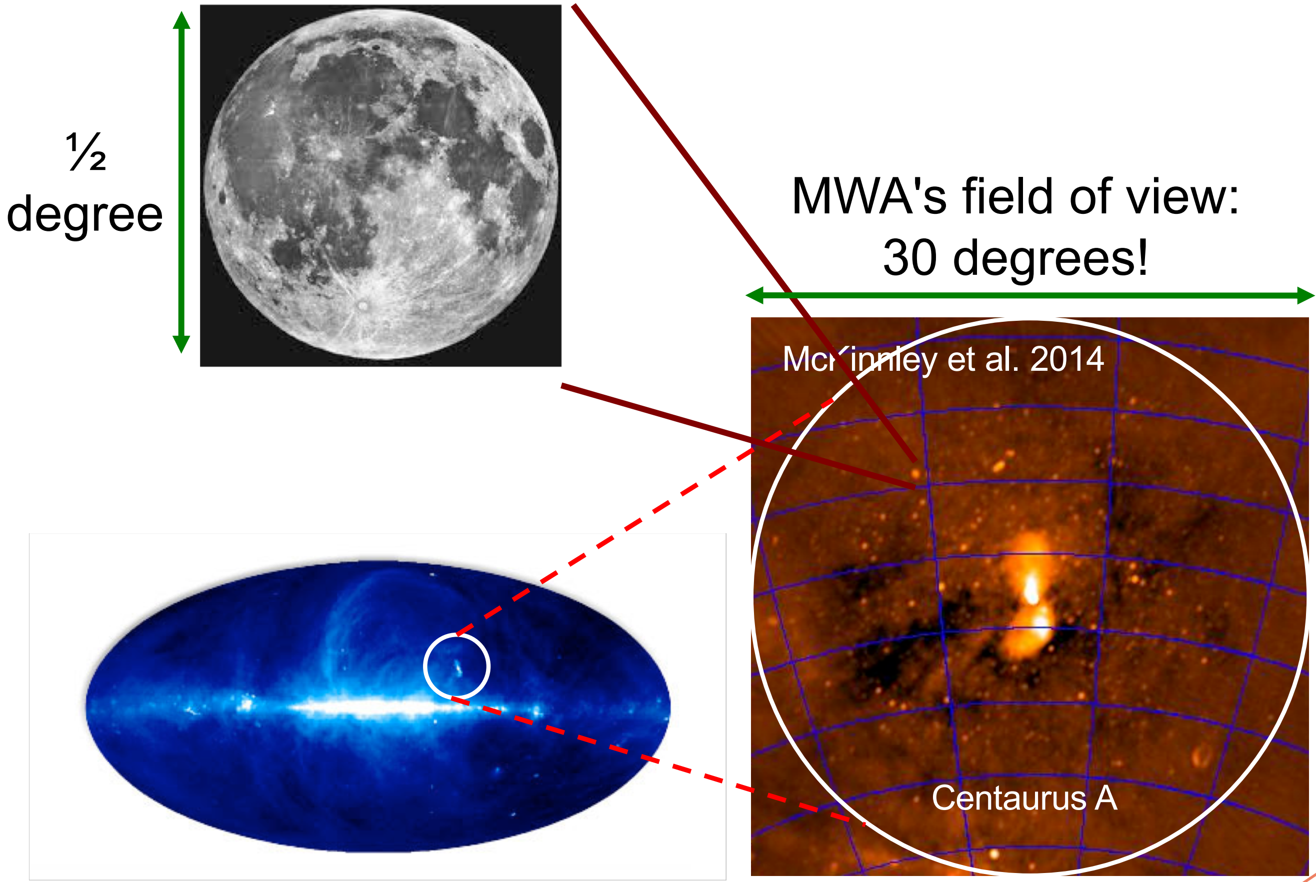
Considering the number of papers produced as a function of dollars spent on operations, MWA is the most cost effective radio telescope in the world

- In the 5 years of operations (2012 – 2017), the Phase I MWA produced over 110 refereed publications. Since late 2017 when Phase II commenced a further 50 publications have been produced taking the total number of MWA publications to over 160. To date these publications have accrued nearly 5000 citations, at a growing rate of citations per year with ~1500 citations being generated per year.
- The breakdown of lead author for all MWA publications to date, demonstrates MWA science is being generated proportionally to the number pf collaboration members in each country.

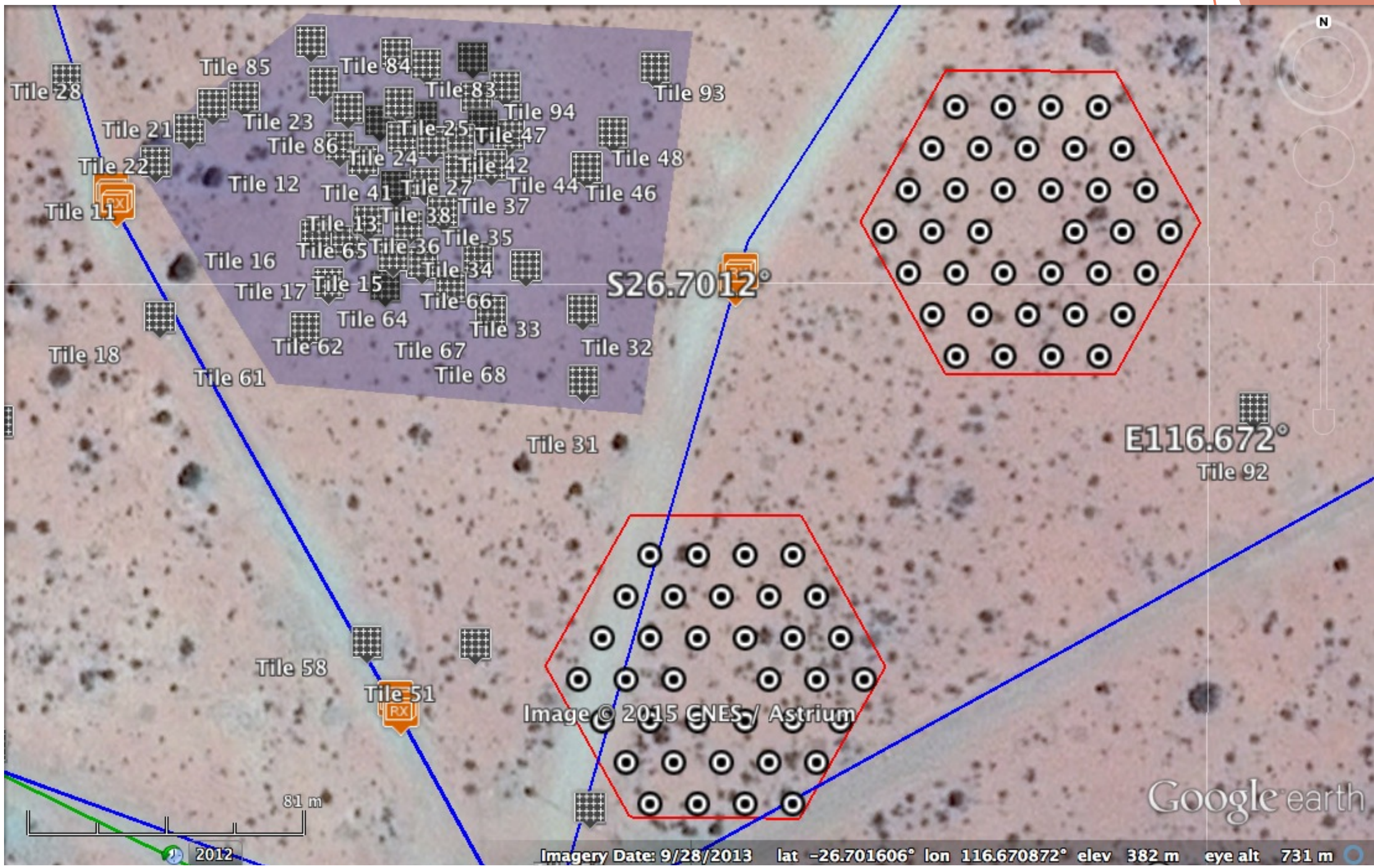




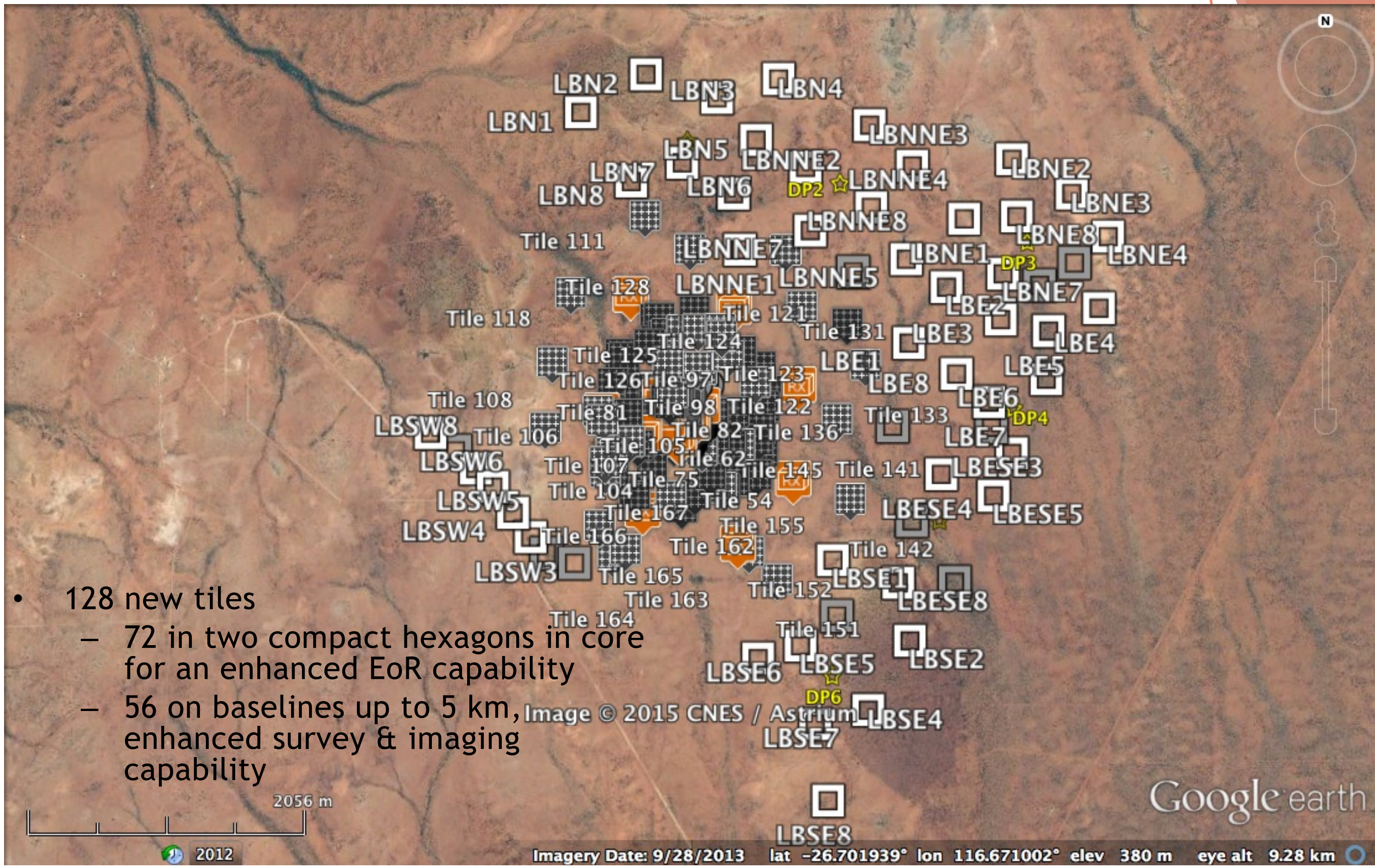
MWA FoV is huge!



MWA phase 2: core region

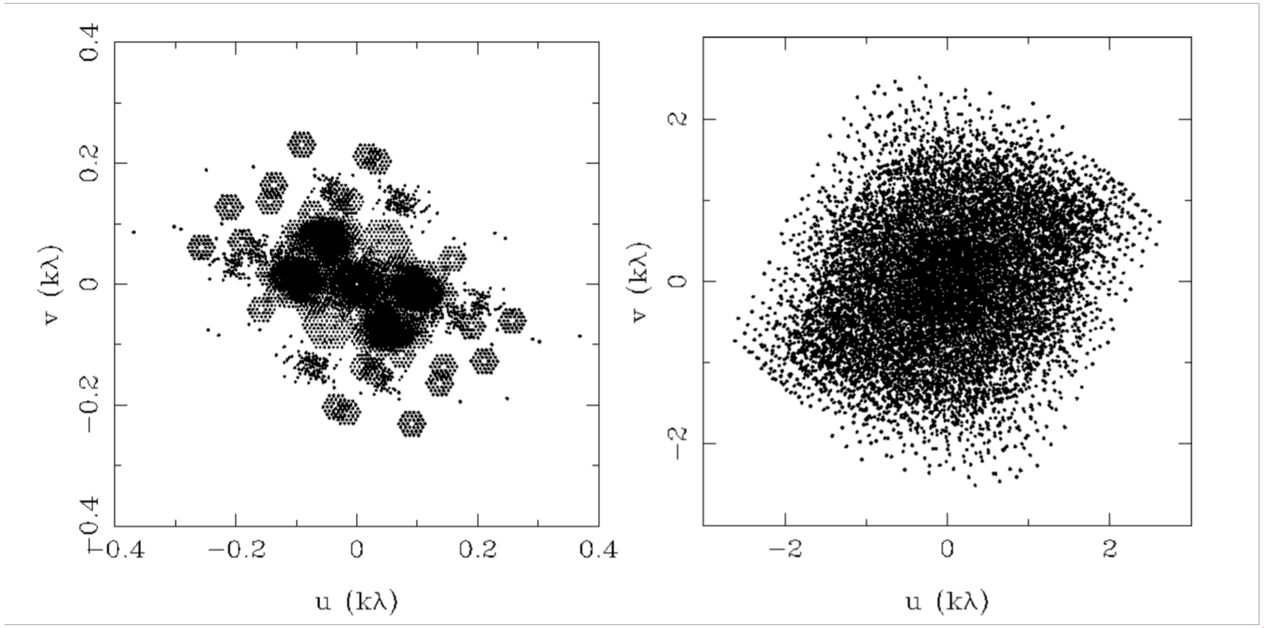


MWA phase2 – long baselines



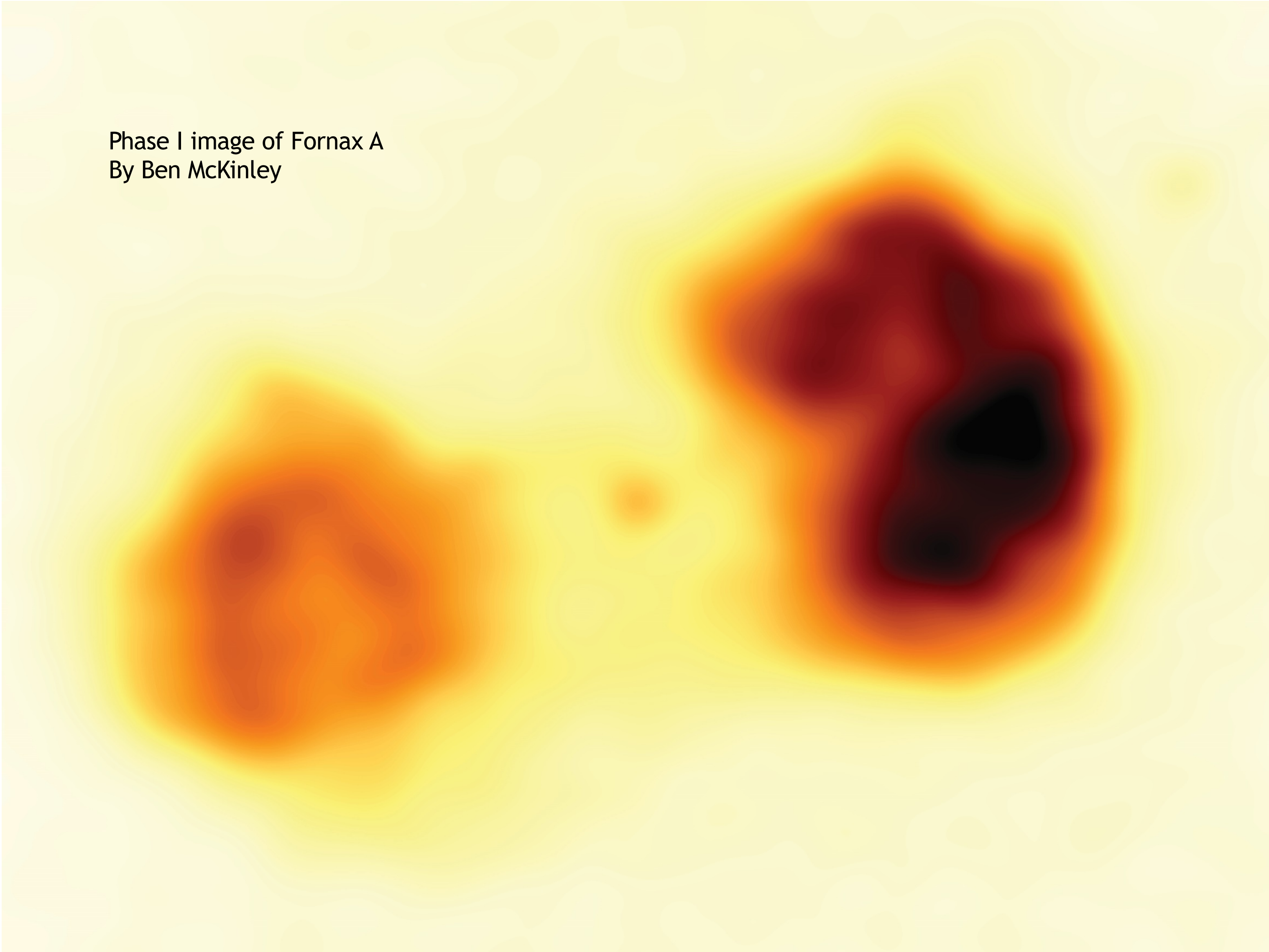
- 128 new tiles
  - 72 in two compact hexagons in core for an enhanced EoR capability
  - 56 on baselines up to 5 km, enhanced survey & imaging capability

Instantaneous UV coverage: Phase II

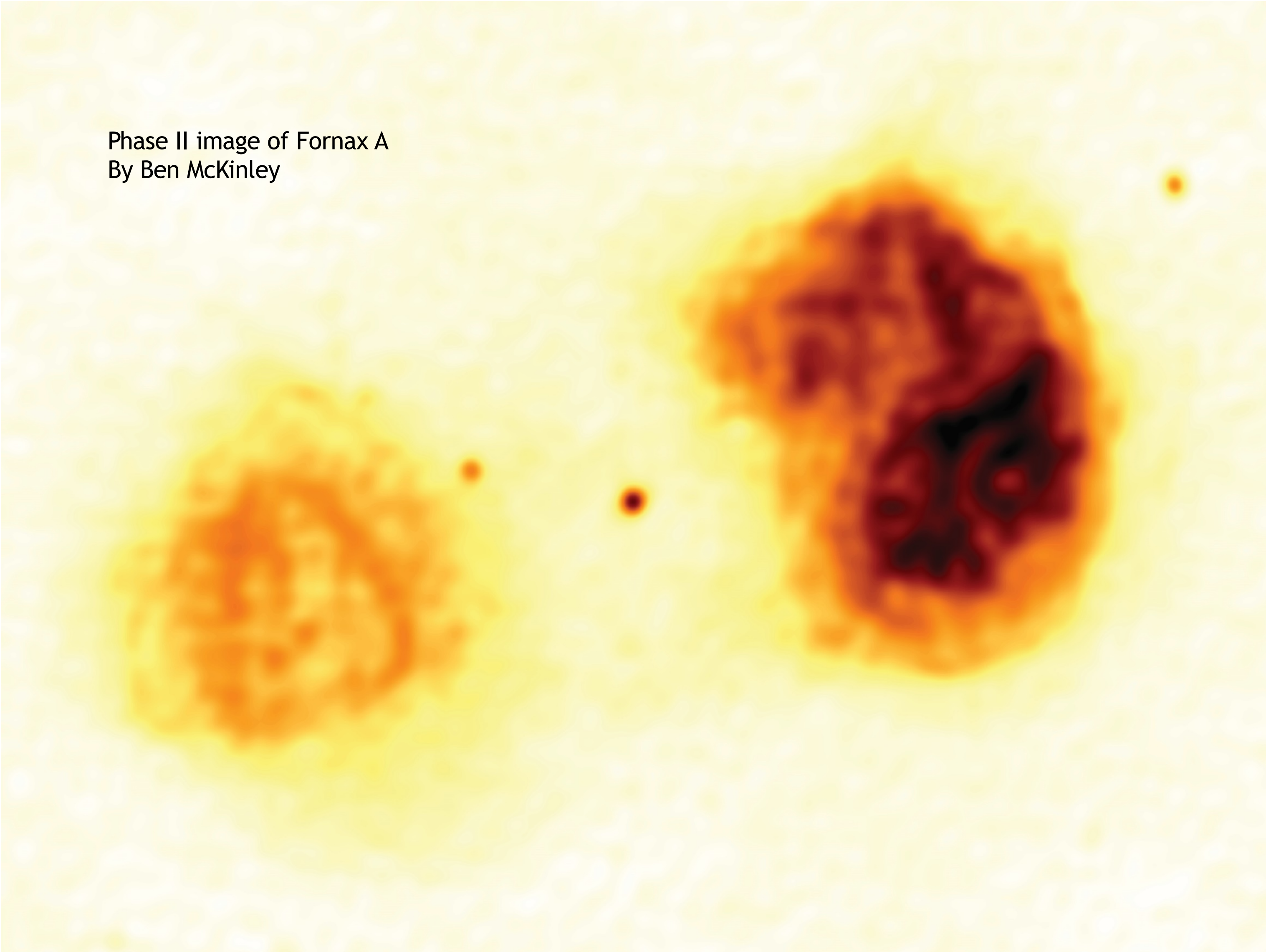


Snapshot, monochromatic
Compact configuration

Snapshot, monochromatic
Extended configuration



Phase I image of Fornax A
By Ben McKinley


Phase II image of Fornax A
By Ben McKinley

Diffuse Source Sensitivity

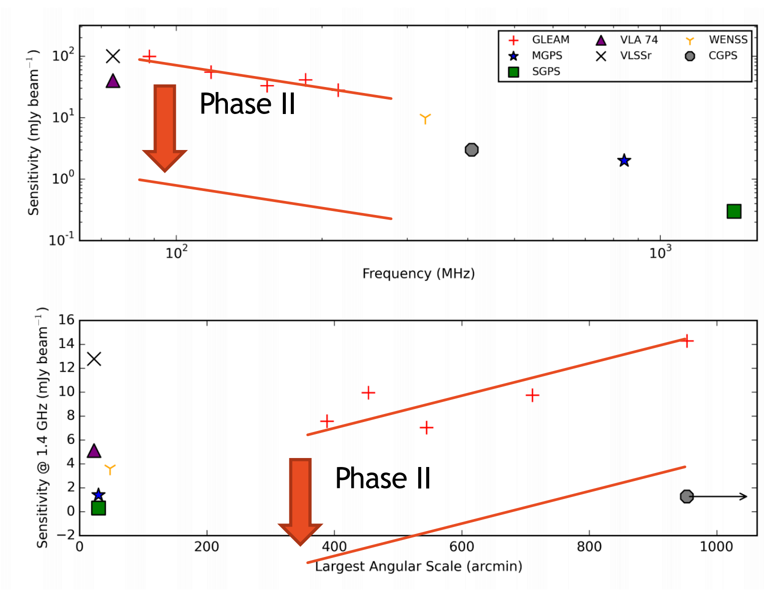


Figure 1. Top panel: this plot shows the logarithm of the frequency vs. sensitivity for low frequency Galactic surveys (< 1.4 GHz). Bottom panel: the spatial sensitivity and corresponding sensitivity, scaled to 1.4 GHz assuming a spectral index of −0.7. The CGPS survey includes single dish data and so recovers all spatial information. The MWA provides both high sensitivity and access to a broader range of angular scales compared with previous surveys of the Galactic plane.

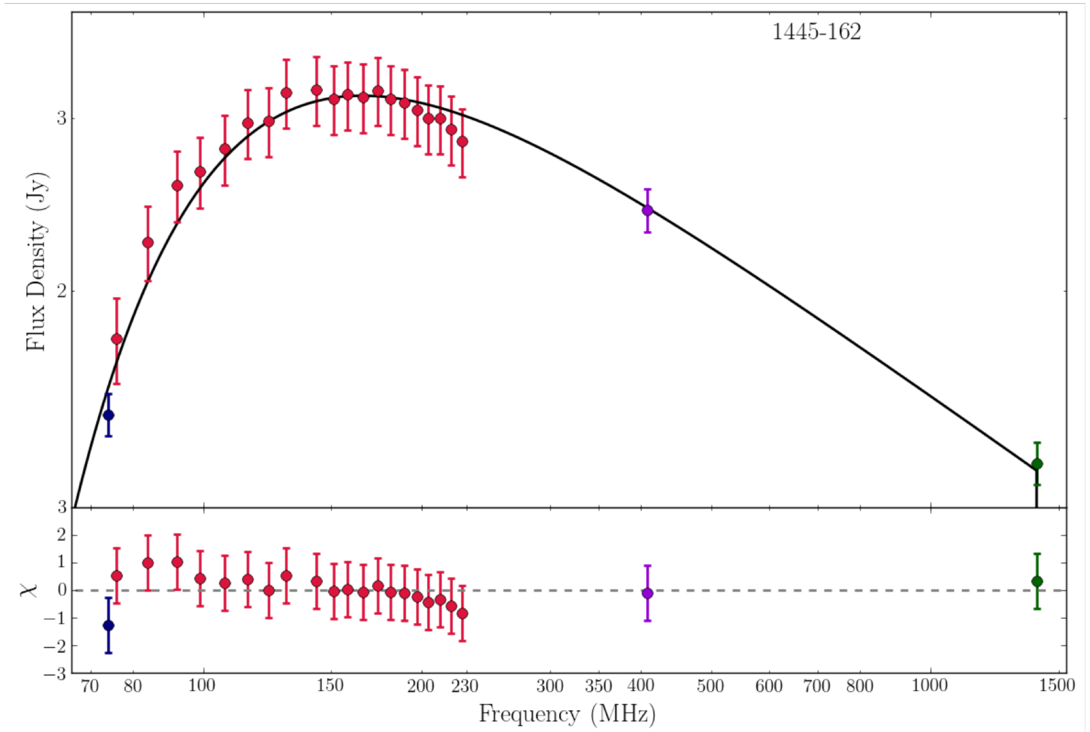
Hindson, Johnston-Hollitt et al. (2016)

MWA Phase I has the best sensitivity for diffuse source sources between 400 arcmin. (200 arcmin for Phase II).

MWA has the best diffuse source sensitivity of any radio telescope

So for mapping large-scale Galactic and other emission the MWA is excellent.

MWA Spectral Coverage



Callingham et al. (2017)

In addition to the excellent diffuse source sensitivity,
the MWA has unprecedented low frequency spectral resolution.

This makes it possible to distinguish between thermal and non-thermal emission using just MWA data!

MWA Technical Details

- Tingay et al. (2013) – Instrument description paper
- Ord et al. (2015) – Correlator paper
- Prabu et al. (2015) – Digital-receiver paper
- Wu et al. (2013) – Archive paper
- Sutinjo et al. (2015) – leakages and beam model
- Tremblay et al. (2015) – High Time Resolution Capabilities
- Wayth et al. (2018) – Phase II definition paper

Current MWA Science

- First results from the Long Baseline Epoch of Reionisation Survey (**Lynch**)
- Towards a New MWA Limit on the Epoch of X-Ray Heating (**Pindor**)
- The Future of EoR Power Spectrum Analysis (**Barry**)
- Simulating MWA observations with OSKAR (**Line**)
- The POlarised GLEAM Survey (POGS) (**Riseley**)
- Galactic diffuse polarized emission at low frequencies (**Sun**)
- Searching for the First Black Holes with the MWA (**Seymour**)
- Physical properties of nearby galaxies using GLEAM Survey (**Yoshida**)
- Detecting and tracking space debris with the MWA (**Hancock**)
- Detection of Meteors and Space Debris with the MWA (**Zhang**)
- Searching for low-frequency emission from Star-exoplanet interactions (**Lynch**)
- Properties of Pulsars at Low Radio Frequencies (**Xue**)
- A preliminary pulsar blind search with MWA incoherent summed data (**Zhang**)
- No low-frequency emission from extremely bright Fast Radio Bursts (**Sokolowski**)
- Rapid follow-up of Gamma-ray Bursts using the upgraded MWA automatic triggering capability (**Anderson**)
- The imaging challenges of faint diffuse emission with MWA Phase II (**Hodgson**)
- A Murchison Widefield Array Phase II follow-up of diffuse, non-thermal cluster emission (**Duchesne**)
- Detecting New SNR with the MWA (**Hurley-Walker**)
- The SKA-Low Aperture Array Verification System (**Wayth**)

EoR

Polarimetry

Galaxies

SSA + NEO

Exoplanets

Plusars

Transients

Cosmic Web + Clusters

Galactic Science

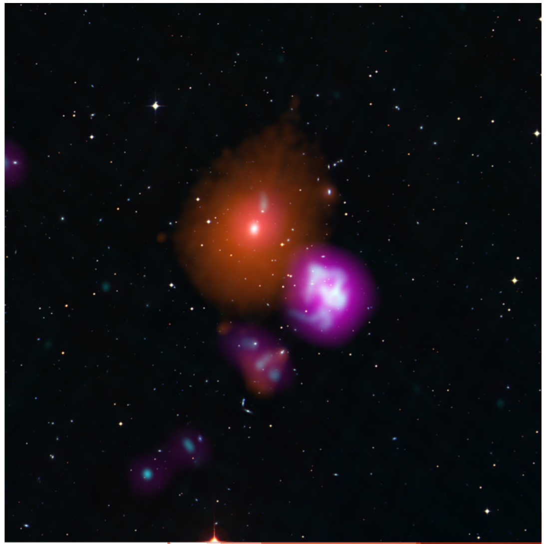
SKA Development

NZ and the MWA

- NZ joined the MWA in December 2011 through a combined government, industry and institutional funding package to the value of 2 million AUD.
  - 522K NZD from VUW for personnel & operating costs
  - 401K NZD from MED (now MBIE)
  - Shared University Research Grant from IBM (joint NZ, AUS & US research divisions) to MJH
- NZ delivered the current MWA Correlator hardware (25 node iDataPlex), participated in commissioning of the Phase I array and notably led the governance of the MWA Executive Board for 4 years.
- At highest point NZ had 18 members in the MWA Collaboration at VUW.
- MWA research was awarded 3 Marsden Grants at VUW to a combined value of 2.04 million NZD

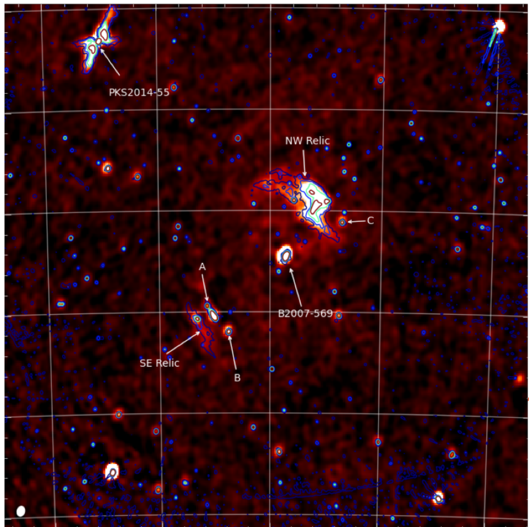
NZ MWA Outputs

- NZ Contributed to ~90 MWA related papers from 2012-2019. NZ led papers included:
  - **Hindson, L., Johnston-Hollitt, M.**, et al. 2016 *"A Large Scale, Low Frequency Murchison Widefield Array Survey of Galactic HII regions between 260<l <340"*,PASA, vo1 30, e020, 17 pages.
  - **Hindson, L., Johnston-Hollitt, M.** et al. 2014, *"The First Murchison Widefield Array low-frequency radio observations of cluster scale non-thermal emission: the case of Abell 3667"*, MNRAS, VoL.445, pp.330-346
  - **Zheng, Q., Johnston-Hollitt, M.**, **Duchesne, S.** & Li, W., 2017, *"Detection of a Double Relic in the Torpedo Cluster: SPT-CL J0245-5302"*,MNRAS, vol 479, pp.730-740
  - **Duchesne, S.** & **Johnston-Hollitt, M.**, 2019, *"The remnant radio galaxy associated with NGC 1534"*,PASA, in press
  - **Duchesne, S.W.**, **Johnston-Hollitt, M.**, Offringa, A.R., Pratt, G.W., **Zheng, Q., Dehghan, S.**, 2019, *"Diffuse galaxy cluster emission at 168 MHz within the Murchison Widefield Array Epoch of Reionization 0-hour field"*, submitted

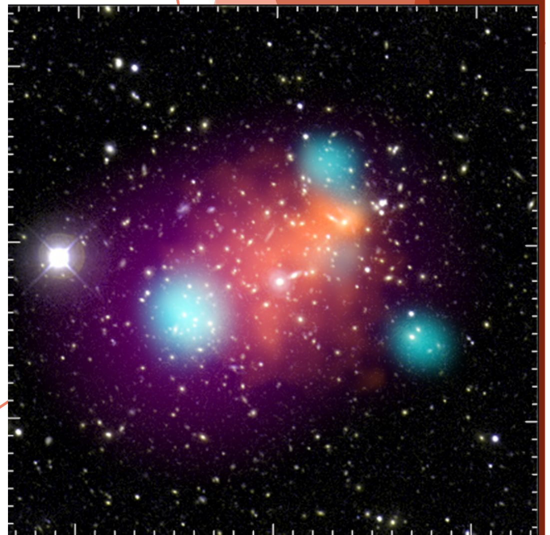


Duchesne et al. 2019

Hindson et al. 2016



Hindson et al. 2014

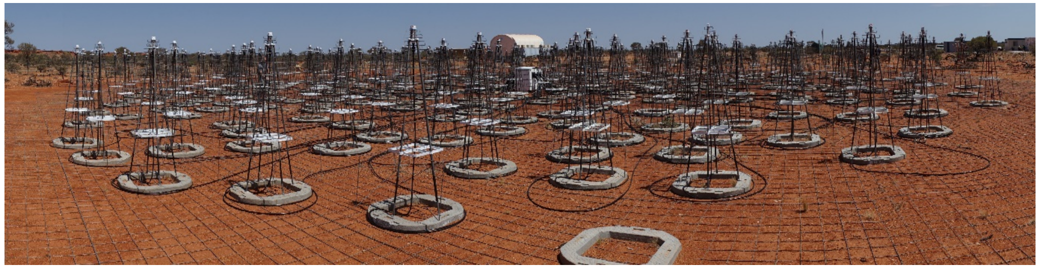


Zheng et al. 2019

MWA as a Testbed SKA

- The MWA is not only an indirect source of technical and scientific knowledge generation to prepare for the future construction and deployment of SKA_Low. The MWA is a vital piece of infrastructure used directly in Australian-led SKA preconstruction work.
- As the official Precursor for SKA_Low, the MWA has always been the primary path to prepare astronomers, engineers, and operation teams to participate in SKA low design, prototyping, construction, and operations.
- The MWA has provided the basis for much of Australia's efforts in the SKA pre-construction program, via the Low Frequency Aperture Array (LFAA) consortium. The MWA has supported two iterations of the Aperture Array Verification System (AAVS) and two iterations of the Engineering Development Array (EDA) as external instruments.
- Through the existing MoU with the LFAA consortium the MWA continues to act as a direct test bed for SKA hardware and signal processing and as a collaboration provides input into the scientific and logistical requirements for SKA.

Aperture Array Verification System 0.5 (AAVS0.5)



Aperture Array Verification System 1.0 (AAVS1.0)

Engineering Development Array 1 (EDA1)

MWA DATA SERVICES

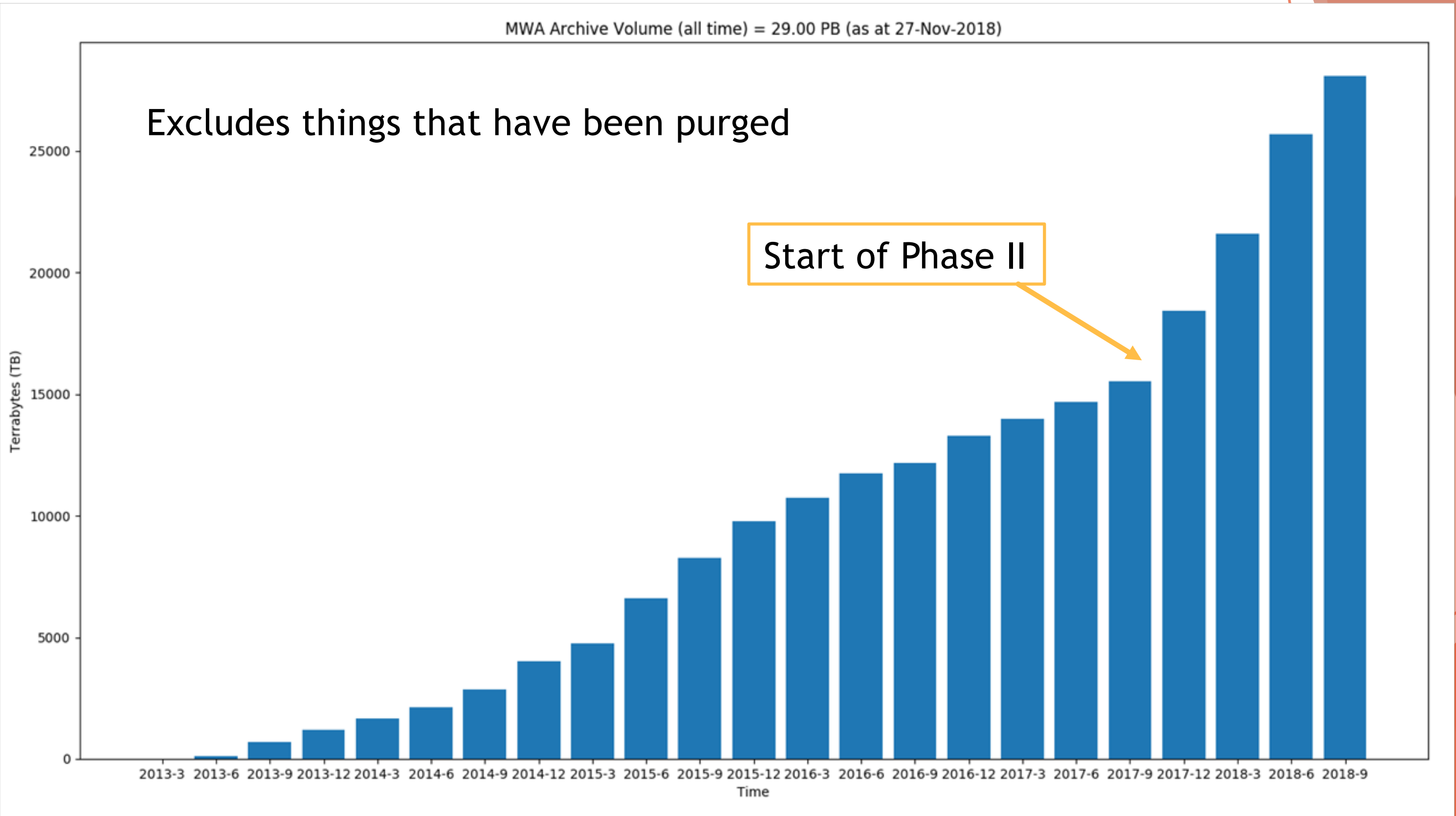
- The ASVO project has seen the completion of the first step of the AAL-funded project to create a portal for MWA public data access. This serves the 30 PB of data collected so far.

Jobs completed: 27,179
Data served out: 639 TB
Users registered: 202

Now serves calibrated visibilities

- Will have a dedicated MWA allocation as part of the 70 million upgrade to Pawsey.
- The possibility of MWA services in other host countries, including China, is also under discussion.

Archive Volume (all time) 30PB



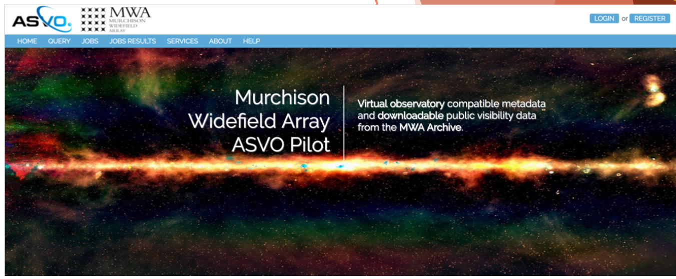
MWA as an Observatory now

MWA
MURCHISON
WIDEFIELD
ARRAY

PAWSEY
supercomputing centre

Stagging,
archiving

Processing



ASVO: initial calibration of visibilities

MWA Member Astronomers

Tier 0

non-MWA Members

VO services like Skyview

Upgrades

- Phase II of the MWA was successfully completed at the end of 2017 and is now in routine operations. MWA now comprises of 4096 antennas arranged in 256 tiles.
- Phase II doubles the number of antennas in the array and doubles the resolution. This comes with approximately a factor of 10 increase in sensitivity due to a reduction in confusion noise (Wayth et al. 2018).
- At present we have retained the original IBM iDataplex correlator which is only capable of correlating 128 tiles and thus the array currently operates in two configurations; a compact configuration for EoR observations, and an extended configuration for higher resolution imaging.
- It is unlikely we will have a monolithic ‘Phase III’ upgrade. That would require of order 10 million AUD and at present there are no identified funding mechanisms to achieve this in a single effort.
- Therefore upgrades will be incremental. Starting with a new correlator which is currently the subject of a design study.

MWA Upgrade Options

Upgrade	Brief description	Feasibility
Upgrade receivers	Replace the systems in the existing receivers to eliminate the coarse channel edge problem, increase bit depth, eliminate the need for the fine Polyphase Filter Banks (PFB) and use standardised data formats suitable for the new correlator.	Feasible. Builds on development work that has taken place over the last few years. Development work required.
Addition of new receivers	Roll out entirely new receiver systems (including using new digital systems described above) to increase the number of active receivers that can be supported in the array beyond 16.	Feasible. This is limited only by available funds if the receiver upgrade project above is complete.
Correlator expansion	Increase the instantaneous processed bandwidth; increase the number of simultaneous tied-array beams.	Feasible. This project is already well developed from a software perspective. New hardware is required.

Already well on the path to a new correlator, which unlike the present system will be more flexible and scalable (Curtin-led design activity with MWA input). The design is almost complete and we will be seeking funding for the new hardware in early 2019. A combined upgrade and addition of new receivers will then be possible to expand beyond the current 128T systems in intermediate steps (160T) towards a full 256T.

Advantages of the new correlator

- Proper fringe tracking and real-time voltage beams
- More flexible frequency and time resolution options, including sub 1-kHz frequency resolution
- The ability to perform much greater time and/or frequency averaging, which reduces the data rate out of the correlator
- Application of pseudo real-time calibration in the correlator
- Capacity to expand system to correlate all 256 tiles
- Capability to increase instantaneous bandwidth; optionally increase offered modes of operation (array beams and/or zoom modes)

NZ’s future in MWA

- New Zealand’s membership of the MWA expires on 31 December 2019
- In order to remain in the collaboration NZ would have to pay a new investment quantum of 500K AUD for the next phase of the project (~2-3 years).
- Note that from the MWA perspective NZ has purchased national membership of the MWA through the lead organization, VUW.
- This means NZ is entitled to up to 25 MWA Collaboration members. It is at the discretion of the lead organization if they wish to sponsor members from other NZ institutions.
- Note that this is how the Canadian and Chinese MWA memberships operate.

Summary

- MWA is the precursor telescope to SKA Low (same site, same infrastructure), not only does the MWA produce science in its own right, it is a vital piece of infrastructure for SKA Low design and prototyping work.
- MWA provides significant risk mitigation paths for SKA (antenna design, COTS-based software correlator, deployment and infrastructure advice).
- NZ has had a very significant role in the MWA to date
- NZ membership of MWA will expire at the end of this year. NZ has the option to continue but only with further investment.
- Happy to discuss: Director@mwatelescope.org
- http://www.mwatelescope.org