MWA OPERATIONS: LESSONS LEARNT

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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. *Demonstration of international cooperation in low frequency radio astronomy.*

- 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. (See Randall's talk yesterday).

- In 2017 the array was substantially upgraded to double the number of antennas to 4096 and to increase the maximum baseline to 5.3km, 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. *Note the cross section of SKA member countries.*

PARTNER INSTITUTIONS

- 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

MWA title positions: compact configuration (blue), extended baselines (orange)
Beardsley et al. (2019)

Snapshot, monochromatic
Compact configuration
Wayth et al. (2018)

Snapshot, monochromatic
Extended configuration
Wayth et al. (2018)

MWA SCIENTIFIC NICHES

- Wide FoV

- Diffuse Source Sensitivity

- Spectral Coverage

McKinnley et al. 2014

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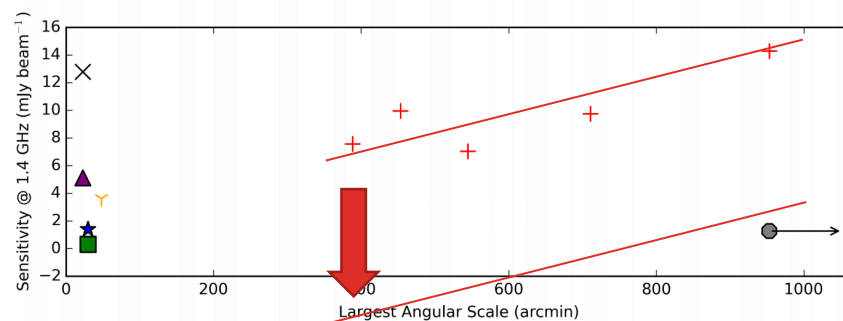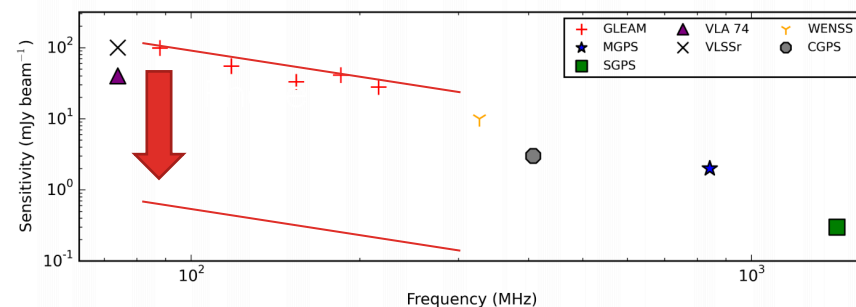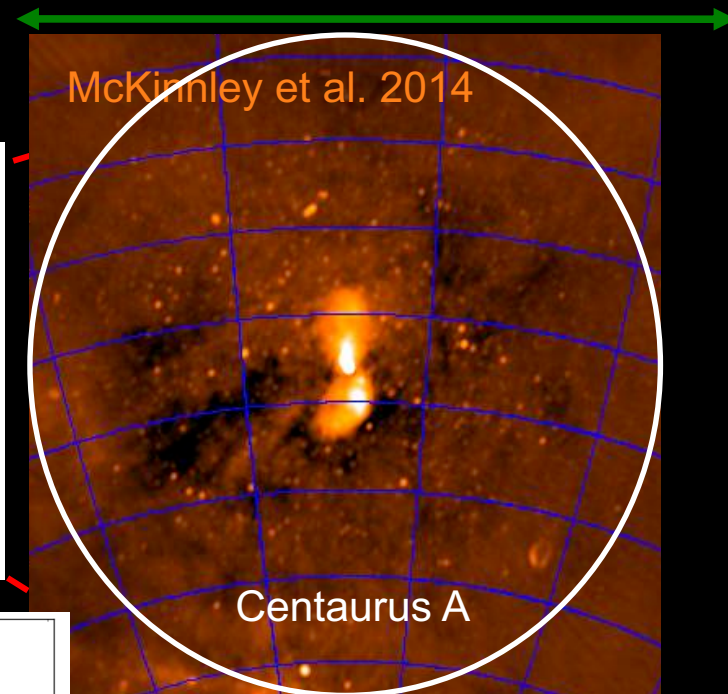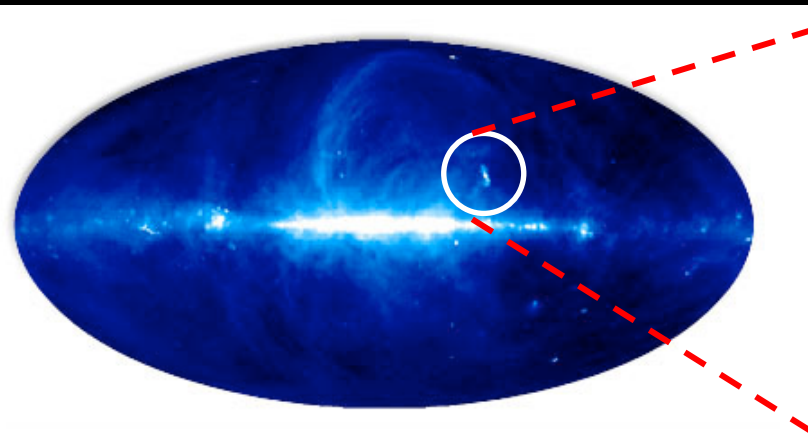
Figure 1. Top panel: this plot shows the logarithm of the frequency vs. sensitivity for low frequency Galactic surveys (< 1.4 GHz). Bottom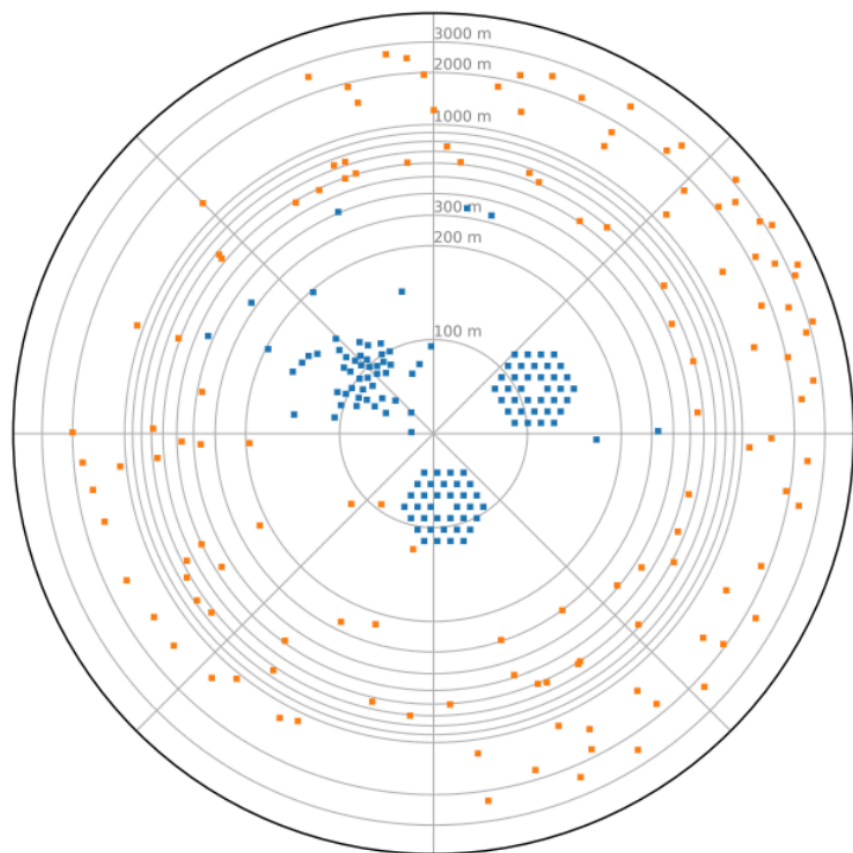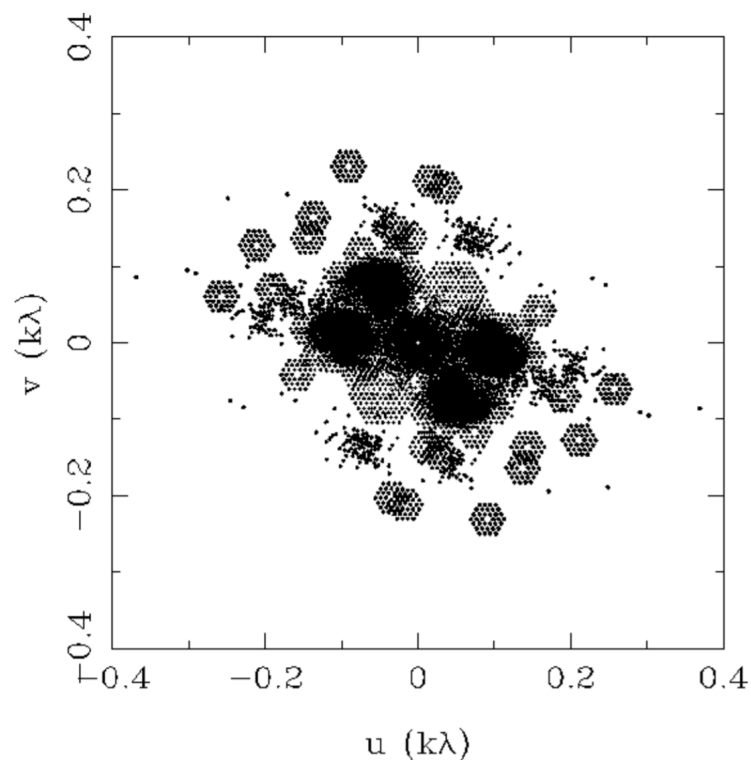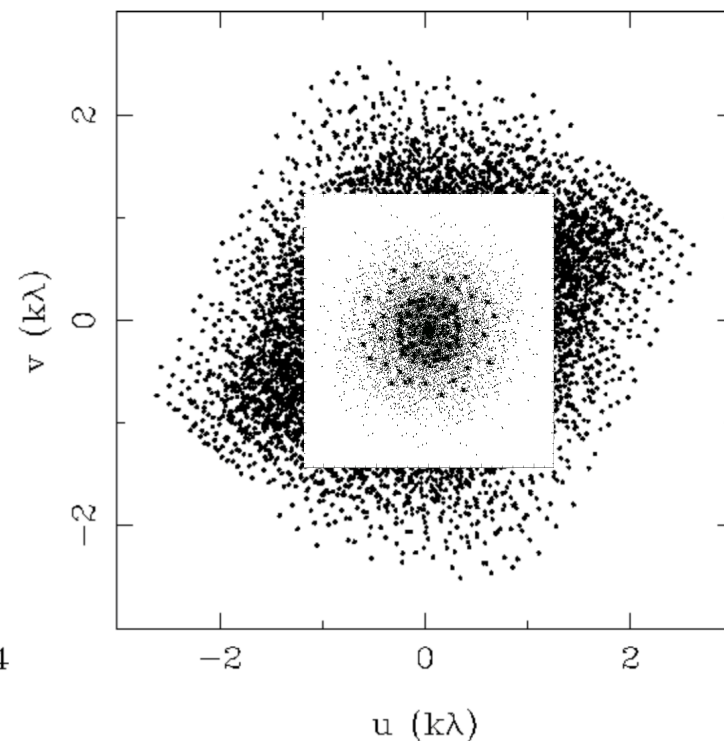 panel: the spatial sensitivity and corresponding sensitivity, scaled to 1.4 GHz assuming a spectral index of −0.7. The CGPS survey includes single dish data and so recovers all spatial information. The MWA provides both high sensitivity and access to a broader range of angular scales compared with previous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

Hindson, Johnston-Hollitt et al. (2016)
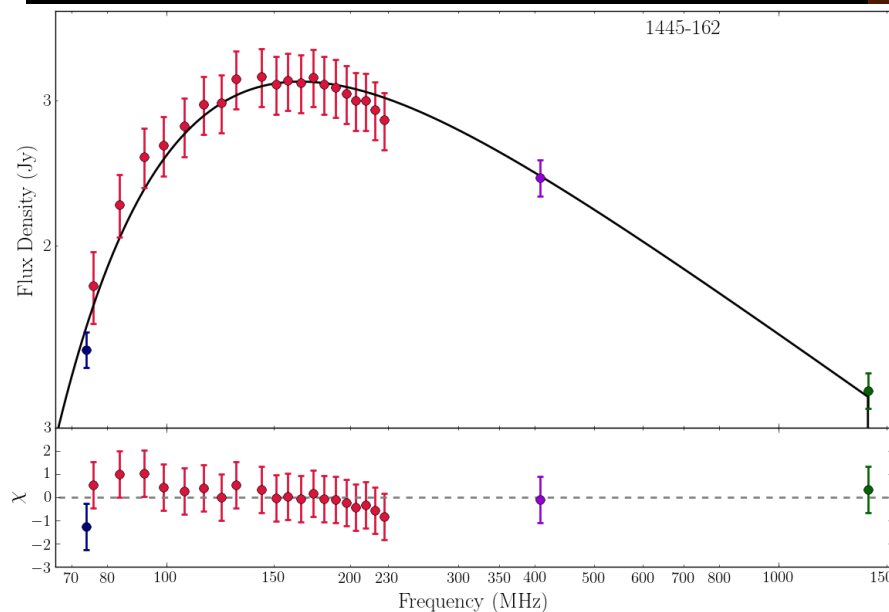
Callingham et al. (2017)

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

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!

OUTPUT

- 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 over 6000 citations, at a growing rate of citations per year with ~1600 citations being generated per year.
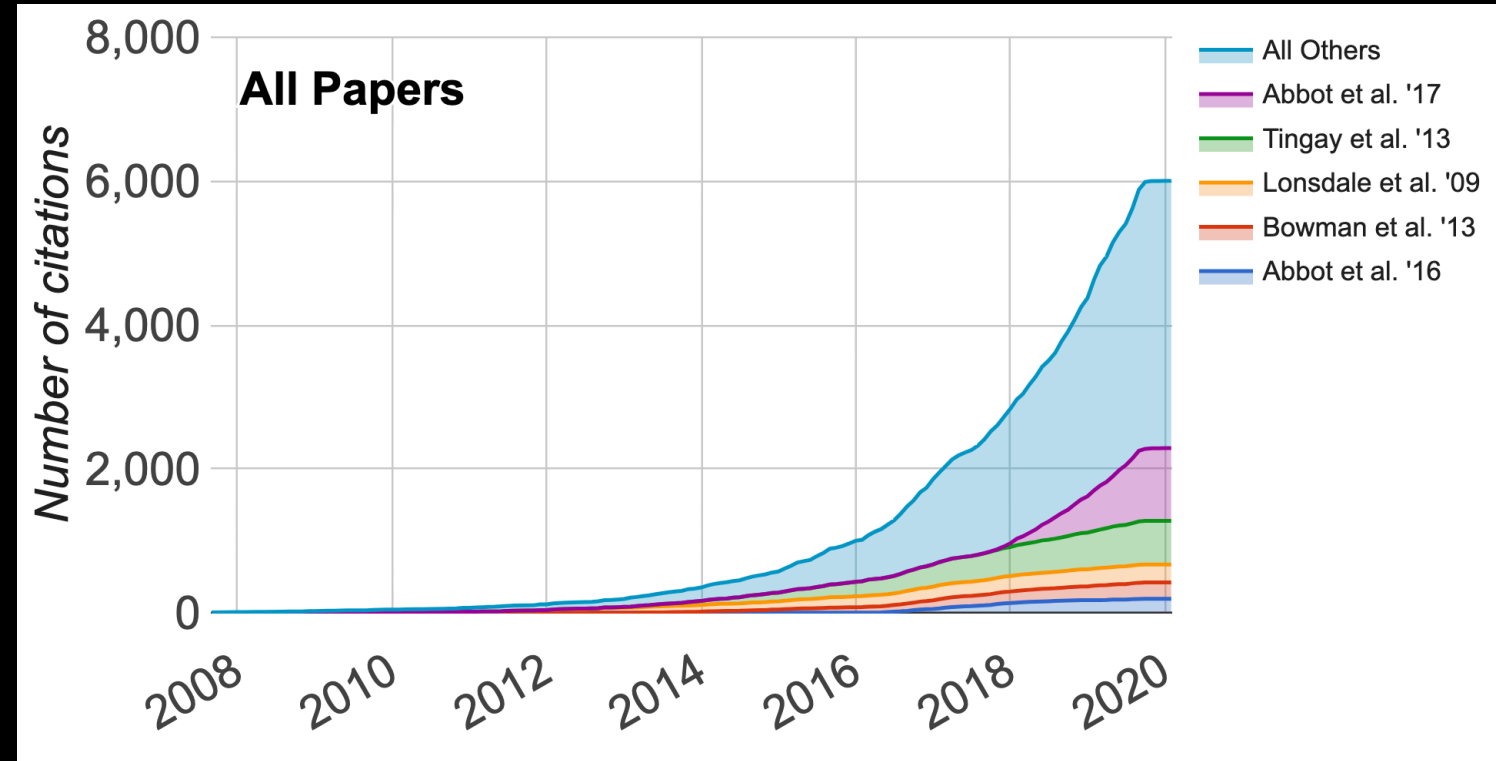
Considering the number of papers produced as a function of dollars spent on operations, MWA is the most cost effective radio telescope in the world

MWA OPERATIONS

- MWA operates a full end-to-end telescope from proposals, through to observations, to data service via the online ASVO portal.

- We are contractually obligated to provide 3000 hours of telescope time per annum in 2 semesters.

- Time is a mixture of Guaranteed Time (GT), Open Access (OA) and Director's Discretionary Time (DDT)

MWA Org Chart


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                              ┌──────────────────┐
                              │   MWA Director   │┄┄┄┄┄┄┄┄┄┄┄┄┄┄┄┄┄┄┄┄┄┄┄┄┄┄┄┄┄┄┄┄┄┐
                              │    (0.5 FTE)     │┄┄┄┄┄┄┄┄┄┄┄┄┄┐               ┊
                              └──────────────────┘             ┊               ┊
     ┌──────────────────┐              │                       ┊               ┊
     │  Admin. Assistant │──────────────┤          ┌─────────────┐  ┌─────────────┐  ┌──────────────────┐
     │    (0.5 FTE)     │              │          │   Program   │  │  Principal  │  │ Principal Scientist│
     └──────────────────┘              │          │   Manager   │  │  Engineer   │  │    (0.2 FTE)     │
     ┌──────────────────┐              │          │  (0.2 FTE)  │  │  (0.1 FTE)  │  └──────────────────┘
     │  Project Officer  │──────────────┤          └─────────────┘  └─────────────┘
     │    (0.8 FTE)     │              │
     └──────────────────┘              │
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| Hardware (0.8 FTE) | Fieldwork Coord. (0.8 FTE) | Data + Archive (0.8 FTE) | M&C (0.8 FTE) | ASVO (1.0 FTE) |
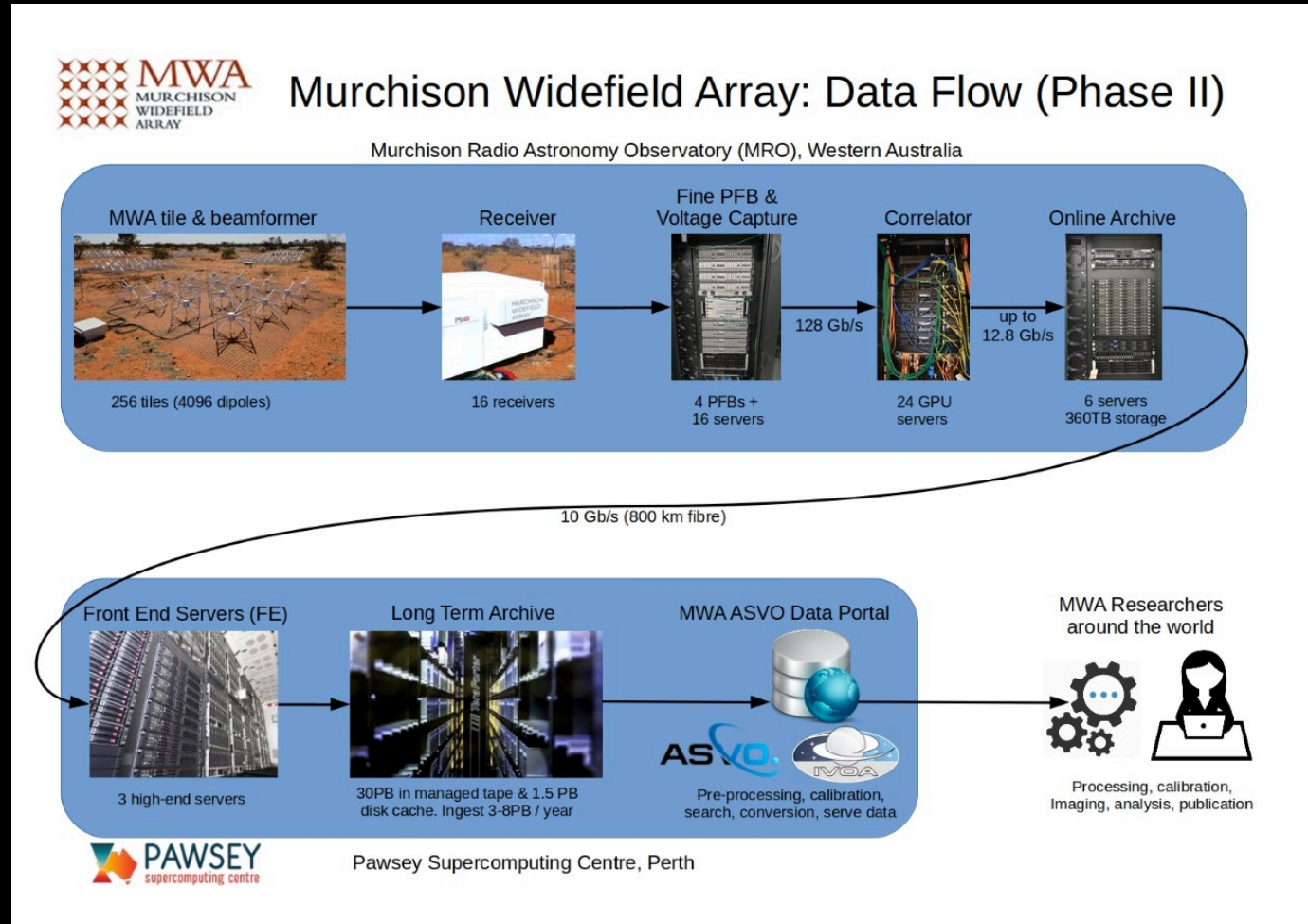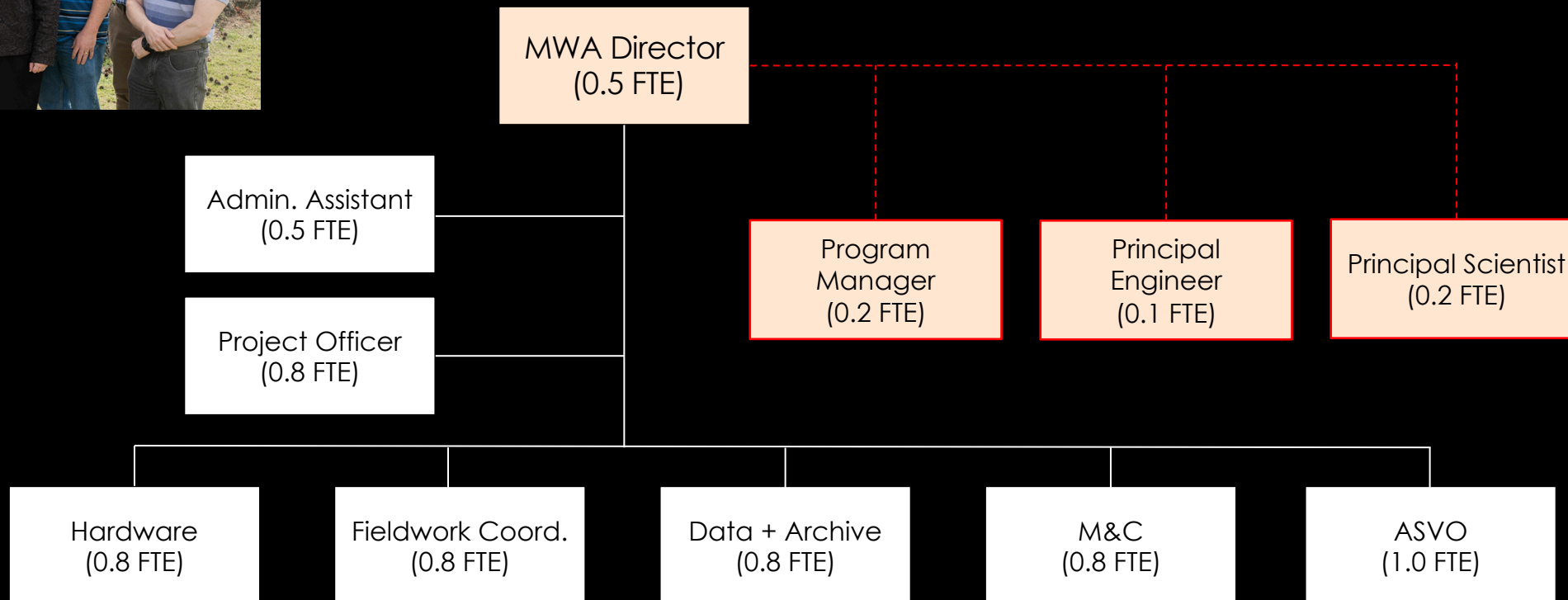
The structure of the MWA Management and Operations Personnel showing contribution to the MWA as well as line management (solid lines) and reporting line (red dashed line). Management are shown in orange shaded boxes, while operations personnel are in white boxes. The total FTE to operate the MWA is only 6.5

RECONFIGURATIONS & MAINTENANCE

- Geraldton company G.Co Electrical was engaged to assist with the Phase II upgrade.

- Following this they were contracted for the maintenance and re-configurations under supervision. Run as a standard contract for a number of hours per annum which can be flexibly deployed.

- This is the result of a long-standing relationship between MWA/Curtin and G.Co which has been enormously successful.

G.Co Electrical staff during the long baseline installation for Phase II

LESSONS FROM MWA OPERATIONS

- **Lesson 1**: Start. Don't waiting until your system is complete, start doing science as soon as you have an instrument capable of producing publishable results.

- **Lesson 2**: Let science teams have early access to the data. This is enormously important with debugging both the instrument and the pipelines.

- **Lesson 3**: Telescopes with no moving parts are low maintenance, you do not need massive support teams to run them.

- **Lesson 4**: Engage local contractors for support. Win-win. BUT you need to engage them early and over a long period.

- **Lesson 5**: Understand possible issues on site and update the Board/Management on risk to ensure no delays.

- So MWA completed the GLEAM survey (Wayth et al. 2015) which covered the sky south of + 30 in 5 frequency bands (70 – 230 MHz). These were processed individually to make 5 x 30 MHz images and also each band was sub-divided into 4 to give 20 x 7.5 MHz channels. The AEGEAN Software (Hancock et al. 2012) was used to generate an extra-galactic catalogue (Hurley-Walker et al. 2017)

- Two errors since found:1) running self-cal on only one channel results in an artificial flattening of the spectral indices across the sub-bands (the 30 MHz bands are fine) and 2) a bug in the AEGEAN software which results in a radial error in flux density from zero at the centre of an image to up to 10% at the edge. This was factored into the error estimates but no one knew why.
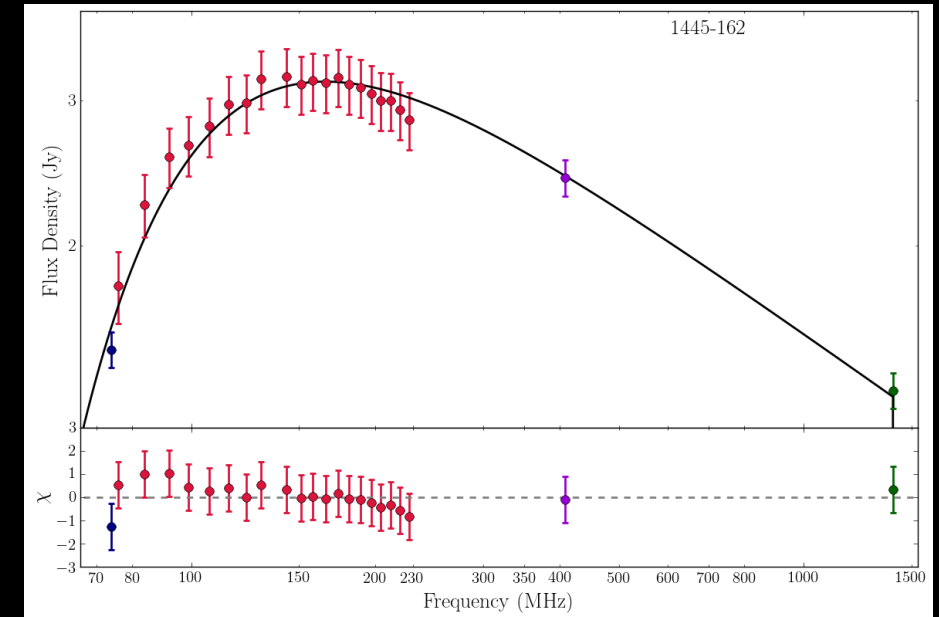
Lesson 6: Your first pipeline will be wrong! Probably in multiple ways. Get as many people as possible to debug it.

Lesson 7: Expect to need to re-process initial data. Note will take several years.

SERVING DATA

- Serving data as close to science ready to the community greatly facilitates science.

- The MWA uses the Australia All-Sky Virtual Observatory (ASVO)

Murchison Widefield Array ASVO Pilot
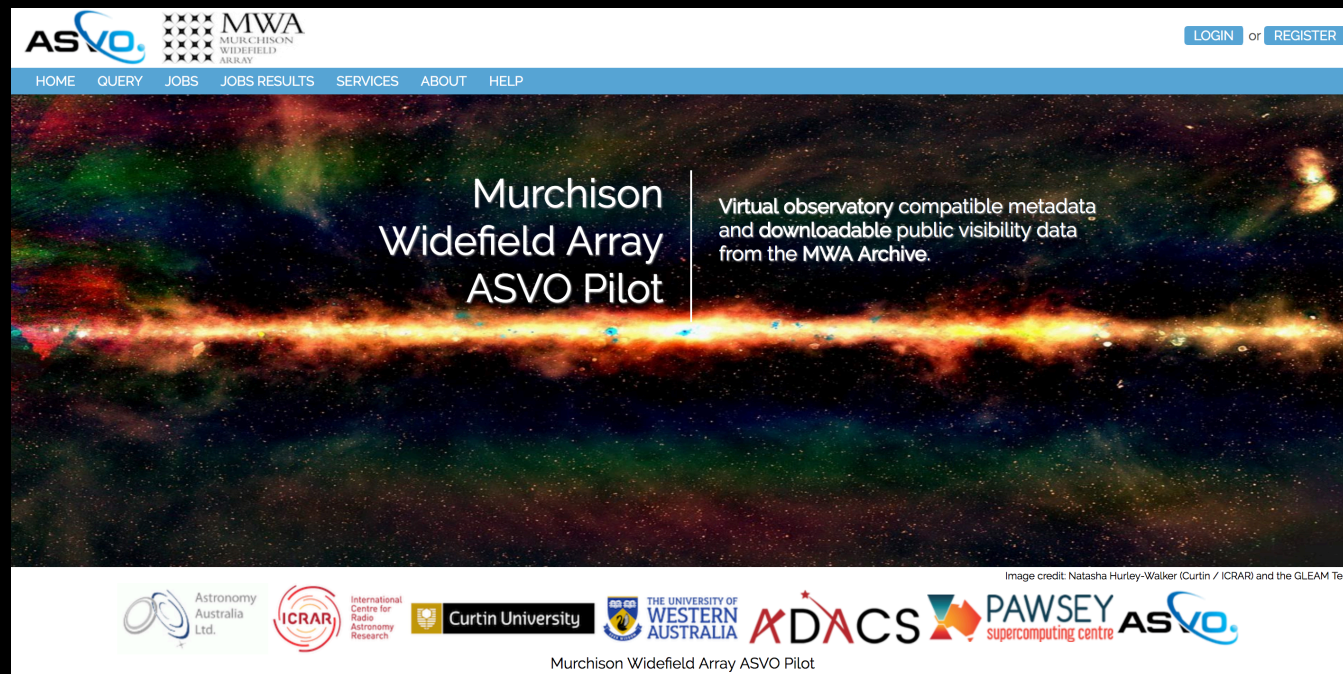
33 PB of Data in the Archive

Jobs completed: 55,328
Data served out: 1,532 TB
Users registered: 312
MWA: public 142:170, active 62:42

Now serves calibrated visibilities!

SERVING DATA

- The ASVO removes the need for people to be experts in MWA imaging. You can now take the calibrated MWA data from the archive and run it through your favourite radio imaging package.

- This provides MAXIMUM flexibility for science.

- Have seen a large increase in the number of public users of MWA data in the last 9 months now that calibrated data is available. Roughly 40% of active users at present are not MWA collaboration members

LESSON 8: To maximise science you want to serve data as close to science ready as possible BUT without restricting scientific opportunities. It's important to consider this balance.

INTEROPERABILTY

- There is an enormous advantage in having the right tools to compare data from one telescope to another.

- In MWA's case as one of several ASVO nodes, the others covering GWs, theoretical data/simulations and optical data, there has been a push to maximise interoperability.

- However, we are under resourced and the push is not always driven by science.

LESSON 9: Do not go crazy on interoperability!

LESSON 10: Do not reinvent the wheel, ensure the full international resources are used.

LESSON 11: Do not develop features which are not actually useful for science.

SCALABILITY: CHALLENGES OF WIDEFIELD IMAGING

- One of the looming issues for radio astronomy in this enormous data regime is to have scalable processing.

- Fields are so large they cannot be approximated as flat, need to understand projection/spherical imaging

- The ionosphere distorts the incoming waves and this distortion is not the same across the image leading to direction dependent effects

- Large fields of view require lots of pixels, increasing data .

- Need HPC to process.

- However, traditional imaging techniques for radio astronomy break down and do not scale.

A Fast and Exact w-stacking and w-projection Hybrid Algorithm for Wide-field Interferometric Imaging

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[2] International Centre for Radio Astronomy Research (ICRAR), Curtin University, 1 Turner Ave., Technology Park, Bentley, 6102, WA, Australia

Abstract

The standard wide-field imaging technique, the w-projection, allows correction for wide fields of view for non-coplanar radio interferometric arrays. However, calculating exact corrections for each measurement has not been possible due to the amount of computation required at high resolution and with the large number of visibilities from current interferometers. The required accuracy and computational cost of these corrections is one of the largest unsolved challenges facing next-generation radio interferometers such as the Square Kilometre Array. We show that the same calculation can be performed with a radially symmetric w-projection kernel, where we use one-dimensional adaptive quadrature to calculate the resulting Hankel transform, decreasing the computation required for kernel generation by several orders of magnitude, while preserving the accuracy. We confirm that the radial w-projection kernel is accurate to approximately 1% by imaging the zero-spacing with an added w-term. We demonstrate the potential of our radially symmetric w-projection kernel via sparse image reconstruction, using the software package PURIFY. We develop a distributed w-stacking and w-projection hybrid algorithm. We apply this algorithm to individually correct for non-coplanar effects in 17.5 million visibilities over a 25 by 25 degree FoV Murchison Widefield Array observation for image reconstruction. Such a level of accuracy and scalability is not possible with standard w-projection kernel generation methods. This demonstrates that we can scale to a large number of measurements with large image sizes while still maintaining both speed and accuracy.

Key words: techniques: image processing – techniques: interferometric – methods: data analysis

Pratley, L., Johnston-Hollitt, M., McEwen, J. D., 2019, Astrophysical Journal, 874, 174, arXiv:1807.09239

CHALLENGES OF WIDEFIELD

- Step 1 is developing new algorithms

- Step 2, which is often missed, is making them efficient.

- Step 1 can be done by radio astronomers, Step 2 generally cannot unless they have a background in HPC as well. The number of people with the required background in both is extremely small.

w-stacking *w*-projection hybrid algorithm for wide-field interferometric imaging: implementation details and improvements

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[2]International Centre for Radio Astronomy Research (ICRAR)- Curtin University, 1 Turner Ave, Bentley, 6102, WA, Australia
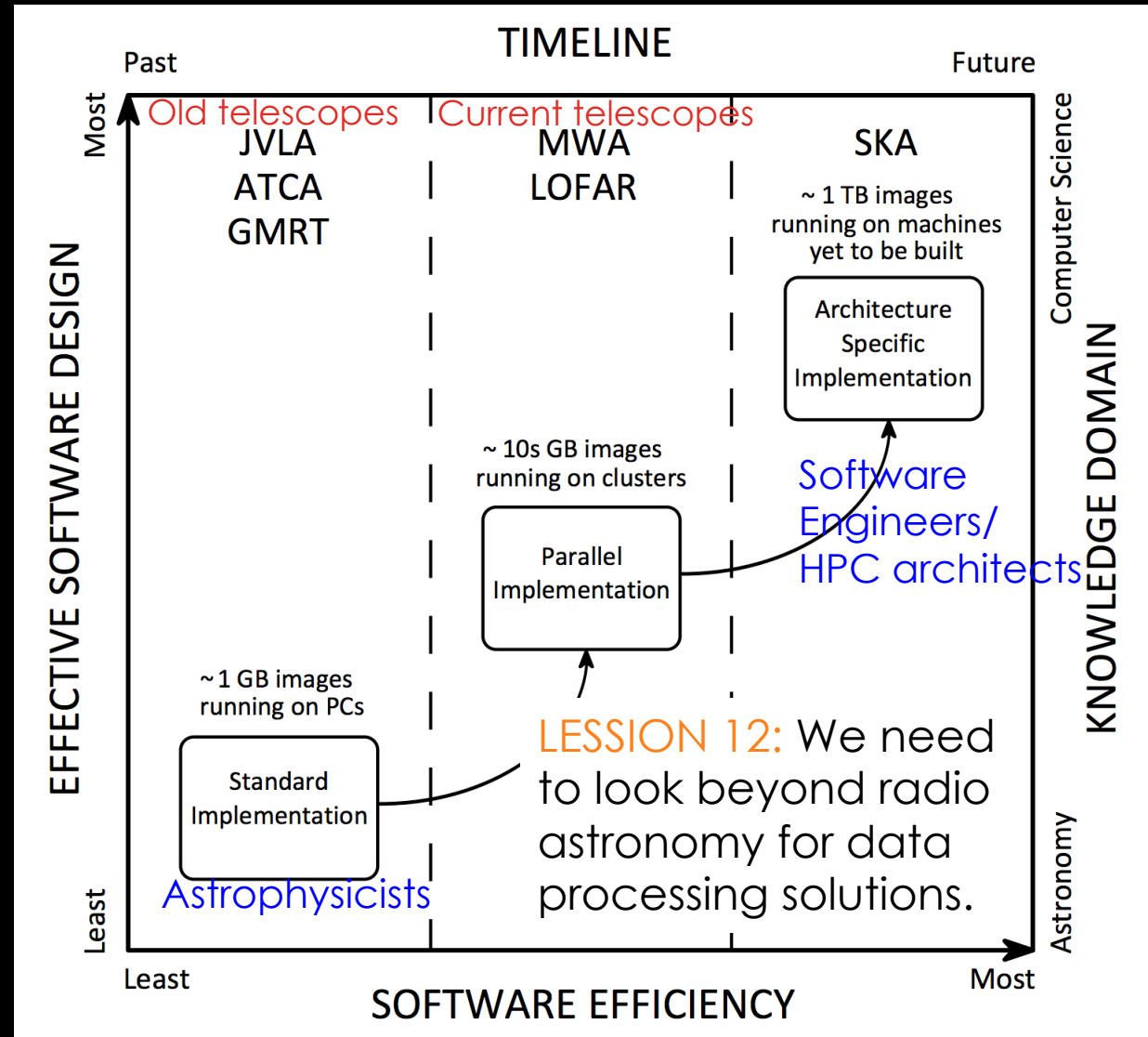
Abstract

We present a detailed discussion of the implementation strategies for a recently developed *w*-stacking *w*-projection hybrid algorithm used to reconstruct wide-field interferometric images. In particular, we discuss the methodology used to deploy the algorithm efficiently on a supercomputer via use of a Message Passing Interface (MPI) *k*-means clustering technique to achieve efficient construction and application of non co-planar effects. Additionally, we show that the use of conjugate symmetry can increase the *w*-stacking efficiency, decreasing the time required to construction and apply *w*-projection kernels for large data sets. We then demonstrate this implementation by imaging an interferometric observation of Fornax A from the Murchison Widefield Array (MWA). We perform exact non-coplanar wide-field correction for 126.6 million visibilities using 50 nodes of a computing cluster. The *w*-projection kernel construction takes only 15 minutes prior to reconstruction, demonstrating that the implementation is both fast and efficient.

Pratley, L., Johnston-Hollitt, M., McEwen, J., Publications of the Astronomical Society of Australia (submitted) arXiv:1903.06555

- In addition to better algorithms, their efficiency and implementation must be considered.

- Radio astronomers are so wedded to their traditional imaging processing techniques, that when considering how to deal with the data flow from new telescopes they want to make the HPC architecture fit the old algorithm.

- Rather, we need to work with HPC specialists to ask 'how can we improve scalability and performance using available HPC architectures?'

TIMELINE

Past — Future

Old telescopes — Current telescopes

JVLA — MWA — SKA
ATCA — LOFAR
GMRT

~ 1 TB images running on machines yet to be built

Architecture Specific Implementation

~ 10s GB images running on clusters

Software Engineers/ HPC architects

Parallel Implementation

~ 1 GB images running on PCs

LESSION 12: We need to look beyond radio astronomy for data processing solutions.

Standard Implementation

Astrophysicists

EFFECTIVE SOFTWARE DESIGN — Most / Least

SOFTWARE EFFICIENCY — Least / Most

KNOWLEDGE DOMAIN — Computer Science / Astronomy

SUMMARY

- So Melanie's 21 Lessons from the MWA.

- They speak to a field that has matured enough to expand and work with others rather than doing it all ourselves: be that contractors, or HPC specialists.

- All of these things are human problems.

- If we can do this than we can get to better science faster.

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