

Pulsar Astronomy with the Murchison Widefield Array (MWA)



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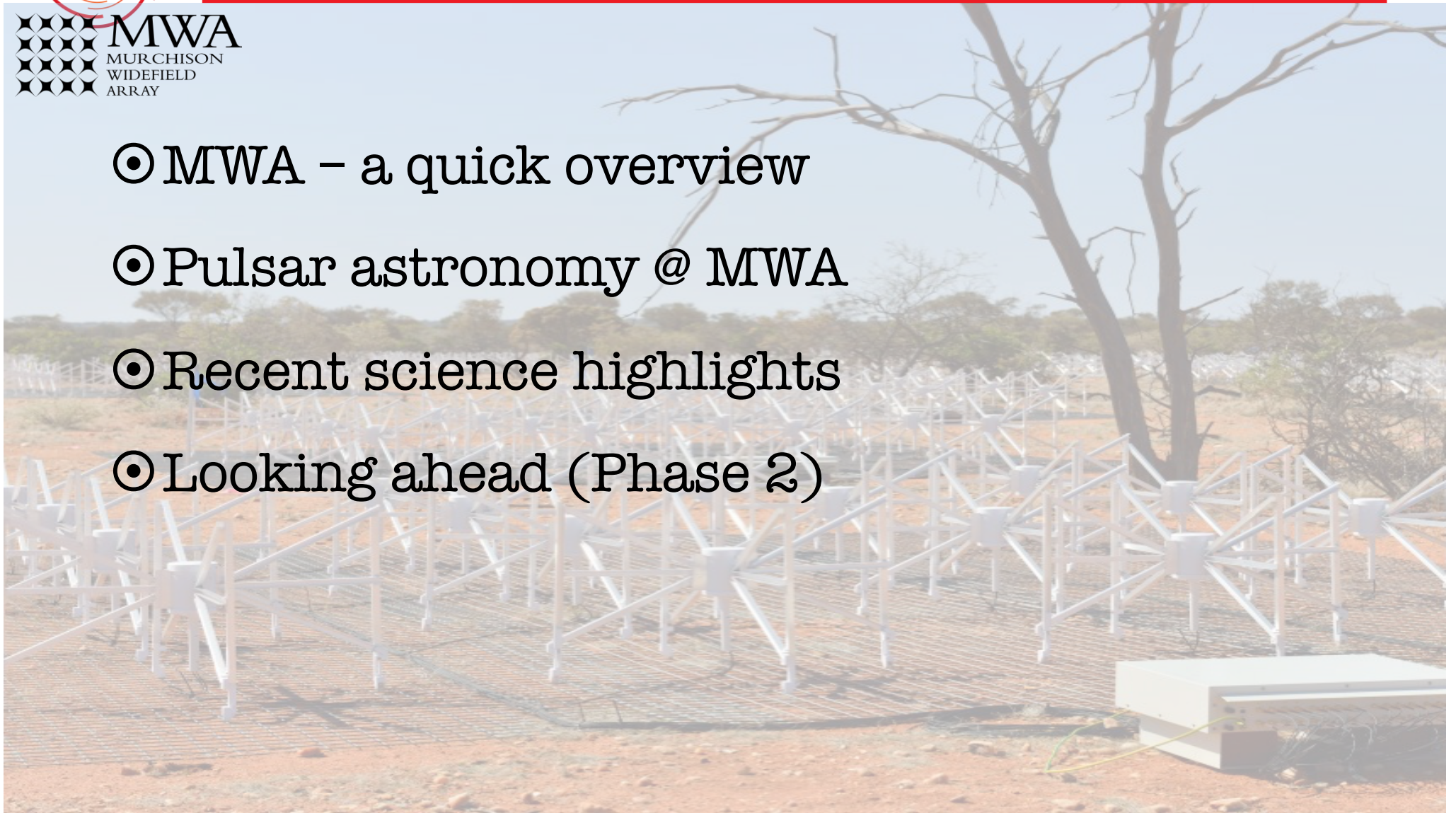
@ APRIM2017, Taipei, Taiwan, 3 – 7 July 2017



Outline



- ◎ MWA – a quick overview
- ◎ Pulsar astronomy @ MWA
- ◎ Recent science highlights
- ◎ Looking ahead (Phase 2)



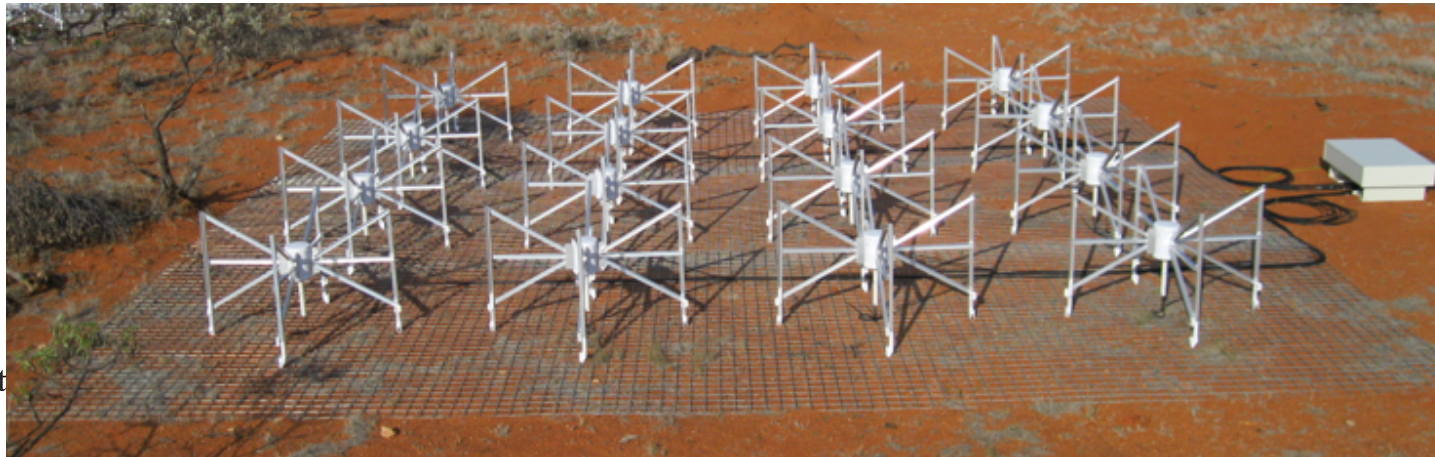
The Murchison Widefield Array

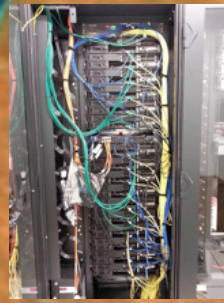


GOVERNMENT OF WESTERN AUSTRALIA



Australian Government





Murchison Shire Boundary

MRO (operated by CSIRO)

On site: data rate into central building ~60 Gbps

41,000 sq. km = The Netherlands

Population density = 0.002 people/sq. km

Geraldton

Off site: data rate into science archive ~3 Gbps (via 10 Gb link)

~200 km

Perth



Pawsey Centre 20 PB storage for MWA archive



Observing & Data Archiving



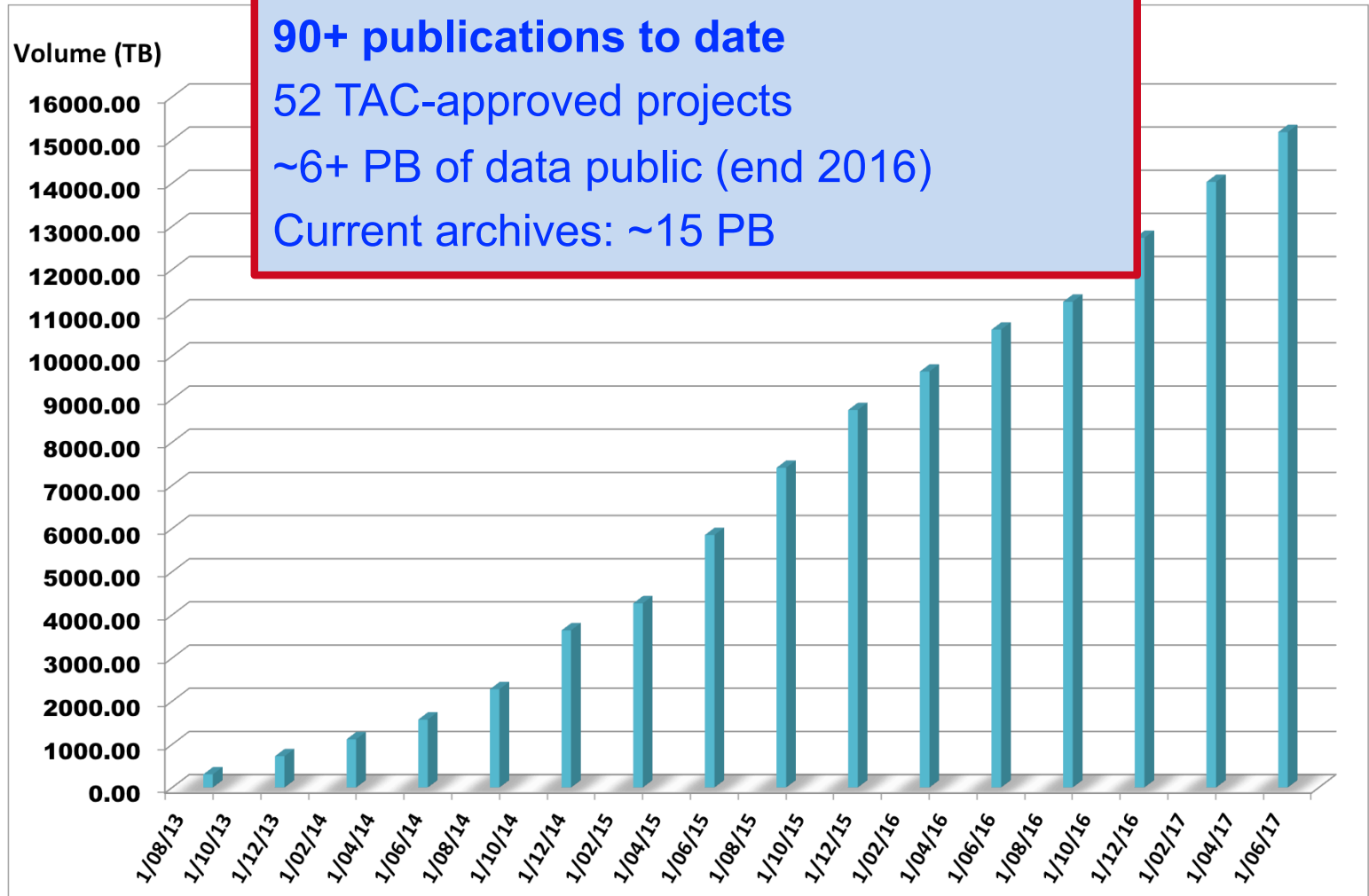
Science operations since 2013B

90+ publications to date

52 TAC-approved projects

~6+ PB of data public (end 2016)

Current archives: ~15 PB



A wide range of science: Epoch of Reionization, Galactic and Extragalactic, Transients, Solar, Pulsars)



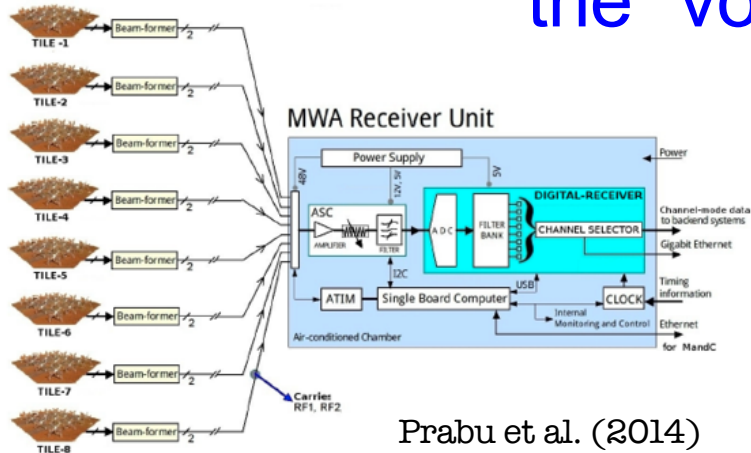
Pulsars with the MWA



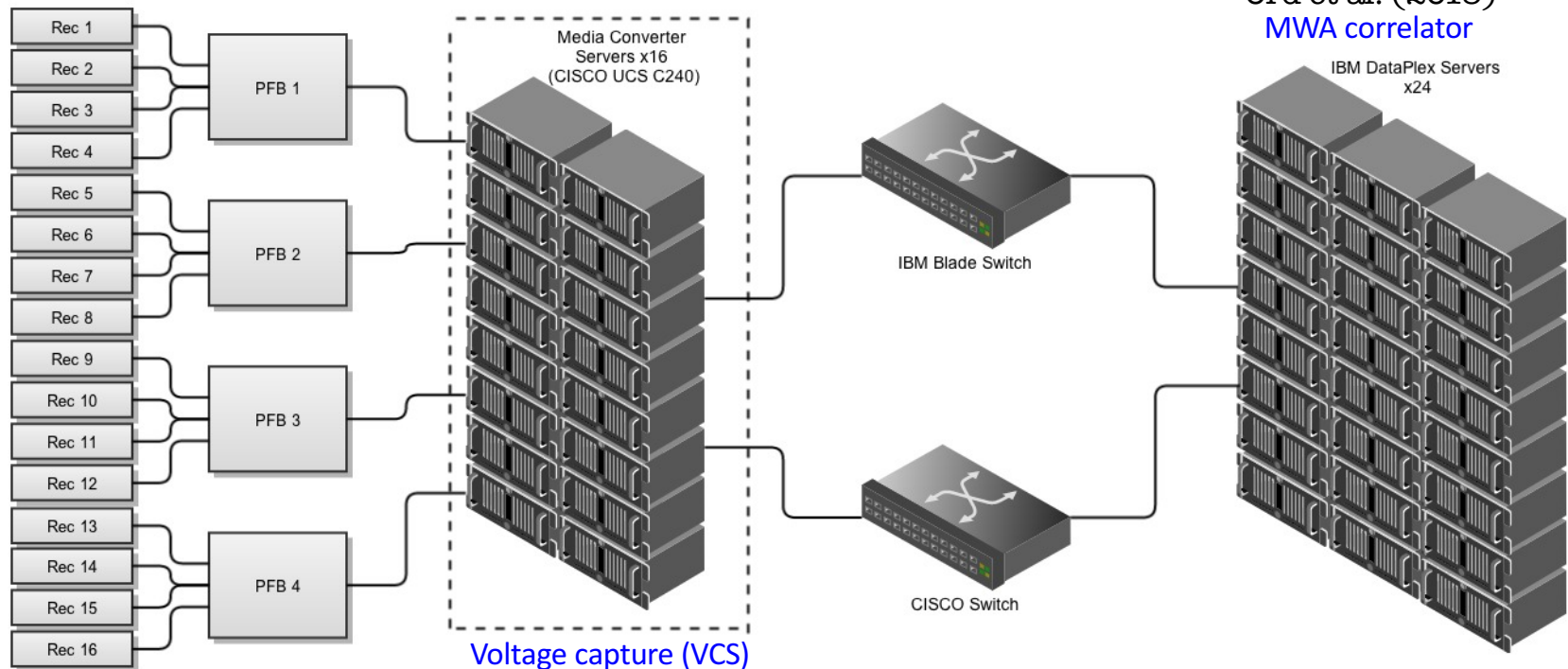
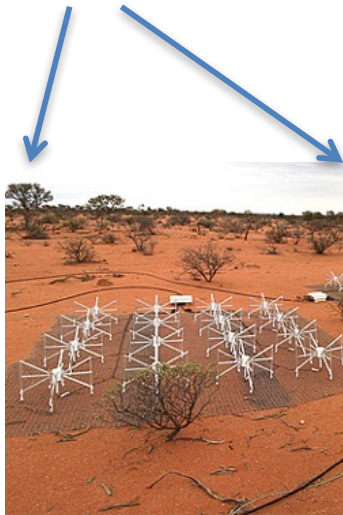


Pulsar observing @ the MWA

the "voltage capture" (VCS) way



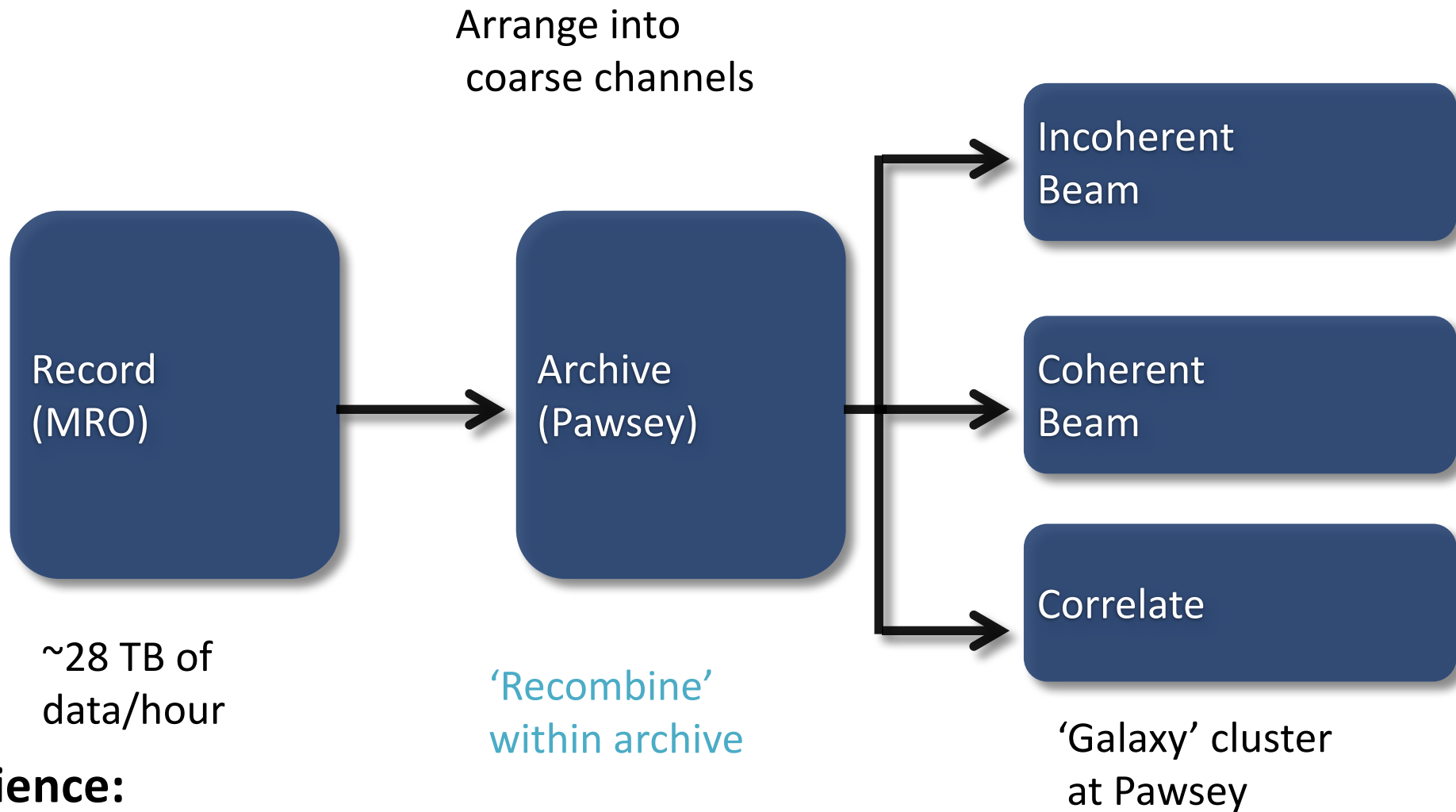
- VCS mode: a functionality to capture raw voltages streaming into the correlator, from **ALL 128 tiles**, at 100-us, 10-kHz resolutions, over a BW = 30.72 MHz
- Aggregate data rate = 24 x 242 MBps (or 7.8 GBps) = **28 TB per hour!**



Tremblay et al. (2015)



VCS Data Processing



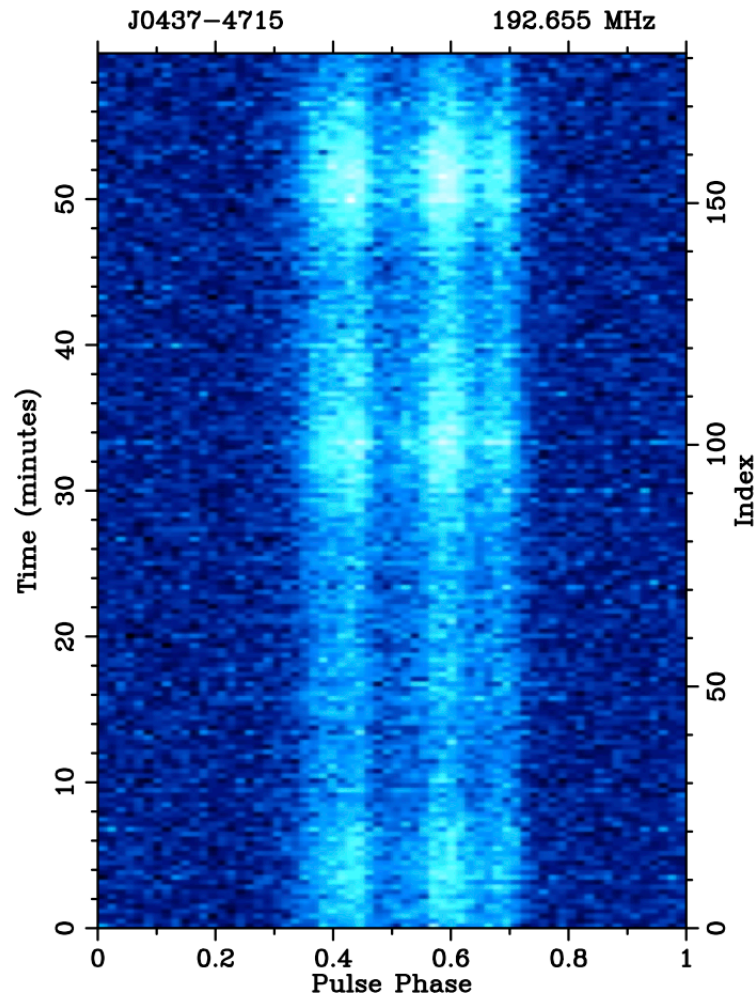
Science:

Pulsars, Fast Transients, FRBs, spectral lines, SETI, passive radar. etc.

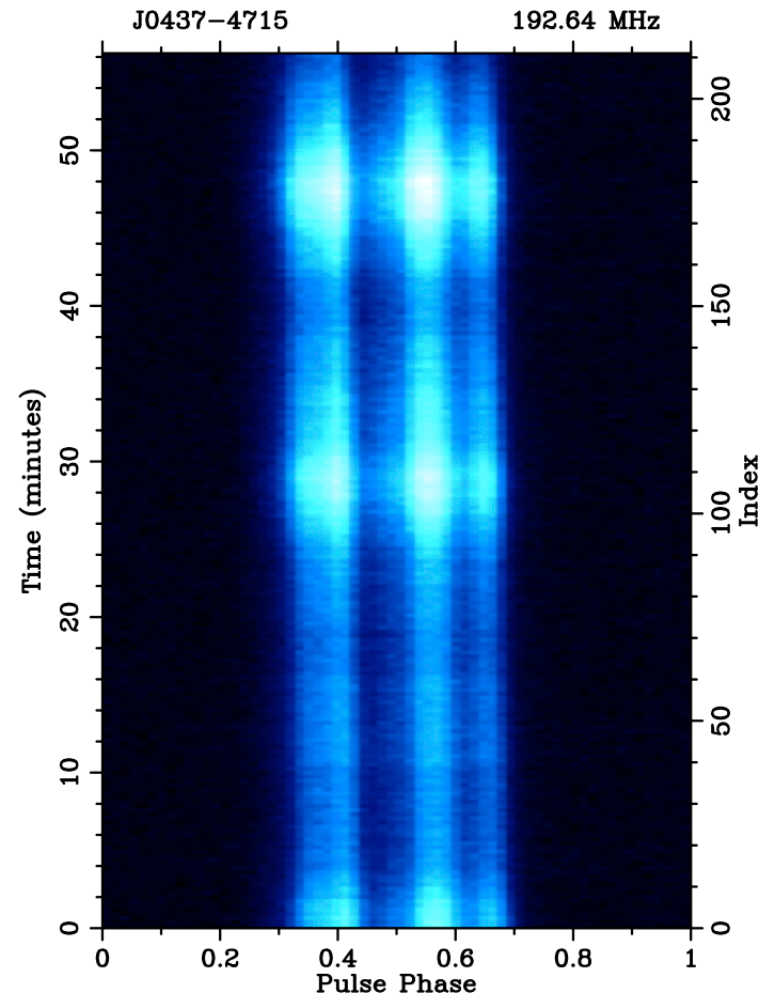


Coherent beam \rightarrow 10 x improved sensitivity

PSR J0437-4715 @ MWA 200 MHz



Incoherent addition of all 128 tiles



Coherent addition of 126 tiles

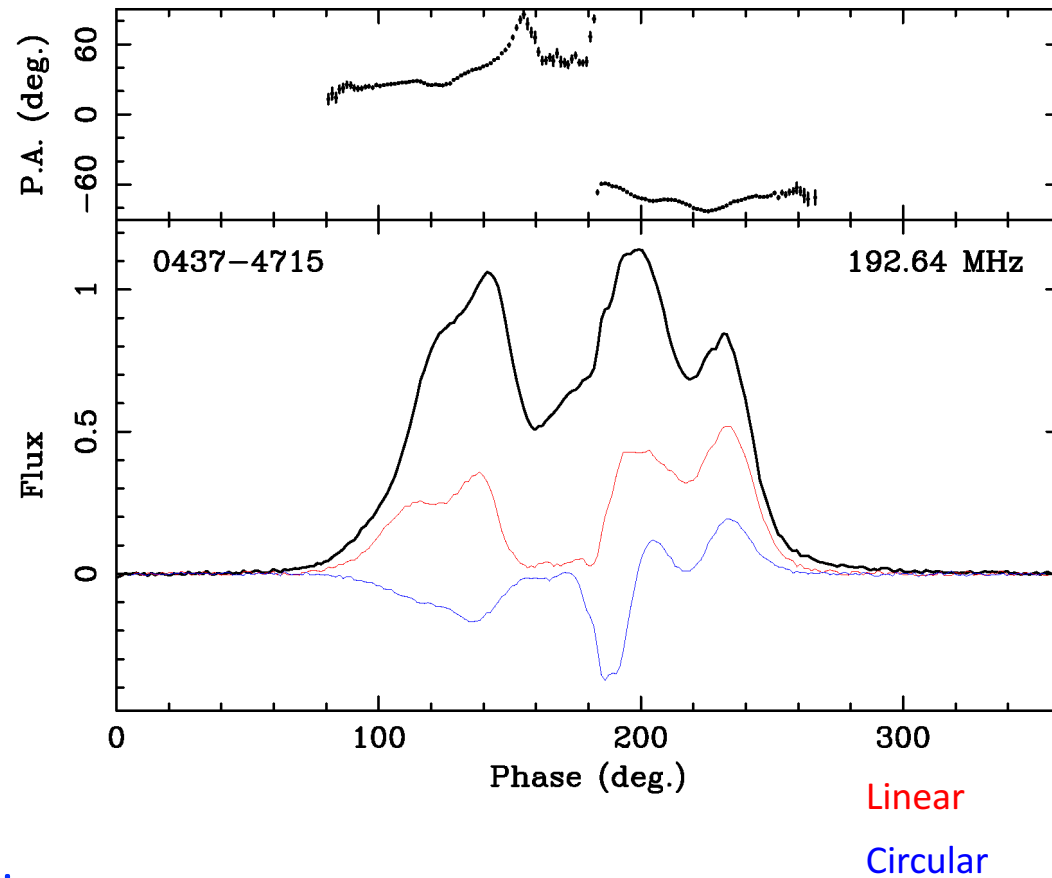
Bhat et al. (2016)



Coherent beam → polarimetry + high time resolution

Ord et al. (2016) in prep.

PSR J0437-4715 MWA @ 200 MHz



Work in progress:

Verification exercise using common targets with Northern telescopes (e.g. LOFAR stations and the GMRT)



Early Science Publications

⊙ From Commissioning data:

- ⊙ *The low-frequency characteristics of PSR 0437-4715 with the MWA*
Bhat et al. (2014)
- ⊙ *The high time and frequency resolution capabilities of the MWA*
Tremblay et al. (2015)
- ⊙ *Simultaneous observations of Crab giants with the MWA and Parkes*
Oronsaye et al. (2015)
- ⊙ **Scintillation arcs** in the low-freq. observations of MSP J0437-4715
Bhat et al. (2016)

⊙ New and upcoming publications:

- ⊙ *Low-frequency observations of the **sub-pulse drifter** PSR J0034-0721*
McSweeney et al. (2017)
- ⊙ *Evidence for a spectral flattening at low frequencies in **Crab giants***
Meyers et al. (2017) – under collaboration review
- ⊙ *Wide-band observations of **millisecond pulsars***
Bhat et al. (2017) – in prep.
- ⊙ *A **census** of southern pulsars at 185 MHz*
Xue et al. (2017) – under collaboration review
- ⊙ **First fringes** between the MWA and the GMRT at 160 MHz
Kirsten et al. (2017) – in prep.

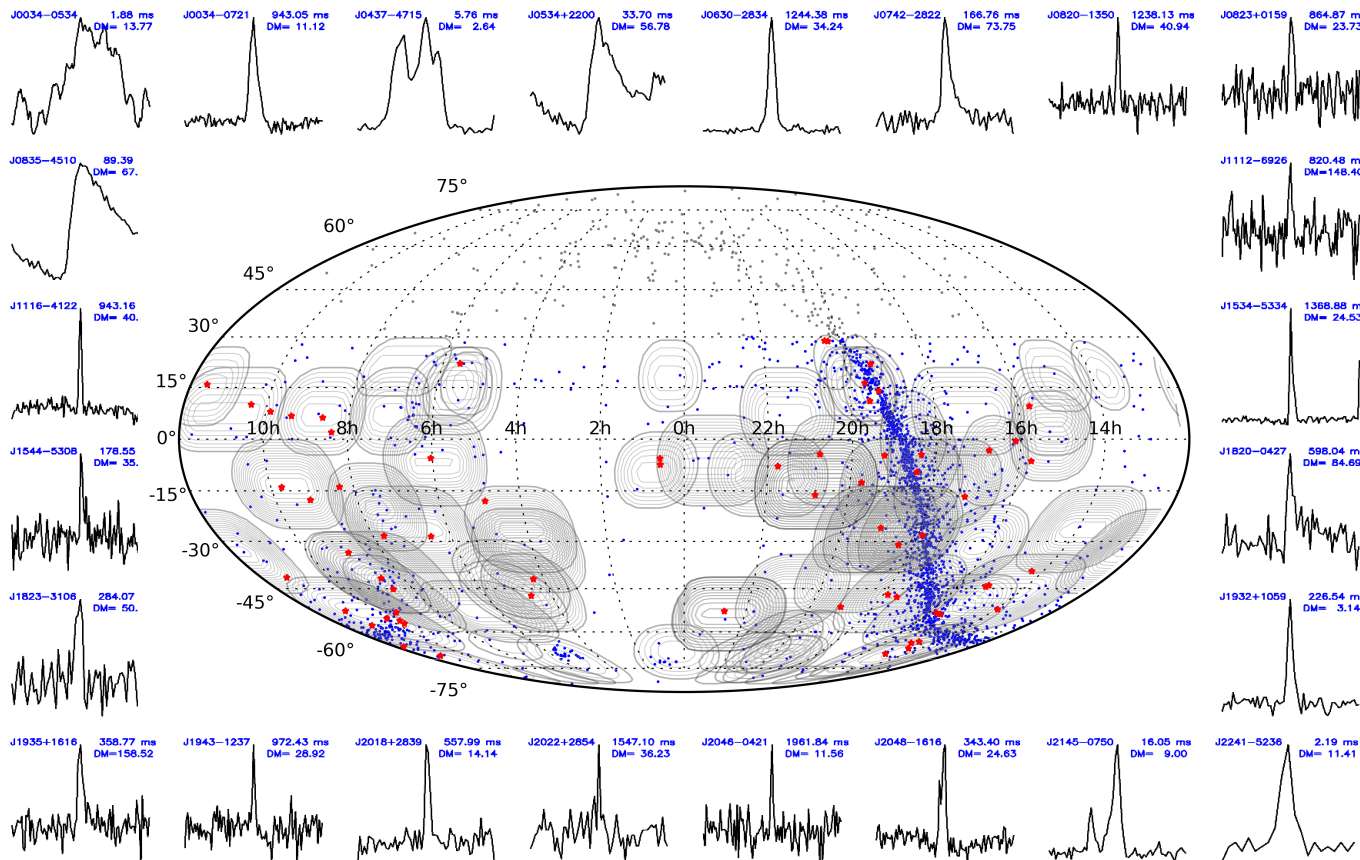


Low-frequency Census of Southern Pulsars

Exploitation of the LARGe field of view (~300 – 600 deg²)

Objects Cataloged pulsars

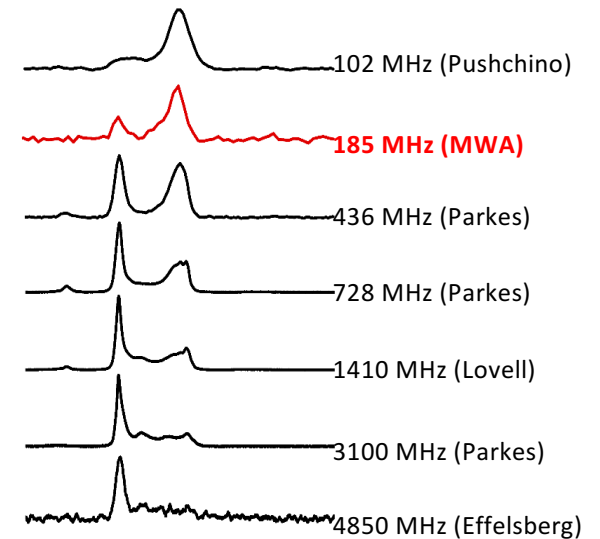
Data Incoherently summed MWA-VCS archival data



Mengyao Xue
(PhD student)

PSR J2145-0750

From 100 MHz to 4850 MHz



First pass:

65 pulsars from processing **44 hr** of observations including 6 millisecond pulsars (MSPs) and 2 binaries

Period range:

1.74 to 1960 ms

DMs out to ~ 180

pc cm⁻³

Xue, Bhat, et al. (2017) under collab. Review

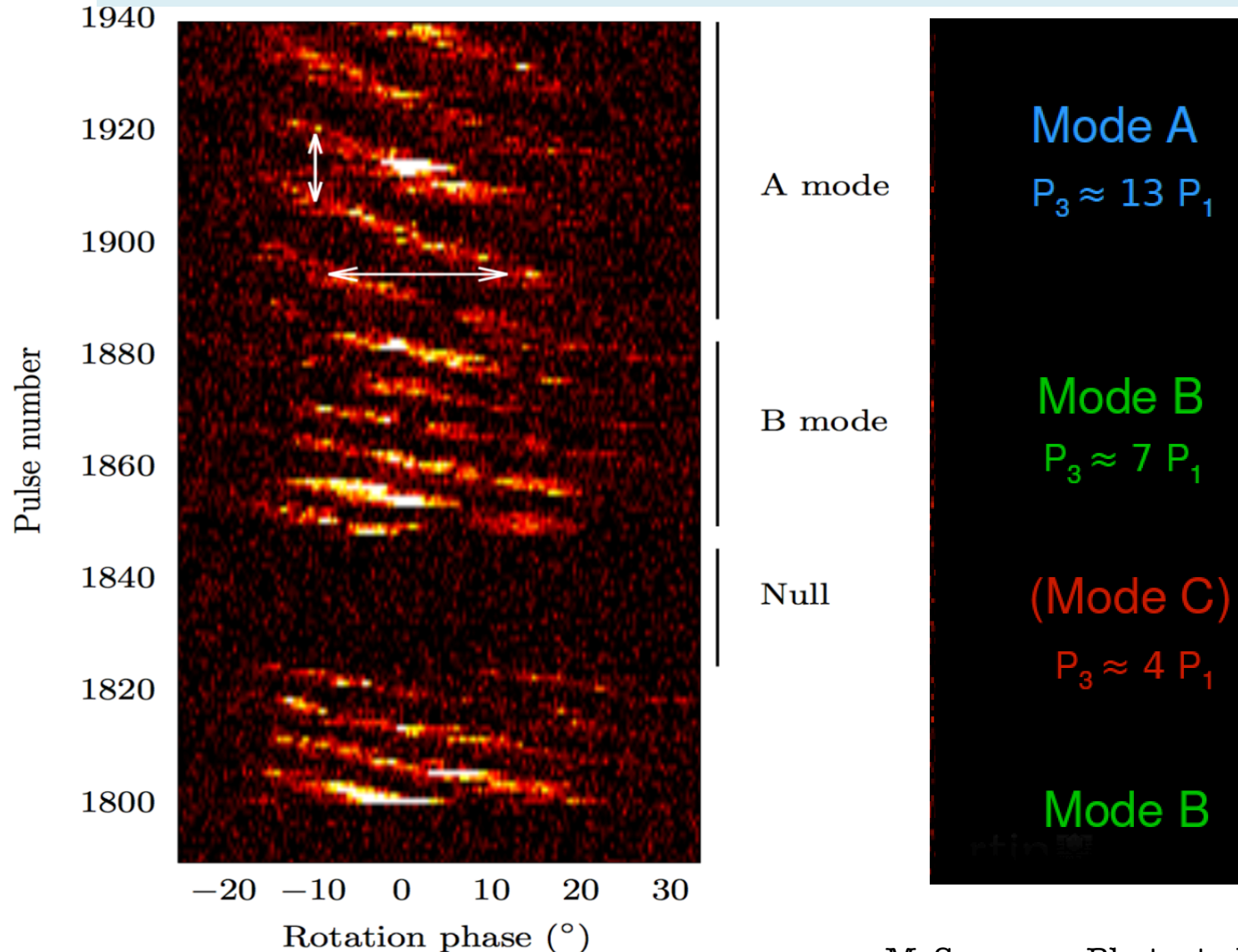


Sub-pulse Drifting in PSR J0034-0721

High time resolution (~ms) and high sensitivity



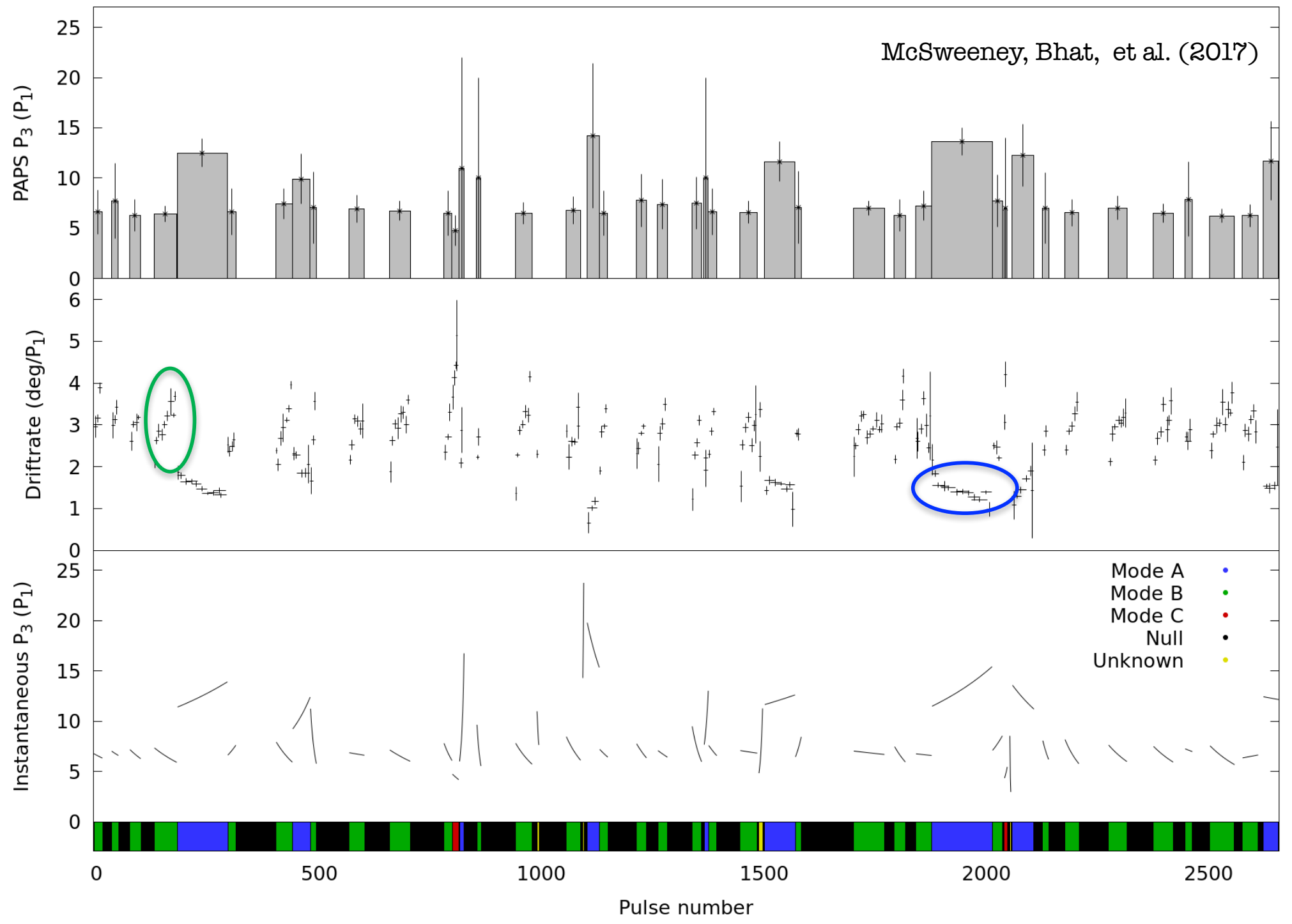
Sammy McSweeney
(PhD student)



MWA observations at 185 MHz

McSweeney, Bhat, et al. (2017), ApJ, 836, 224

McSweeney, Bhat, et al. (2017)



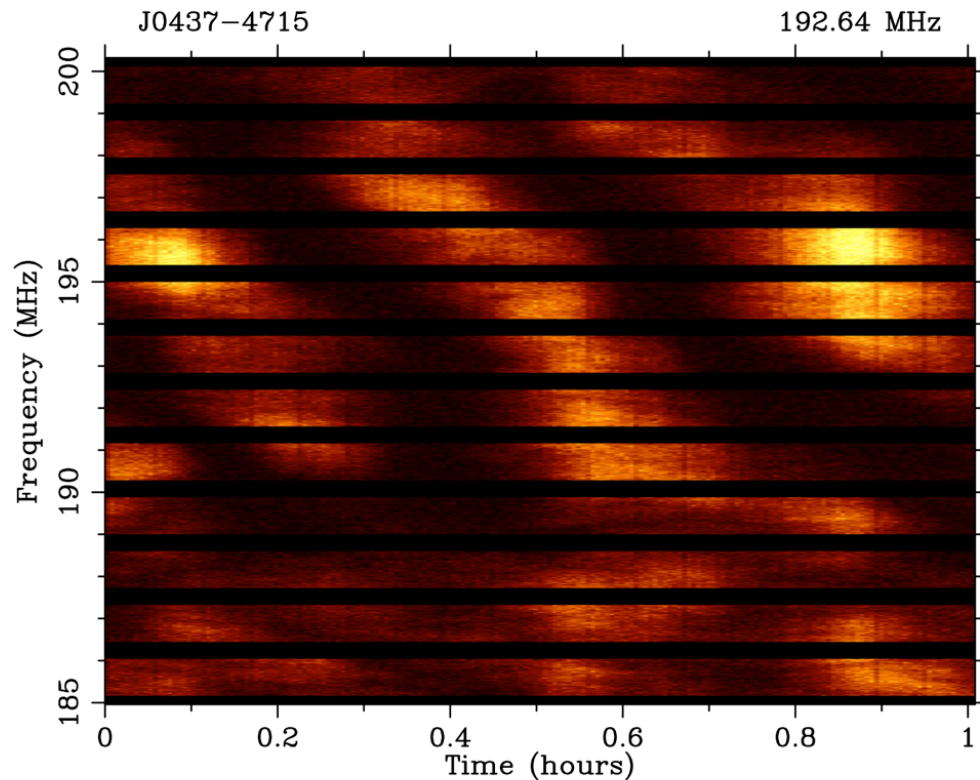


Scintillating Millisecond Pulsars @ MWA

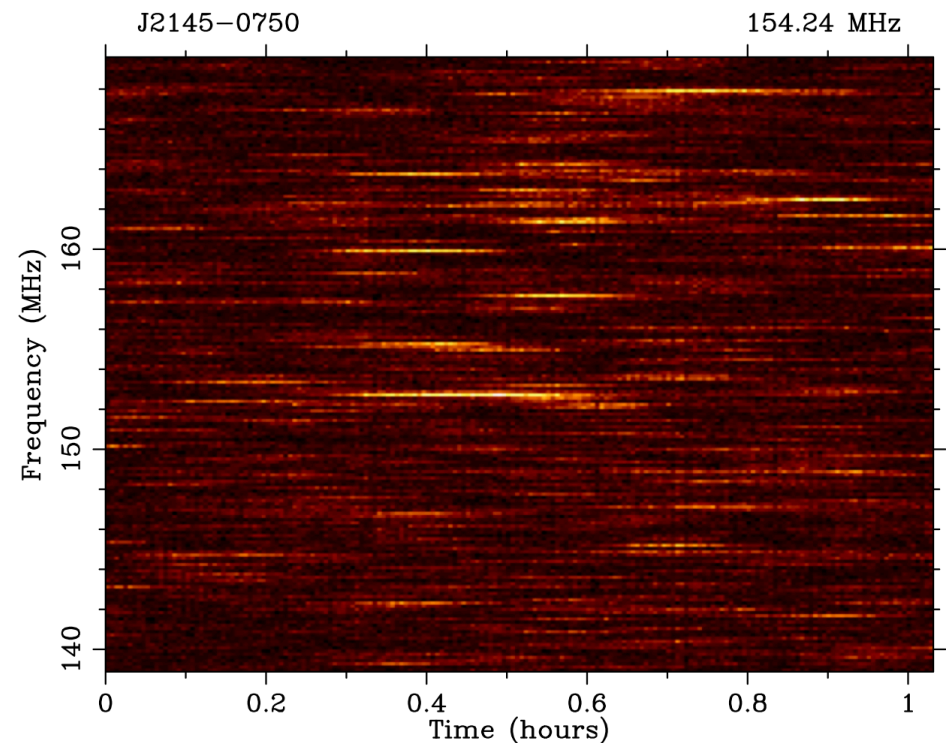
High time resolution + High spectral resolution

- Time resolution = 10 seconds

Spectral resolution = 10 kHz



MSP J0437-4715 @ 185-200 MHz

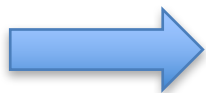


MSP J2145-0750 @ 140-170 MHz



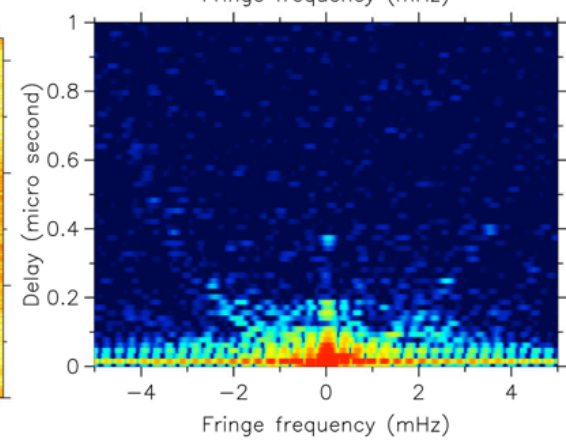
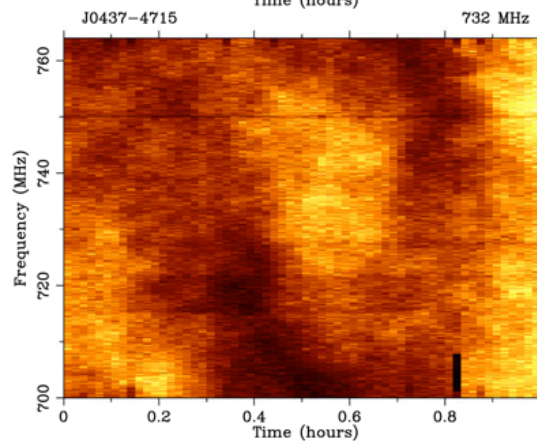
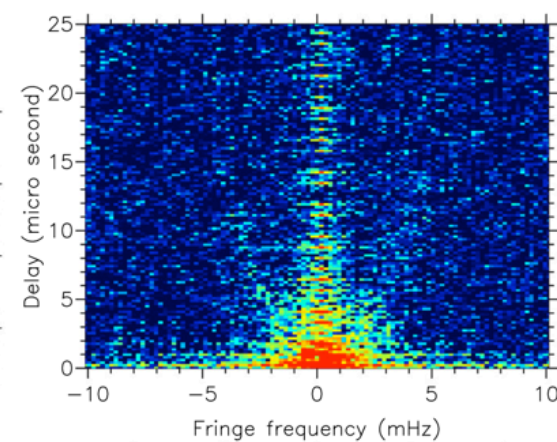
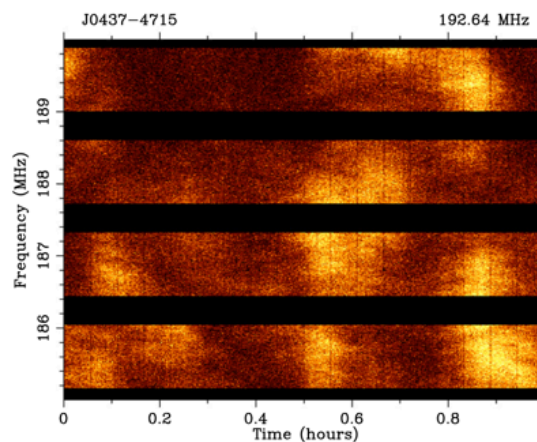
Scintillation arcs in Millisecond Pulsars

Parabolic scintillation arcs seen in the “secondary spectra” of MSP J0437-4715



THE ASTROPHYSICAL JOURNAL, 818:86 (8pp), 2016 February 10

BHAT ET AL.



Bhat et al. (2016), ApJ, 818, 86

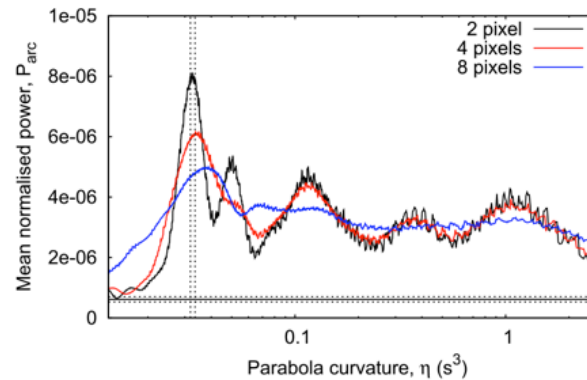
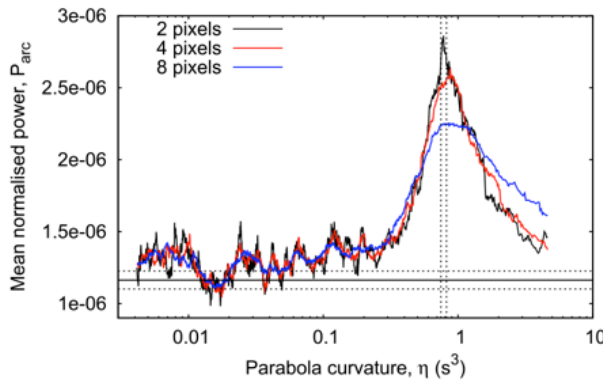
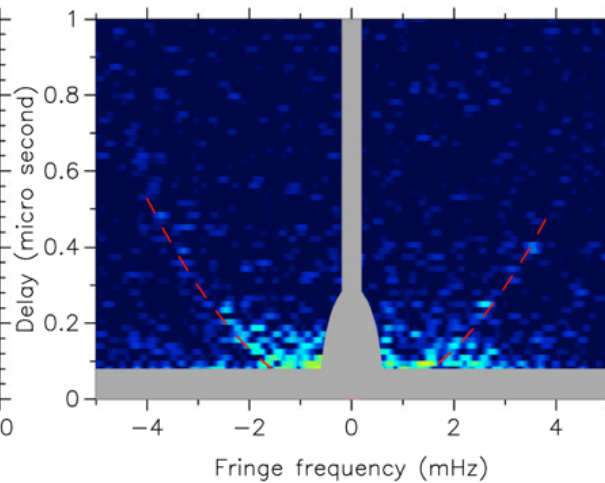
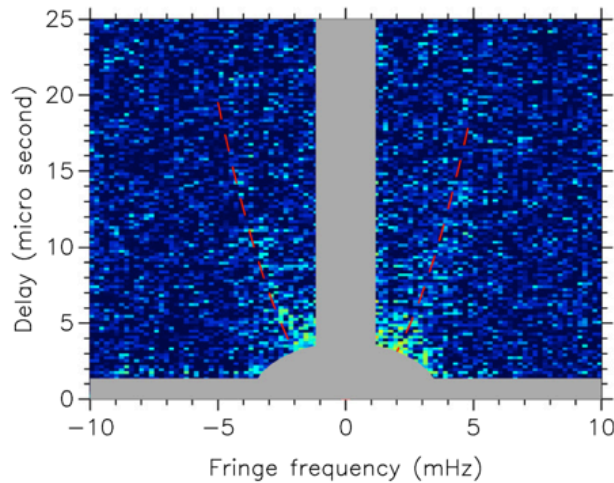


Arc curvature \rightarrow Localizing the 'screen'

The arc curvature η scales as λ^2 once the pulsar's (and the Earth's) orbital motions are fully accounted for

THE ASTROPHYSICAL JOURNAL, 818:86 (8pp), 2016 February 10

BHAT ET AL.



MWA measurements:

$$s = 0.26 \pm 0.01$$

Screen distance = 115 ± 2 pc

Parkes measurements:

$$s = 0.27 \pm 0.01$$

Screen distance = 114 ± 2 pc

The Local Bubble located at ~ 100 - 120 pc in the pulsar's direction

$$P_{\text{arc}}(\eta) = \frac{1}{N} \sum_{i=1}^N S_2(\eta f_{t,i}^2, f_{t,i})$$

Bhat et al. (2016)

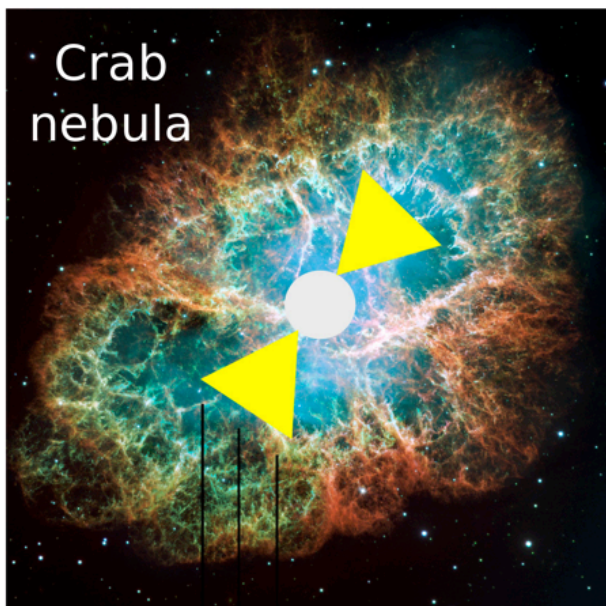


Crab Giant pulses from MHz to GHz bands

Complementarity with Other Facilities (e.g. Parkes)



Bradley Meyers
(PhD student)



Crab
nebula

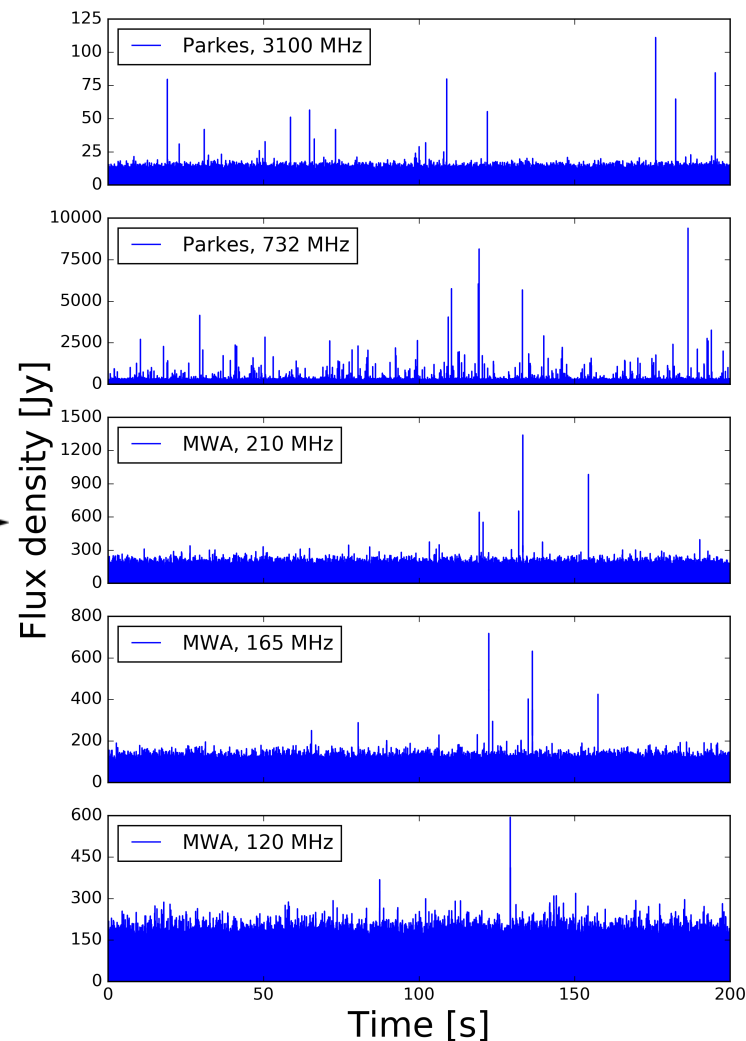


MWA



Parkes

Simultaneous observations with the MWA and Parkes spanning ~100 to ~3100 MHz

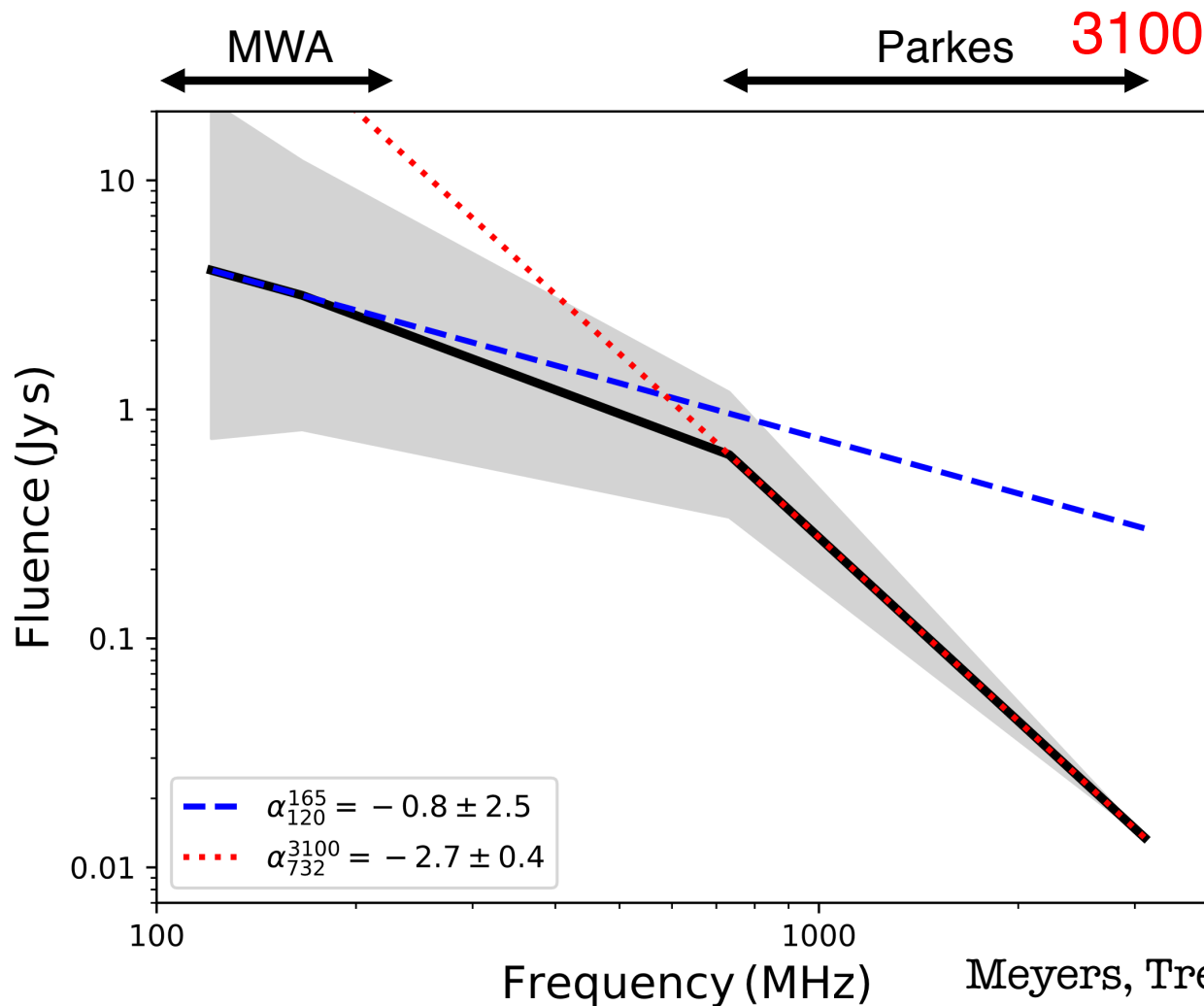


Meyers, Tremblay, Bhatt, et al. (collab. review)



Crab Giant pulses from MHz to GHz bands

Evidence for flattening spectrum:



3100-732 MHz: $\alpha \approx -2.7$

65 MHz: $\alpha \approx -1.0$

$\alpha \approx -0.8$

If the spectrum remains steep at low frequencies, we expect >10 times more detectable giant pulses

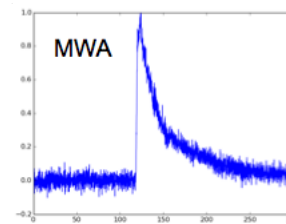
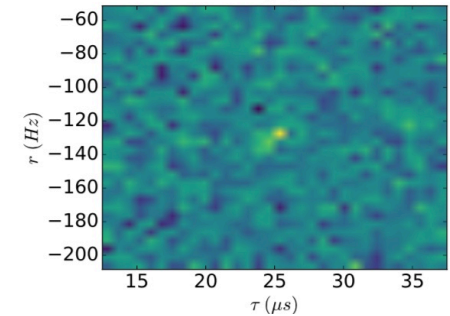
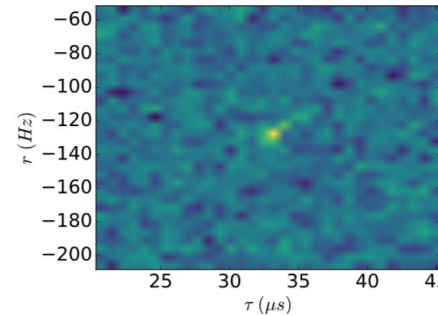
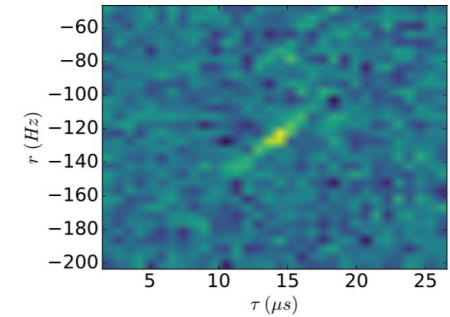
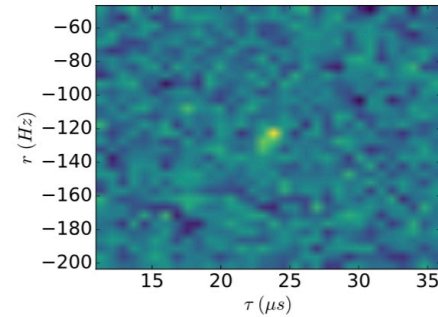
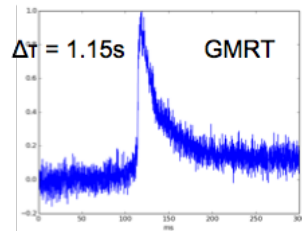
Meyers, Tremblay, Bhat, et al. (collab. Review)



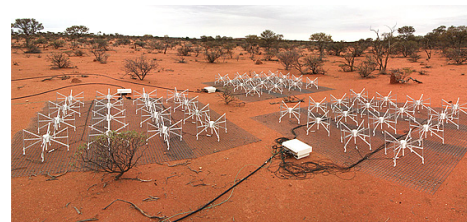
VLBI between MWA and GMRT

Common sky visibility with other low-frequency facilities (e.g. GMRT)

Baseline ~ 6500 km
Fringes on Crab giant pulses
Seen in 19 of the 24 channels
Frequency band: 140 – 170 MHz



Kirsten et al. (2017) in prep.



Franz Kirsten





The Engineering Development Array (EDA)

- ❑ A station comprised of 256 MWA dipoles (16-tile equivalent)
- ❑ Test & verification system aimed at MWA & SKA-Low prototyping
- ❑ Development for integration of external signals->MWA
- ❑ Direct baseband stream sampled at Nyquist 655.36 MHz

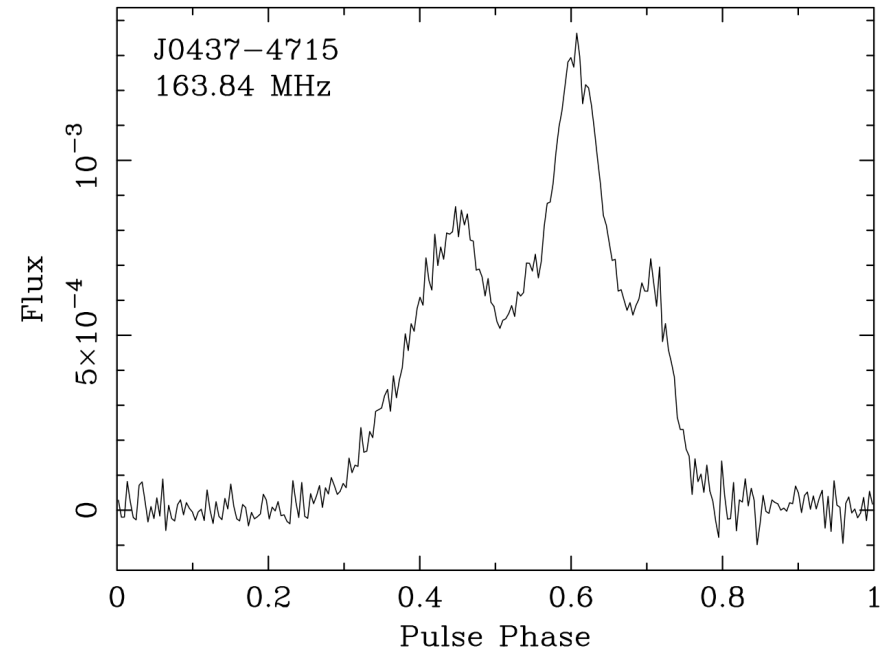
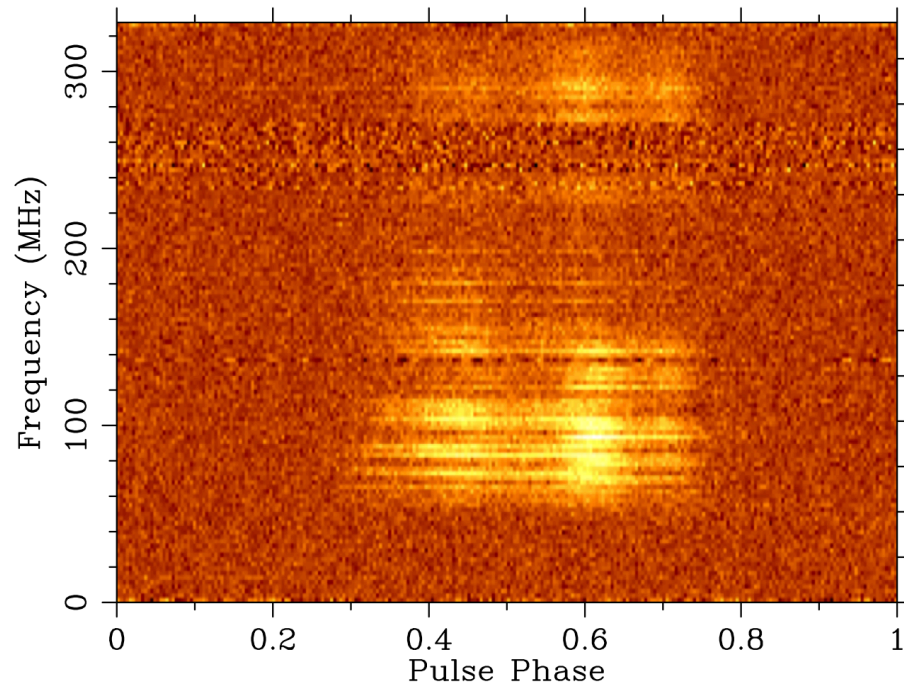
Wayth et al. (2017), PASA, Submitted





First pulsar light: PSR J0437-4715

Access to full bandwidth baseband data and integration of the pulsar processing software





Summary

- ⦿ MWA is opening up a new window for pulsar astronomy in the southern hemisphere; compliments other Australian facilities (e.g. Parkes, UTMOST)
- ⦿ Pulsar Science ramping up – projects that exploit both archival data + targeted observations, co-ordination with other facilities (e.g. Parkes, GMRT)
- ⦿ Phase 2 MWA + new high time resolution backend will bring a major paradigm shift in pulsar science @ MWA; e.g. wide-field searches, routine observations + science relating to emission mechanism and ISM studies.
- ⦿ The MWA is the official Precursor for SKA-Low; provides an excellent platform for related development