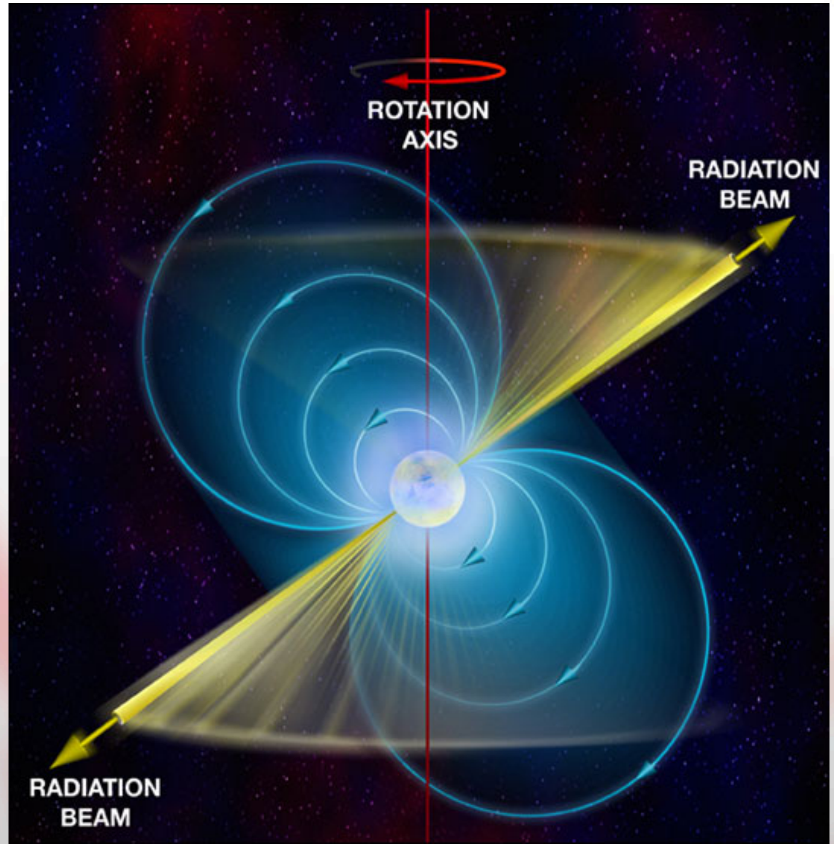
On higher time resolution than the current VCS

ICRAR

International Centre for Radio Astronomy Research



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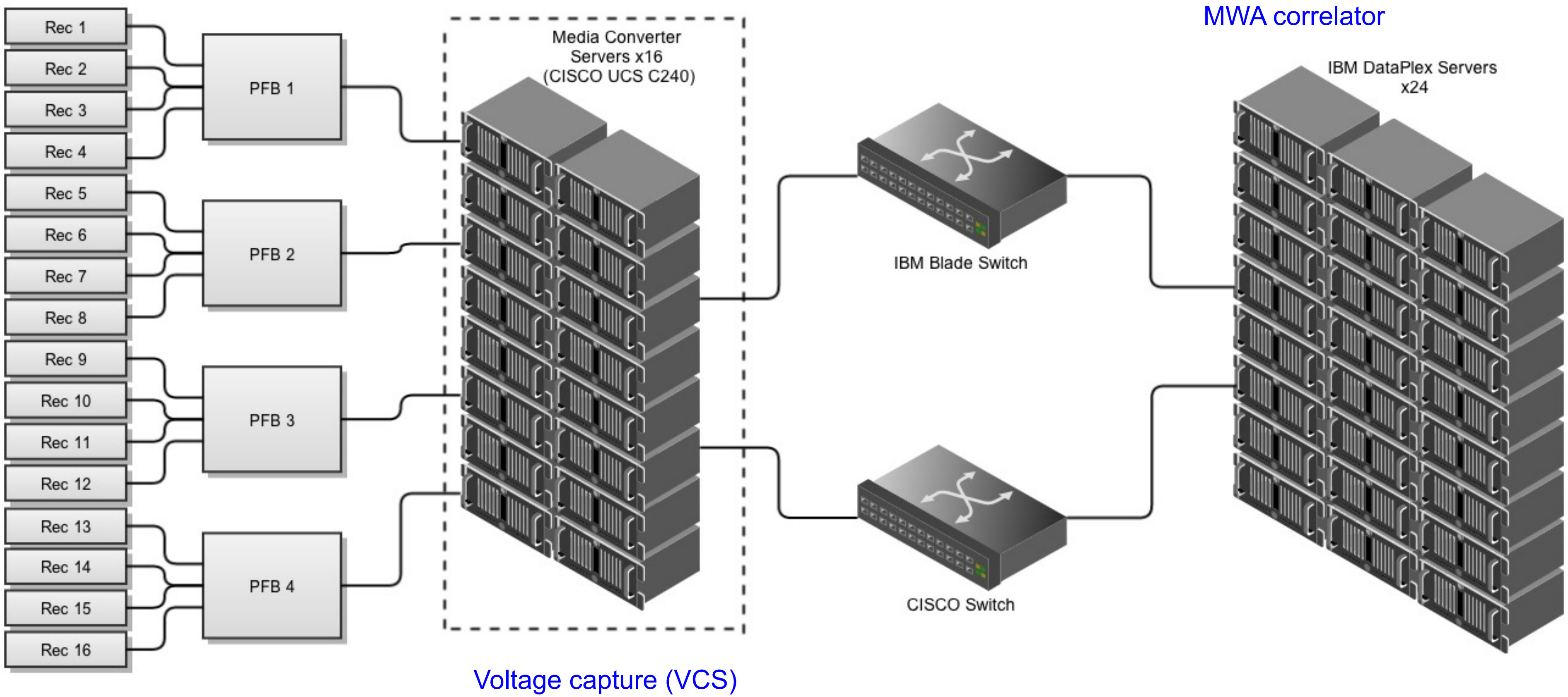
The University of Western Australia
Achieve International Excellence

The MWA extension/expansion meeting, 15-16 October 2014, Sydney

Voltage Capture System (VCS): MWA's high time resolution gear

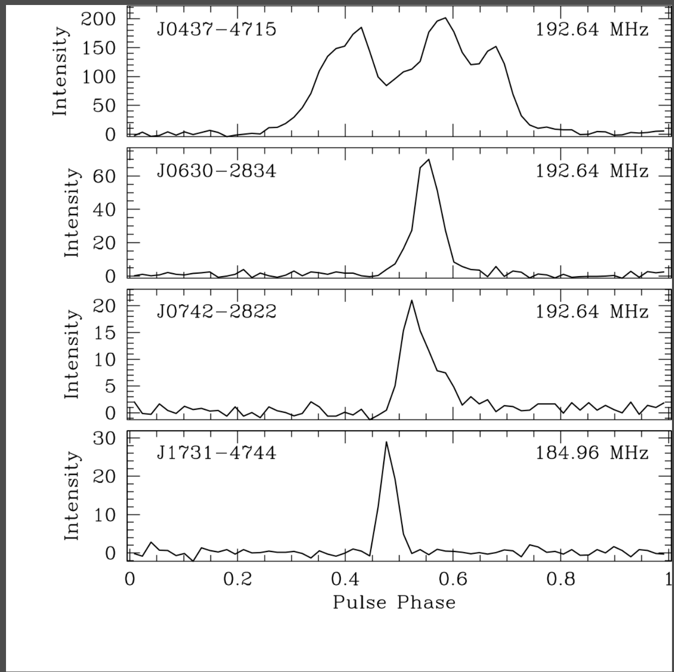
- VCS – a functionality to capture voltages streaming into the correlator, from ALL 128 tiles, at 100-us, 10-kHz resolutions, over 30.72 MHz
- Aggregate data rate = 24 x 242 MBps = 7.8 GBps or 28 TB per hour



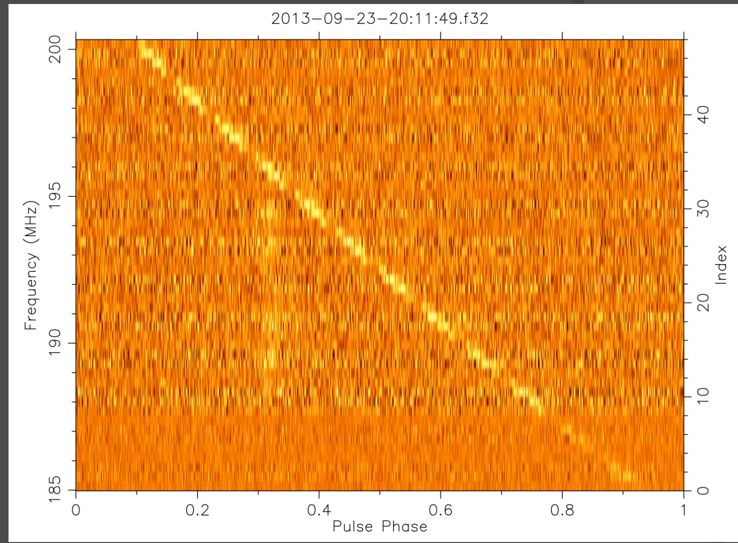
Tremblay et al. (2014), in prep.

Example data from VCS commissioning

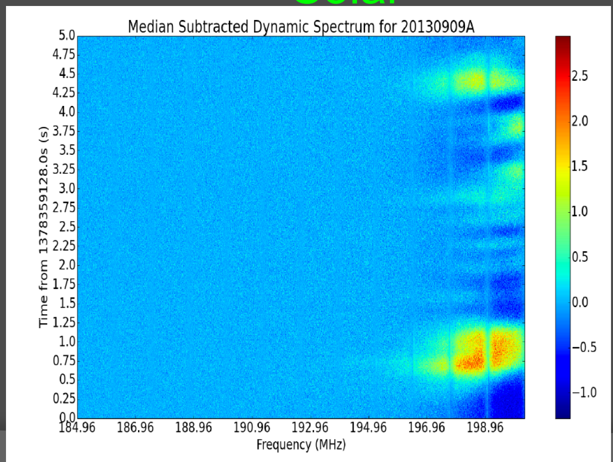
Pulsars



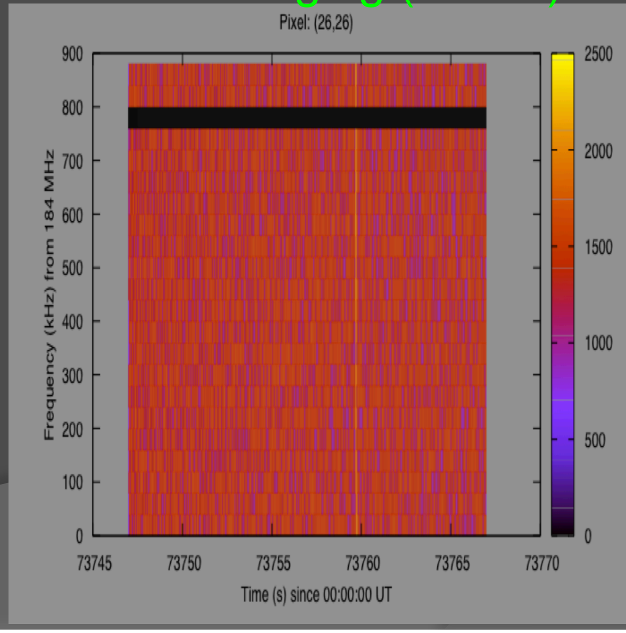
Transients (Crab giant pulse)



Solar



Fast Imaging (50 ms)

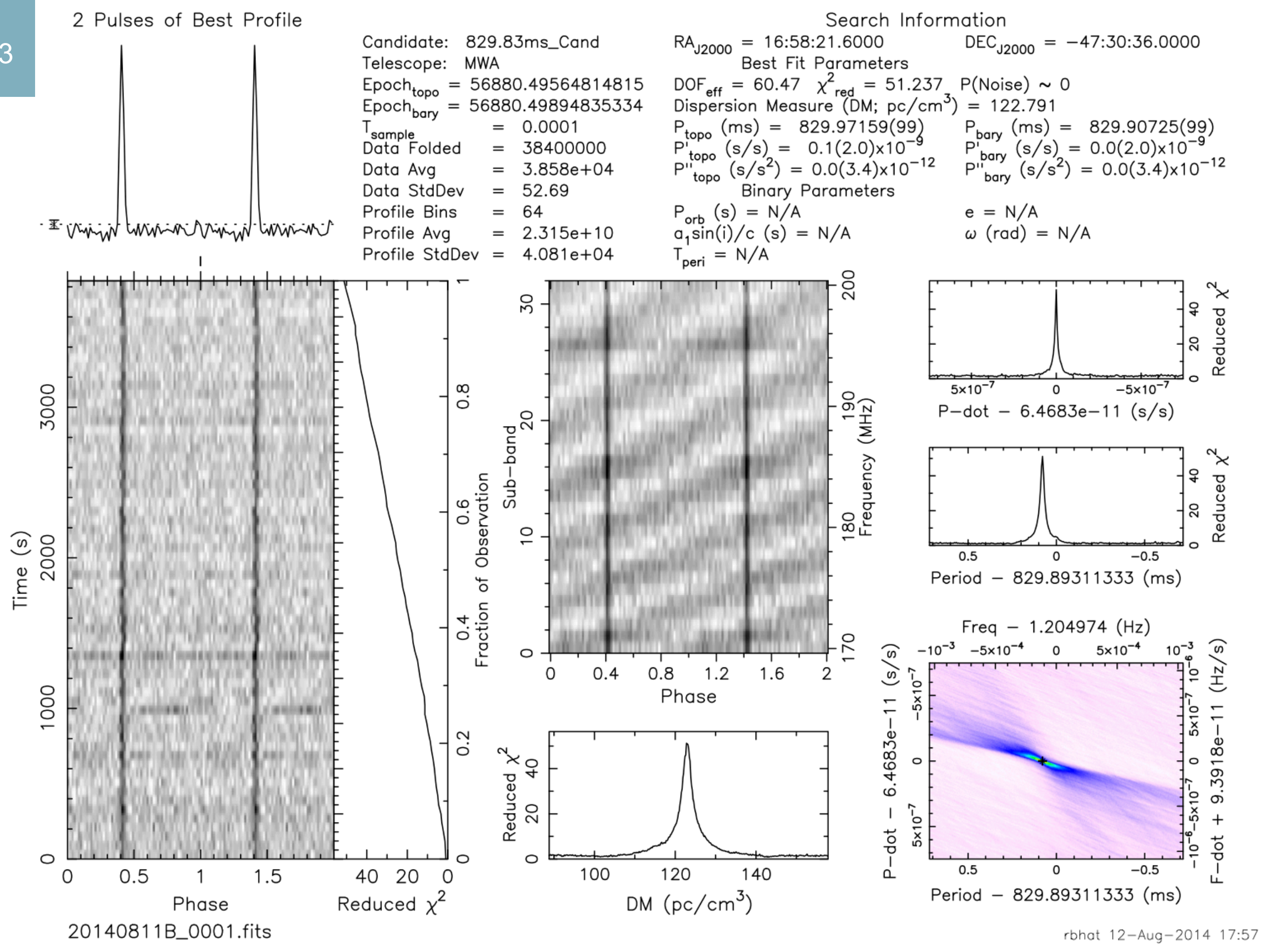


First pulsar from the full-BW VCS mode

PSR J1731-4744

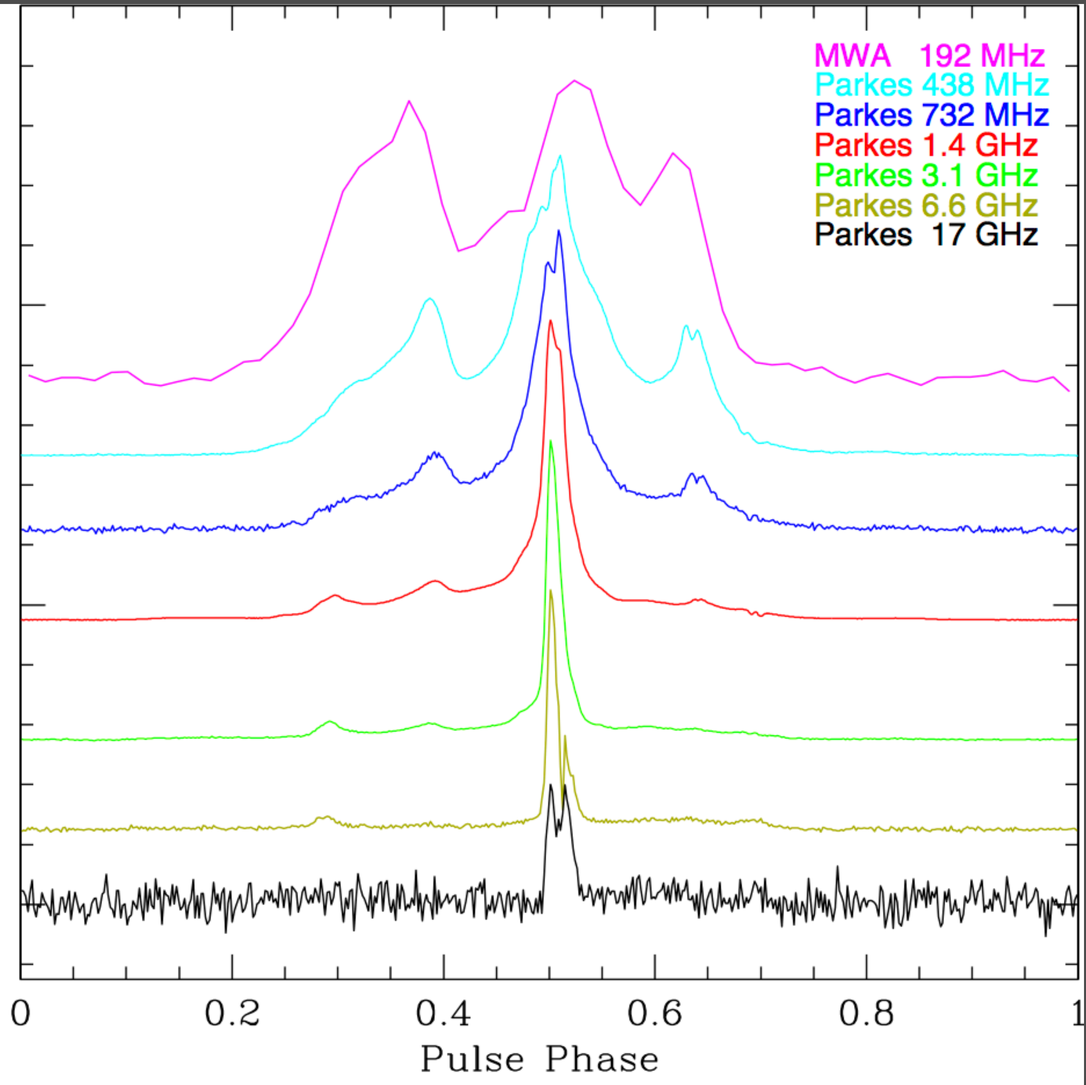
DM = 123 pc cm^{-3}

Drift scan observation from 12 August 2014



- Incoherent addition of 128 tiles + 24 x 1.28 MHz ➔ only 10% of the full MWA array sensitivity

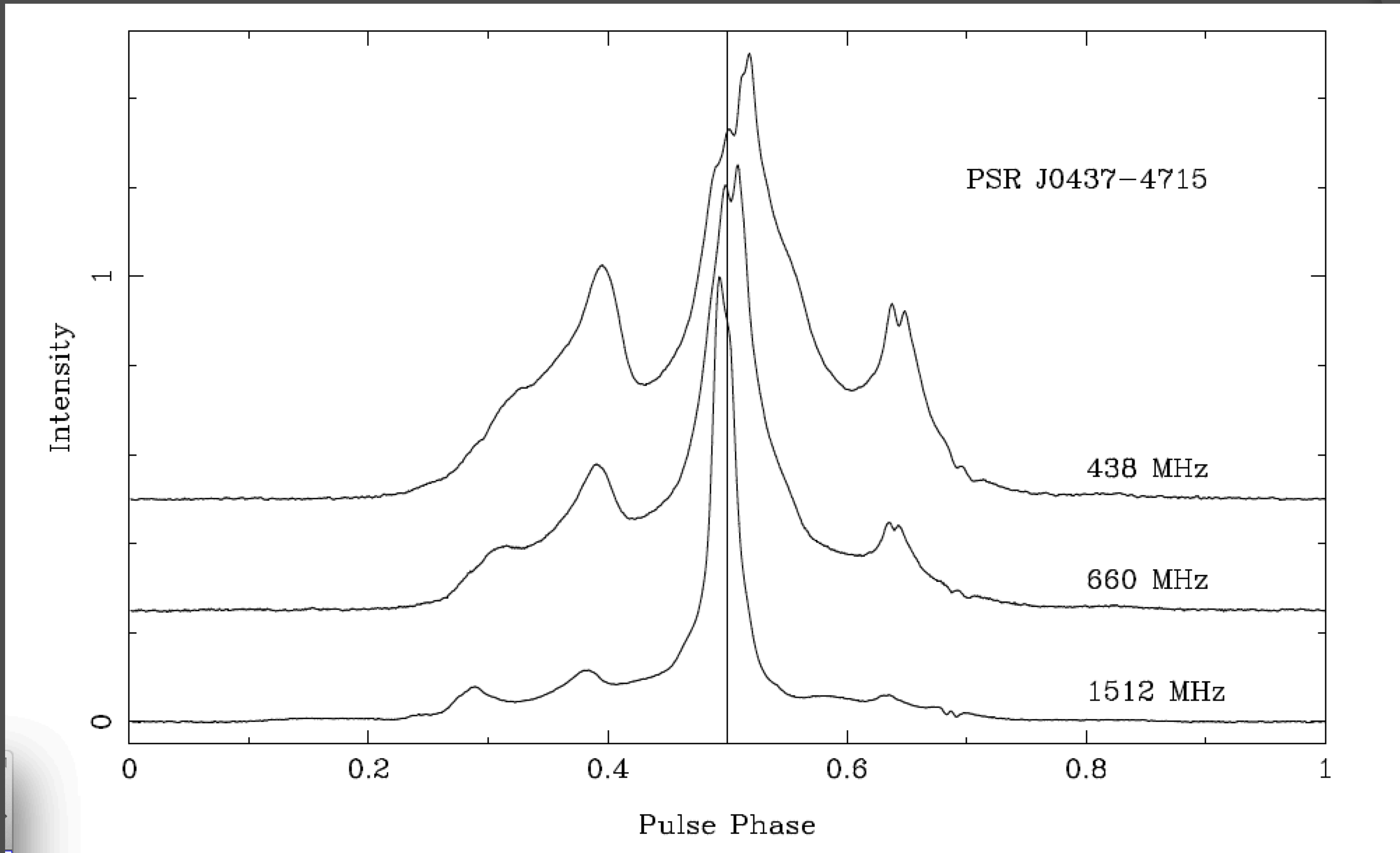
MSP J0437-4715 from 0.2 to 17 GHz



Bhat et al. (2014)

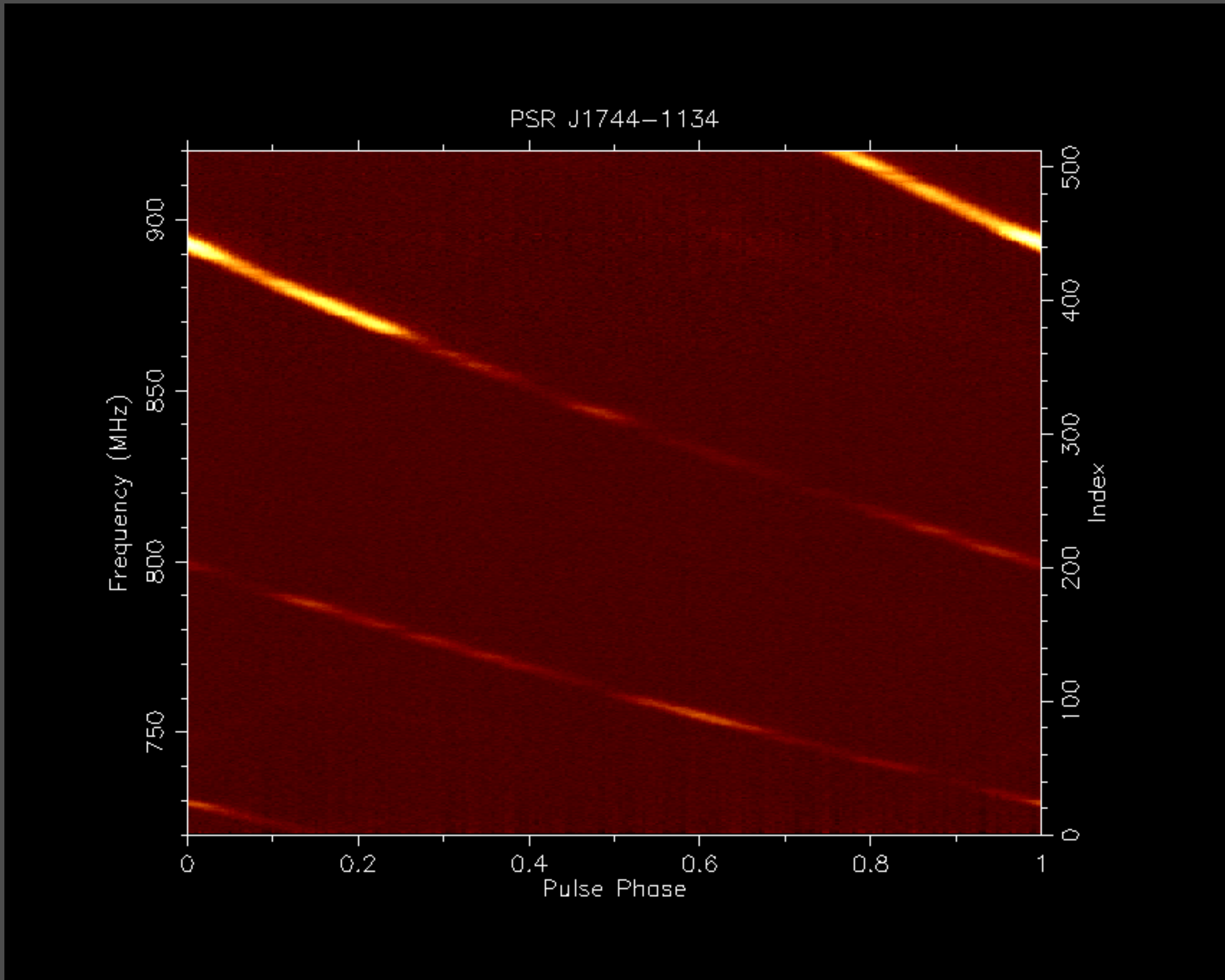
- 100 us is an amazing resolution for a variety of science (FRB seacrches, pulsar surveys etc), but a major limitation for MSPs
- MWA resolution ~ 100 us
- Parkes resolution ~ 5 us
- Higher time resolution for MSP studies in general, particularly for taking full advantage of MWA for measuring DMs at high precisions)

MSP J0437-4715 @ 5-10 us resolution

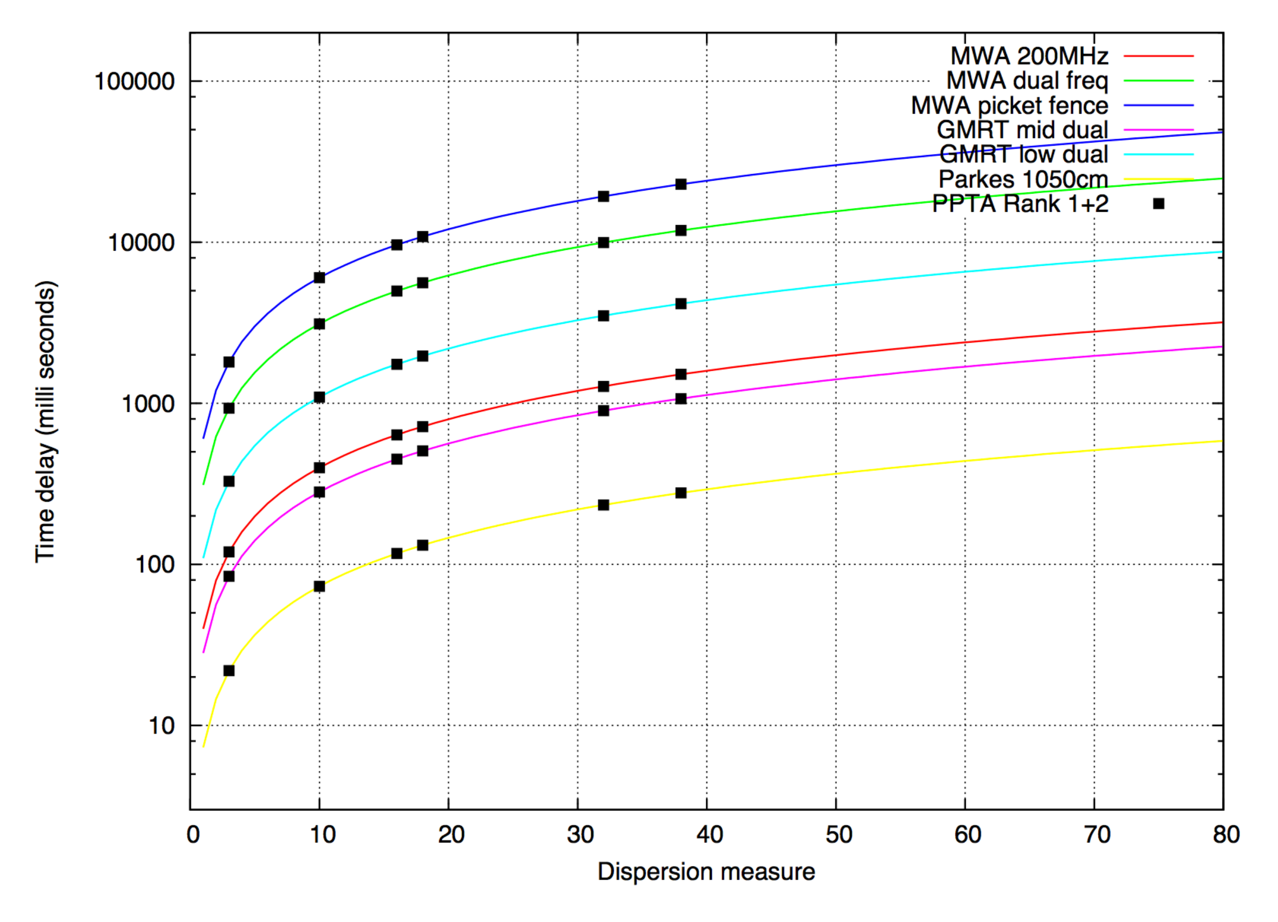


Navarrao et al. (1997)

Dispersion delays are large at low freqs.



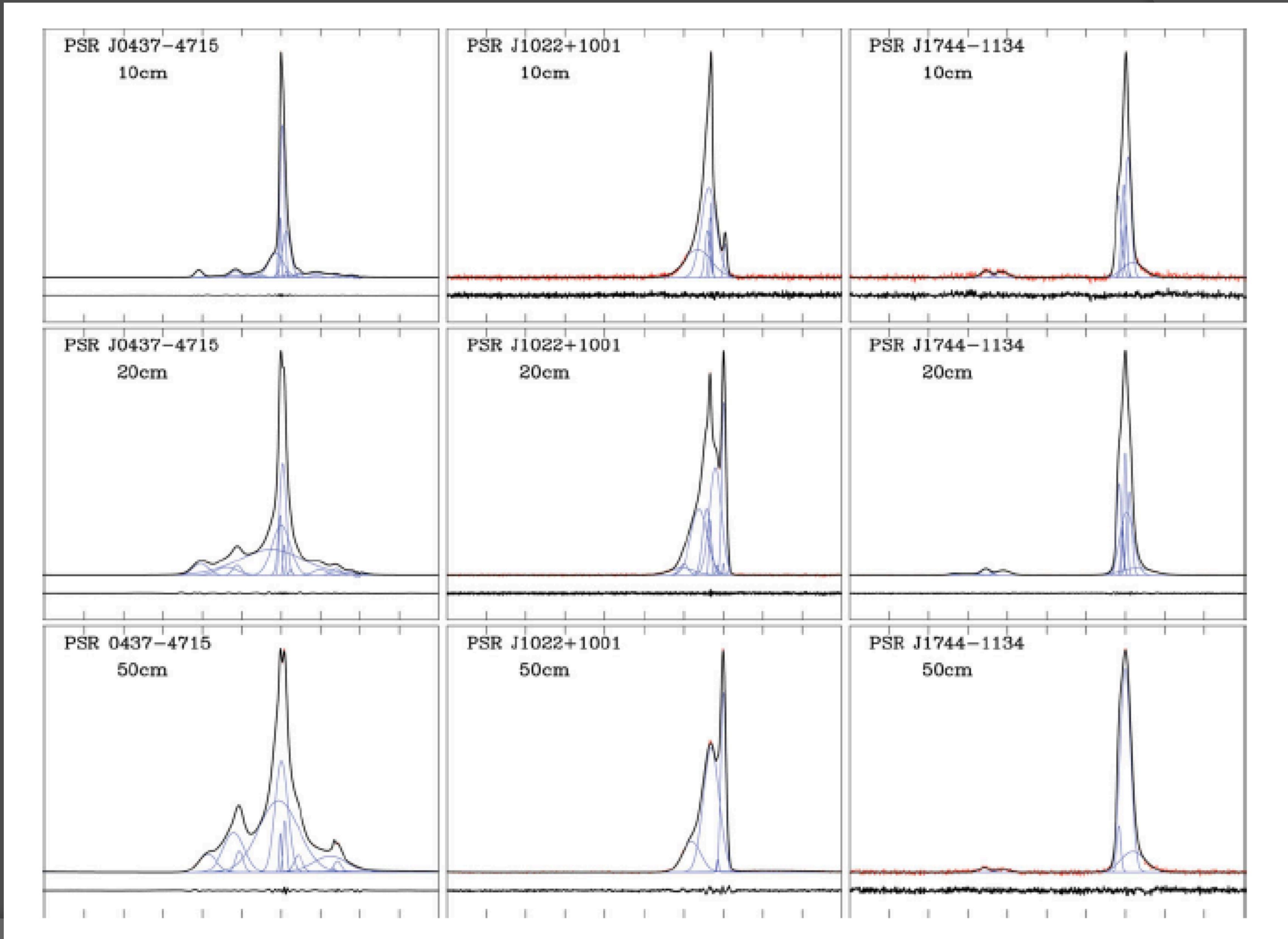
MWA for precision DM measurements



- Dispersion delays in the MWA band are ~ 1-2 orders of magnitude larger
- Important subtlety – the ISM sampled at low frequencies is different, since $\theta_{scatt} \sim \nu^{-2}$
- Also need to model the frequency evolution of the pulse profile

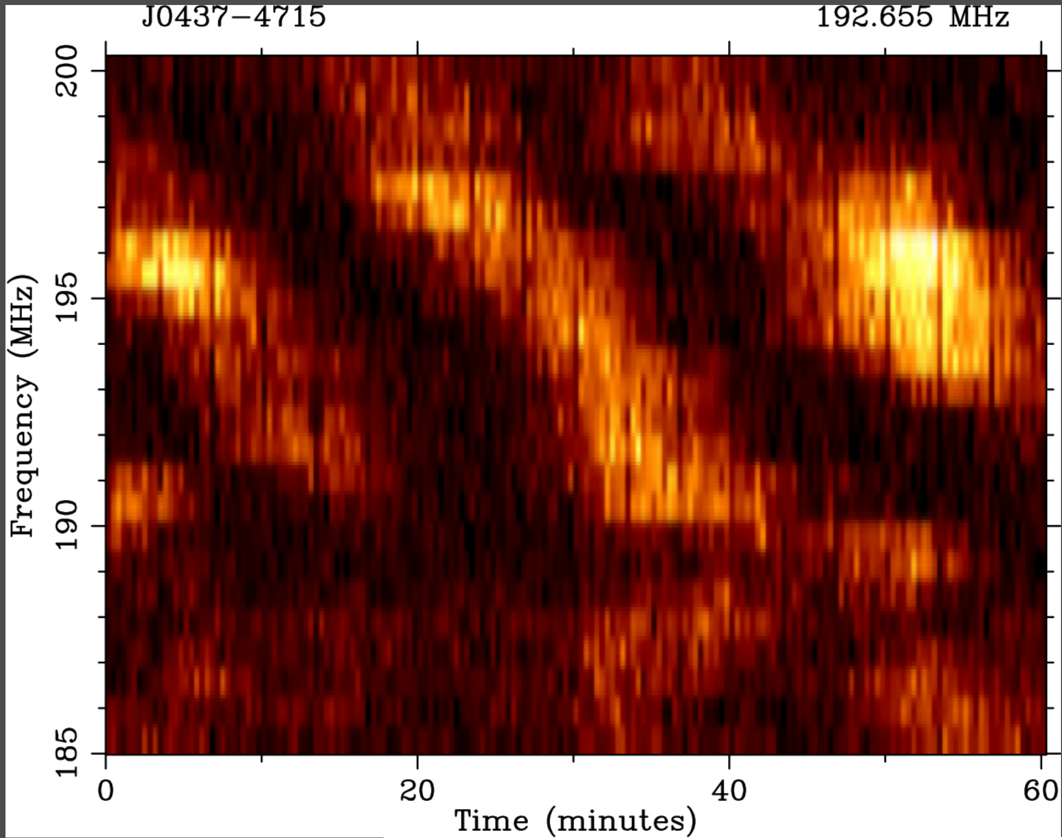
- "picket fence" : distribute 24 x 1.28 MHz band to sample the 80 – 300MHz range

PPTA MSP pulse profiles @ ~ 3-5 μs



Manchester et al. (2013)

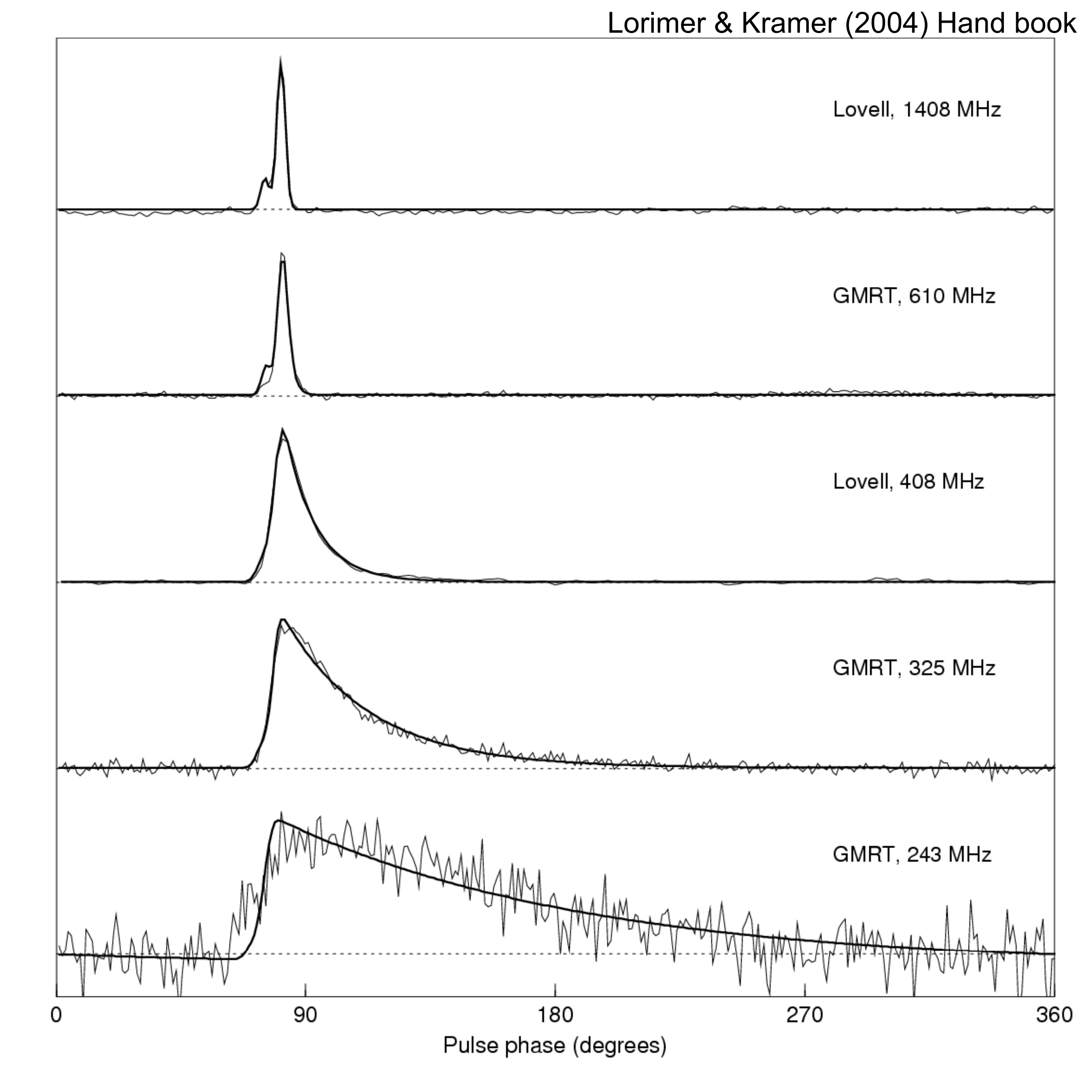
Scintillation analysis for ISM characterisation



Bhat et al. (2014), **ApJL**, 791, L32

- Useful for estimating first order scattering delays; $2\,\pi\,\nu_d\,\tau_d \sim 1$
- Scintillation bandwidth scales as ~ ν^4, and as ~ DM^{-2}
- Will be limited by sensitivity and (frequency) resolution for pulsars at high DMs (> 10 pc cm^{-3}) in the MWA band

Pulse broadening from scattering



Cyclic Spectroscopy

A novel signal processing technique for the removal of scattering

Demorest (2011), Walker, Demorest & van Straten (2012)

$$S_x(\nu;\alpha) = E\left\{X(\nu+\alpha/2)X^*(\nu-\alpha/2)\right\}$$

- α = k/P = harmonics of spin frequency
- v = radio frequency
- X(v+α/2) = RF spectrum "mixed" with harmonic of spin frequency
- upper and lower "sidebands" cross-multiplied

Transfer – scattered signal

$$y(t) = h(t) \star x(t)$$

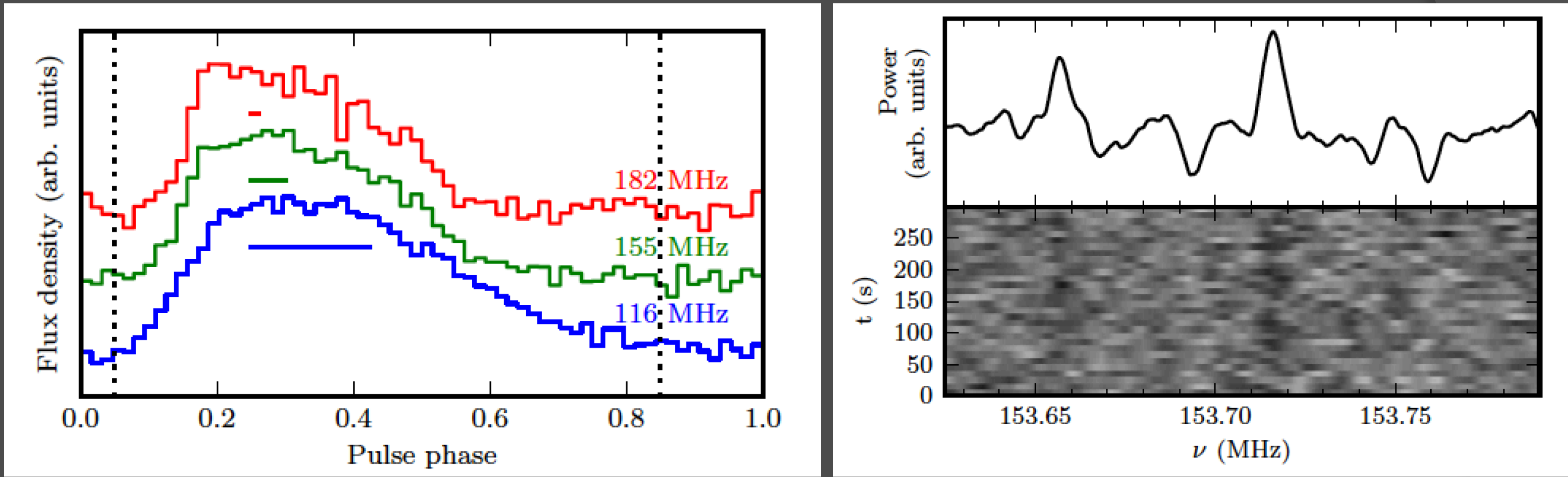
$$Y(\nu) = H(\nu)X(\nu)$$

$$S_y(\nu;\alpha) = H(\nu+\alpha/2)H^*(\nu-\alpha/2)S_x(\nu;\alpha)$$

- Inversion to recover the original pulse shape (i.e. coherent de-scattering) and the scattering function
- CS implemented in the DSPSR software package (van Straten & Bailes 2011)

Cyclic spectroscopy for ISM characterisation

Archibald et al. (2014) – demonstration with LOFAR observations



- For pulsars that require high spectral resolution (< 10 kHz) for scintillation analysis
- Combination of pulse phase resolution and high spectral resolution
- Scintillation analysis (in frequency) while also resolving scattering tail
- Powerful analysis technique if not limited by instrumental resolution

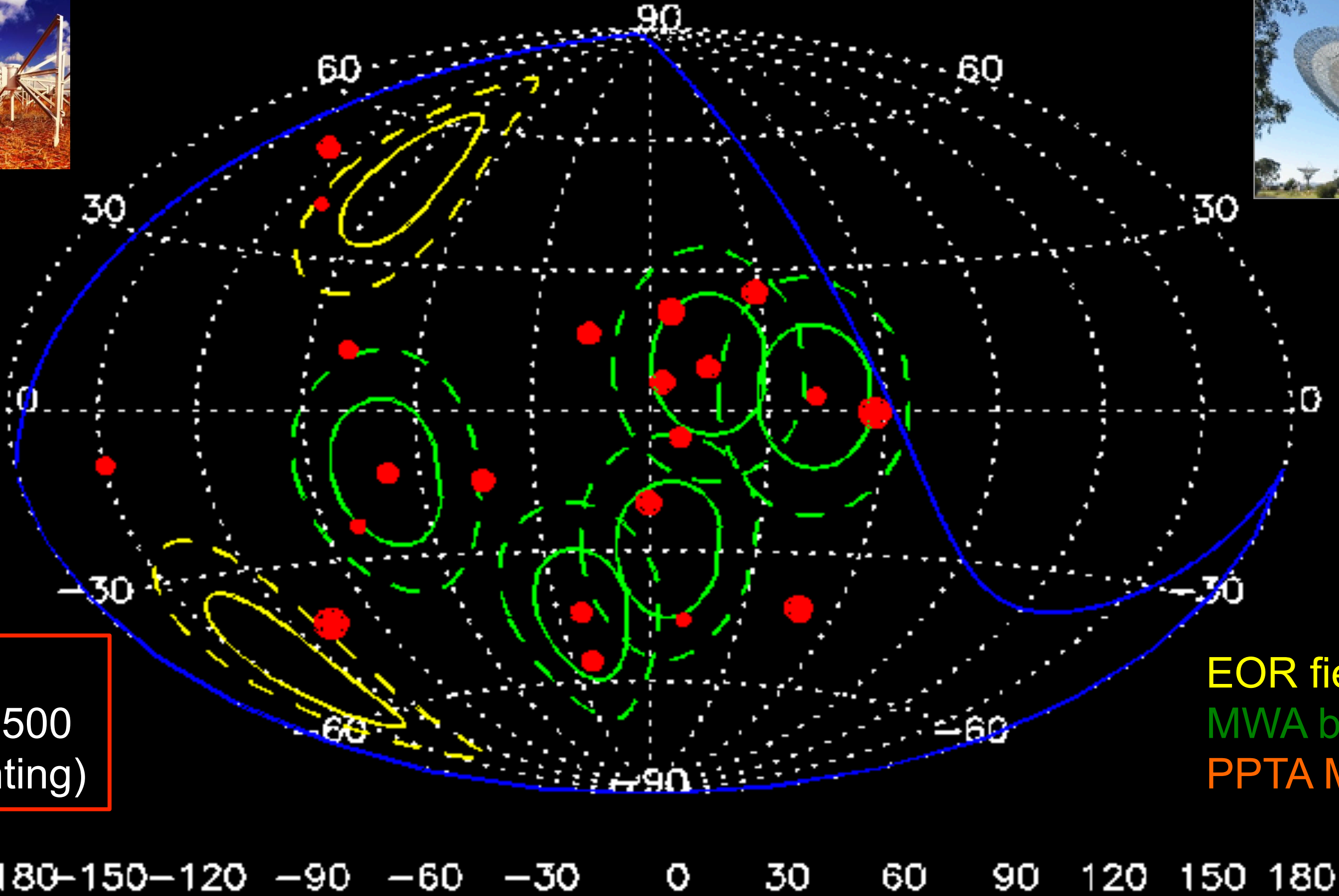
Expanded MWA for Pulsars

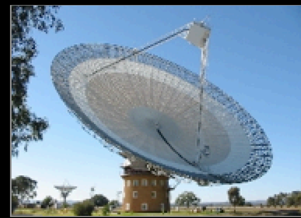
- Time resolution will no longer be a limitation! (assuming they are going to be ~1-2 MHz channels going to the correlator / high time backend)

- Sensitivity gain from more tiles + wider BW means a powerful pulsar instrument e.g. Timing-array MSPs observable with S/N ~ 50 – 5000 (in ~1 hr)

- Fully exploit the MWA low frequency coverage for high-precision DMs, scintillation and scattering (e.g.) cyclic spectroscopy) and their scaling in frequency.

Taking advantage of the large Field of View





Detectability:
S/N ~ 20 to 1500
(~1 hour pointing)

EOR fields
MWA beams
PPTA MSPs

- Exploit the MWA's Large Field-of-View – e.g. Observations of multiple pulsars in a single pointing
- Modest observing time (~10 hr per month) to support a high profile science project in pulsar astronomy
- Commensal Observing? – e.g PSRs J0437-4715 and J1022+1001 are within the beams of EoR fields

Expanded MWA for Pulsars

- Packed core (e.g. 128T within ~500m) – pulsar surveys would become computationally feasible, with an order of magnitude decrease in the # of tied-array beams to form and search

- Long-baselines will enable sub-arc minute localization of new pulsar or RRAT discoveries, as well as for FRB localization

- Potential unambiguous localization (~5-10σ) may be possible for a new Parkes pulsar with $S_{1400} > 1$ mJy ($S \sim \nu^{-\alpha}$, where $\alpha \sim -1.5$), i.e. quicker localization than that possible via conventional gridding (factor ~ 2 – 6 improvement possible with gated imaging)

Finer time resolution in Phase 1?

- 100 us is an amazing resolution for a range of high time resolution science, however a major limitation for MSPs

- Effective time resolution is probably coarser than 100 us!
- PFB inversion to recover the time resolution? (e.g. APSR)

- Resurrect the 2PiP spigot, for recording a subset of coarse channels and receivers, for demonstratory experiment
- Trial this on select bright objects (e.g. J0437-4715, J1937+2134) that are bright enough (S/N~200) within the recording constraints