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A Low Frequency Census of Southern Pulsars with the MWA

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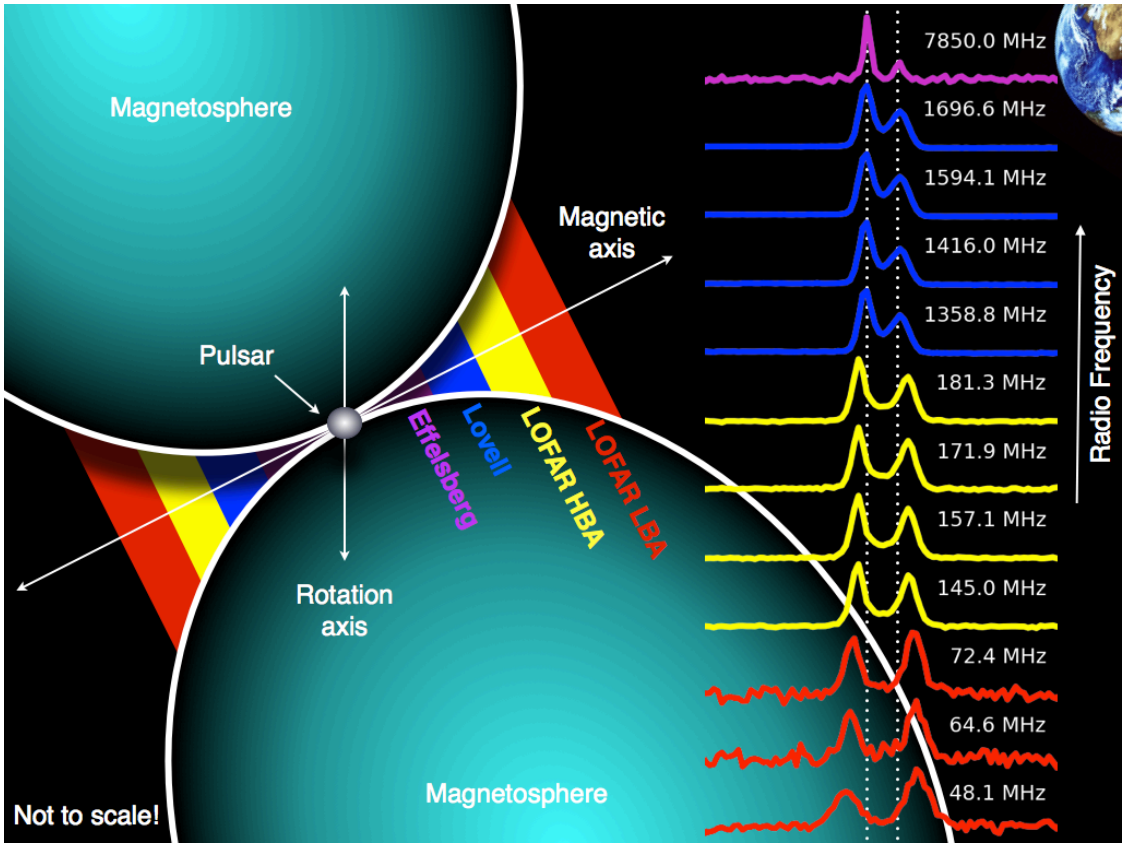
Outline

- Low-frequency studies of pulsars
- MWA and MWA-VCS
- Data and processing pipeline
- Results
- Future work and summary

Pulsar studies at low radio frequencies

- The first pulsar was discovered at 81.5 MHz
- Provide insights into the emission mechanism of pulsars
  - Profile evolution with frequency
  - Spectral index (low frequency turn over; break; flattening)
- Provide valuable information about the interstellar medium
  - Galactic Free Electron Density Model
  - Galactic magnetic field
- Future pulsar detection prospects with the SKA1-low



Credit: Tom Hassall

Pulsar studies at low-frequencies

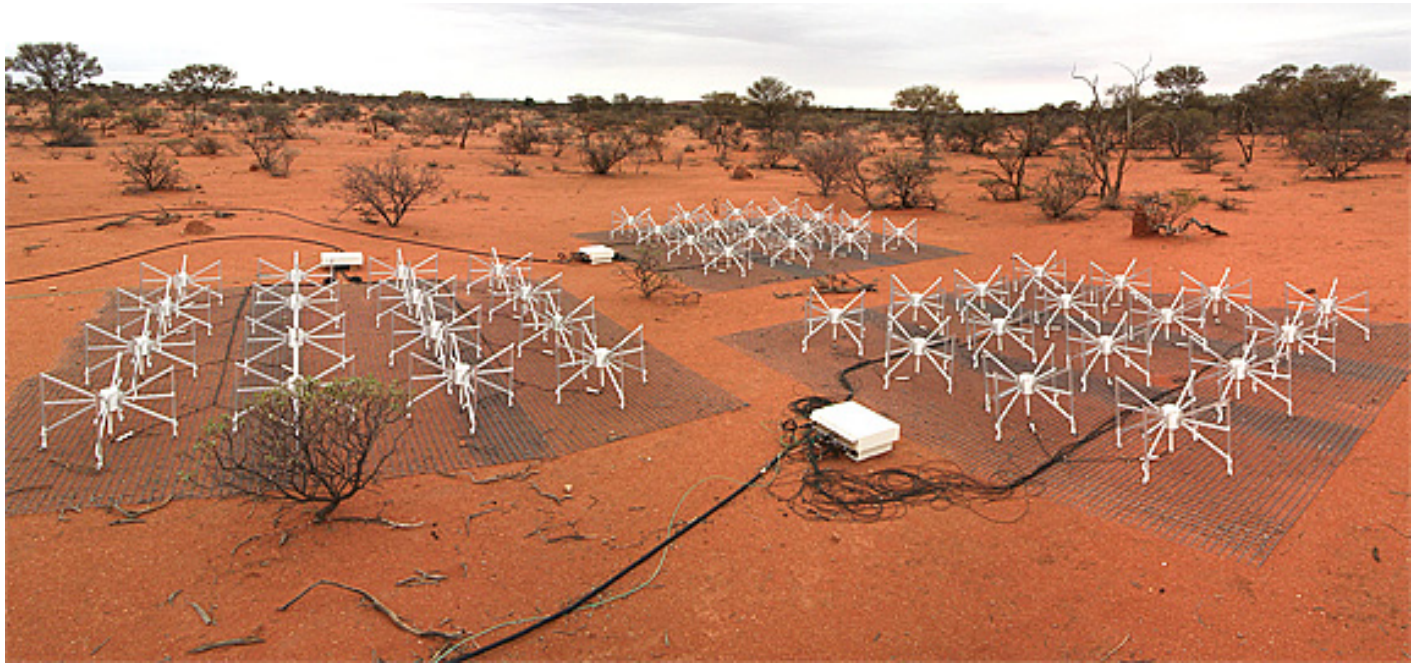
MWA & MWA-VCS

Murchison Widefield Array (MWA)

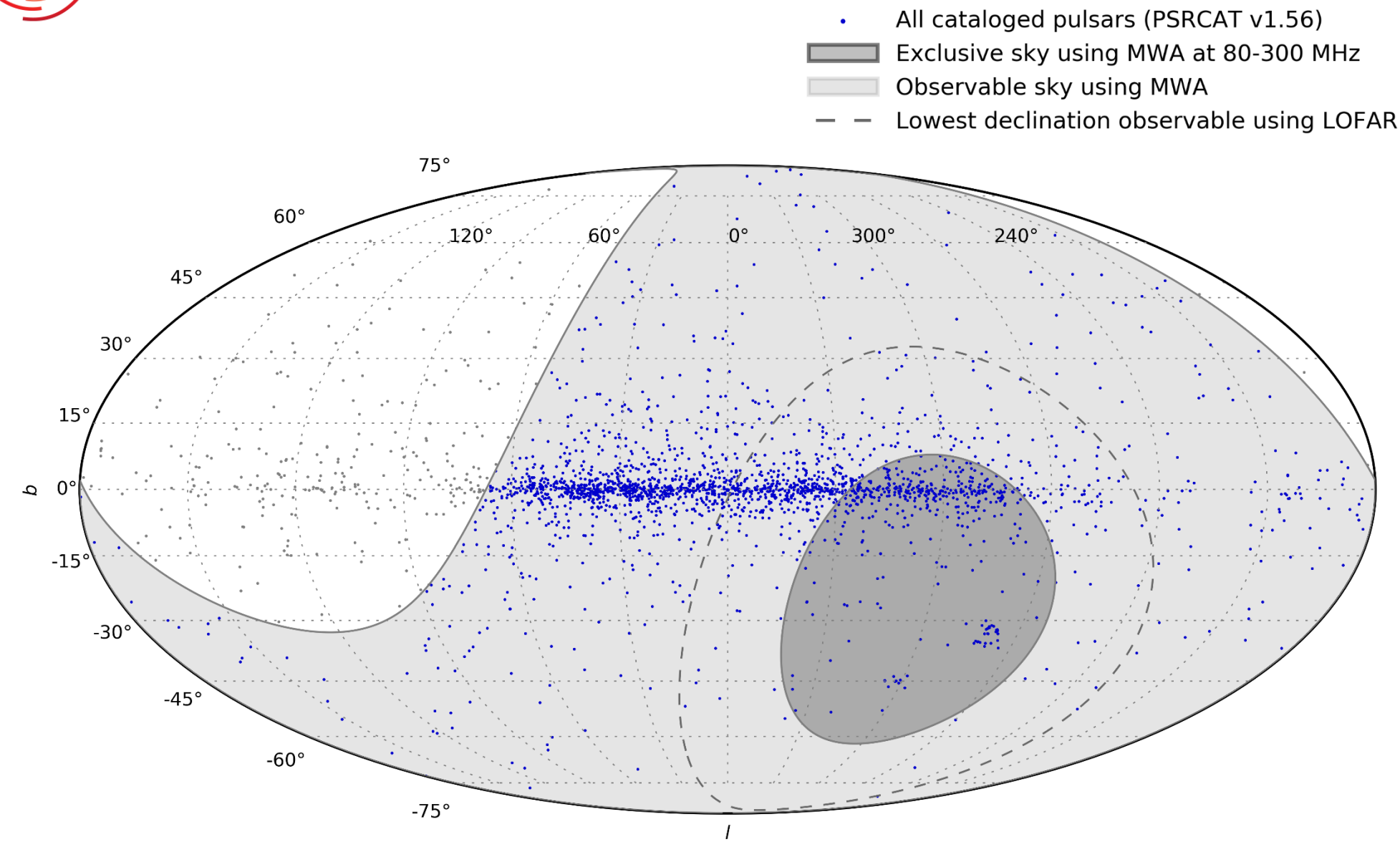
- Working frequency: 80-300 MHz
- 128 Tiles (each consists 16 dipoles, 4×4 dual polarisation array)
- Instantaneous bandwidth: 30.72 MHz

Voltage Capture System (VCS) of MWA

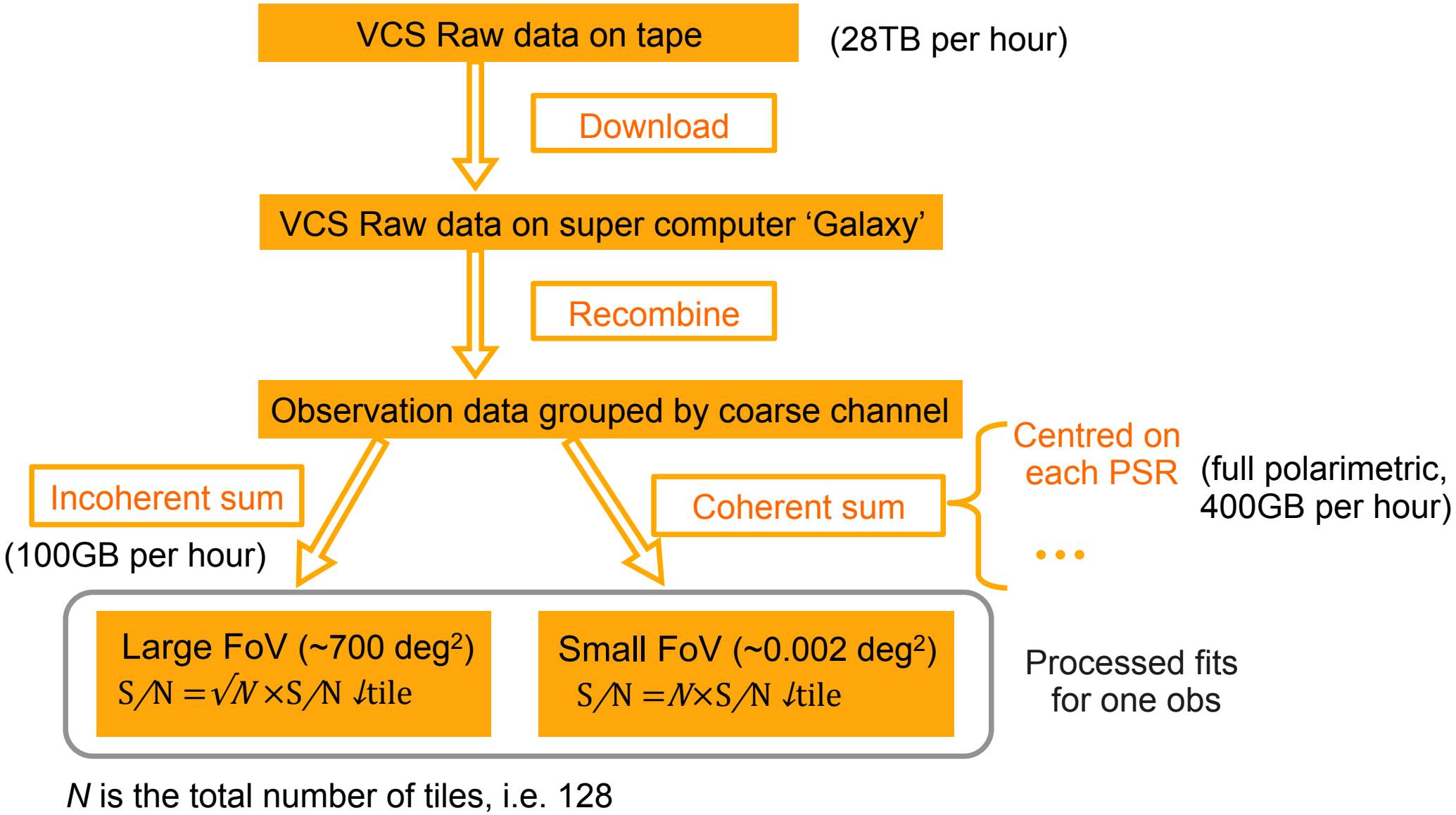
- Time resolution: 100 μs
- Frequency resolution: 10 kHz



A Southern Pulsar Census with MWA



Work Flow of MWA-VCS Data Processing



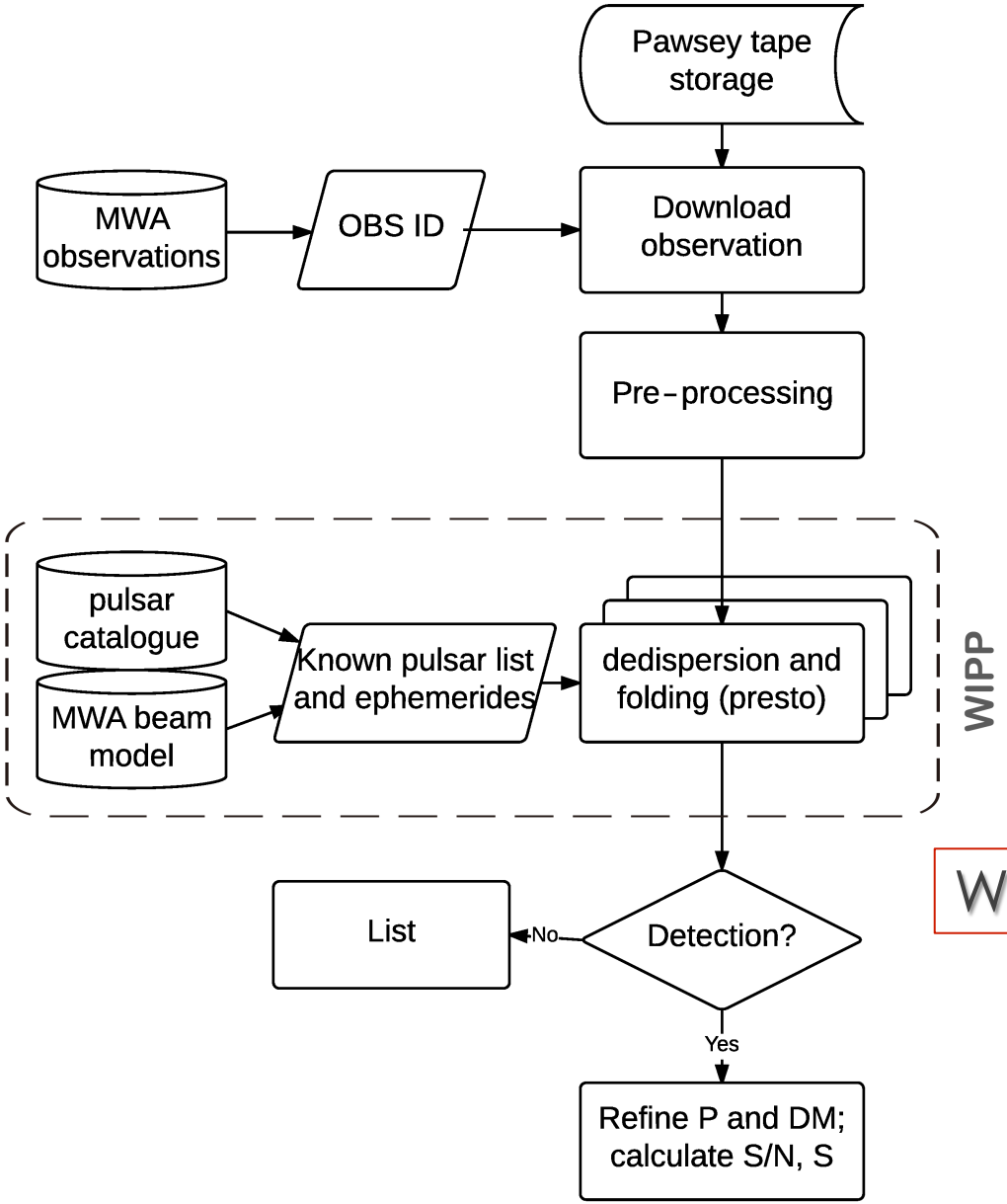
N is the total number of tiles, i.e. 128

Observational data used in this census

- Archival data for a variety of scientific projects
  - Pulsar emission studies
  - Monitoring of millisecond pulsars
  - Rotating Radio Transients (RRAT) observing
  - Searching for FRBs

- ~47/106 hours (59/136 observing sessions) VCS observation at 185MHz
  - Efficiently cover the sky
  - Make use of VCS data that have been pre-processed for other research purpose

Processing Pipeline



For each observation

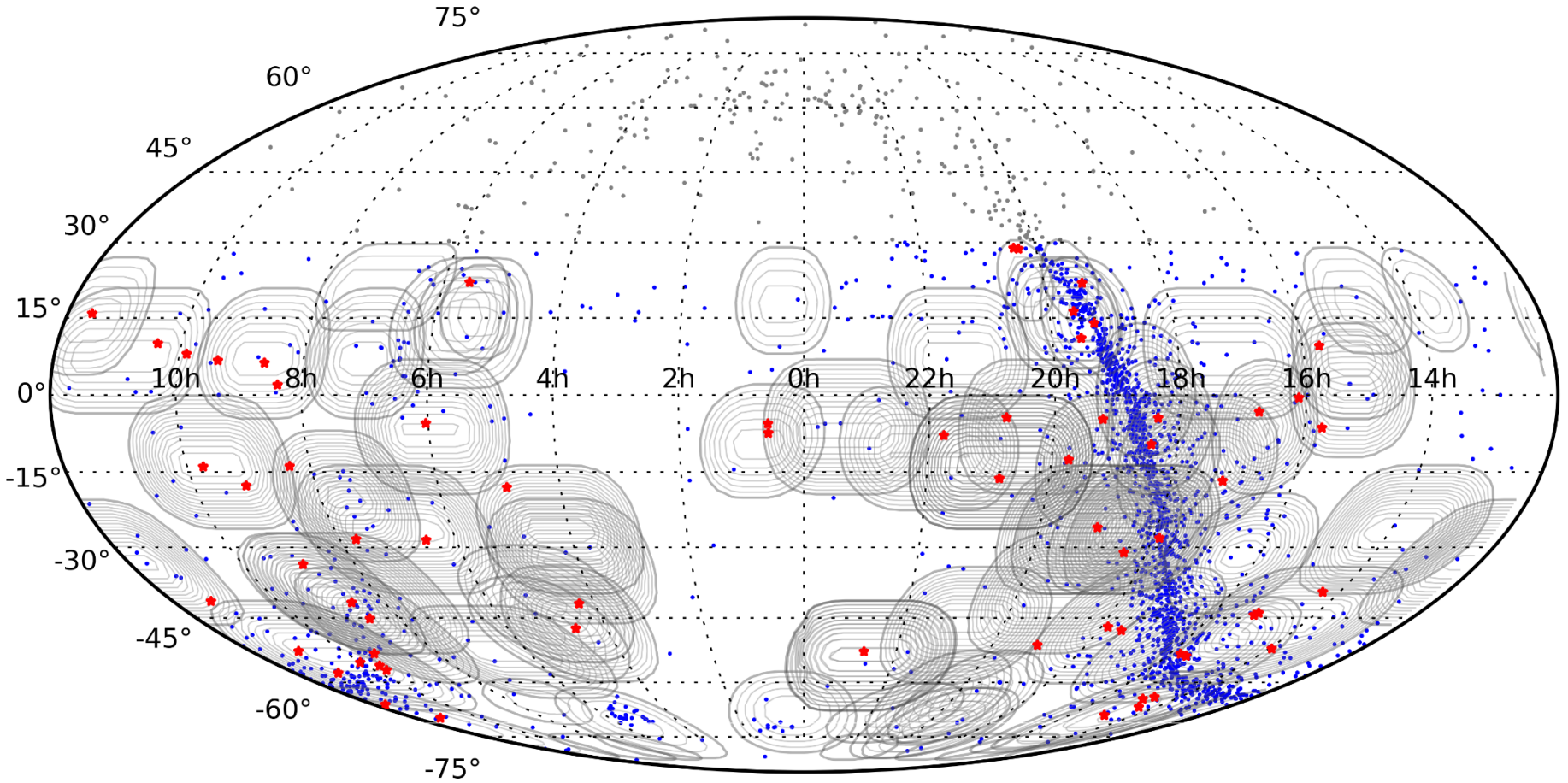
For each pulsar

WIPP: Wide-field Pulsar Pipeline

Results

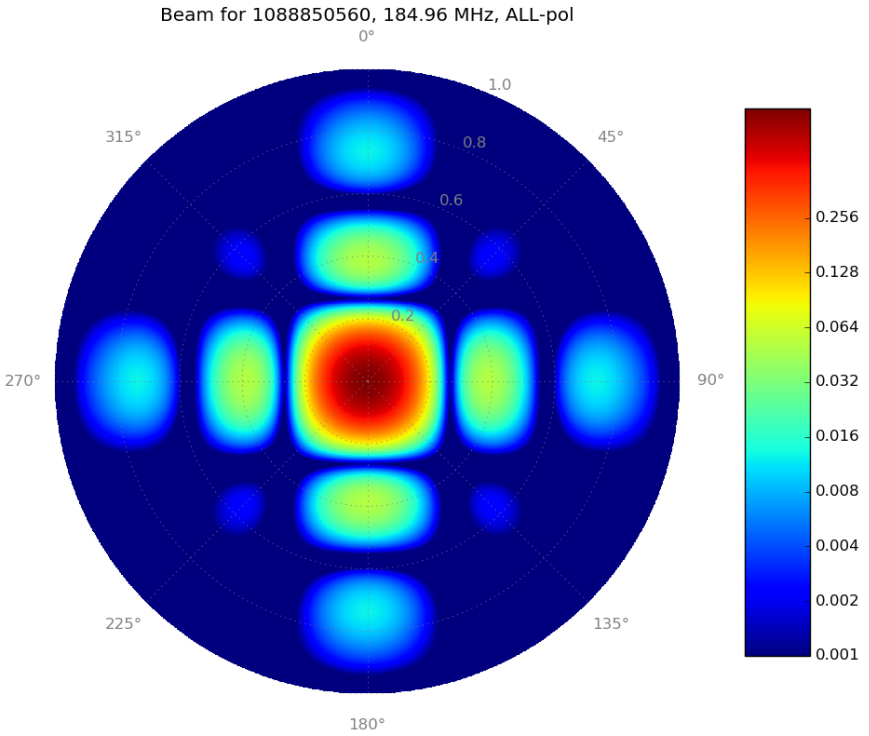
65 pulsars in 47 hours of observations, **6** millisecond pulsars (MSPs)

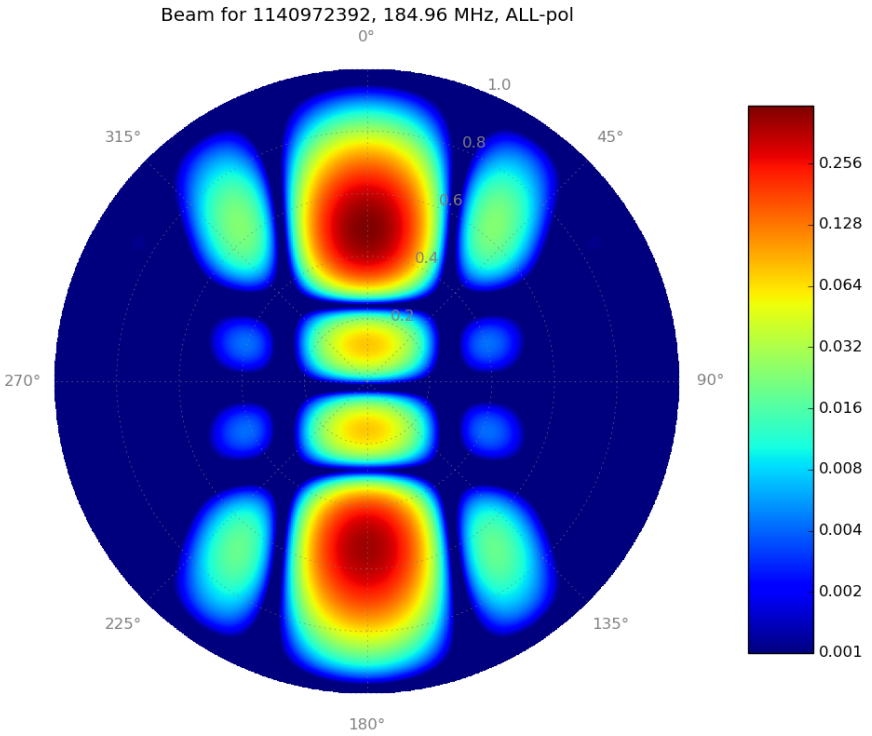
- Known (catalogued) pulsars outside the MWA's Dec limit
- Known pulsars visible to the MWA
- ★ MWA-VCS pulsars



MWA primary beam pattern

@185 MHz

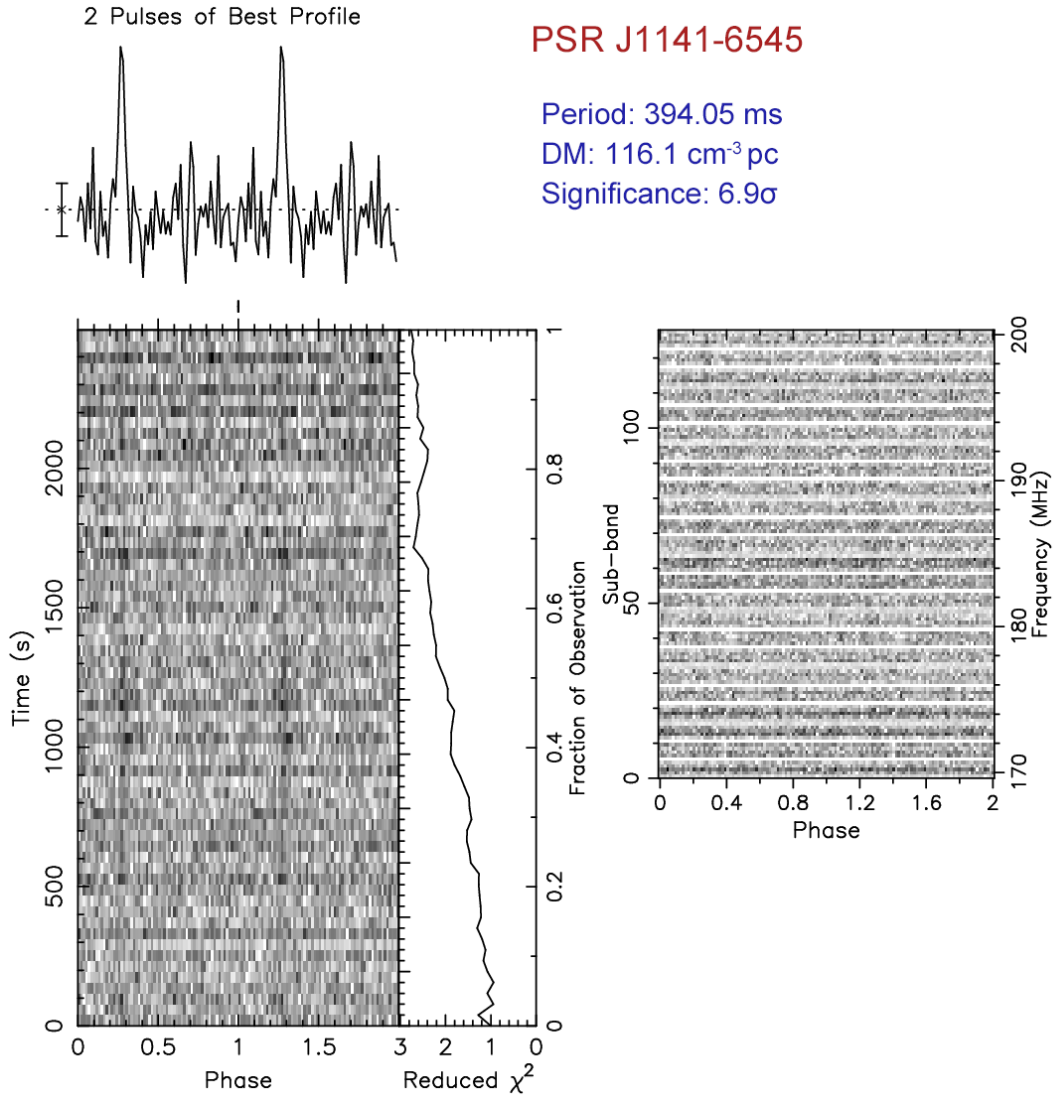




pointing to zenith

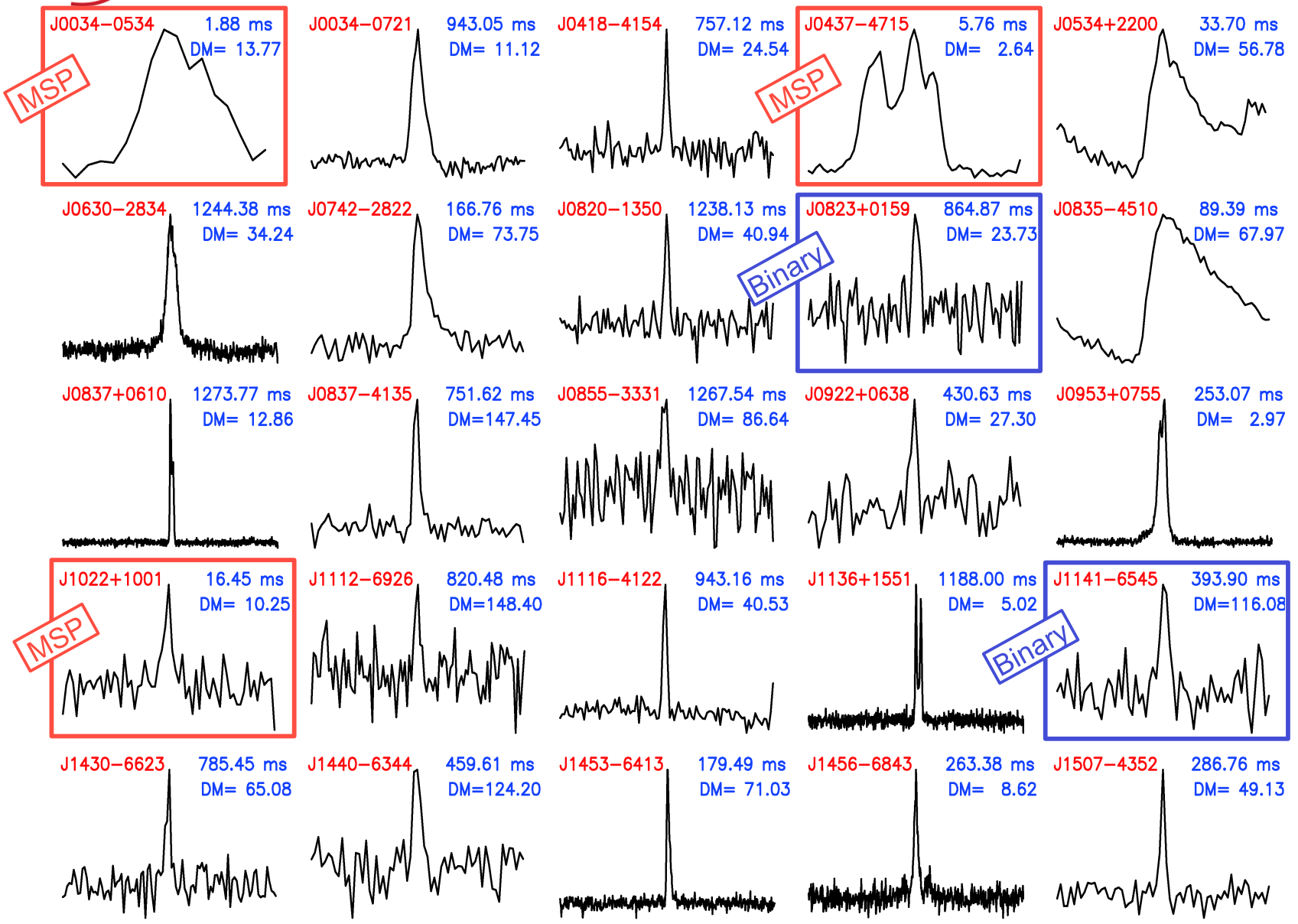
with strong grating lobe
Azimuth: 0° Elevation: 45°

Pulsar detected in grating lobe



MWA observation 1140972392
Pointing center
RA: 11^h15^m Dec: +18.73°

Pulse profiles for MWA-VCS pulsars



@185 MHz

DM range:
2.64 to 180
cm^{-3} pc

Period range:
1.74 to 1960
ms

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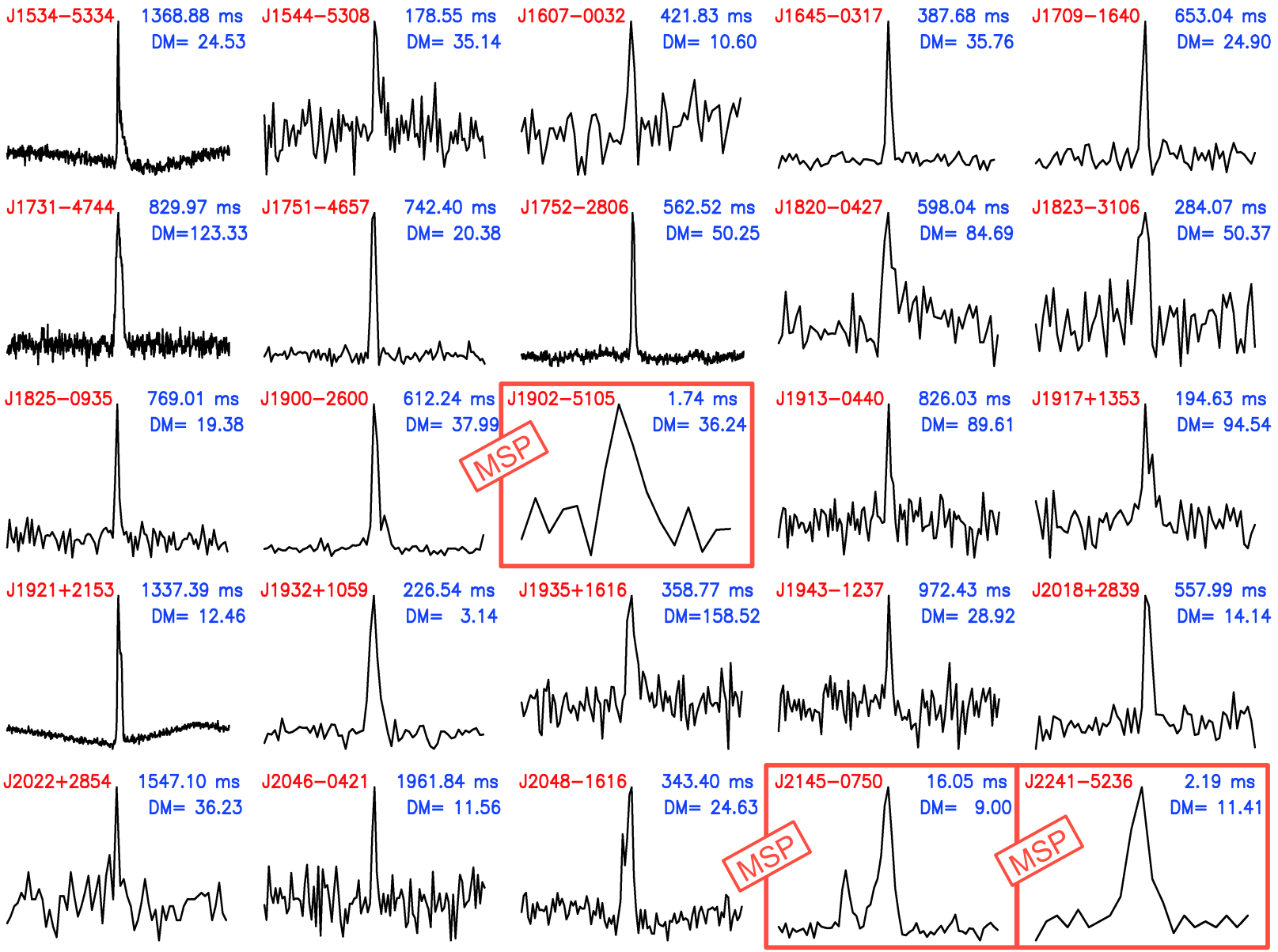

@185 MHz

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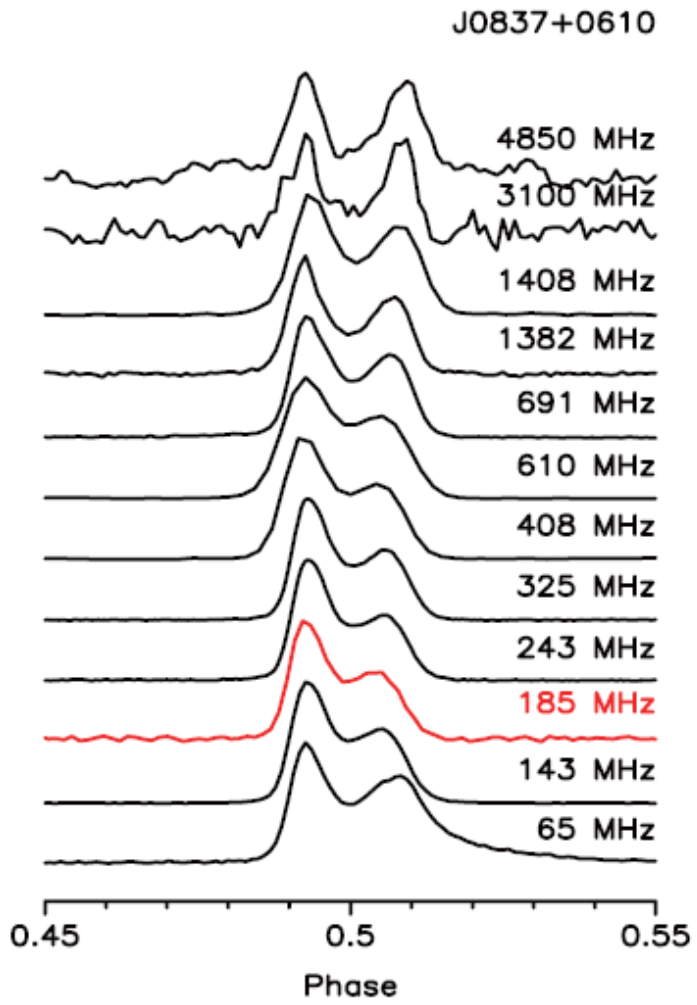
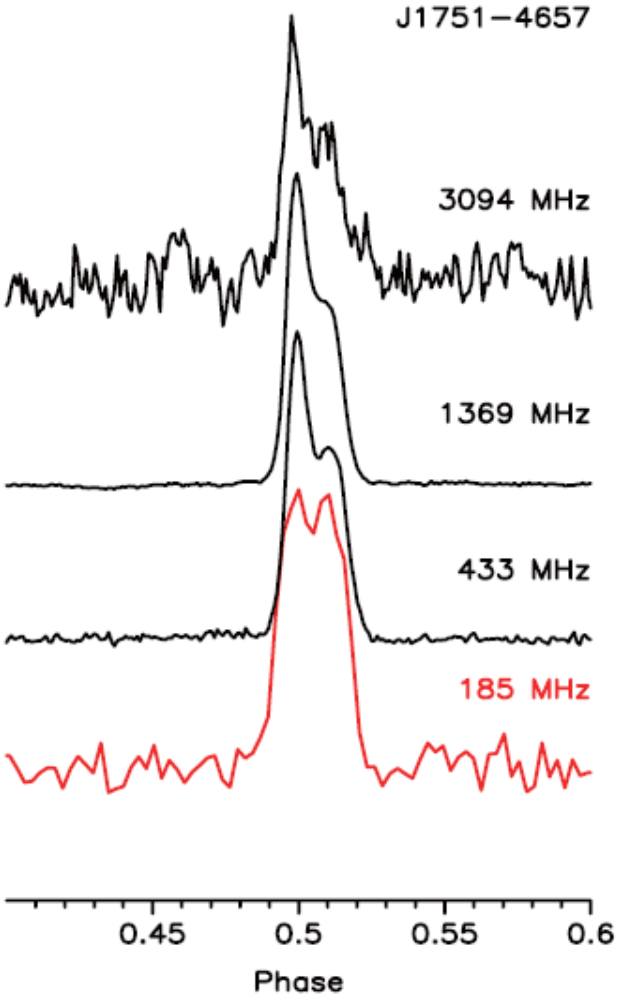
Pulse Profile Evolution with Radio Frequency

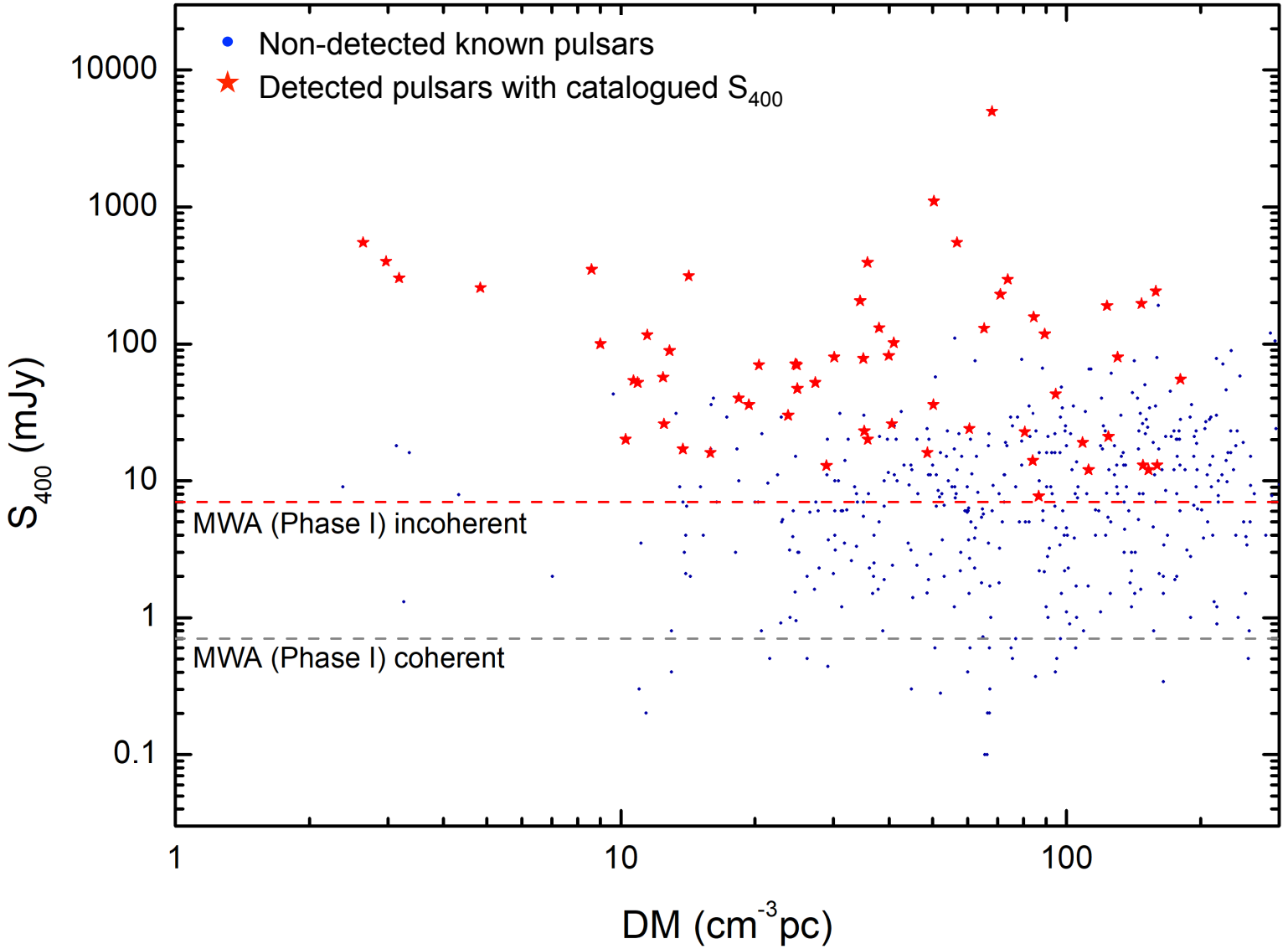


Normal PSR
Period: 1274 ms
DM: 12.9 cm^{-3} pc

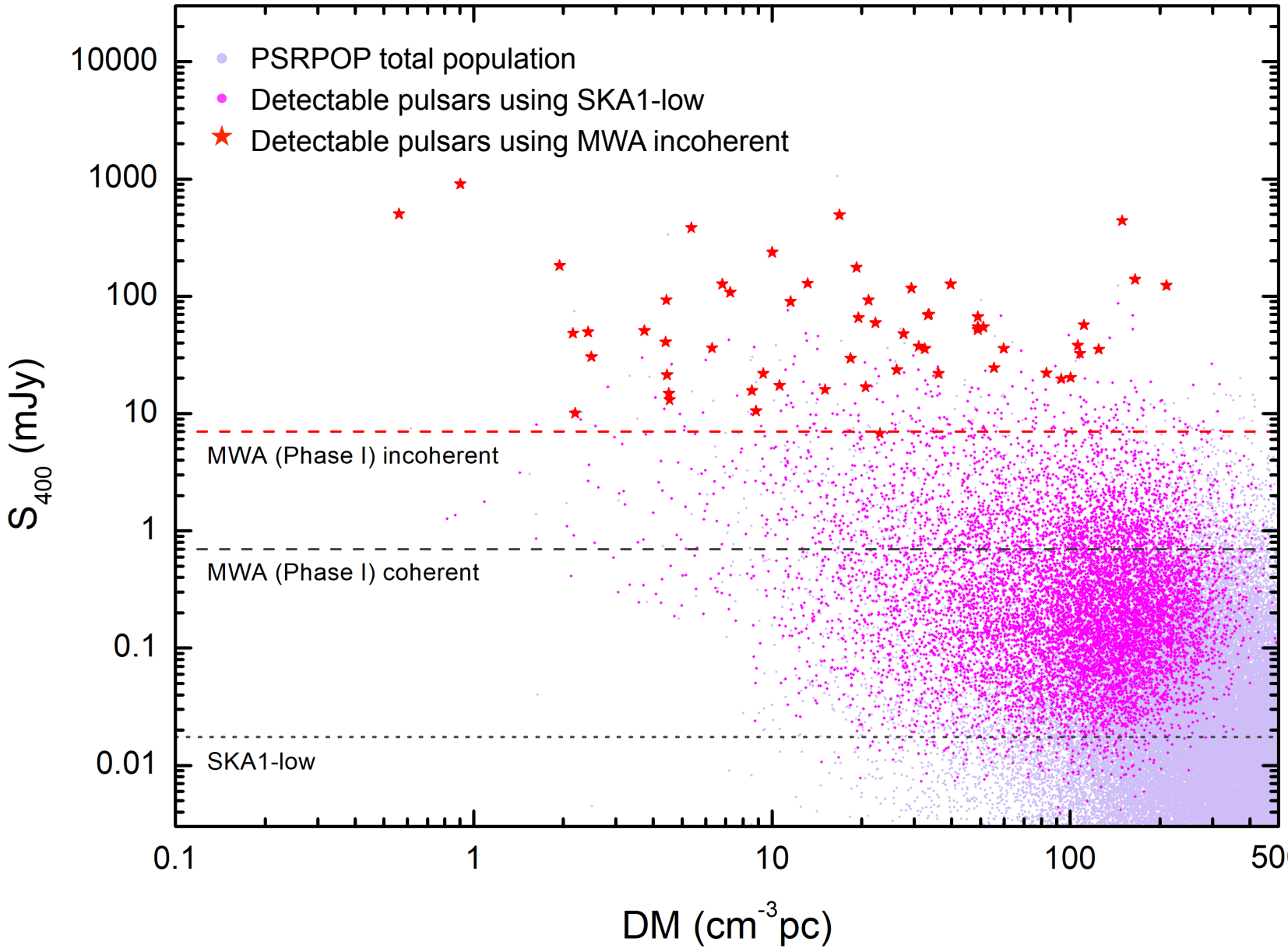


Normal PSR
Period: 742 ms
DM: 20.4 cm^{-3} pc

MWA pulsar detections



Simulated pulsar population (with PsrPopPy)



1 of 14400 realisations

SKA1-low: ~ 9400 pulsars

Summary

Current census:

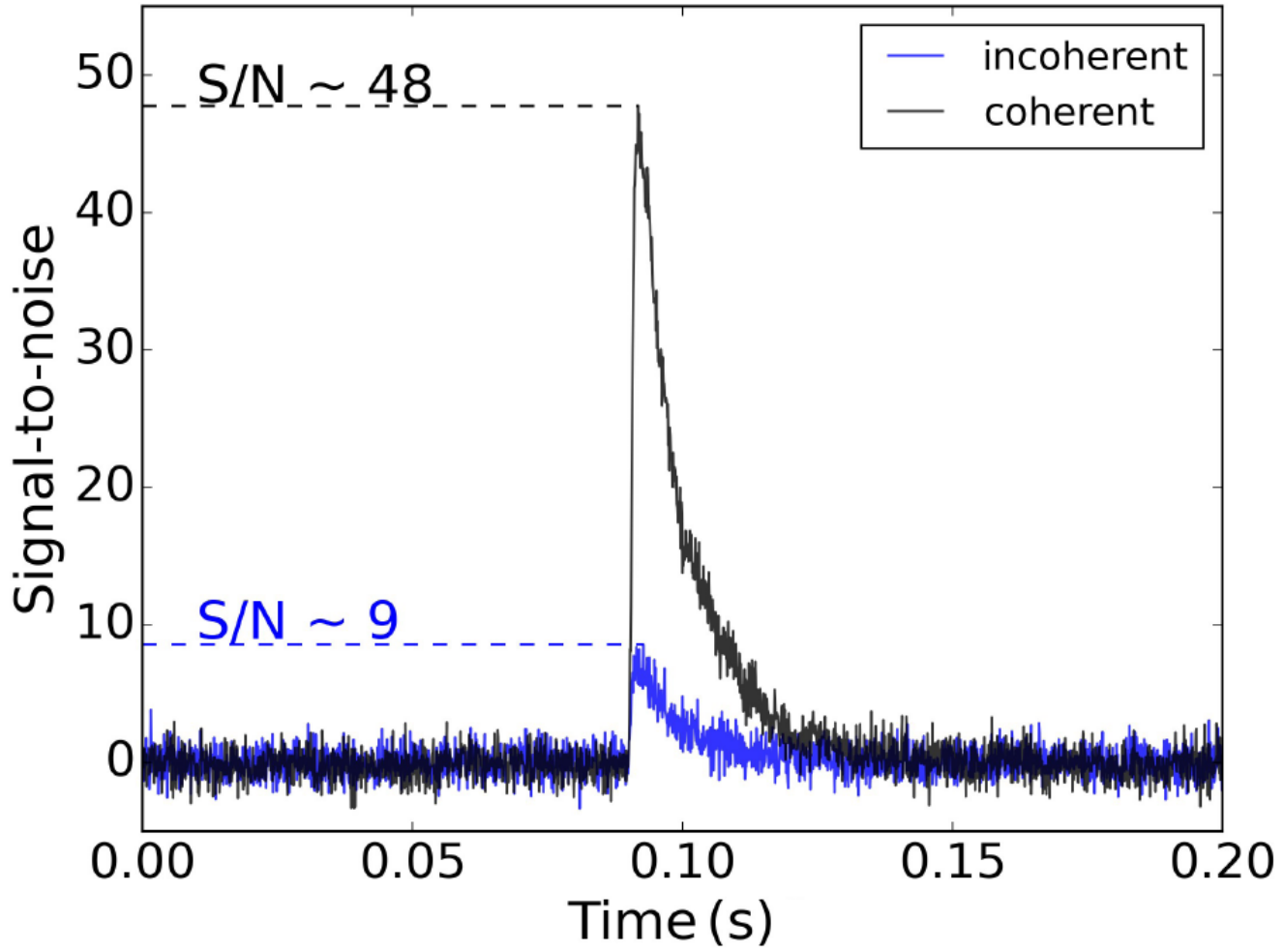
- **~10%** percent of the full MWA sensitivity
- Signals from each of the 128 MWA tiles are summed **incoherently**
- **Summed polarisation (total intensity)**
- **65 pulsars** (6 MSPs & 2 non-recycled binaries) in **47 hours** (59 observing sessions) of VCS archival data
- Their **flux densities** and **pulse profiles** at MWA band have been compared with other works
- Forecast the **prospects of SKA1-low** pulsar detection capabilities
- Watch out for the paper Xue et al. (2017)

Our ultimate goal:

- **Coherently** beamform on hundreds of pulsars in the Southern sky
- **Full polarimetric, high S/N** detections
- **SKA-low** early pulsar science, pulsar observing and searching strategies, estimating the potential of pulsar-related discoveries

Incoherent vs. coherent beams

Giant pulse from the Crab Pulsar (J0534+2200)



Credit: Bradley Meyers

Estimating pulsar flux densities

S/N, period (P) and pulse width (W)

System temperature (Tsys)

Beam power → Gain (G)

→ Mean Flux density (S)

$$S_{\mathrm{mean}} = \frac{\mathrm{S/N}_{\mathrm{peak}} T_{\mathrm{sys}}}{G\sqrt{n_{\mathrm{p}} t_{\mathrm{int}} \Delta f}} \sqrt{\frac{W}{P - W}}$$

n_p: number of polarisations summed (=2)

t_{int}: integration time (5min~1.5hours)

Δf: observation bandwidth (=30.72MHz)

$$\sigma = \frac{2k_{\mathrm{B}}}{\sqrt{n_{\mathrm{p}} t_{\mathrm{int}} \Delta f N}} \frac{T_{\mathrm{sys}}}{A_{\mathrm{eff}}},$$

For single tile: / T_sys = 0.1 (Tingay et al. 2013)

1-sigma noise: 5mJy

S/N ~ 4 -> ~20mJy @ 185 MHz
-> ~7mJy @ 400 MHz