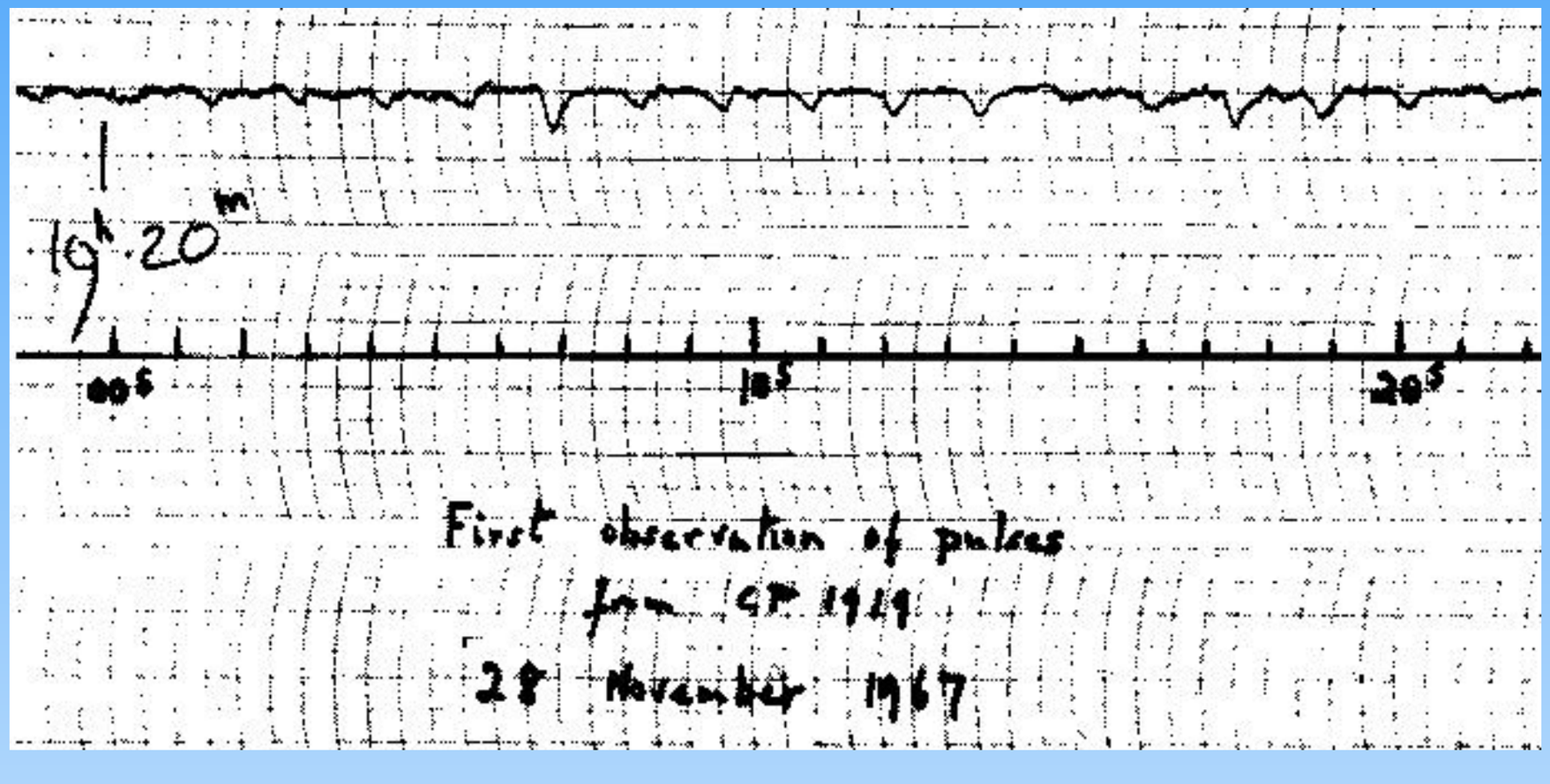
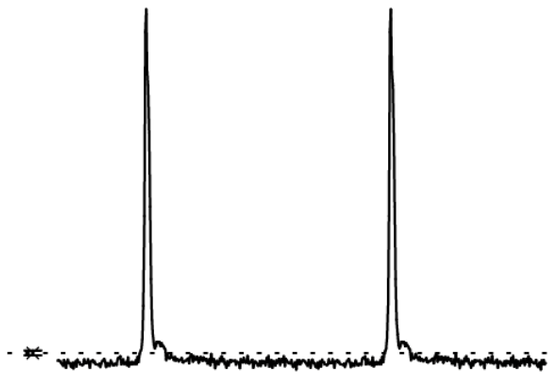


Pulsars at Low Frequencies

Kevin Stovall
NRAO

URSI 2018

2 Pulses of Best Profile



Candidate: PSR_1921+2153
Telescope: LWA1
$Epoch_{topo}$ = 57448.64125484182
$Epoch_{bary}$ = N/A
T_{sample} = 0.00010449
Data Folded = 34406400
Data Avg = 2.223e+05
Data StdDev = 2369
Profile Bins = 256
Profile Avg = 2.987e+10
Profile StdDev = 8.685e+05

Search Information

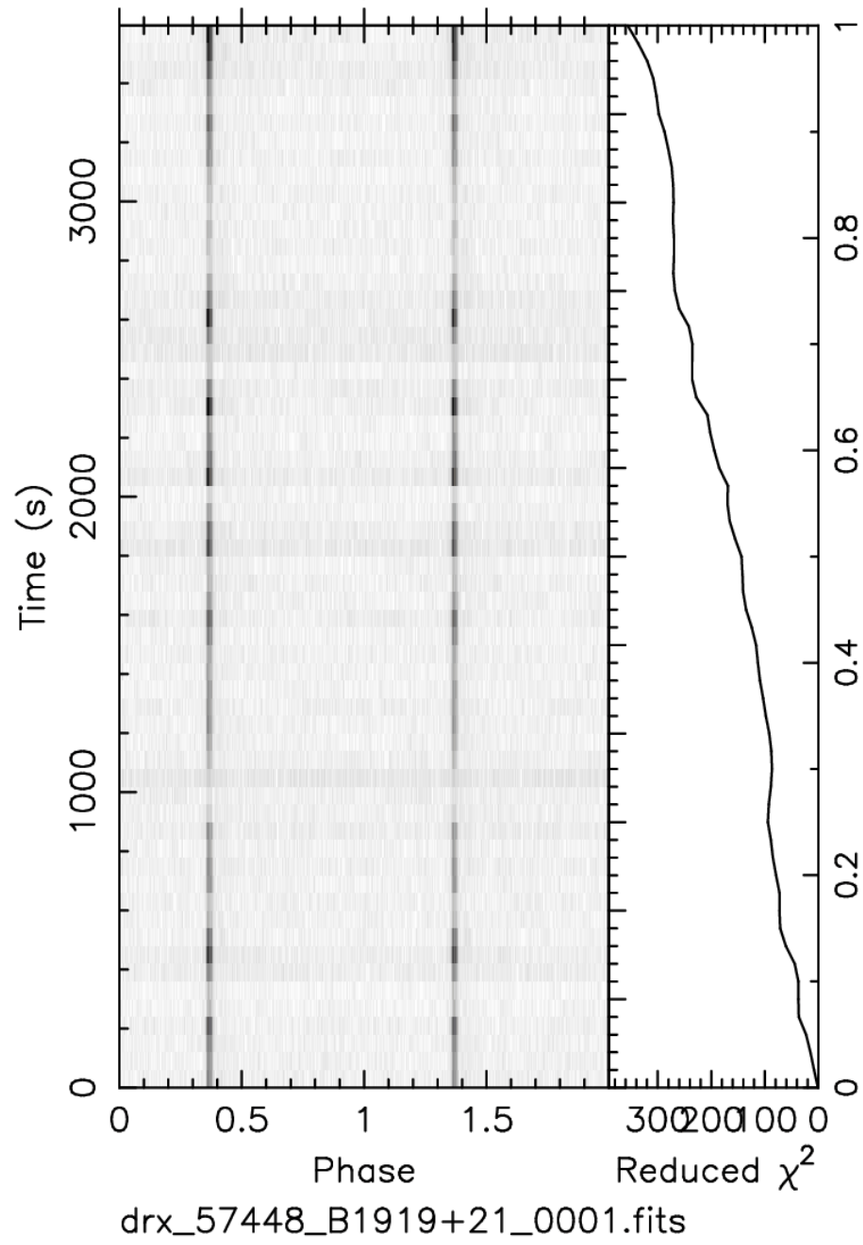
RA_{J2000} = 19:21:44.8150 DEC_{J2000} = 21:53:02.2500

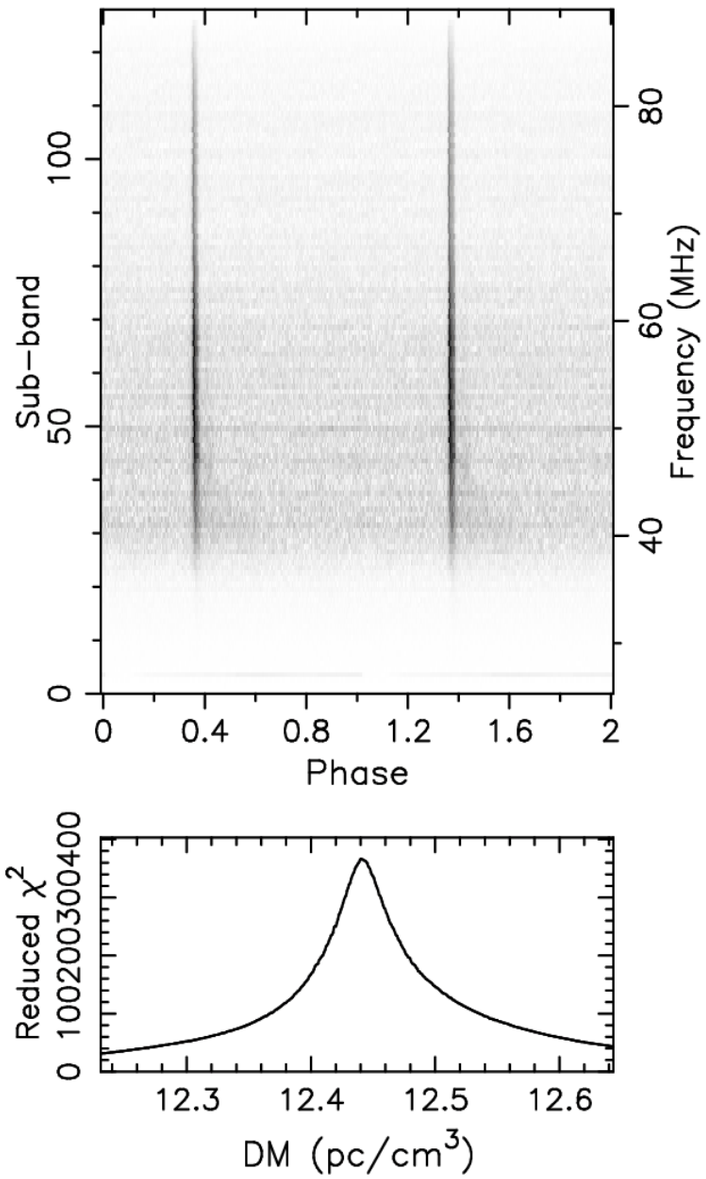
Folding Parameters

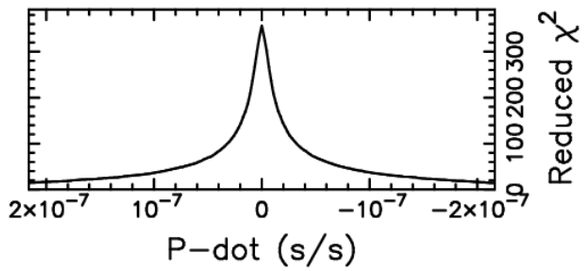
DOF_{eff} = 244.68 χ^2_{red} = 356.065 P(Noise) ~ 0
Dispersion Measure (DM; pc/cm^3) = 12.437
P_{topo} (ms) = 1337.23547(47) P_{bary} (ms) = N/A
P'_{topo} (s/s) = 0.0(1.0)x10^{-9} P'_{bary} (s/s) = N/A
P''_{topo} (s/s^2) = 0.0(1.8)x10^{-12} P''_{bary} (s/s^2) = N/A

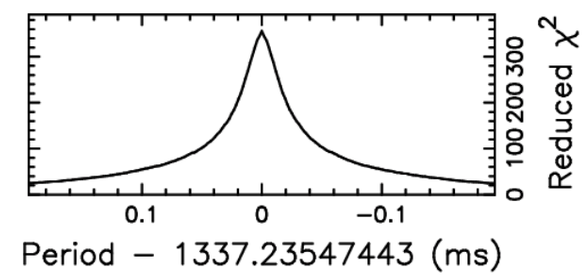
Binary Parameters

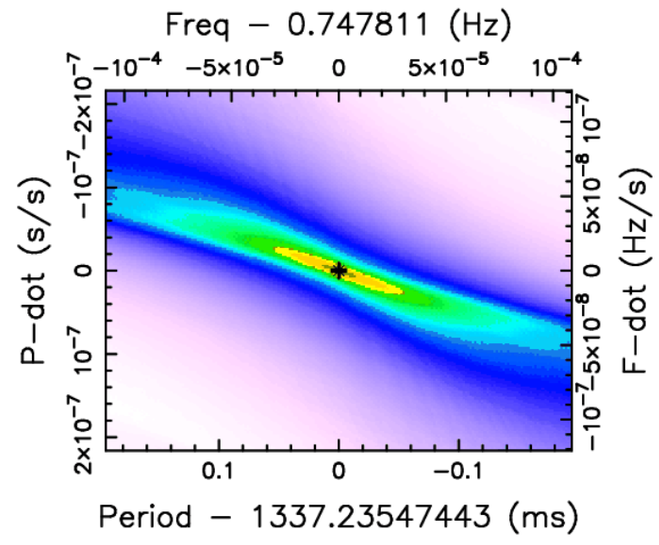
P_{orb} (s) = N/A e = N/A
$a_1 \sin(i)/c$ (s) = N/A ω (rad) = N/A
T_{peri} = N/A











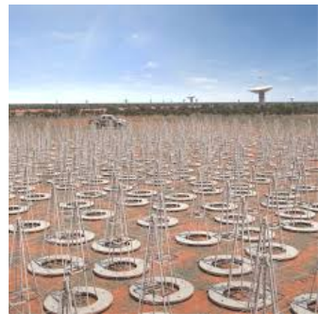
drx_57448_B1919+21_0001.fits

kstovall 27-Mar-2016 02:56

Renaissance of low radio frequencies

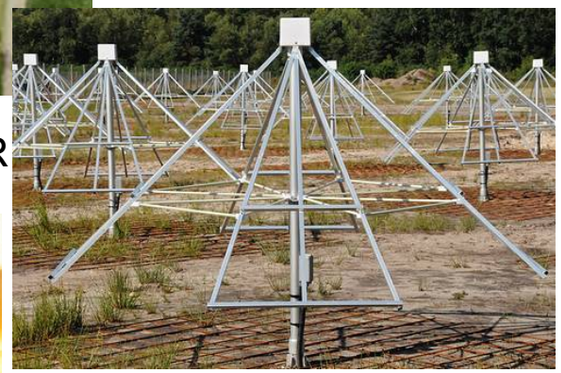
IPS array

DE601



SKA Low

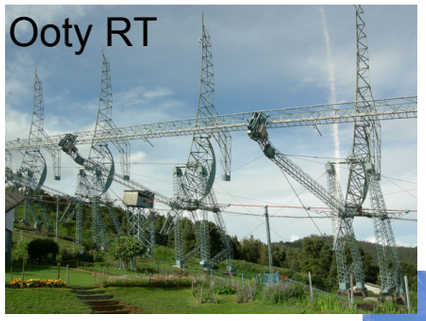
LOFAR



NenuFAR

LWA

Ooty RT



DKR-1000

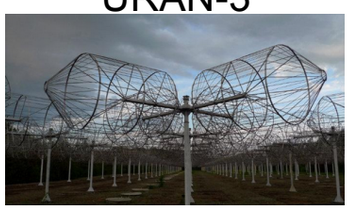
VLA

MWA

UTR-2

GURT

URAN-3



BSA

uGMRT

Vlad Kondratiev

Past Telescopes

Typically transit instruments

Low BW and/or Polarizations

Limited time resolution

Modern Telescopes

Full tracking

Large BW and Pol

Limited time resolution

Pulsars at Low Frequencies

- Pulsar Searches
  - Fast survey speed
  - Steep Spectra

- Intervening Medium
  - ISM - dispersion, scattering, Faraday rotation
  - Solar wind, CMEs
  - Ionosphere

- Pulsar Emission
  - Rapid profile evolution vs frequency
  - Spectral turnover
  - Studies of specific sources

Pulsar Timing Arrays

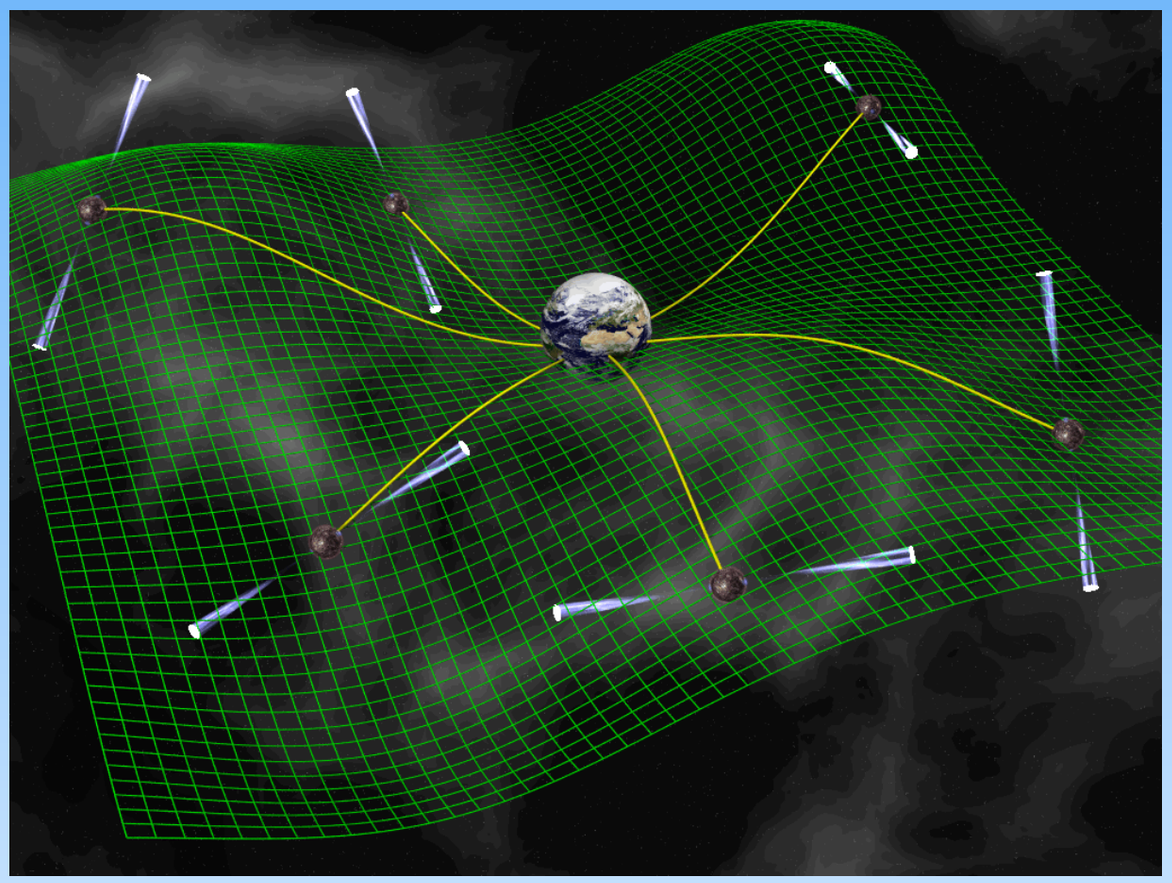
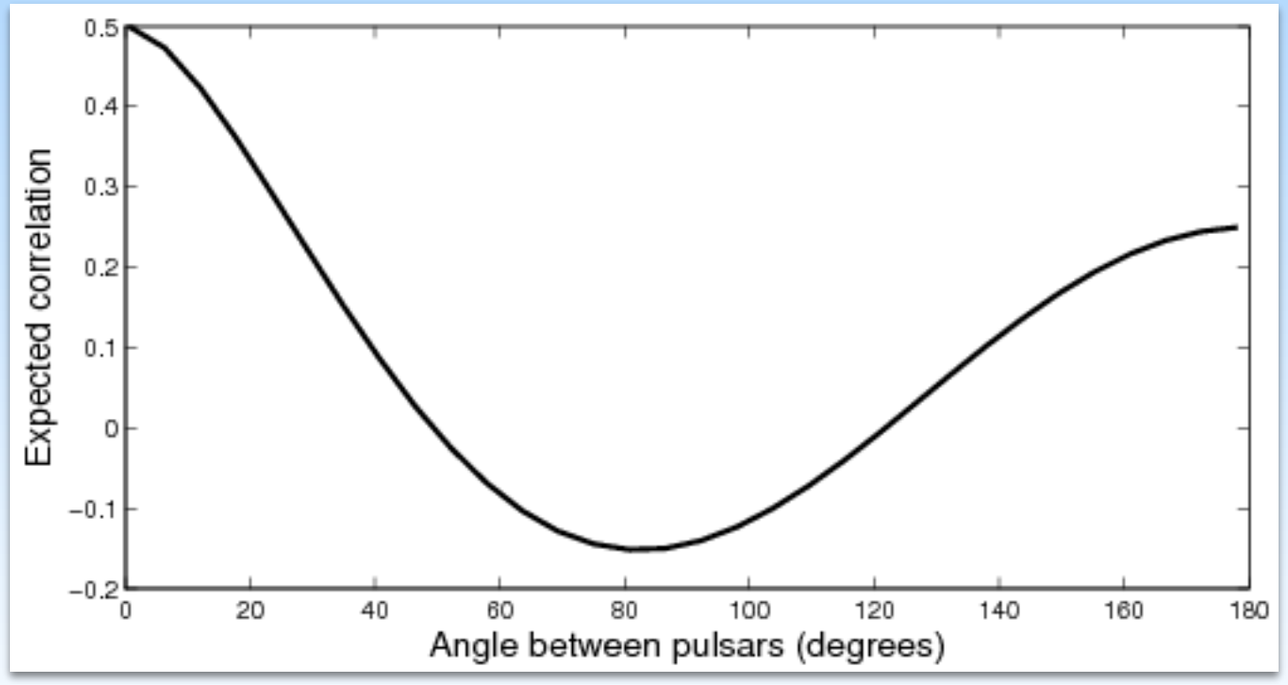


Image Credit: David Champion

- North American Nanohertz Observatory for Gravitational Waves (NANOGrav)
- European Pulsar Timing Array (EPTA)
- Parkes Pulsar Timing Array (PPTA)
- International Pulsar Timing Array (IPTA)

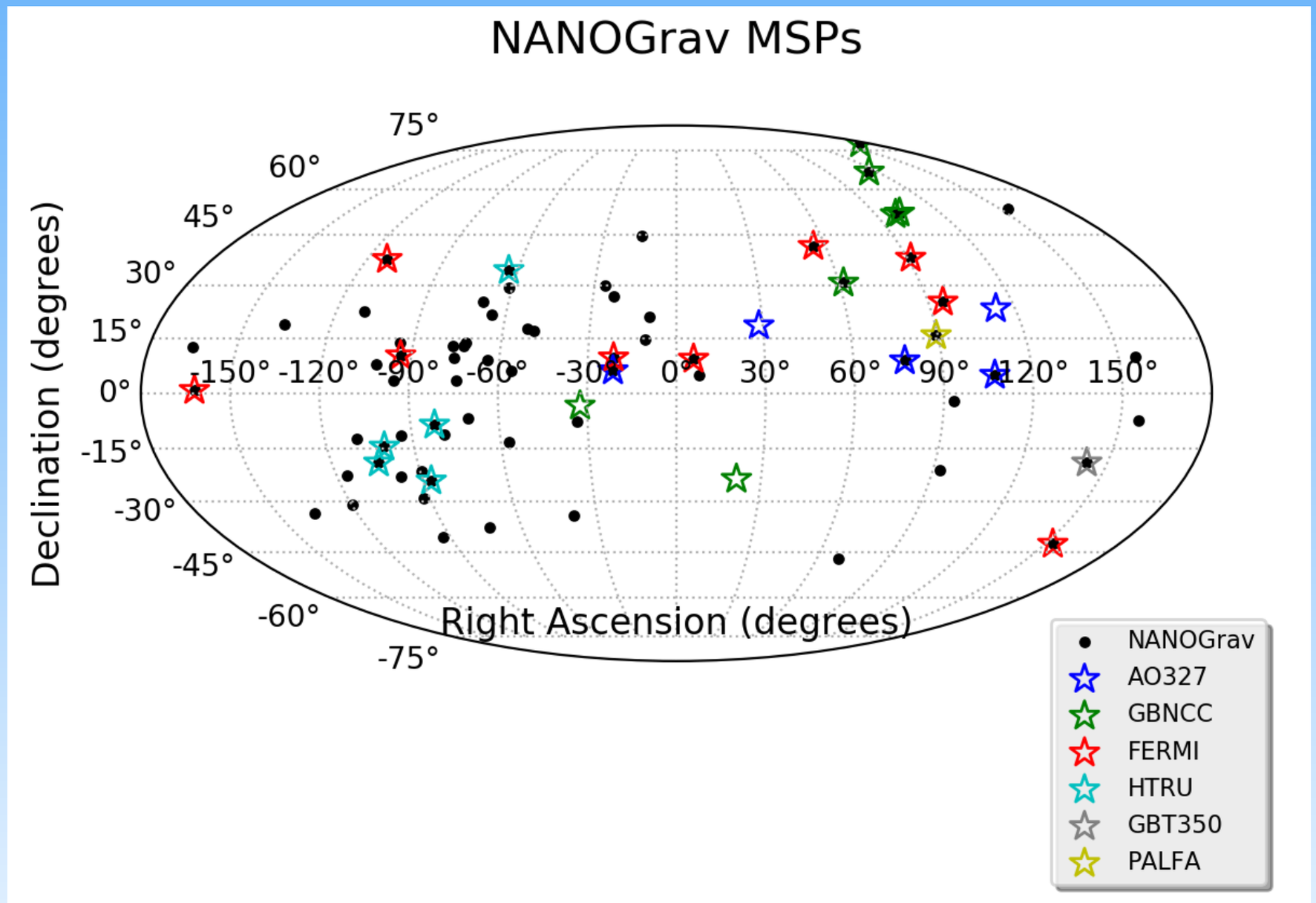
Pulsar Timing Arrays (PTAs) monitor a set of very stable millisecond pulsars (MSPs) to look for GW signals. Such signals would be correlated vs. pulsar angular separation.

Hellings & Downs Curve



Hellings & Downs 1983, ApJ, 265, 39

Pulsar Searching



Why search?

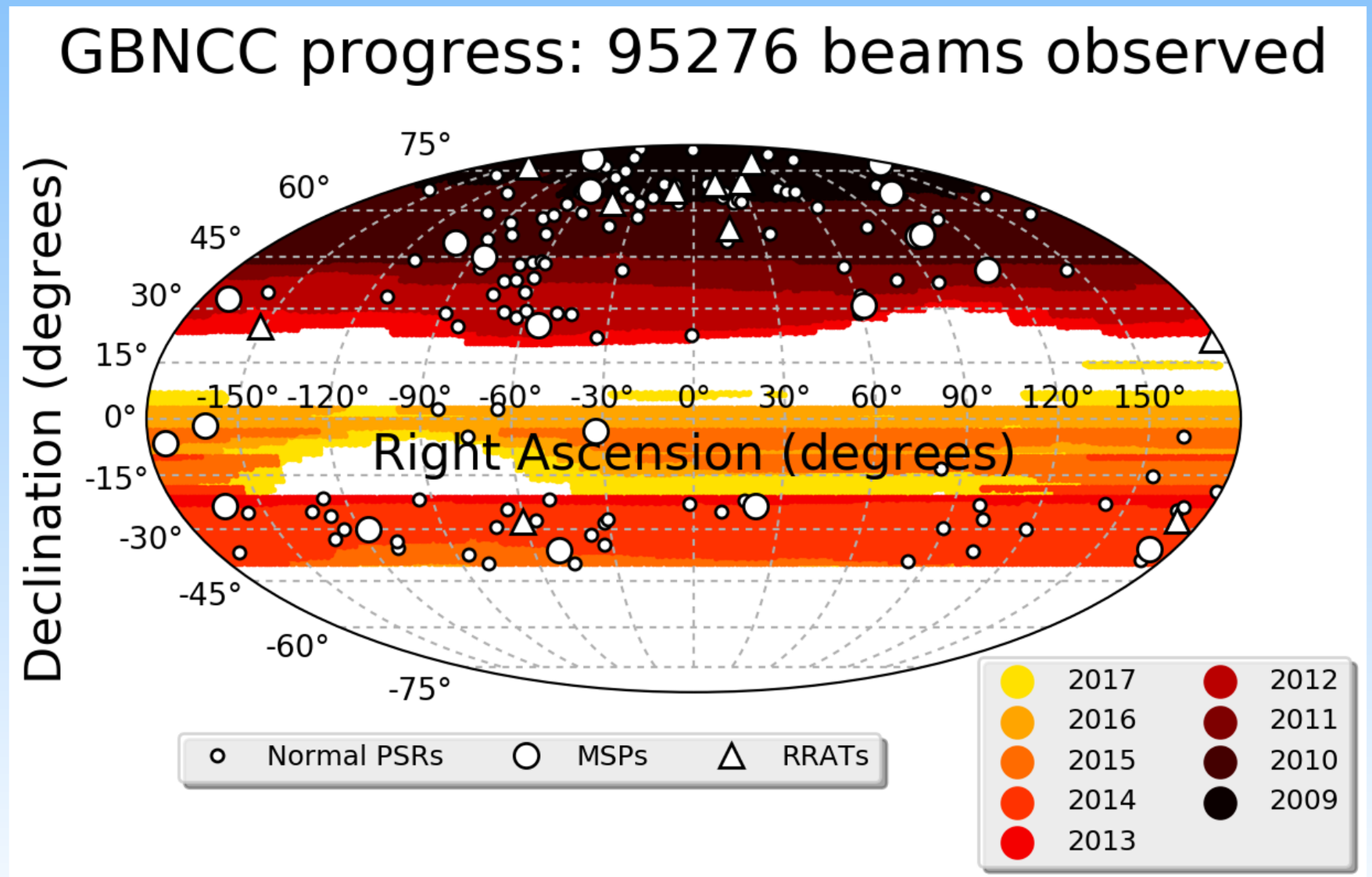
- Find MSPs for PTAs.
- Populations of pulsars, neutron stars, binaries.
- Find new interesting binaries such as DNSs, double pulsars, pulsar-black hole system?

Pulsar Searching

Green Bank North Celestial Cap Survey

Survey of the full sky visible to the GBT at 300 - 400 MHz

- 156 Discovered sources
- 20 MSPs, 6 now in PTAs
- 23 binaries
- ~6 multi-wavelength counterparts

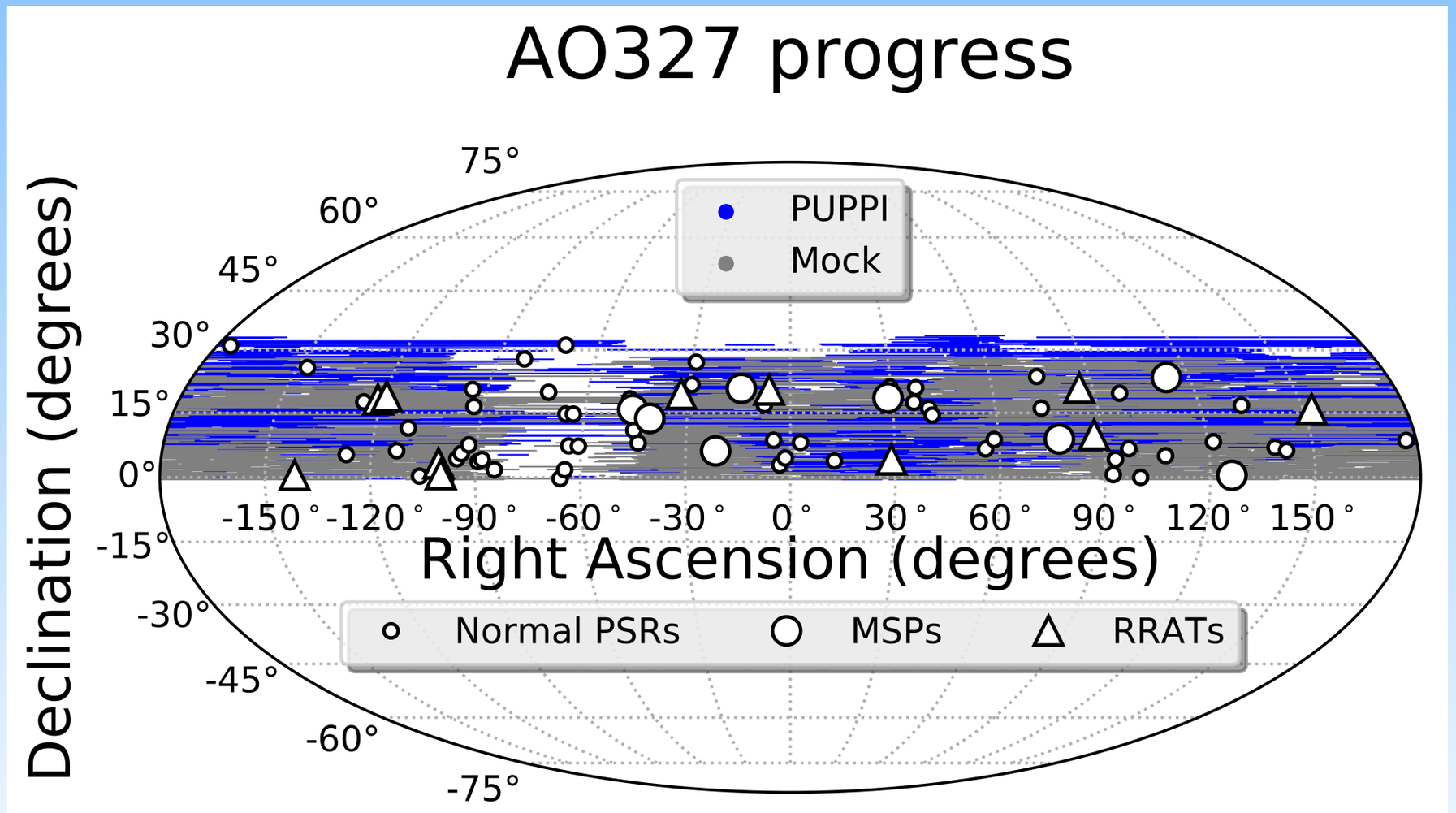


Pulsar Searching

Arecibo Observatory 327 MHz Driftscan Survey

Survey of the full sky visible to AO at 297 - 357 MHz

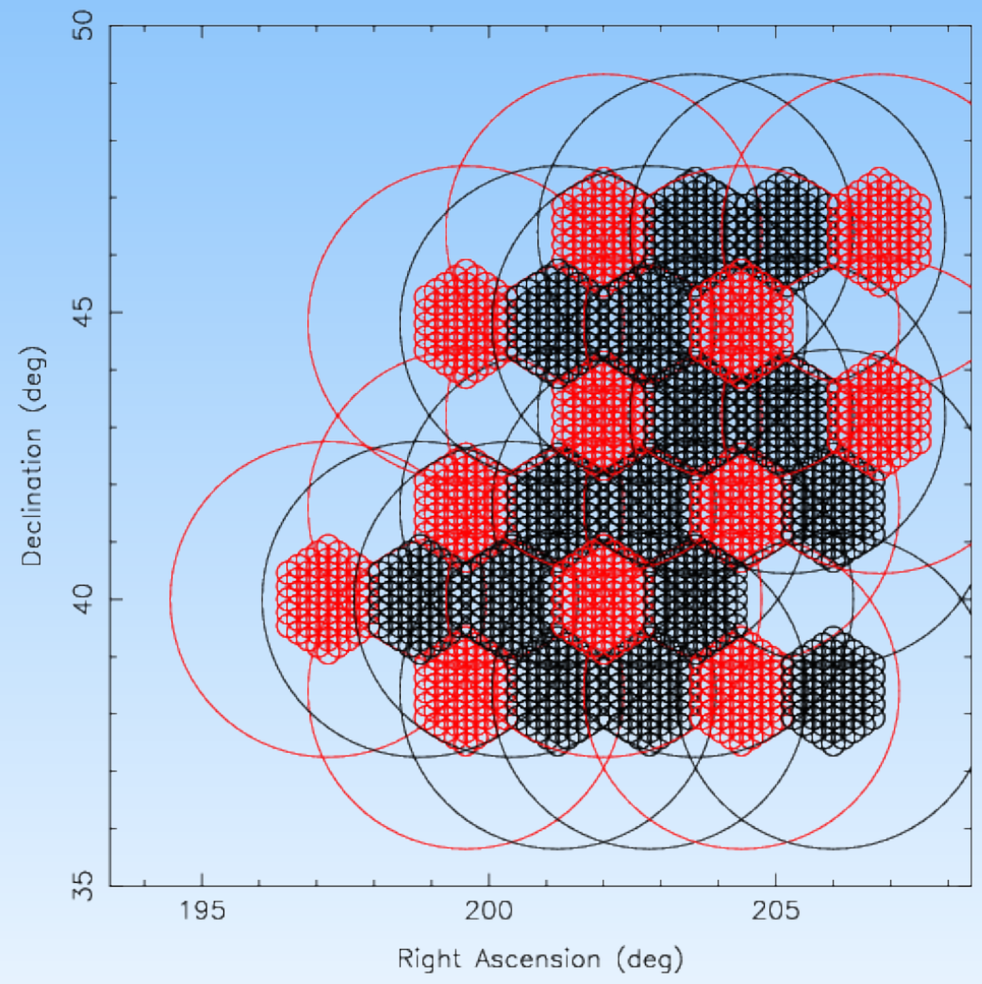
- 75 Discovered sources
- 8 MSPs, 4 now in PTAs
- 8 binaries (3 DNSs)
- ~3 multi-wavelength counterparts



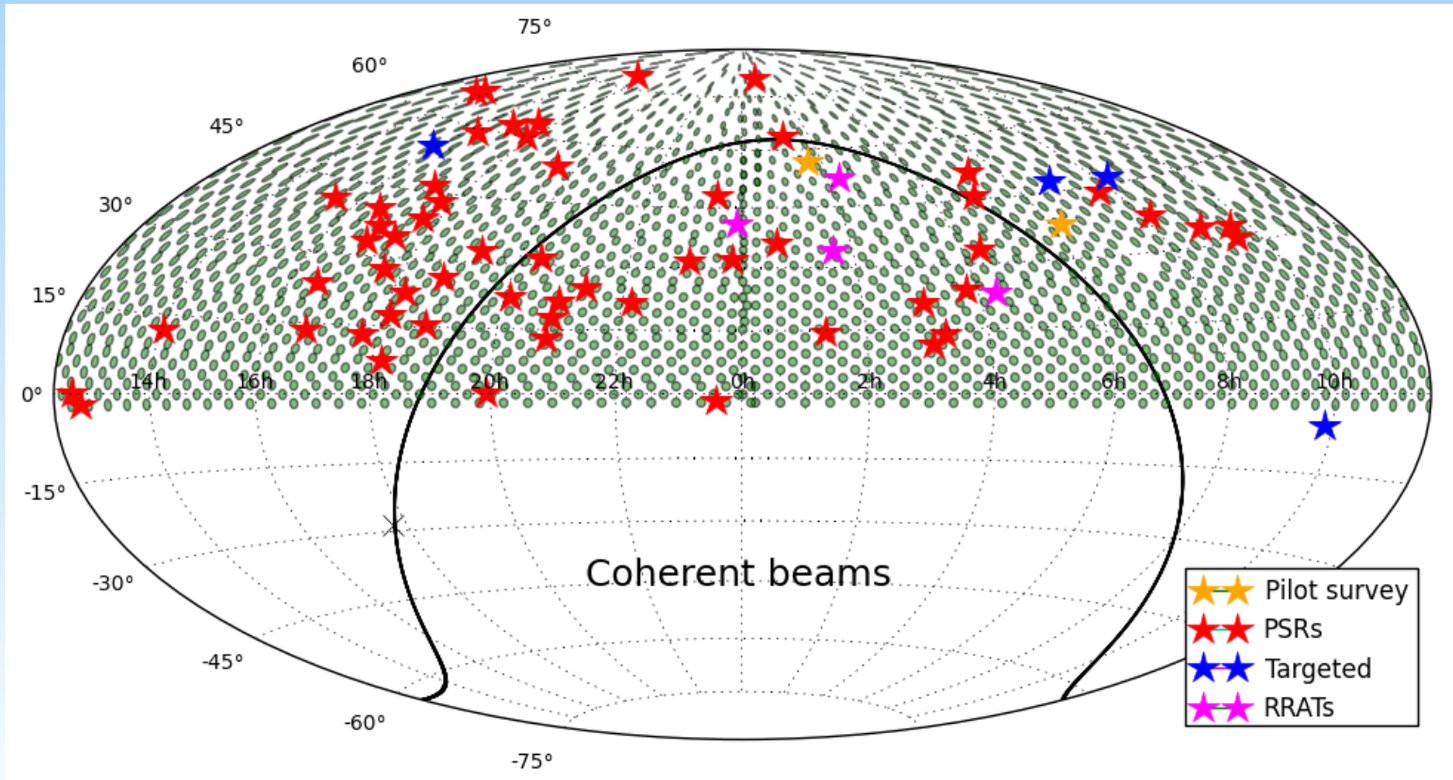
Pulsar Searching

The LOFAR Tied-Array All Sky Survey (LOTAAS)

Survey of the northern hemisphere at 119 to 151 MHz

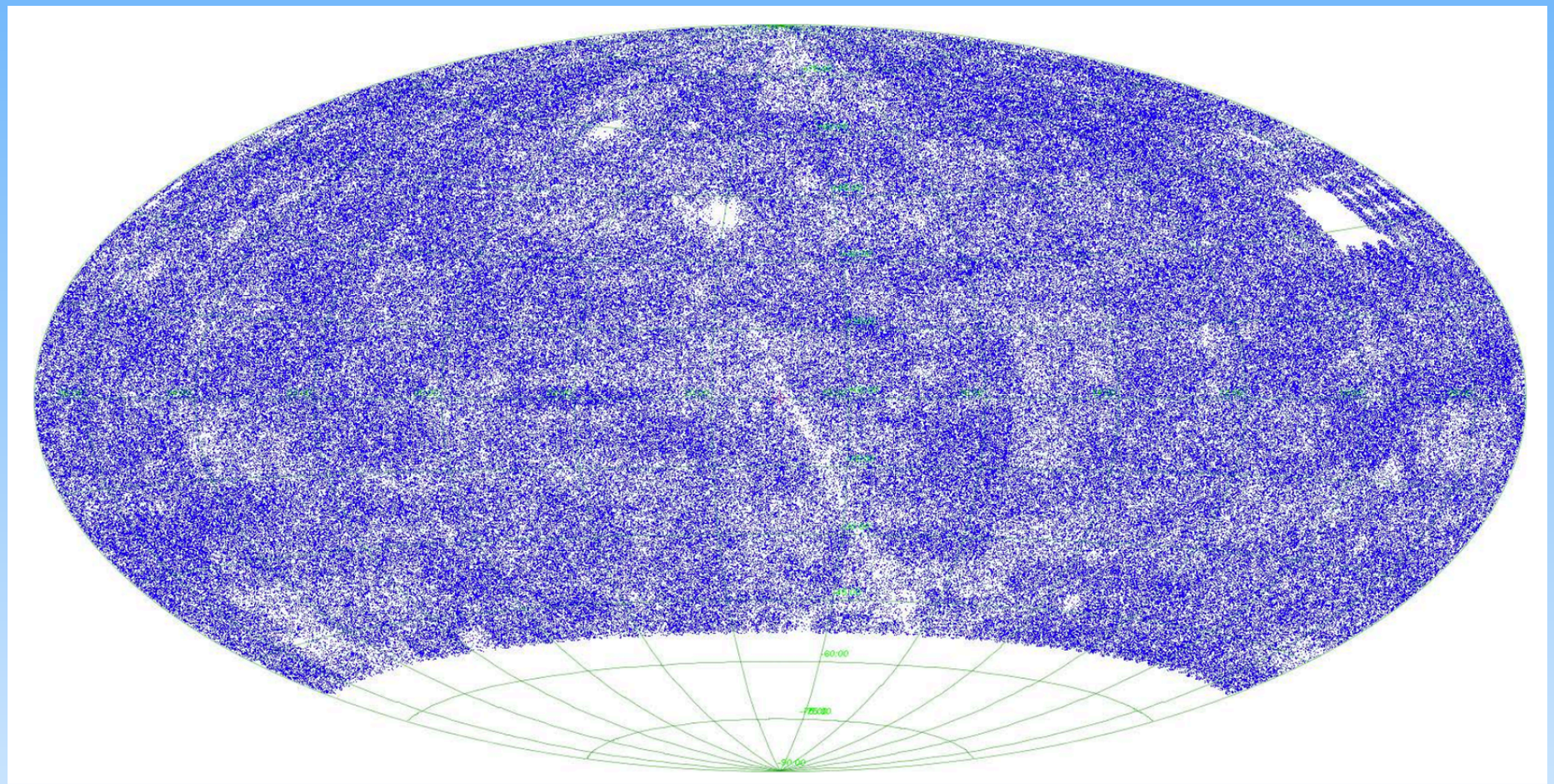


- 78 Discovered sources
- 4 MSPs
- Recently discovered the longest period pulsar (24 s)



Pulsar Searching

The GMRT 150 MHz All-sky Radio Survey - Alternative Data Release TGSS ADR



Intema et al. 2016

Frail et al. 2016 - Identified 16 steep spectrum sources coincident with Fermi Gamma-ray associated sources, 7 have now been detected as pulsars.

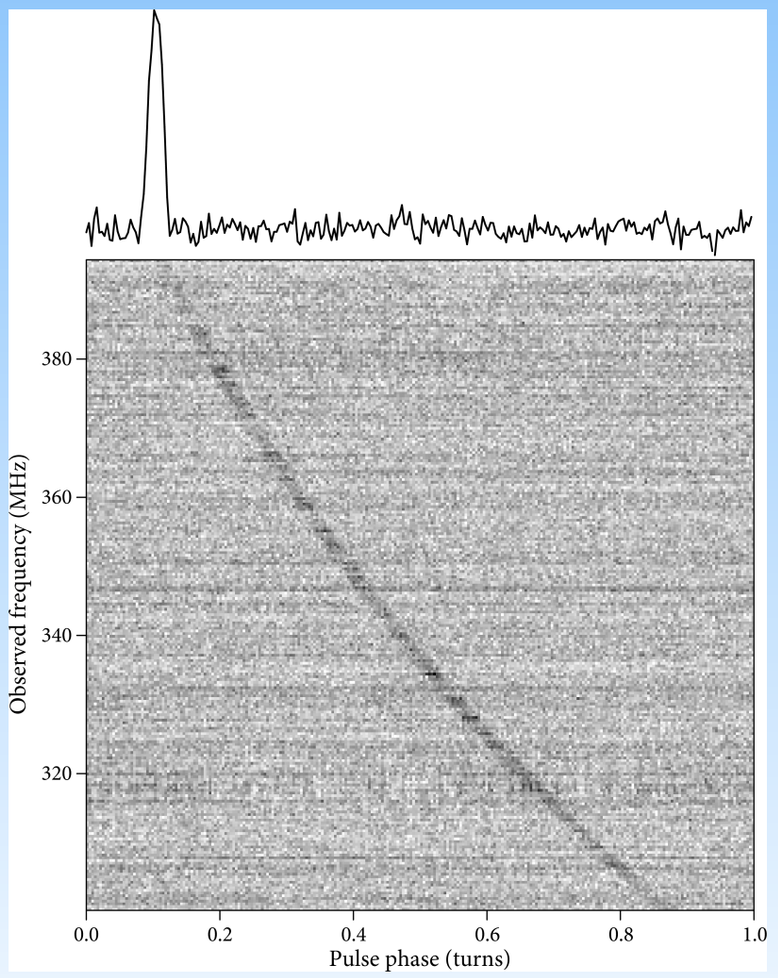
Imaging observations can identify pulsars based on spectrum, polarization, multi-wavelength counterpart, scintillation.

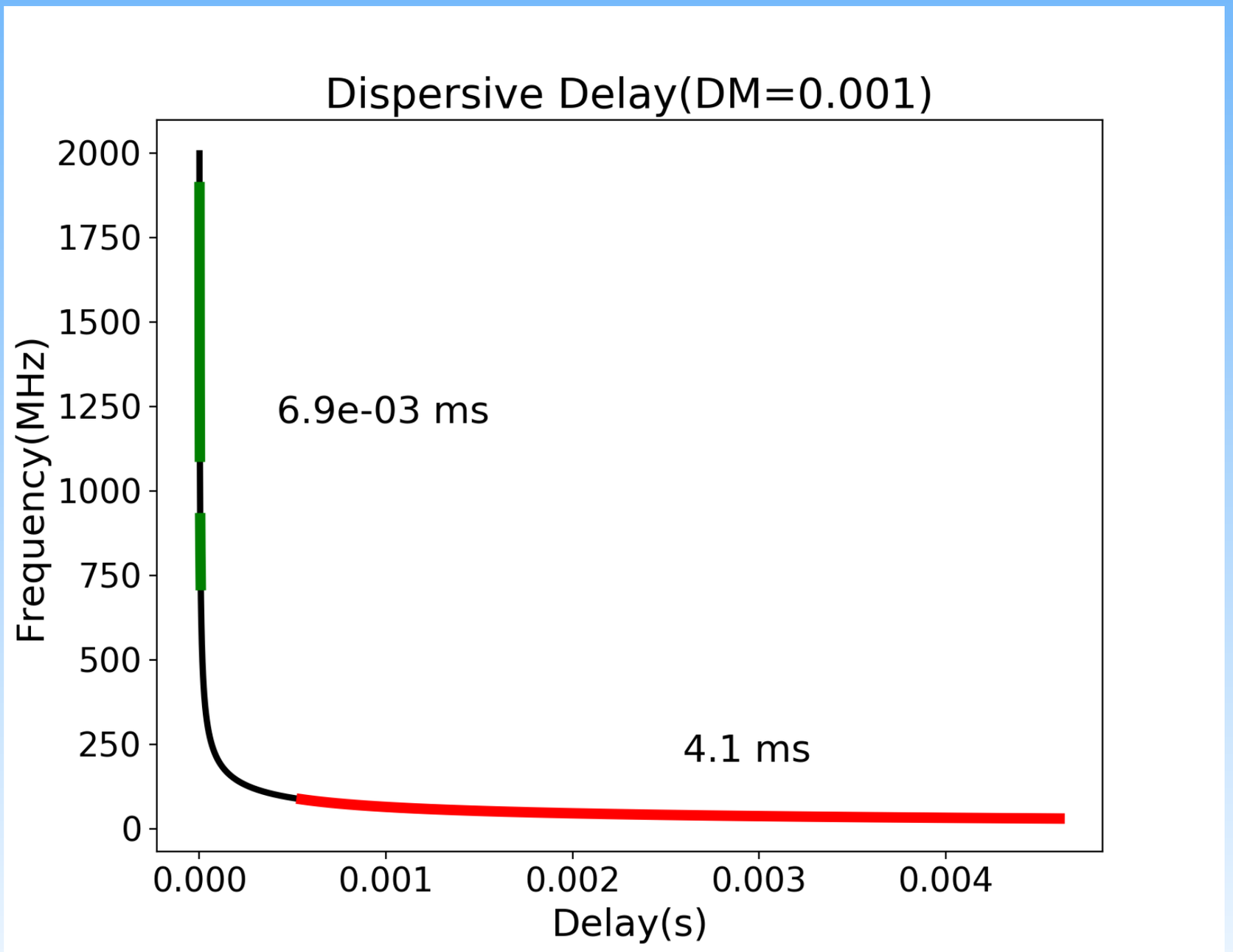
Intervening Medium Dispersion

Dispersion

Delay $\propto$ DM ν^{-2}

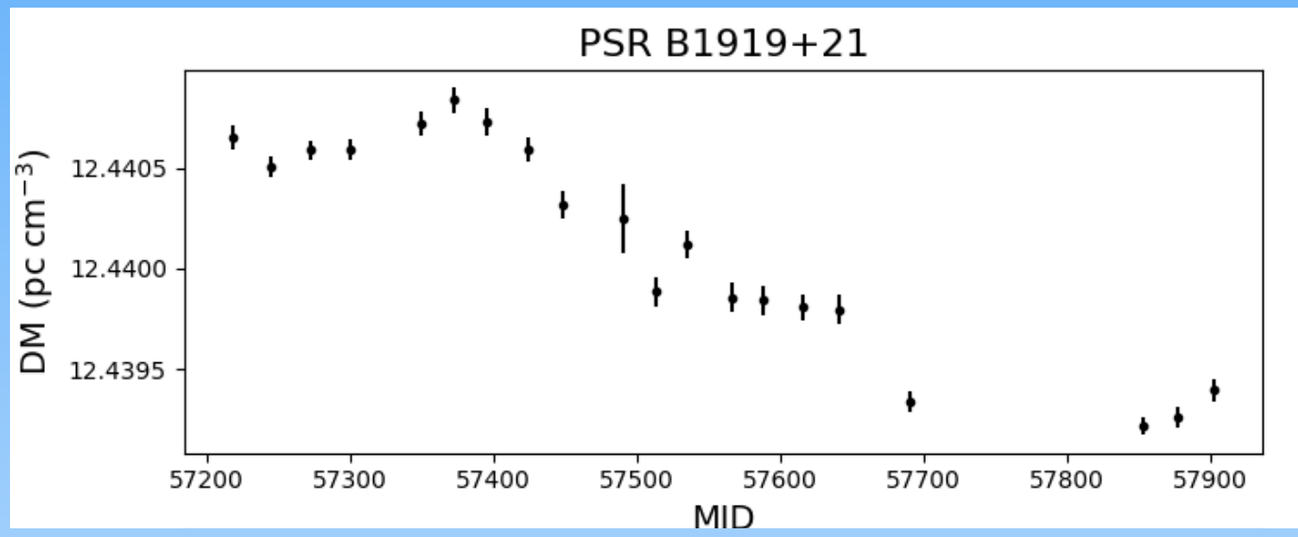
$\mathrm{DM} = \int_0^d n_e dl$

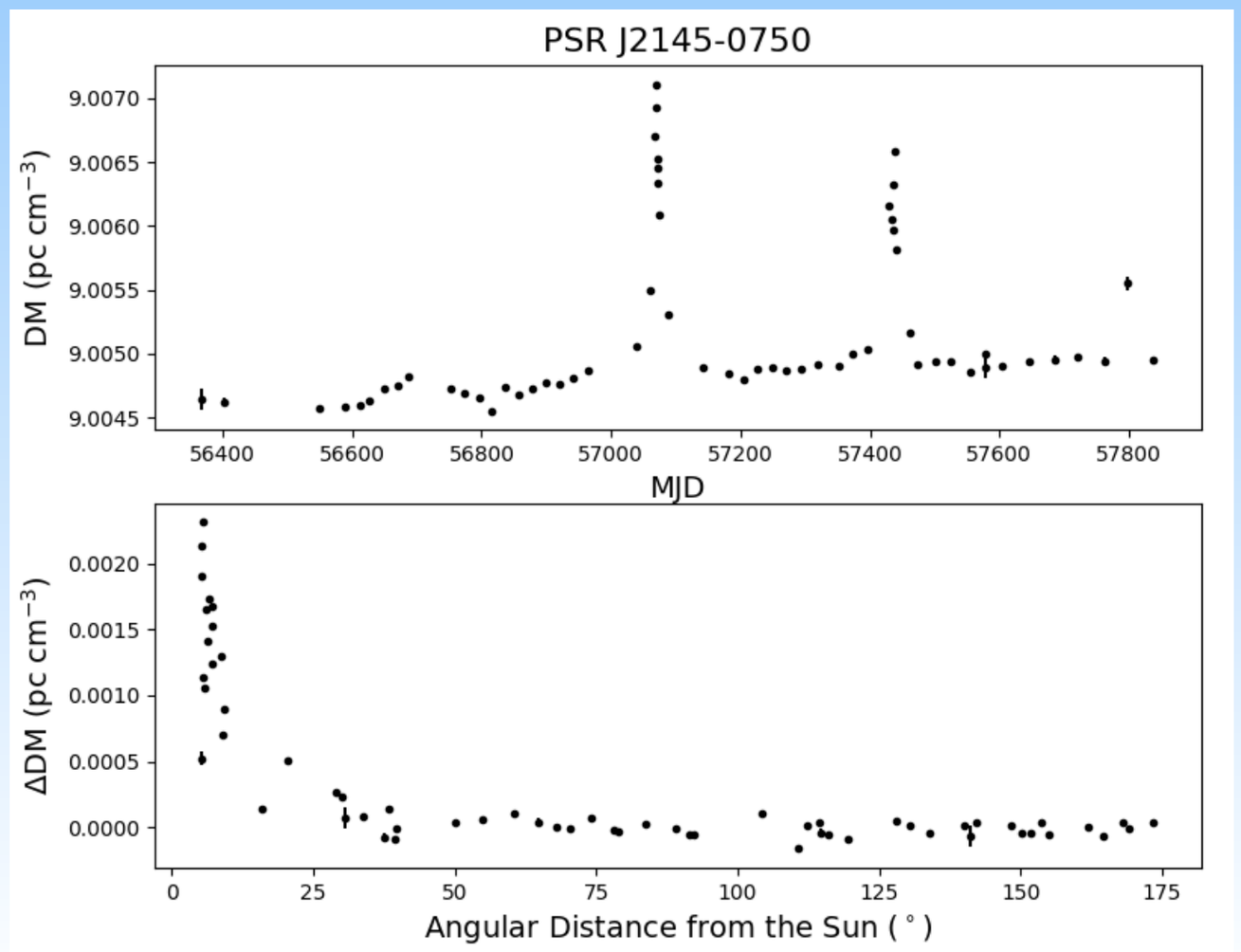




Intervening Medium Dispersion

DM(t) variation commonly seen in PTA data, can now also be easily measured in slow pulsars.





Regular low frequency observations likely to not be useful for direct correction of PTA datasets. (See Cordes, Shannon, & Stinebring 2016), but will still give information on ISM, solar wind, etc.

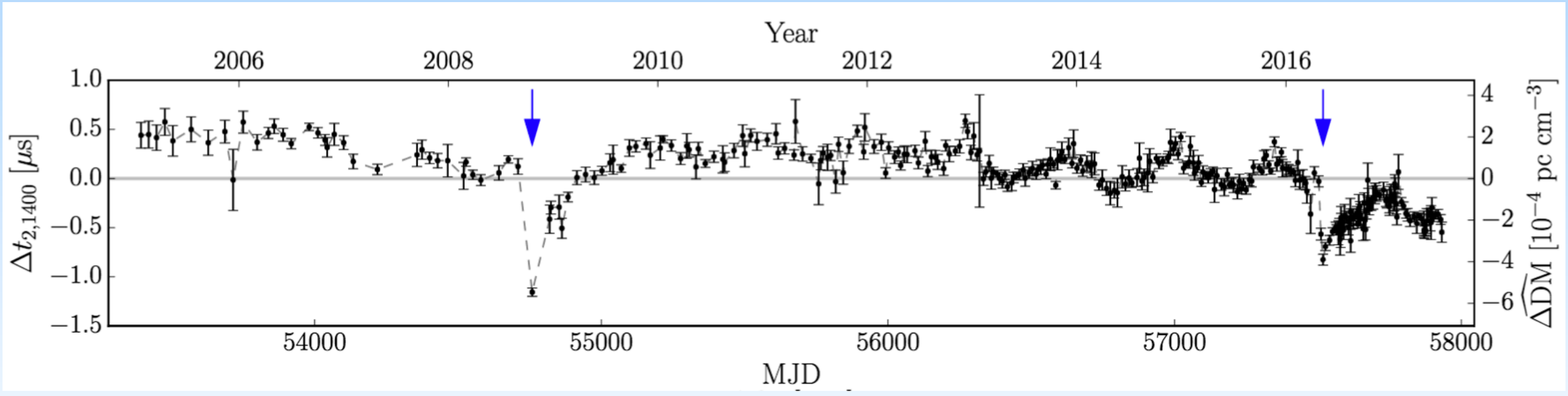
Intervening Medium Dispersion

DM Events

- In 2009, DM of J1713+0747 dropped by ~0.0013 pc/cm^3 and recovered over ~100 day period. A similar event happened again in 2016.

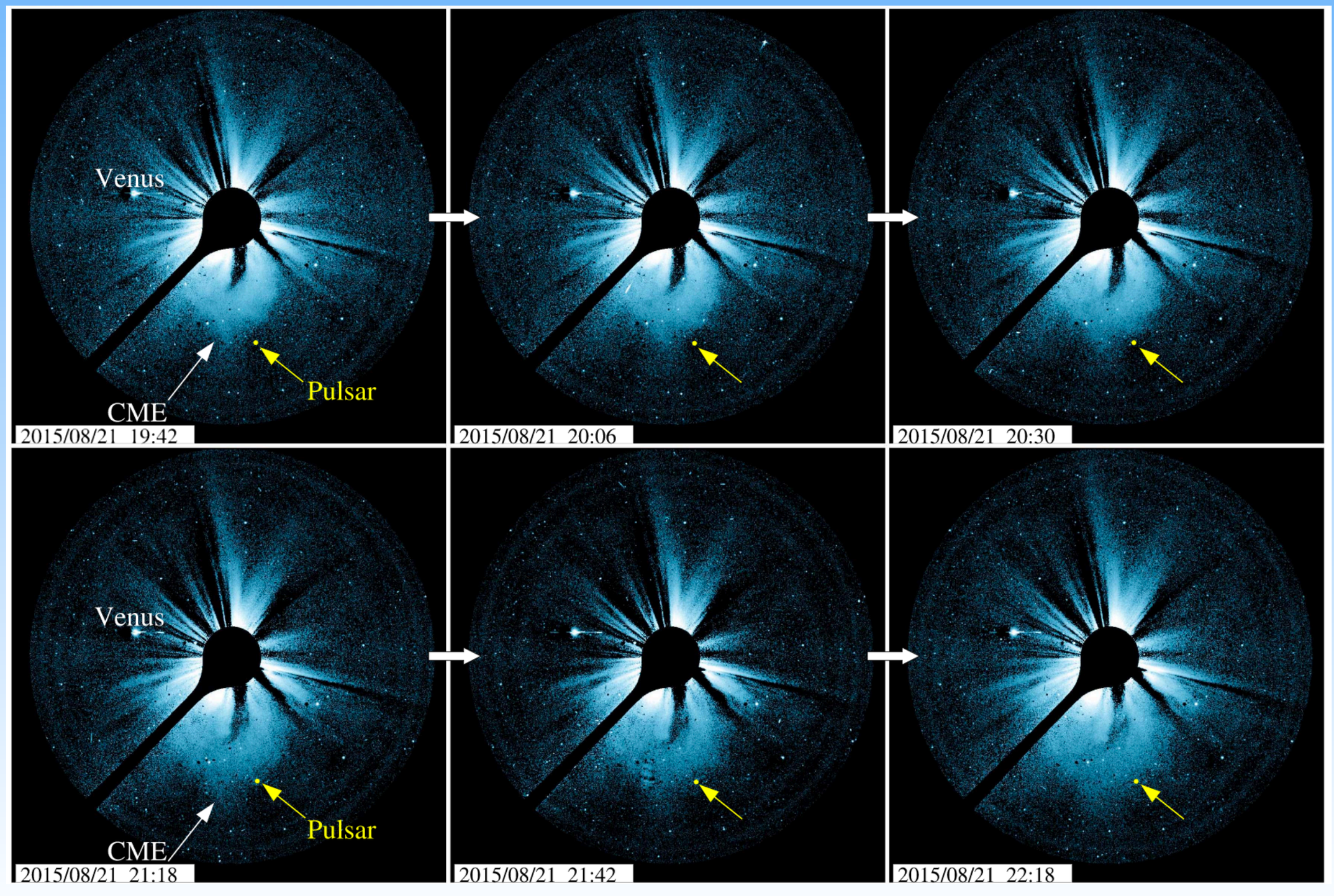
- Mid 2006, J1603-7202's DM slowly increased by ~0.003 pc/cm^3 and then decreased over ~200 days.

- Would be good to be able to study such events in greater detail using frequent observations using a low frequency telescope.



Lam et al. 2018, submitted

Intervening Medium
CME

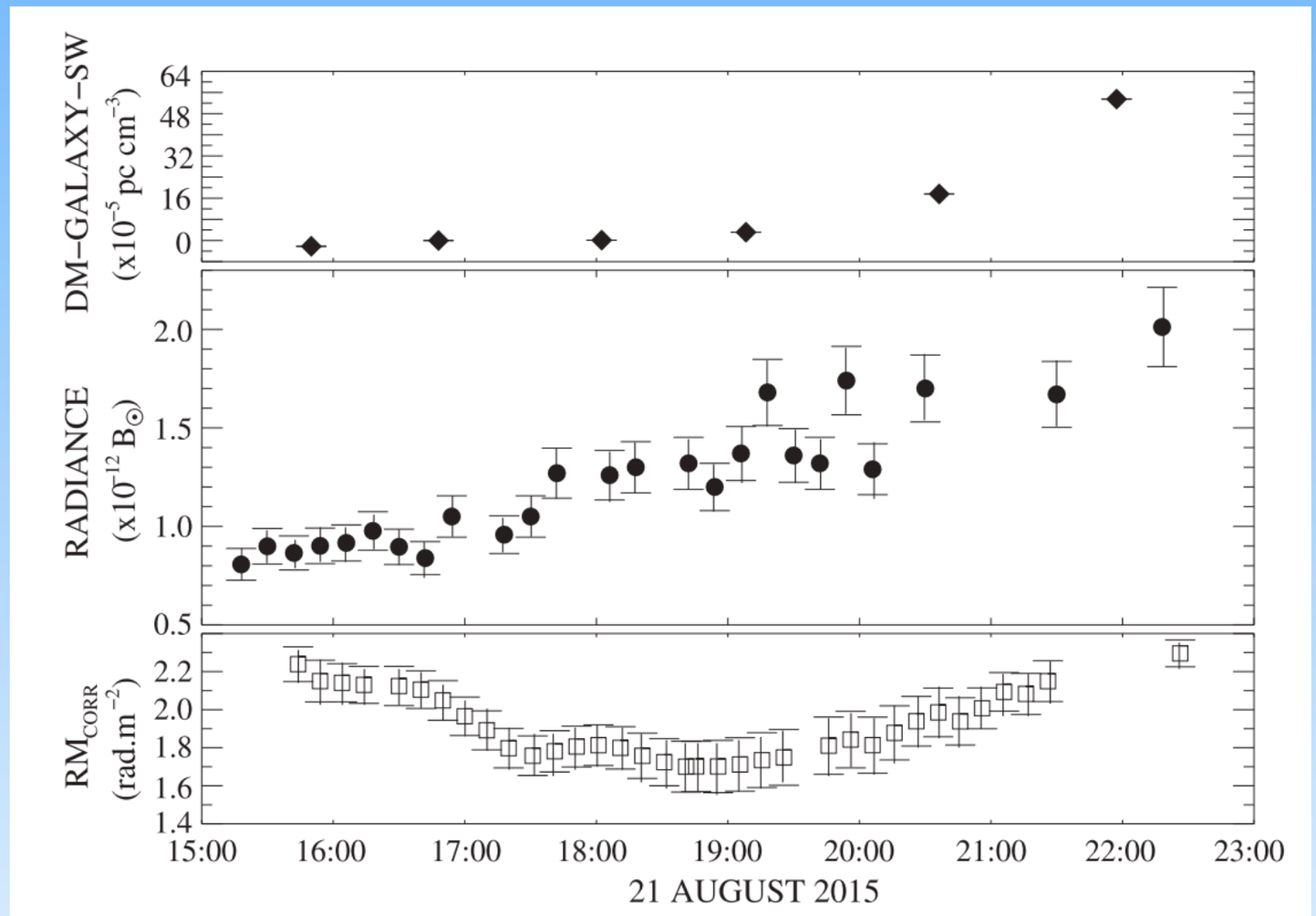


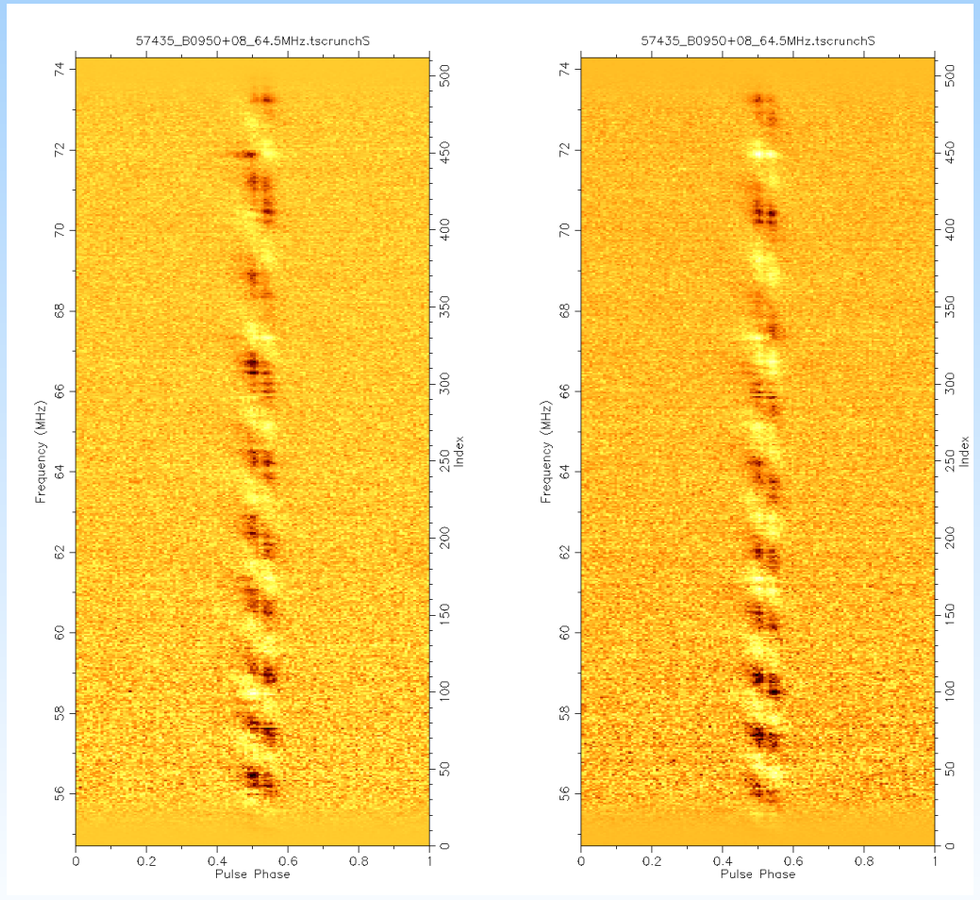
Intervening Medium
CME Density & Faraday rotation

$$\Delta\Psi_{PPA} = \lambda^2 \times RM$$

$$RM = \frac{e^3}{2\pi m_e^2 c^4} \int_0^d n_e B_{||} dl$$

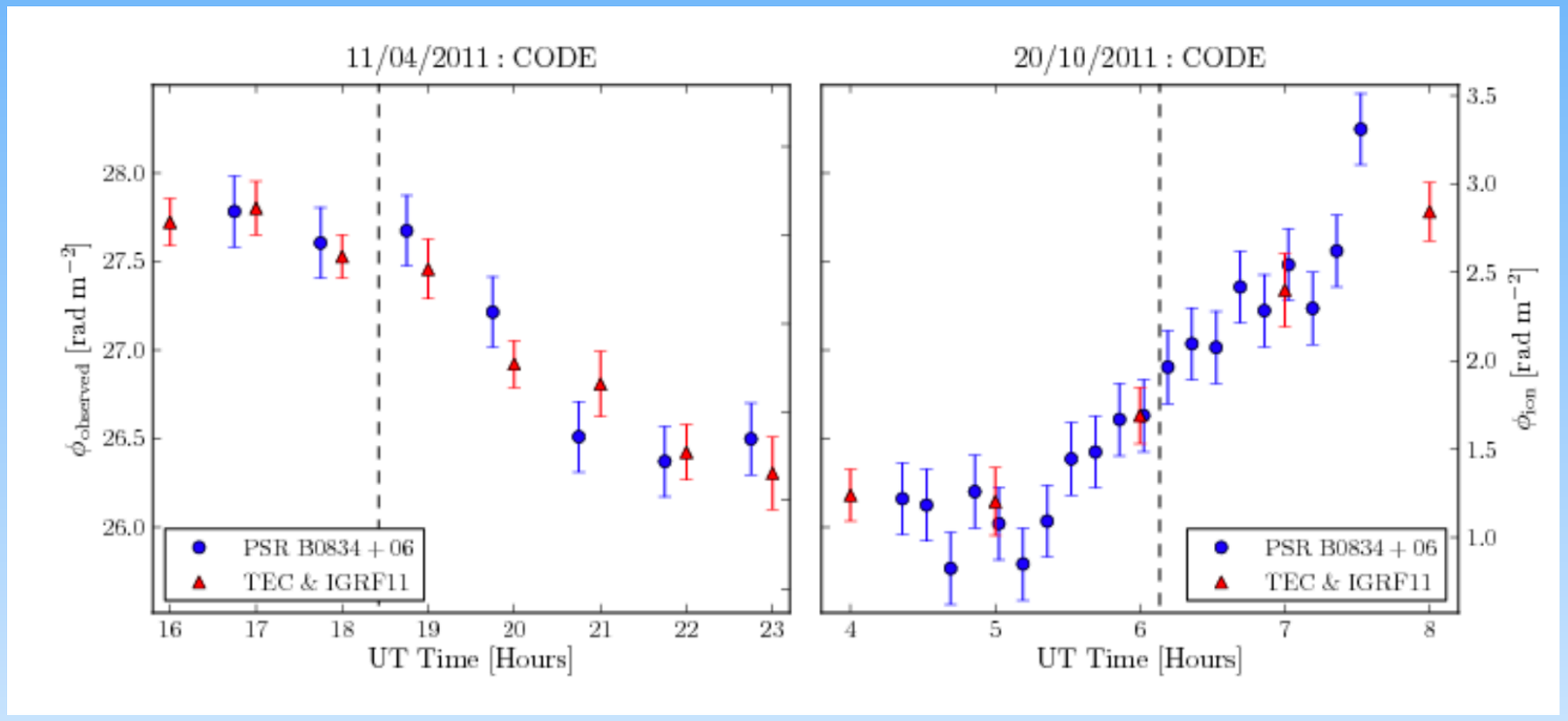
$$\langle B_{||} \rangle = 1.23 \mu G \frac{RM}{DM}$$





Currently 86 pulsars with ELAT < 5 deg. and DM < 100 pc/cm^3 (32 with published RM measurements).

Intervening Medium
Faraday rotation in ionosphere

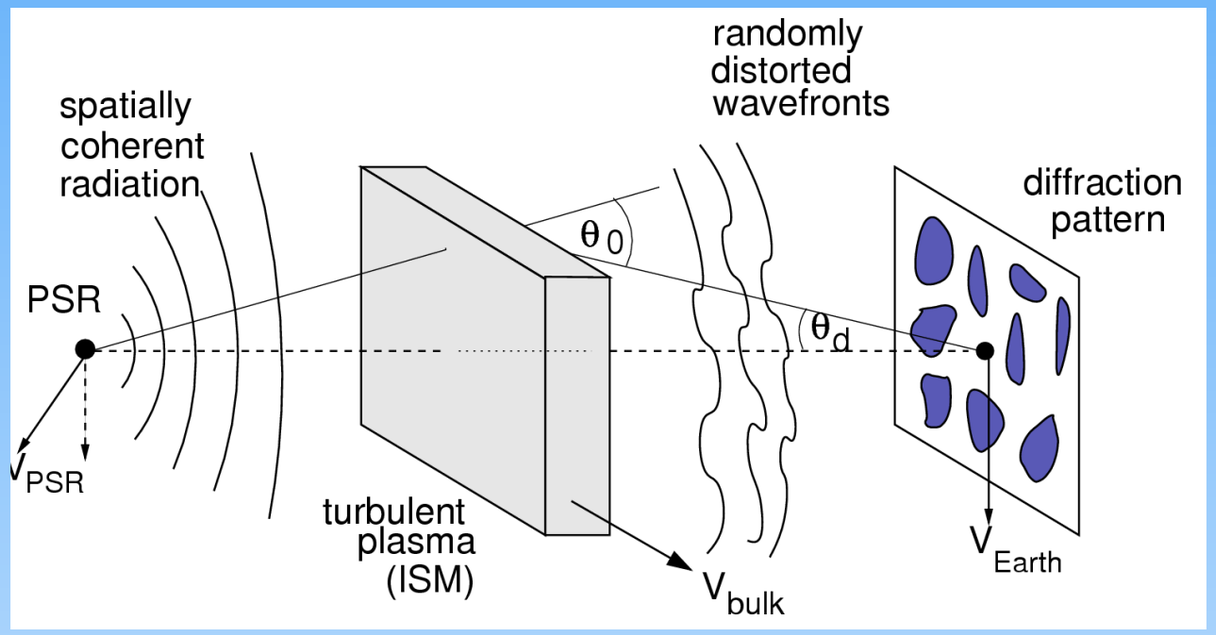


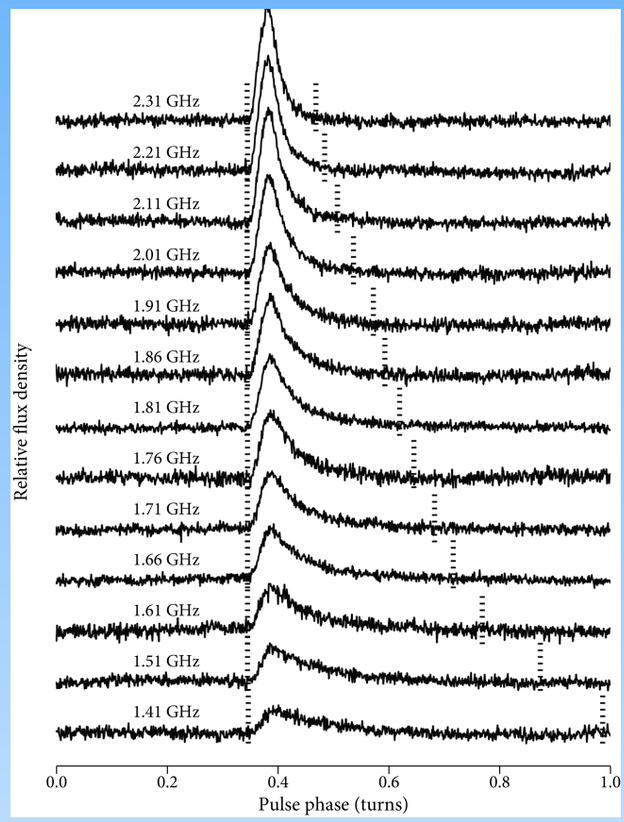
C. Sotomayor-Beltran 2013

RMs from low frequency telescopes ~0.001 rad/m^2, but ionosphere models have errors ~0.1 rad/m^2. -> Regular observations can lead to improved understanding of ionosphere -> Measurements of lower magnetic fields.

Malins et al., submitted

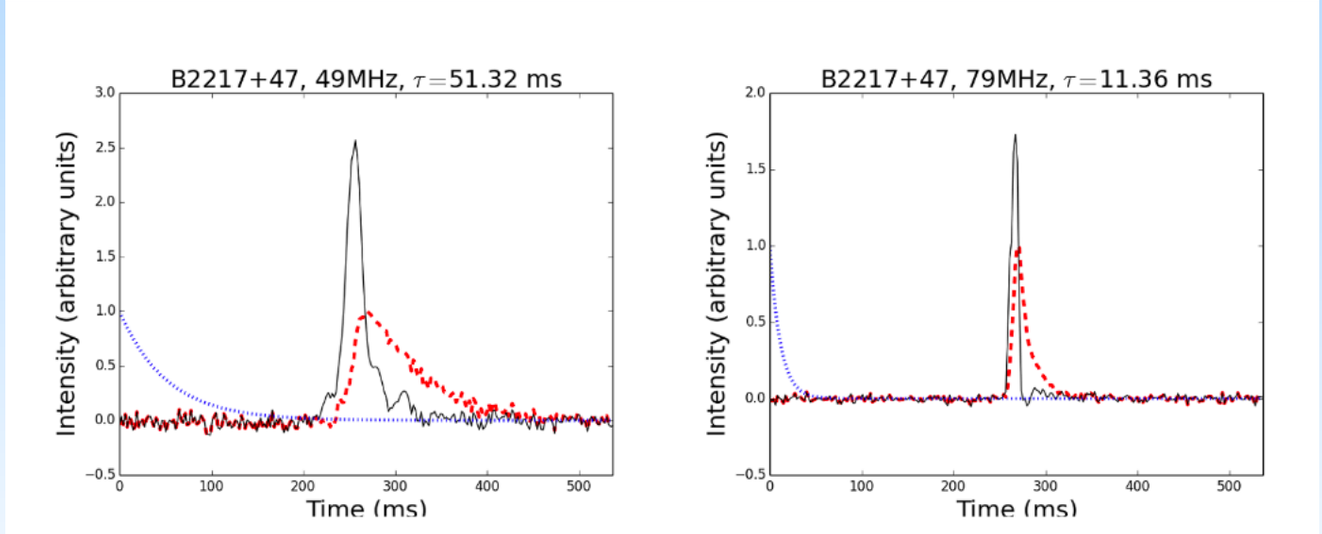
Intervening Medium Scattering





Study the time scale of scatter broadening at different frequencies and how it scales. Also, study scattering changes versus time.

Krishnakumar et al. 2017
Lewandowski et al. 2013, 2015a,b
Bansal et al., in prep

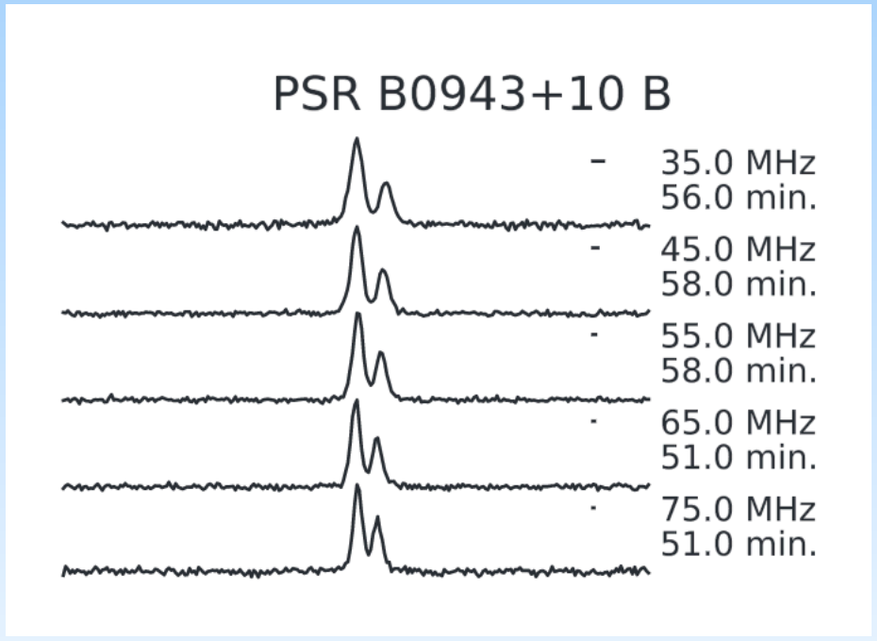


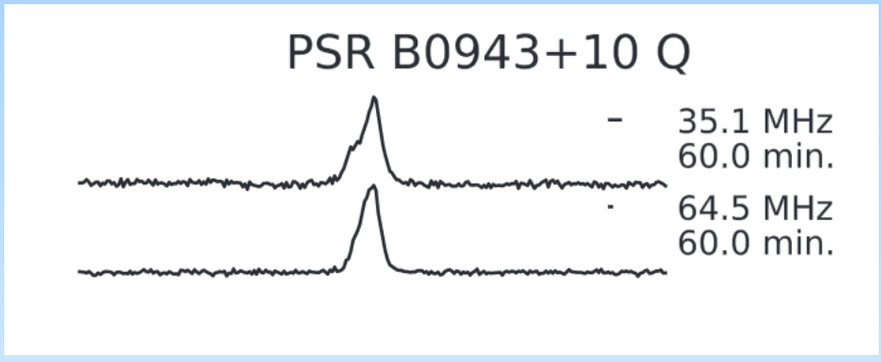
Tsai et al. 2017

Pulsar Emission

B0943+10

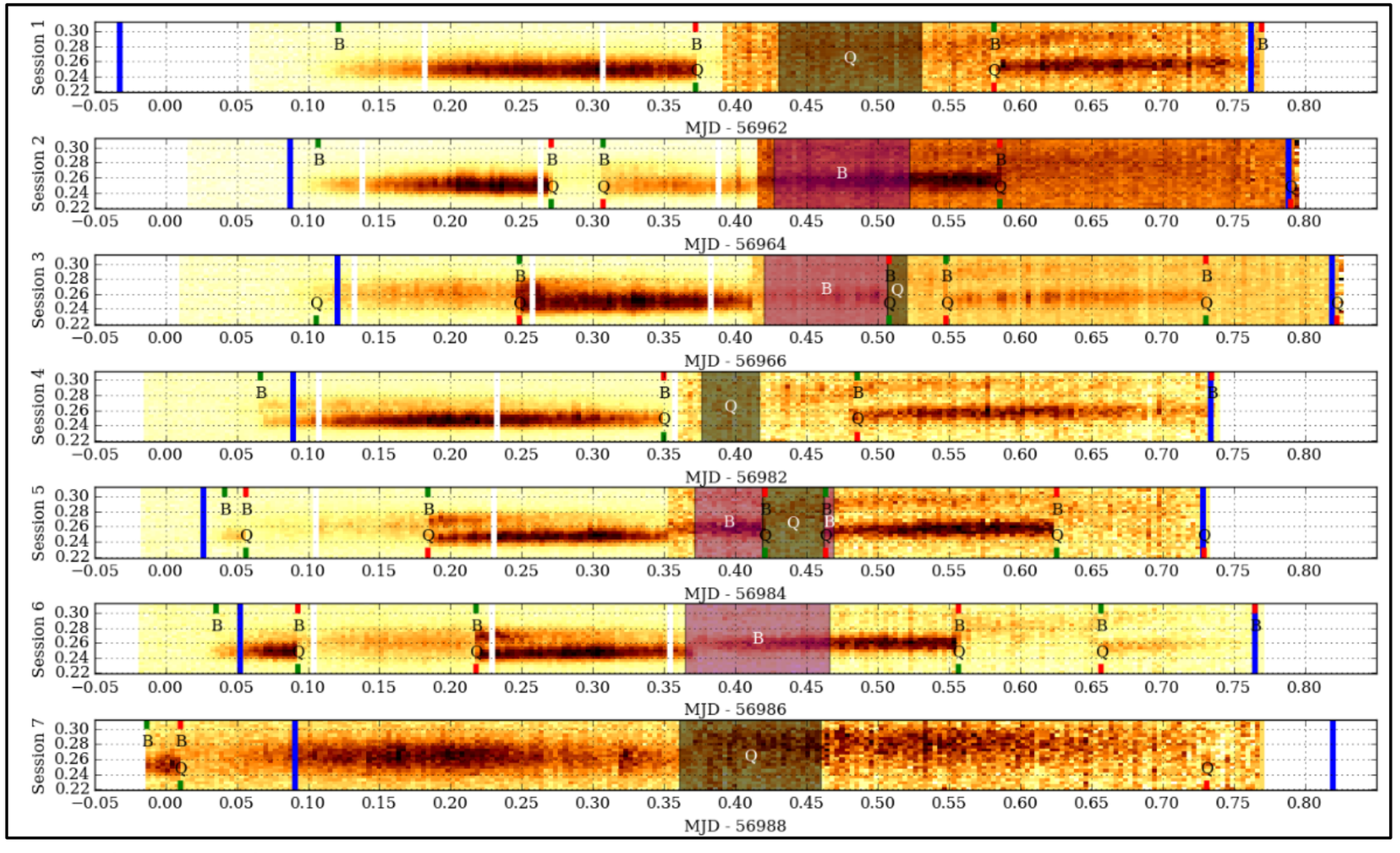
- Switches between two radio modes, a bright mode (B) and a quiet mode (Q). The inverse occurs, apparently simultaneously in X-rays.
- Very steep spectrum pulsar, spectral index ~ -2.6.





Pulsar Emission

- Study of B0943+10 by XMM-Newton, supported by LOFAR, LWA1, and Arecibo.
- Revealed that there are X-ray pulses during B-mode. Also have begun to rule out some models for X-ray emission. Q-mode is best fit by power-law unpulsed emission and thermal black body pulsed emission.

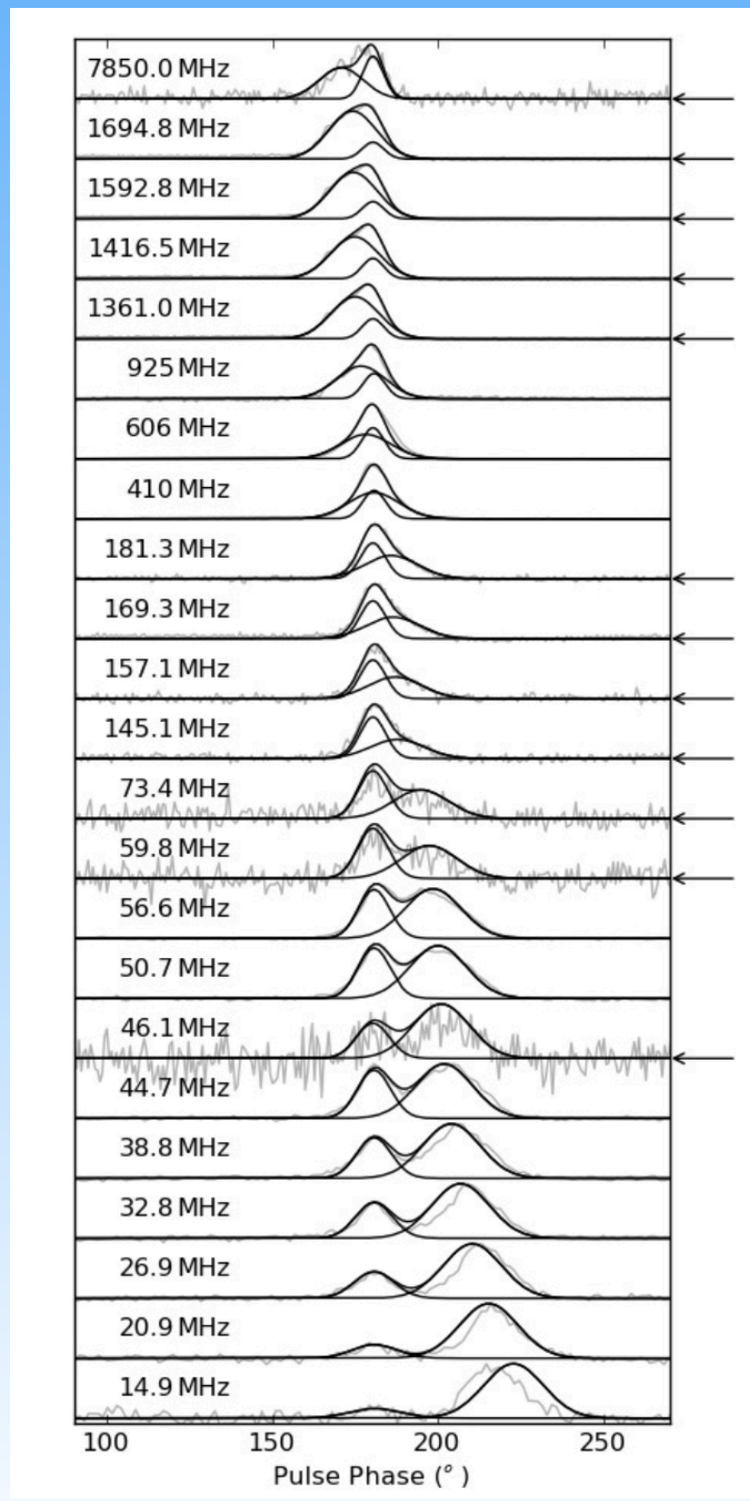


Mereghetti et al. 2016 LOFAR+Arecibo+LWA

Pulsar Emission

- Radius to frequency mapping - Higher frequency generated higher in pulsar magnetosphere.
- However, pulsars studied by Hassall et al. 2012 were all consistent with emission coming from confined region, they argue that pulsar magnetosphere is likely complex.

B0809+74

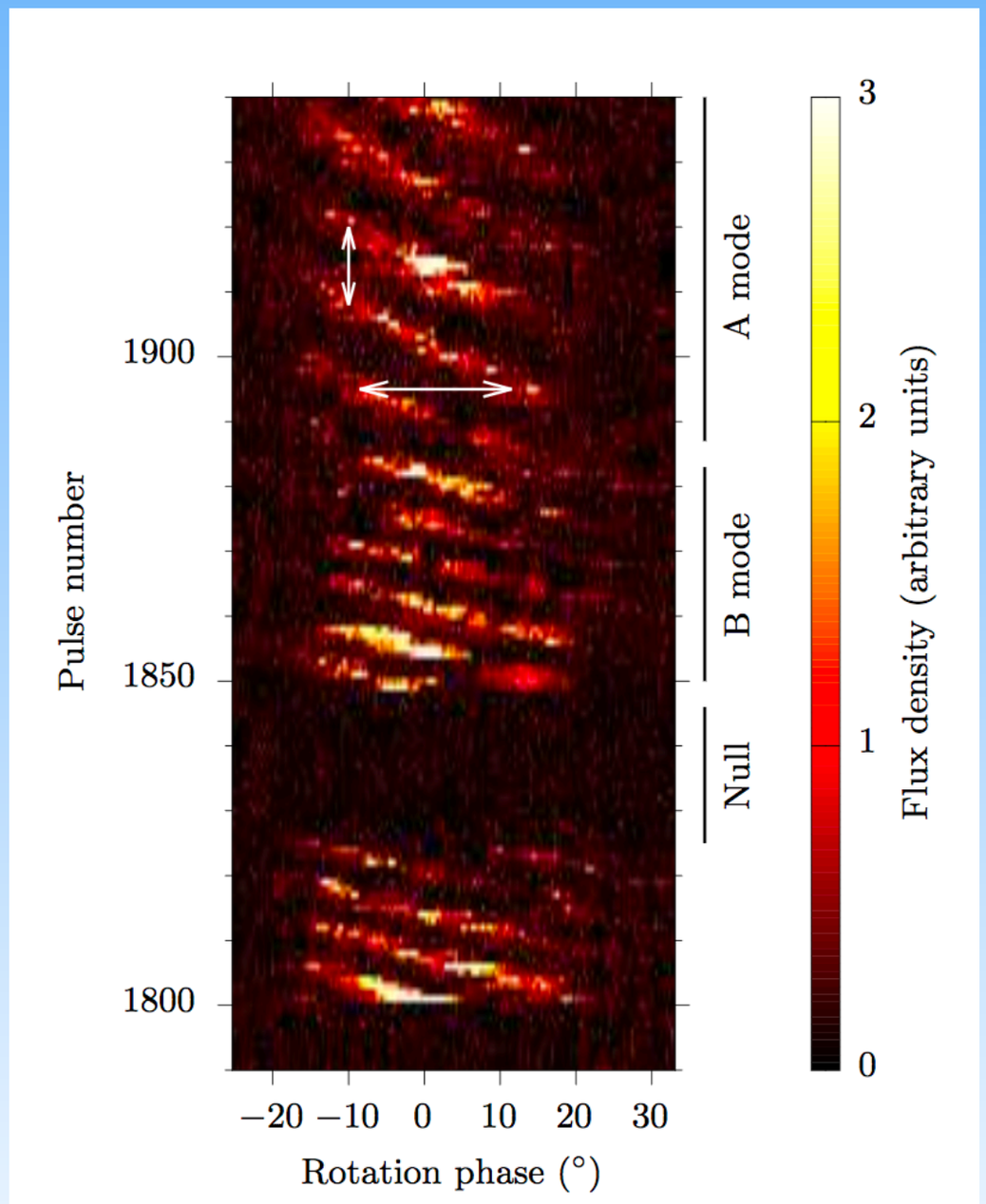


Hassall et al. 2012

Pulsar Emission

- Some pulsars have drifting subpulses, thought to be due to sub-beams drifting around the magnetic axis like a “carousel”.
- B0031-07 has 3 modes of drifting as well as periods of nulls.

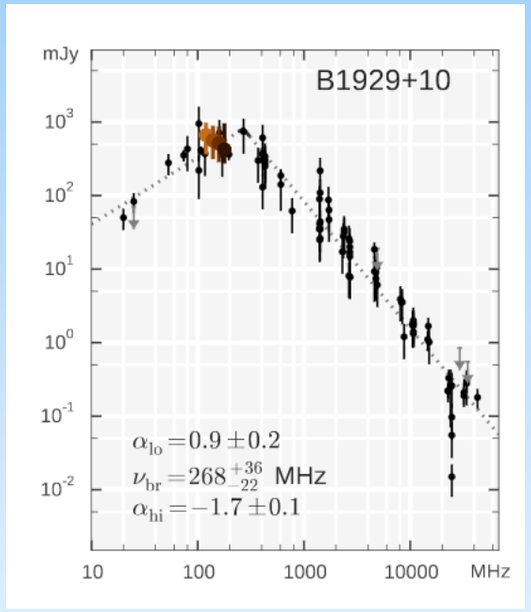
B0031-07

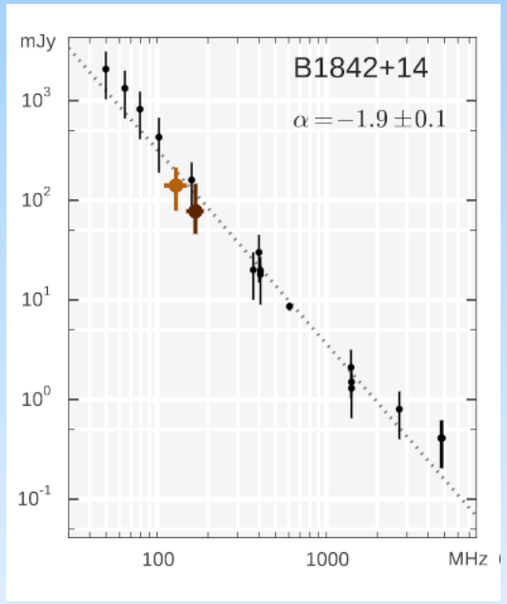


McSweeney et al. 2017

Pulsar Emission

- Another avenue to constrain the pulsar emission mechanism is the study of their spectral properties. Many turnover at some frequency (~100-200 MHz), others don't.
- The turnover in many pulsars have been largely unconstrained due to lack of low frequency measurements.
- Flux measurements at low frequencies are currently being made for many more pulsars that are much more precise than past measurements.





MWA ~70 pulsars
LWA ~100 pulsars
LOFAR >250 pulsars

Thank You!

- Pulsar Searches
  - Fast survey speed
  - Steep Spectra

- Intervening Medium
  - ISM - dispersion, scattering, Faraday rotation
  - Solar wind, CMEs
  - Ionosphere

- Pulsar Emission
  - Rapid profile evolution vs frequency
  - Spectral turnover
  - Studies of specific sources