In a zoo of radio pulsars below 100 MHz

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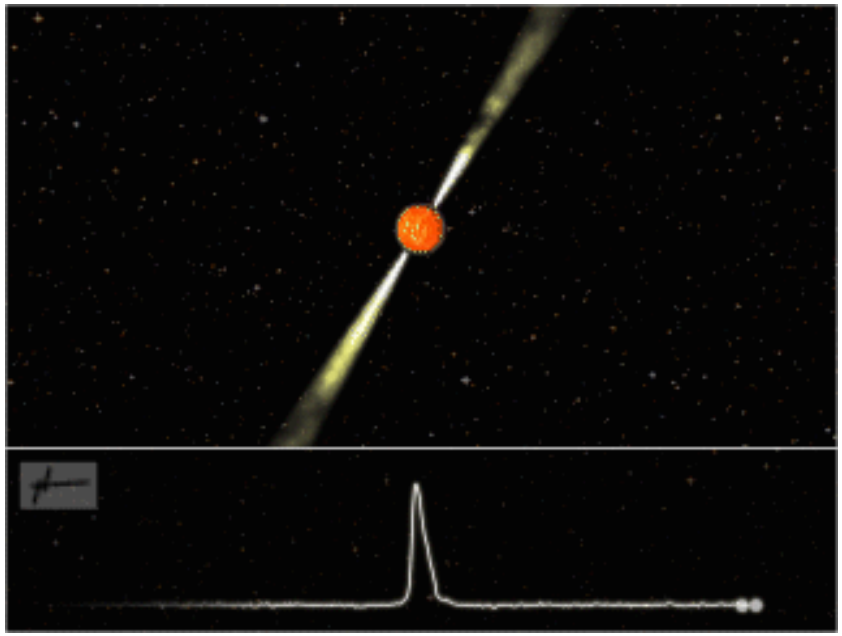
Pulsars

- Pulsars are rotating magnetized neutron stars discovered by J. Bell-Burnell in 1967

- Steep spectrum ~ -1.4

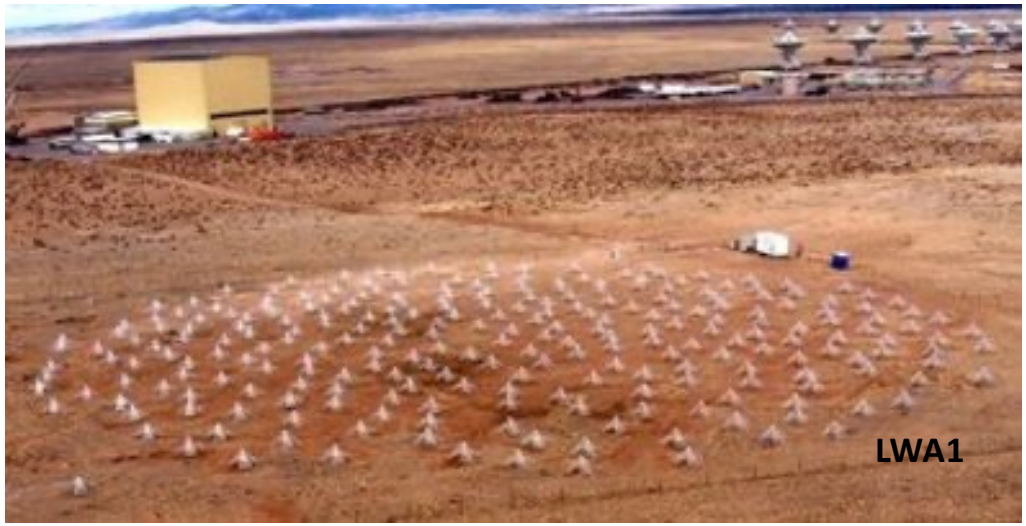
- Extreme properties
  - masses ~ 1.4 solar mass
  - radii ~ 10 km
  - magnetic field strength ~ 10^8 G

❑ Ideal probes of Interstellar Medium
  - Dispersion Measure
  - Scattering
  - Rotation Measure



Credit: Joeri van Leeuwen

Long Wavelength Array (LWA)



Frequency Range: 3-88 MHz

First station ("LWA1") completed April 2011

Second NM station ("LWA-SV" completed July 2017

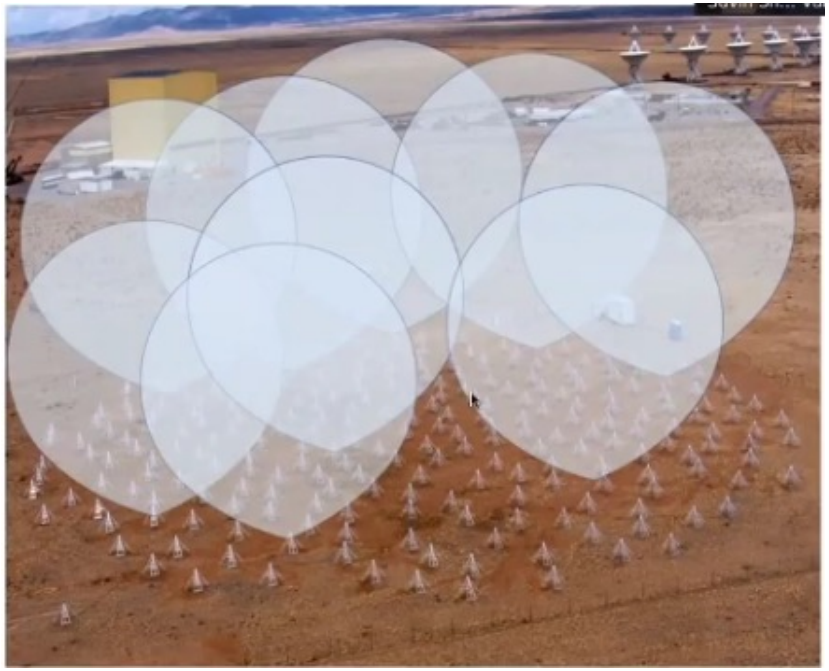
Next up: "LWA-NA" mini-station (64 dipoles) 2023 Construction

OVRO-LWA Imaging and Beamforming superstation

LWA swarm – 1" resolution

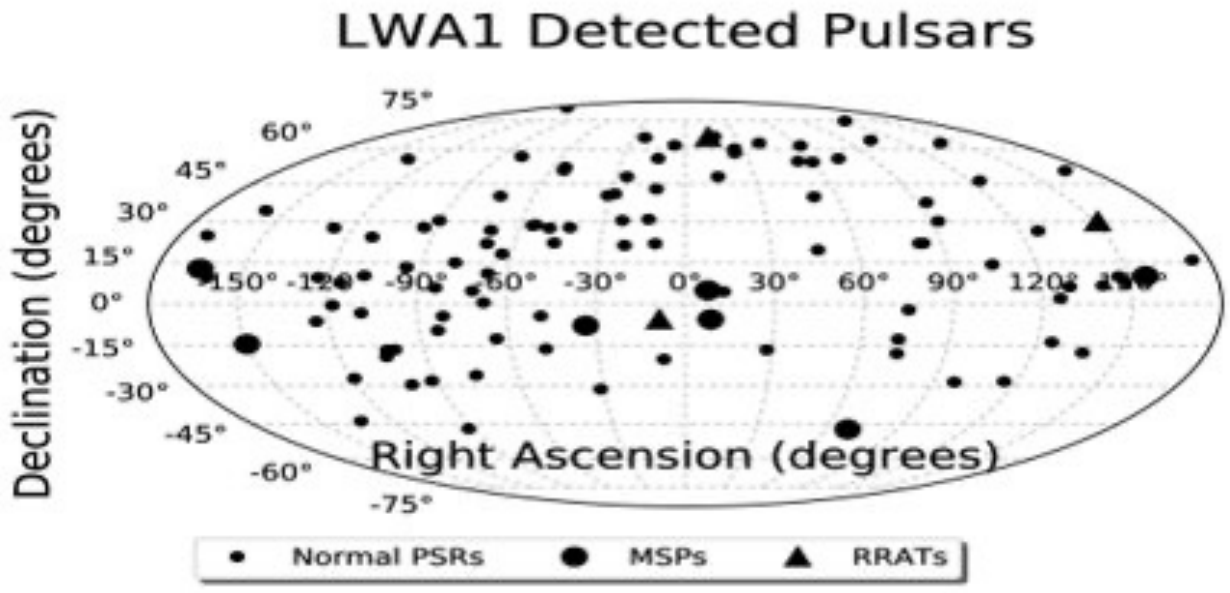
Observing Modes

- 256 dual-polarization antennas
- Distributed within a 100 x 110 m ellipse
- Two primary observing modes: Digital Beamforming and All-sky mode



LWA Pulsar Monitoring and Reduction

- Pulsar Observations Since 2013, Monitoring began in September 2015 (Stovall et. al. 2014)
- 108 Sources, including Pulsars, MSPs and RRATs
- Automated Robust observing with a Python based script (Jayce)
- Sources observed at a cadence of about 3-6 weeks + dedicated campaigns
- Observations at 4 frequencies, 35.1 MHz, 49.8 MHz, 64.5 MHz and 79.2 MHz each with 19.6 MHz bandwidth



LWA Pulsar Monitoring and Reduction

- Automated Data reduction incorporating standard pulsar software and LWA Software Library (Dowell et. al. 2012) tools.
- More than 11000 hours of reduced and archived data available publicly (~170 TB), spanning ~10 years for some sources.

Index of /PulsarArchive

Name	Last modified	Size	Description
Parent Directory		-	
B0031-07/	2023-02-08 11:02	-	
B0053+47/	2023-02-12 19:23	-	
B0105+65/	2023-03-28 22:56	-	
B0136+57/	2023-01-05 05:02	-	
B0138+59/	2023-03-03 15:22	-	
B0149-16/	2023-03-04 23:50	-	
B0301+19/	2023-01-03 16:20	-	
B0320+39/	2023-04-07 02:39	-	
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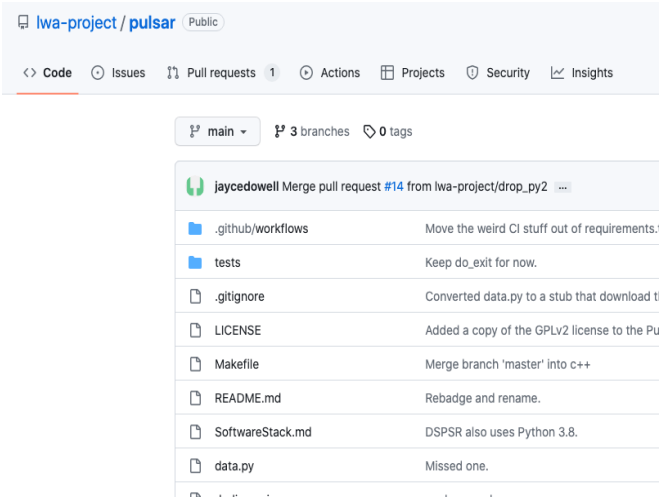
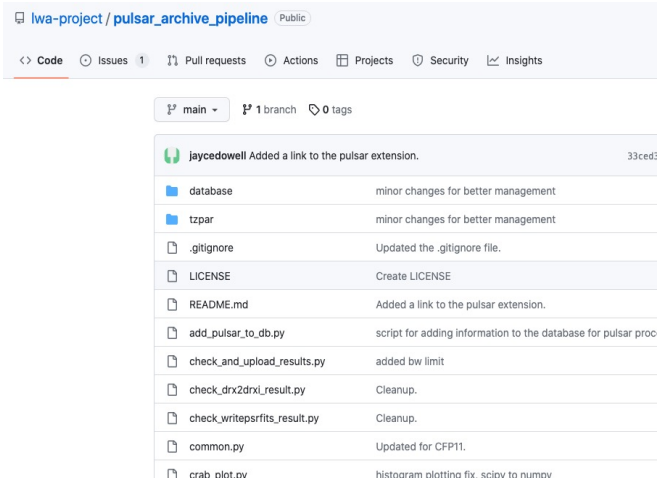
https://lda10g.alliance.unm.edu/PulsarArchive/

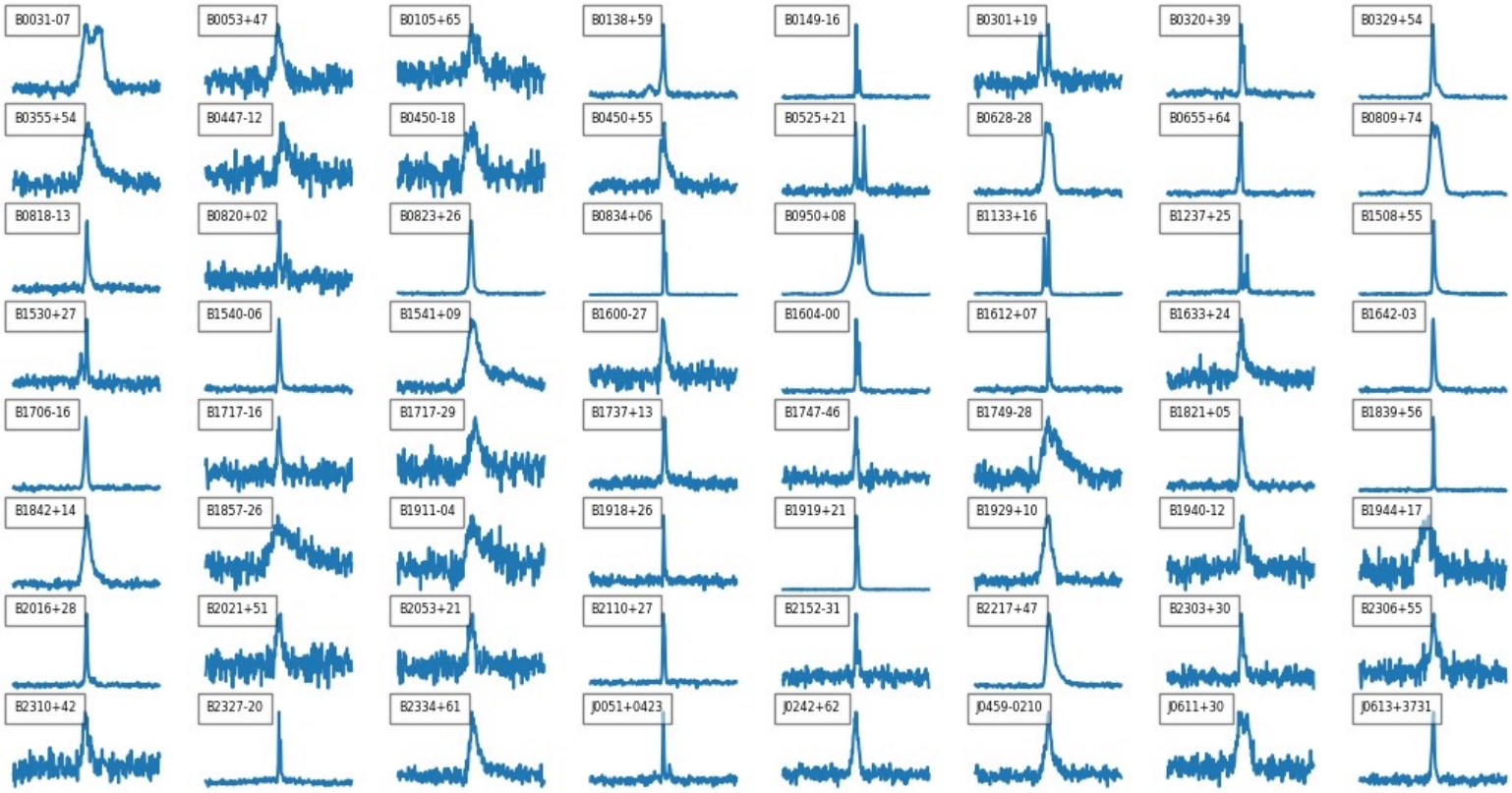


https://github.com/lwa-project/pulsar



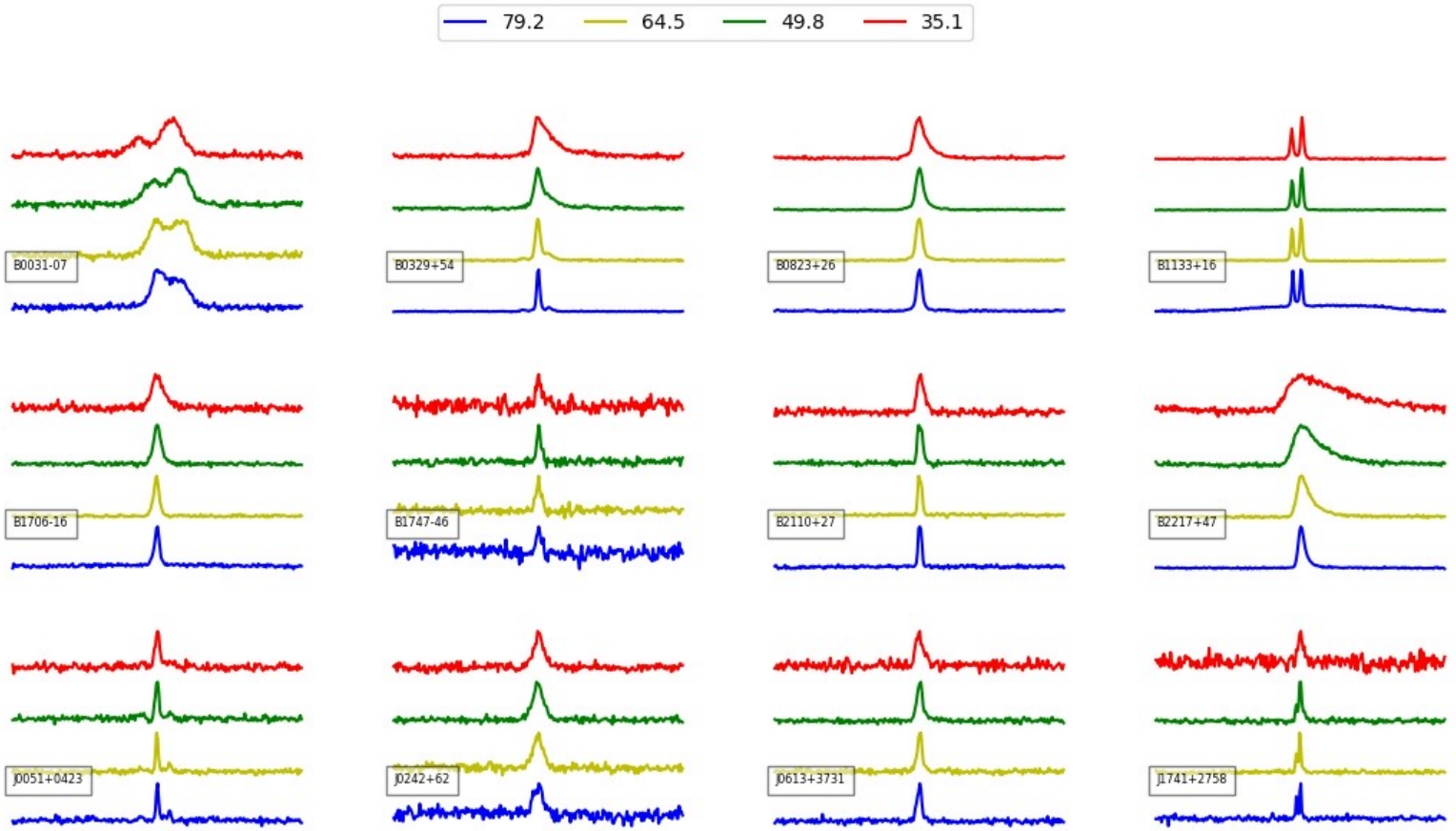
https://github.com/lwa-project/pulsar_archive_pipeline

Average Pulse Profiles

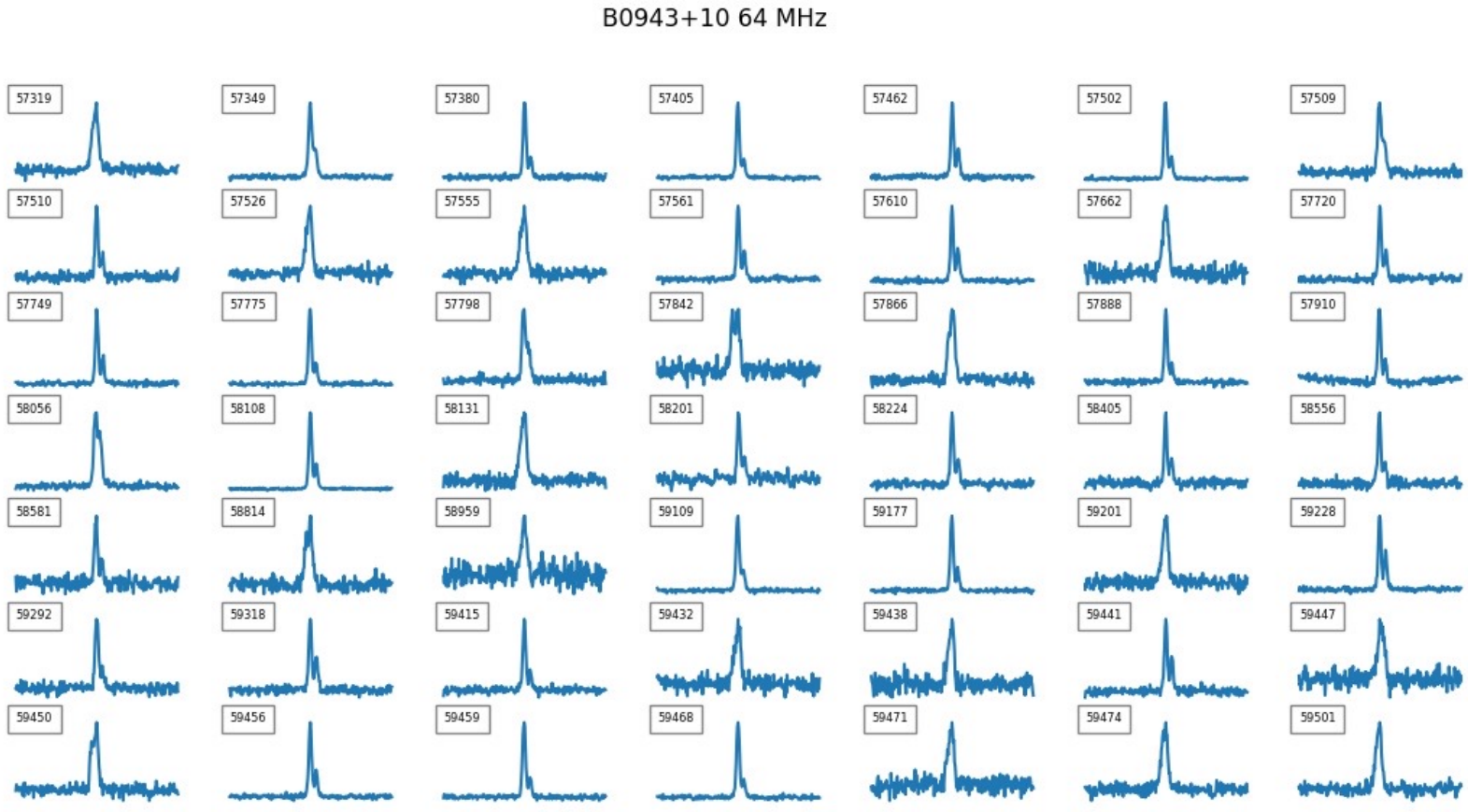


All profiles at 64.5 MHz

Profile Evolution



Mode change


B0943+10 64 MHz
57319
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59228
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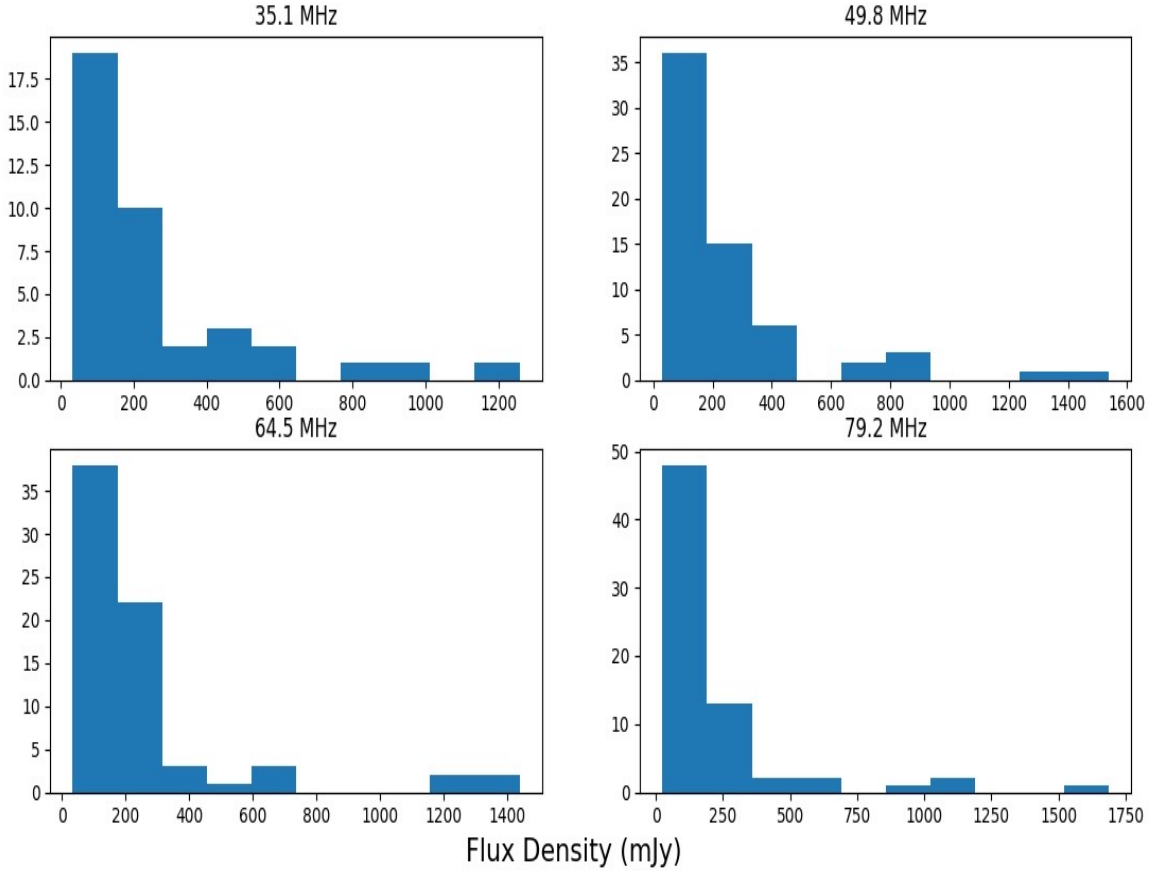
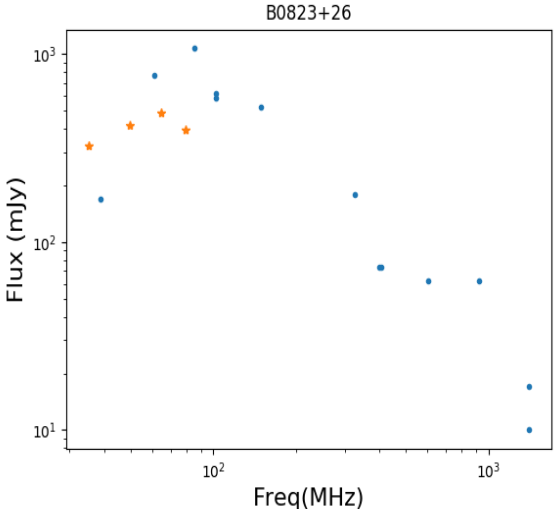
Flux density distribution and spectra



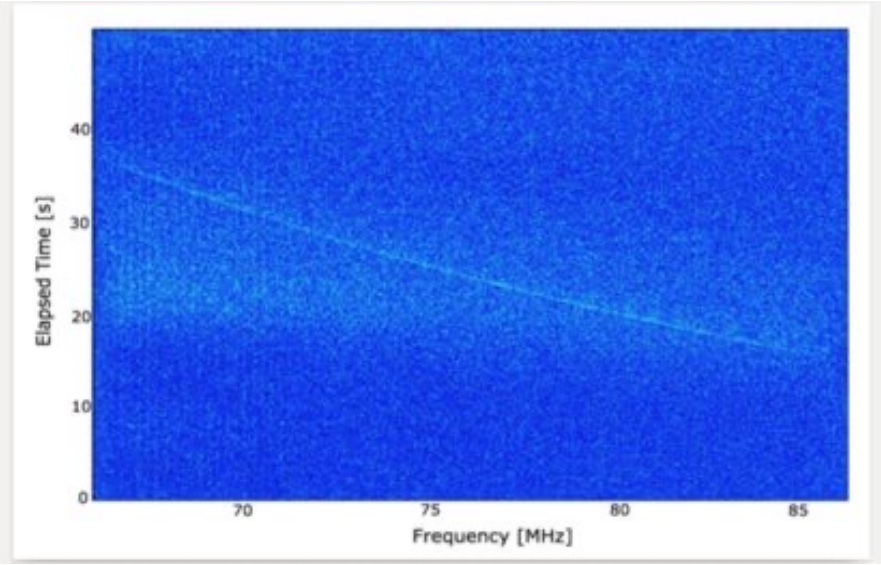


Non-Stationary Interstellar Medium

- Integrated column density of free electrons between the observer and the pulsar.

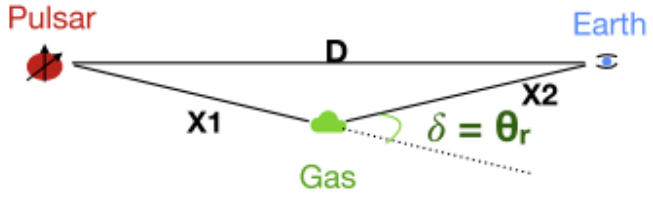
$$\mathcal{DM} \equiv \int_0^d n_e \, dl$$

$$\Delta t = \frac{\mathrm{DM}}{2.41 \times 10^{-4}} \left(\frac{1}{\nu_{\mathrm{low}}^2} - \frac{1}{\nu_{\mathrm{high}}^2} \right)$$

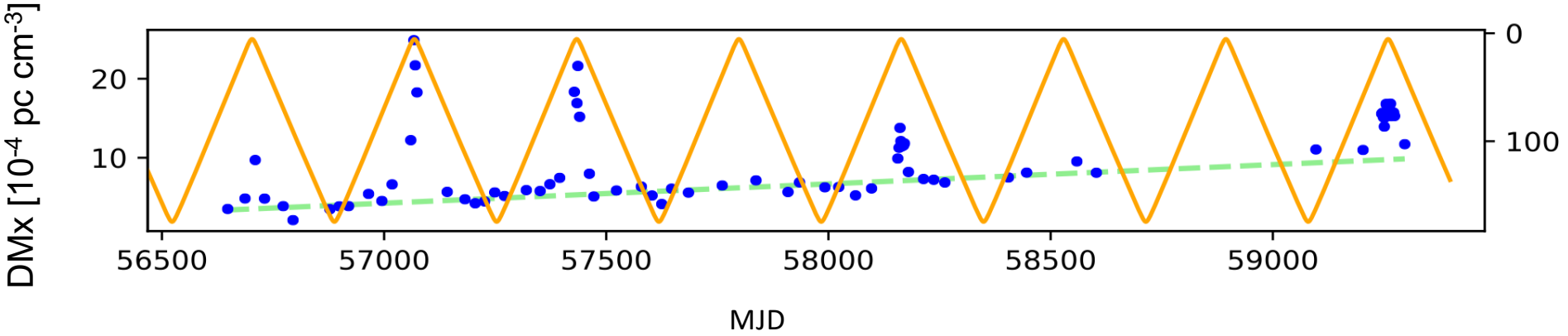


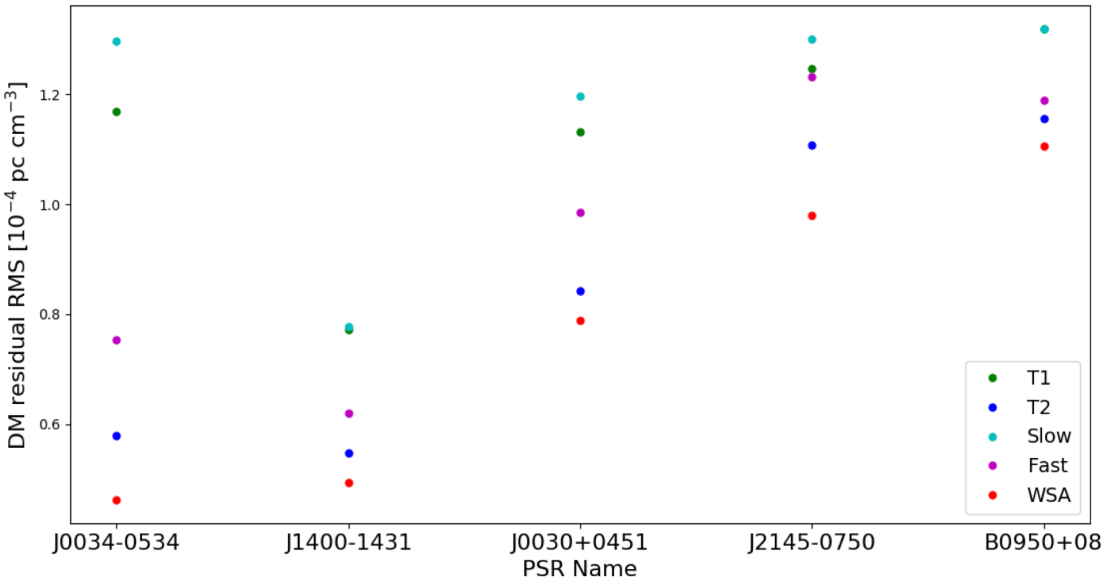
Credit: Eftekhari et al. 2016

- Stronger effect at low frequencies
- Can be affected by
  - Proper motion of the pulsar through the ISM
  - Structures in the ISM: see Bansal et. al 2019
  - External factors such as solar winds
  - Variations from Ionosphere



Efficiency of Solar Wind Models

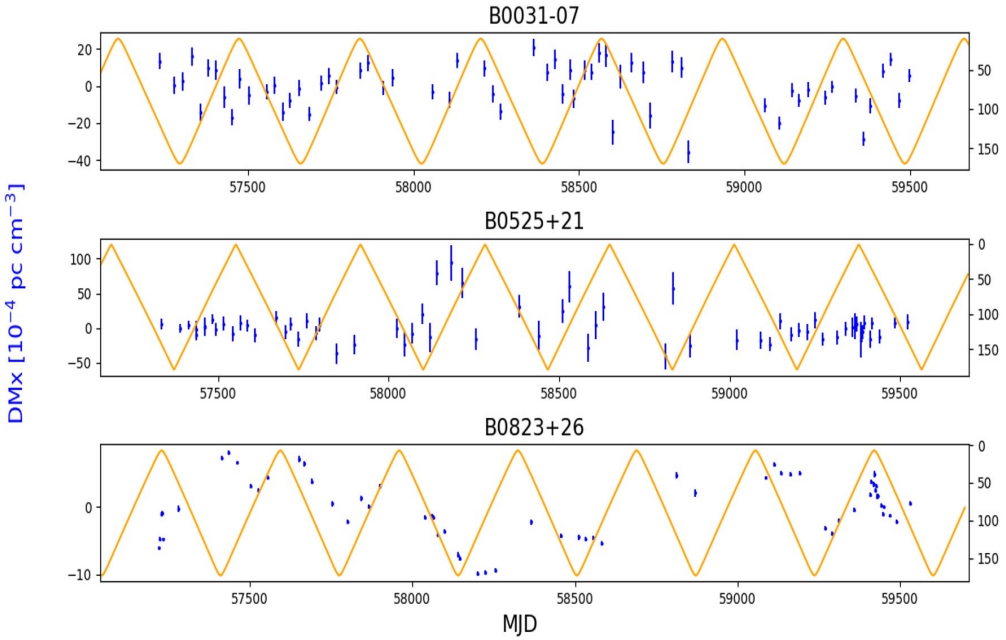


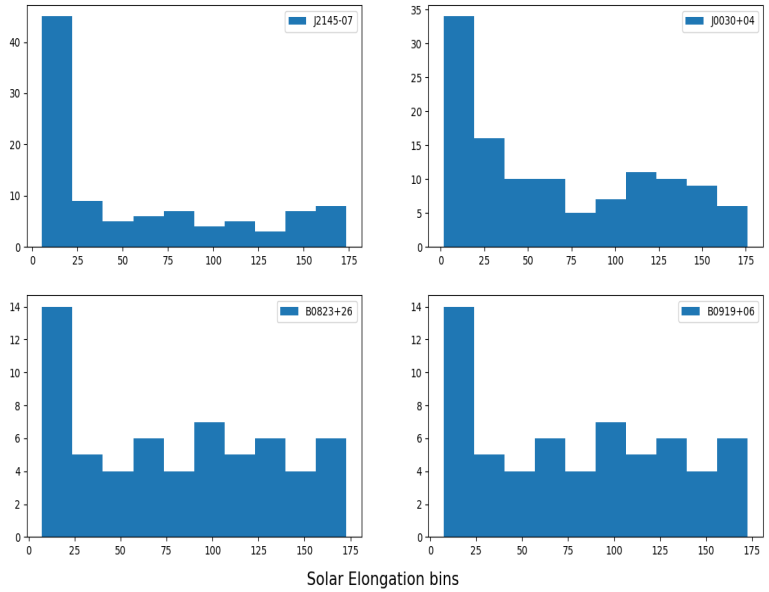


- Stationary models for timing corrections are inadequate, need a hybrid approach
- Temporal models for space weather need modification to accurately capture all solar wind effects.

Kumar et. al. 2022

can we improve?

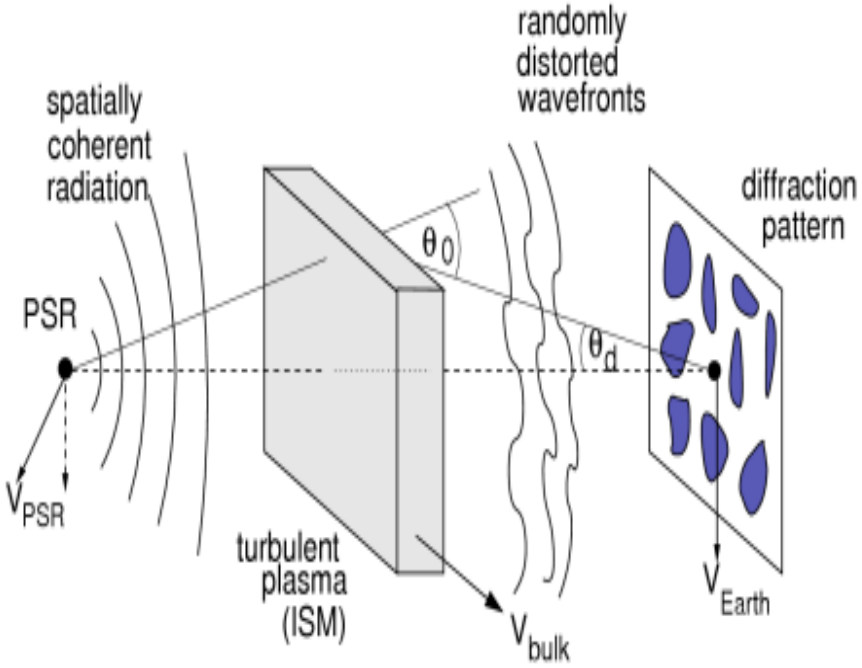


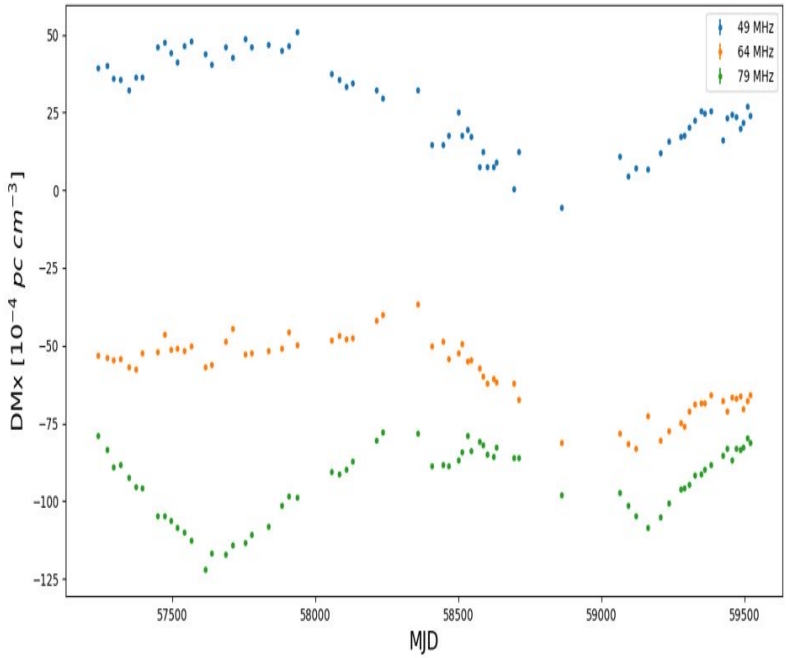


About 25 LWA pulsars have solar elongation angles below 10 deg

- Need better pulsar, MSP/well behaved
- Better sampling

DM → Scattering





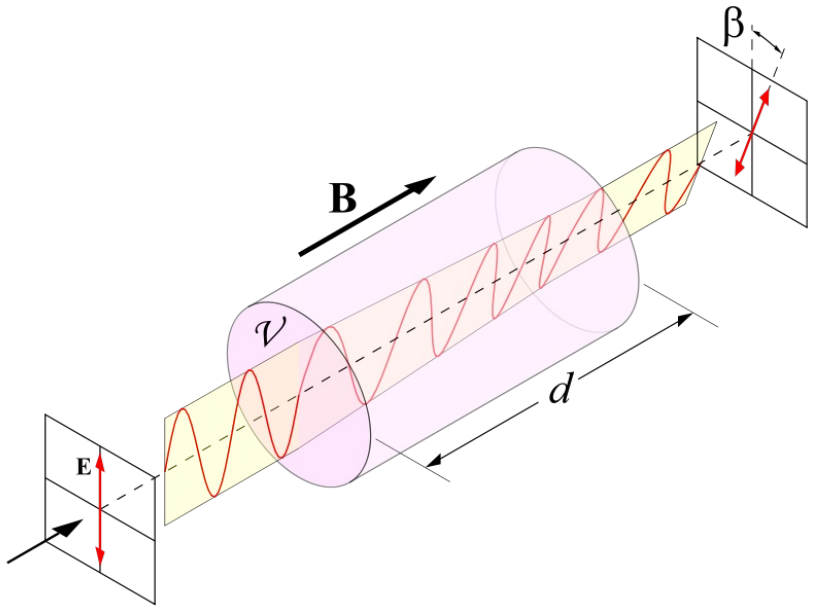
B2217+47

Pulsars for probing Galactic B-field

- Polarized : Faraday Rotation

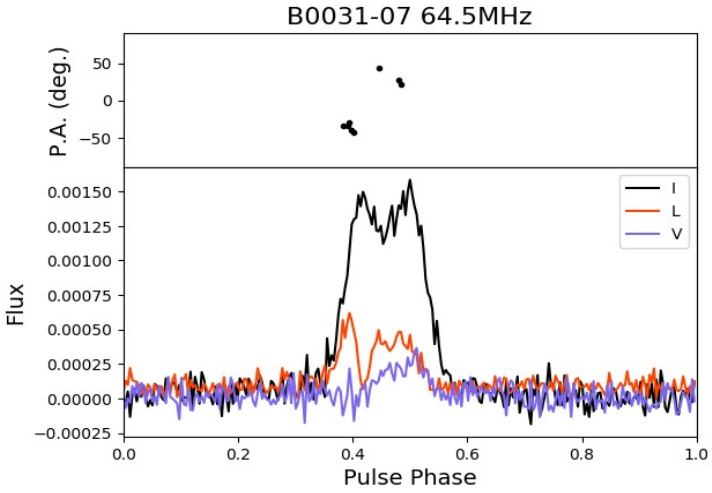
$$\langle B_{\parallel} \rangle = \frac{\int_0^d n_e B_{\parallel} \mathrm{d}l}{\int_0^d n_e \mathrm{d}l} = 1.232\ \mu\mathrm{G} \left(\frac{\mathrm{RM}}{\mathrm{rad\ m^{-2}}} \right) \left(\frac{\mathrm{DM}}{\mathrm{pc\ cm^{-3}}} \right)^{-1}$$

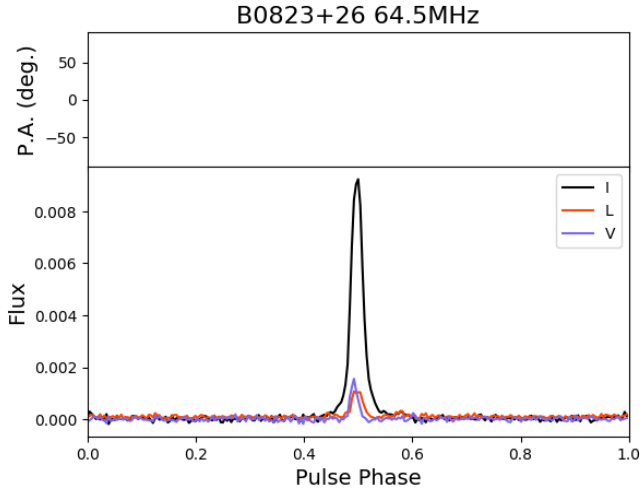
- Rotation of the Position Angle (PA) gives the RM
- We can measure DM independently, to get the average magnetic field strength

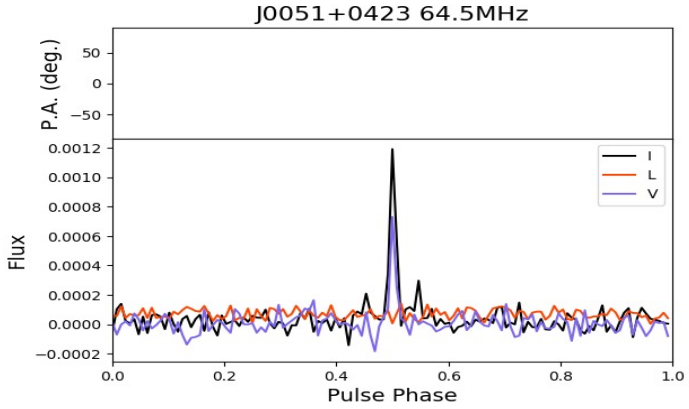


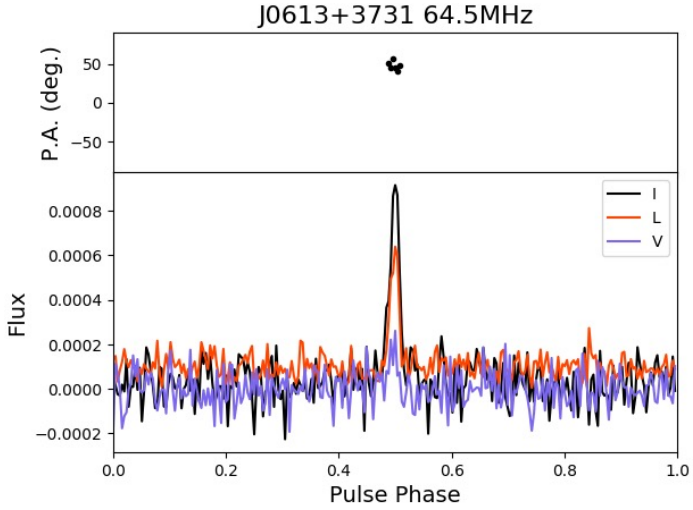
Credits: Wikipedia

Polarization Profiles





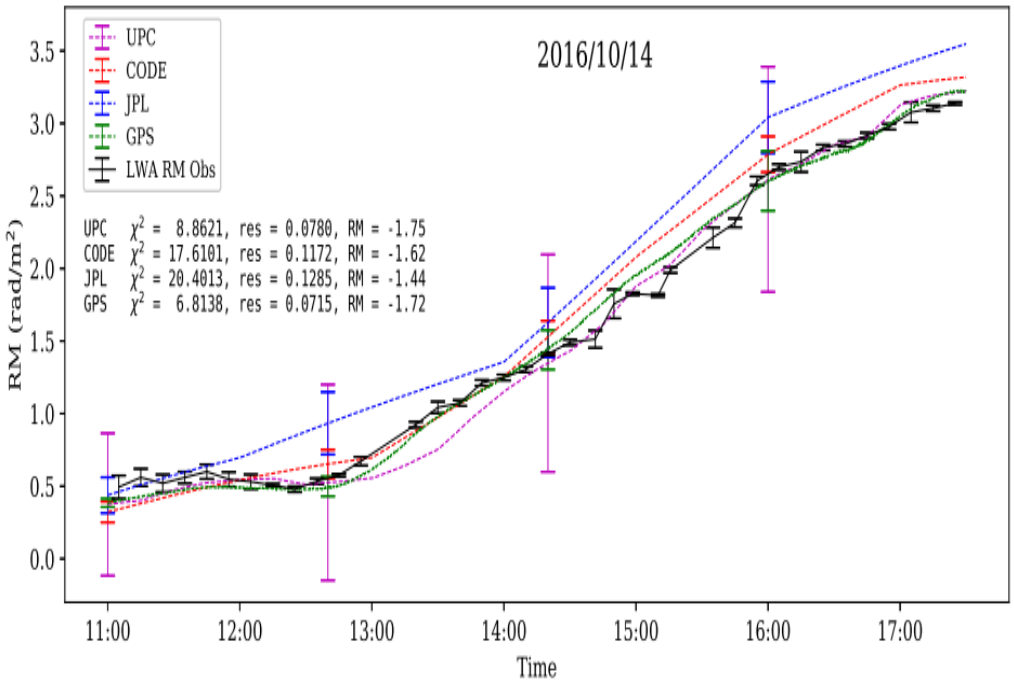


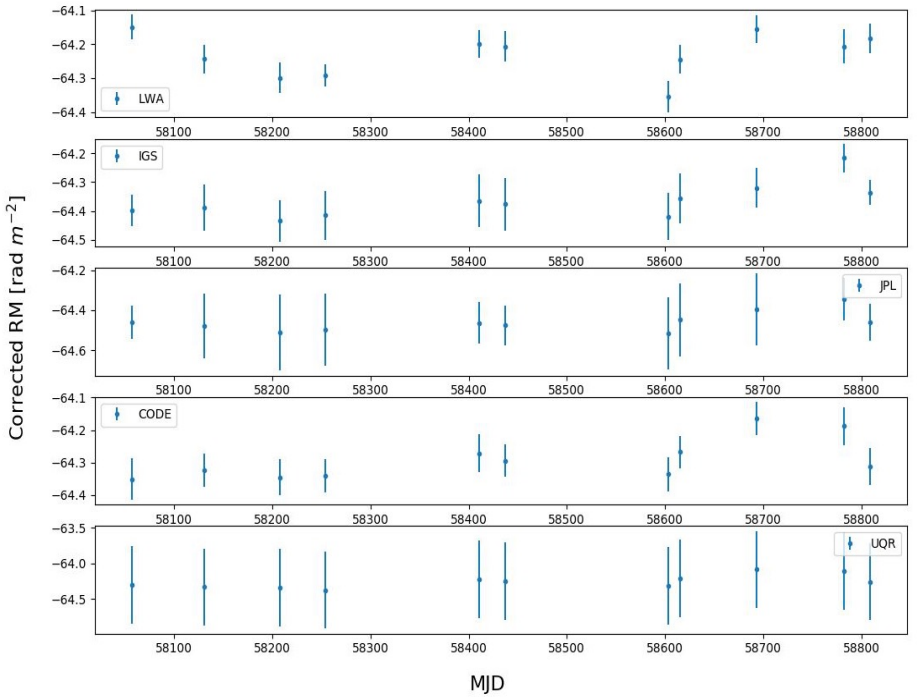


We have detected polarization in 27 pulsars in 1 or more frequency bands

Ionospheric Corrections matter

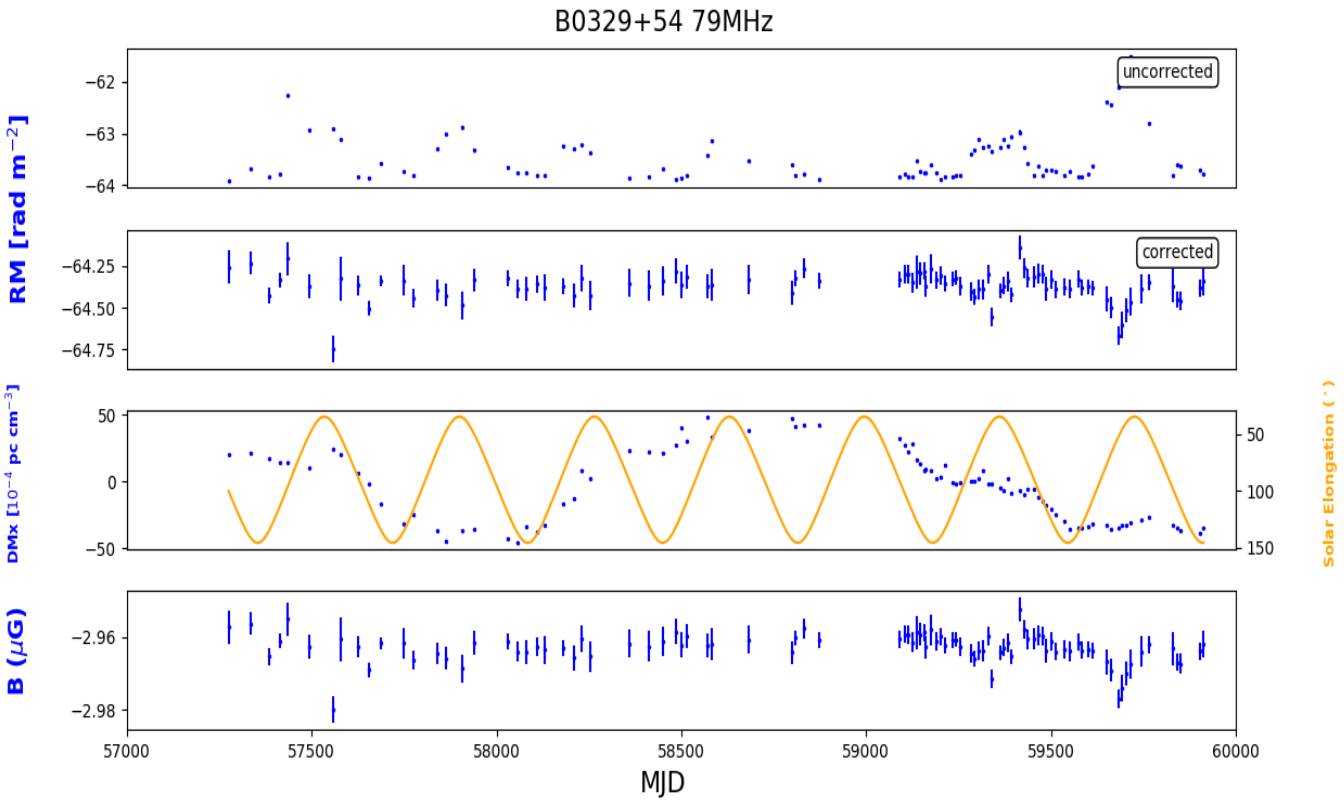
Ionosphere changes rapidly, need better sampling





Malins et al 2018

RM variations



- RM variations over time in about 20 pulsars
- Currently limited by our ability to do Ionospheric correction
- Gives an upper limit of ~0.1 rad/m^{-2} on RM variations
- Based on DM fluctuations the limit on B-field variations is ~ 10 nG on ~10 AU scales (assuming pulsar velocity of 100km/s)

Summary

- LWA pulsar program continuously monitors 108 target, at a cadence of 3-6 weeks and additional dedicated campaigns
- We are using this data to build the low frequency pulsar catalog below 100 MHz and to measure the basic pulsar properties/parameters like pulse profile, DM, period at the lowest frequencies.
- Since propagation effects like dispersion and scattering are frequency dependent, we are using the long-term data to investigate the impact of ISM on these observations, study the behavior of ISM and search for extreme propagation effects.
- Using the long-term profiles, we also search for any abnormal change/evolution in pulsar emission.