InPTA
Indian Pulsar Timing Array

NCRA • TIFR

Probing the Universe with Multimessenger Astrophysics (PUMA22)

Using low-frequency scatter broadening measurements for precision estimates of DM and its implications in GW detection using PTAs

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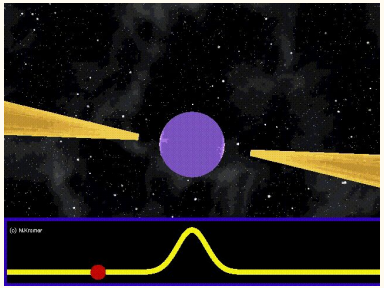
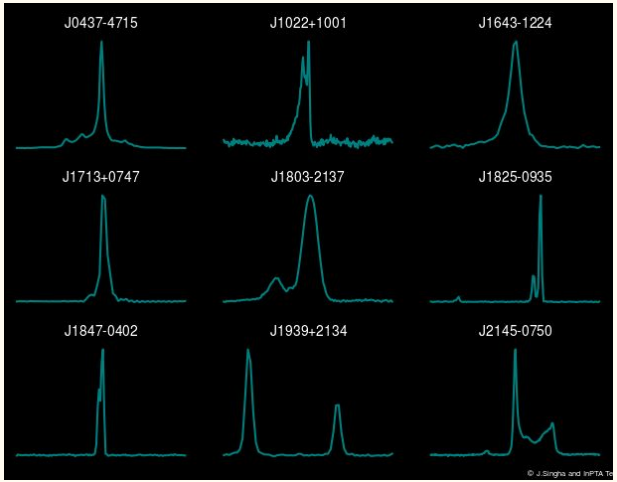
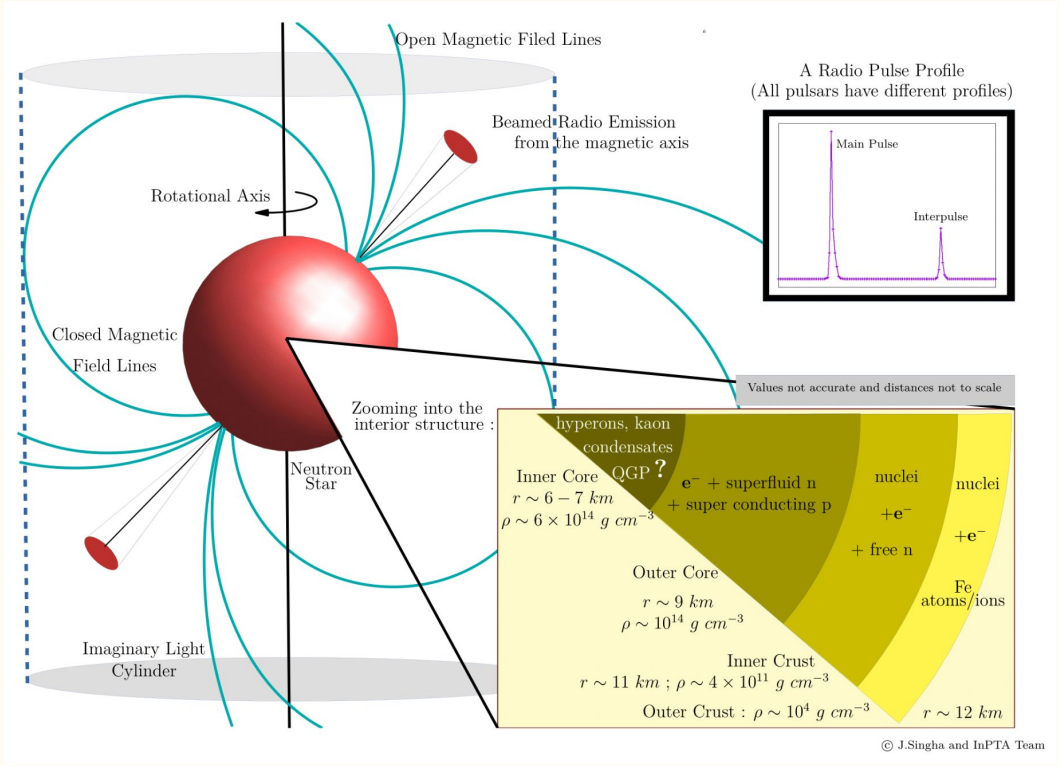
(on behalf of the Indian Pulsar Timing Array (InPTA) collaboration)

Pulsars

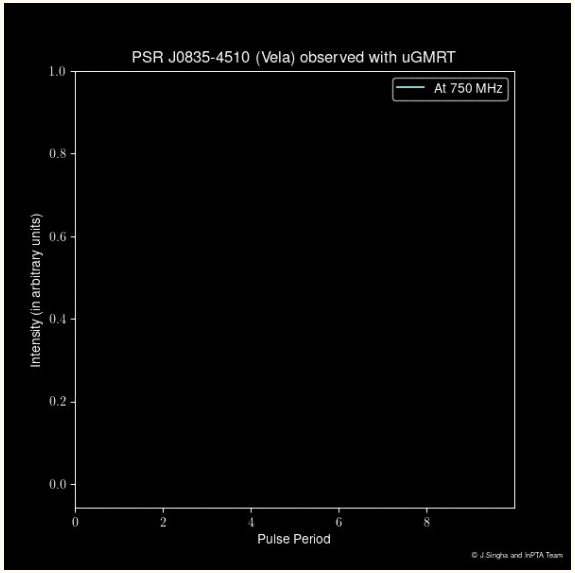


P.C.: LIGO Scientific Collaboration Website

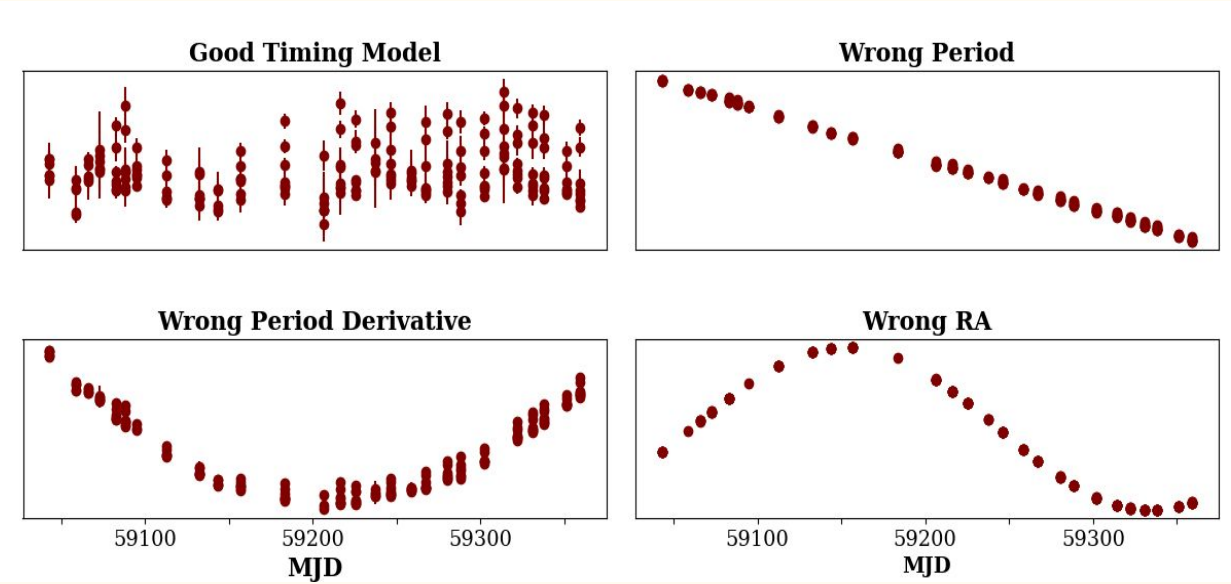




Pulsar Timing

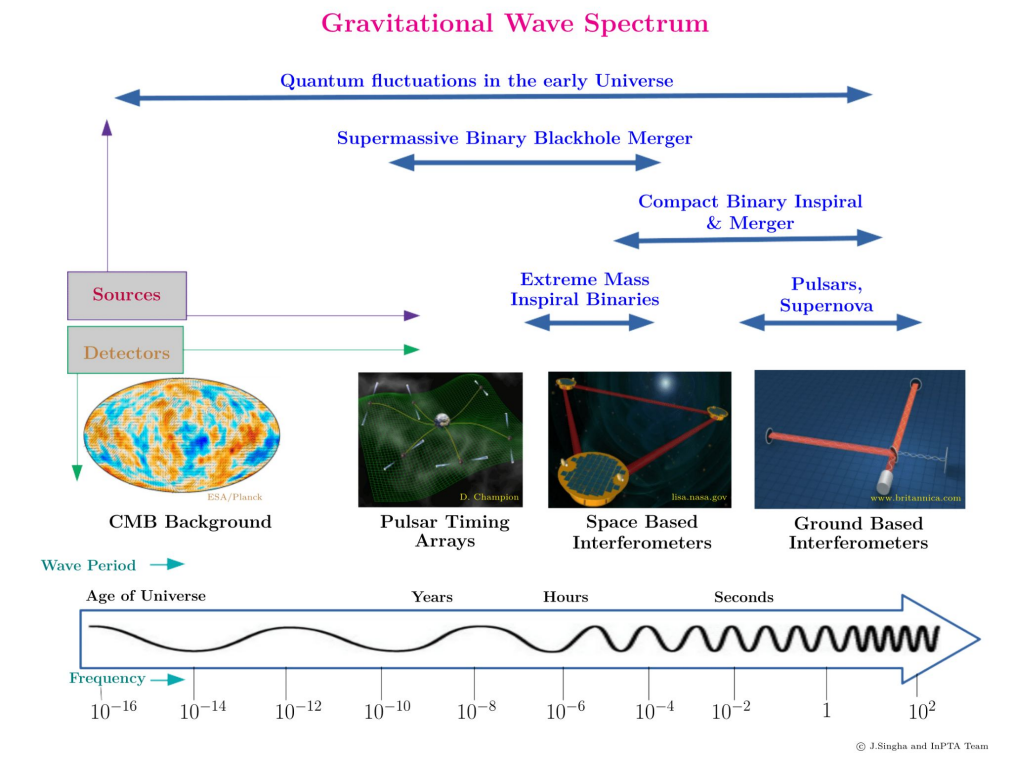


Time series of Vela Pulsar (data collected from uGMRT)



Any deviation from the timing model is manifested in the timing residuals of the pulsar.

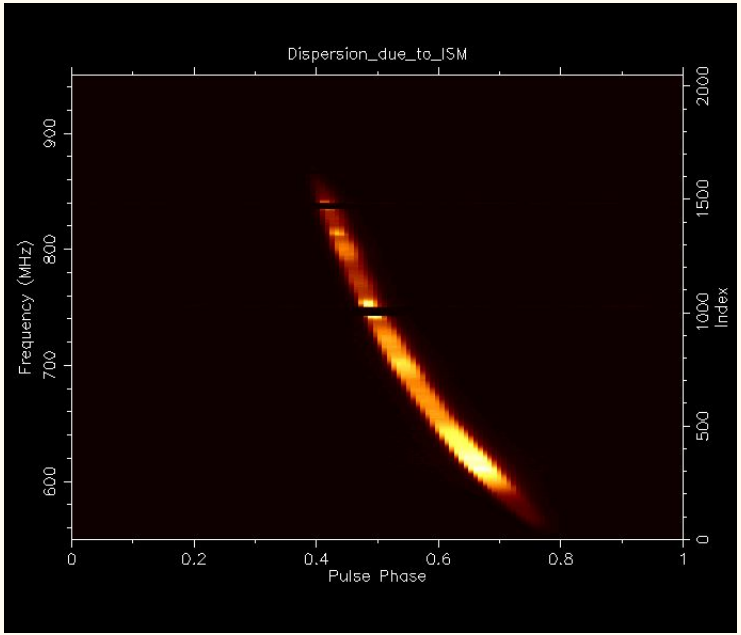
Pulsar Timing Array : *a cosmic web of GW detectors*



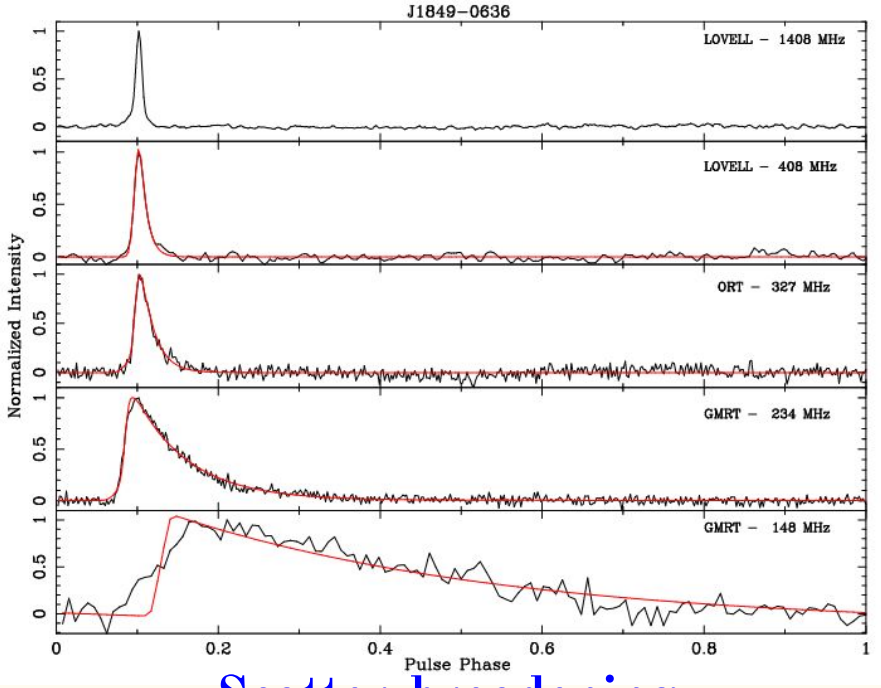
- Precision Timing of an ensemble of millisecond pulsars to detect Nano-hertz Gravitational waves : Pulsar Timing Array Experiments
- International Pulsar Timing Array :
  1. *Parkes Pulsar Timing Array (PPTA)*
  2. *North American Nano-hertz Observatory for Gravitational Waves (NANOGrav),*
  3. *European Pulsar Timing Array (EPTA),*
  4. *Indian Pulsar Timing Array (InPTA)*
- A few Emerging PTAs : CPTA, SAPTA, ……..

Propagation Effects

Interstellar medium (ISM) smears and distorts the pulsar signal and delays it. Two of these propagation effects - dispersion and pulse broadening - are important for PTAs



Dispersion



Scatter-broadening

Krishnakumar et al, 2017

Motivation

- Propagation effects are strong functions of frequency and are dominant at frequencies below 1 GHz.
- ISM is dynamic which causes variations in DM and/or scattering properties.
- For PTAs, DM variations are characterised usually by using dual band timing.
- 200 MHz BW @ 500 MHz give better precision than 1.2 GHz BW @ 2 GHz.
- Dispersion and scatter-broadening introduce a systematic deviation in the pulse time-of-arrival (ToA).

Evaluating the effects of dispersion and scatter-broadening on DM estimates are important for PTAs

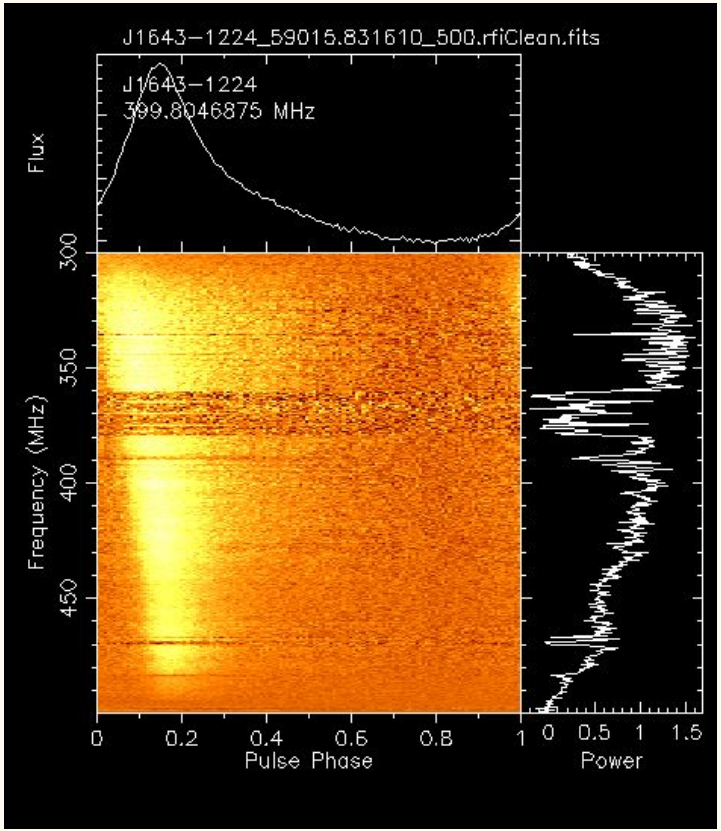
The Indian Pulsar Timing Array (InPTA)

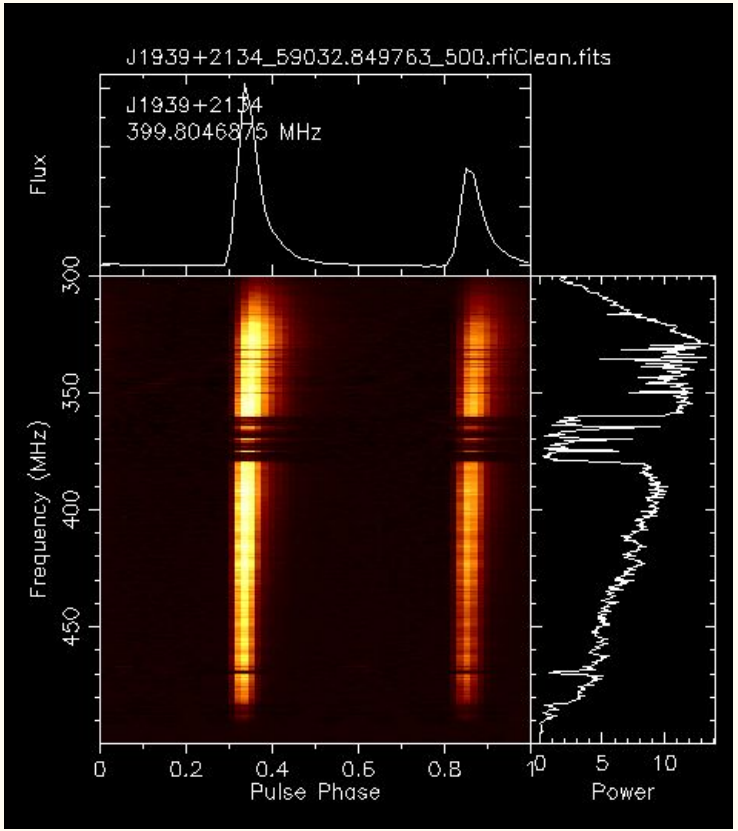
https://inpta.iitr.ac.in

The upgraded Giant Metrewave Radio Telescope

- InPTA observes a sample of 14+ pulsars with a cadence of around 14 days
- Simultaneous observations at 300-500 MHz (Band 3) and 1260-1460 MHz (Band 5) are possible due to subarrays and multiple beams capabilities of uGMRT
- Each band observed with 200 MHz bandwidth
- Coherently de-dispersed data with 300-500 MHz
- **Two pulsars in our sample show marked scatter broadening in Band 3**
- **First Data Release :** arXiv:2206.09289

Prominent scatter-broadening in PSRs J1643-1224 and J1939+2134





Bias in two frequency DM measurements ?

- Recently, we have published precision DM measurements with the wideband Band 3 and Band 5 InPTA observations

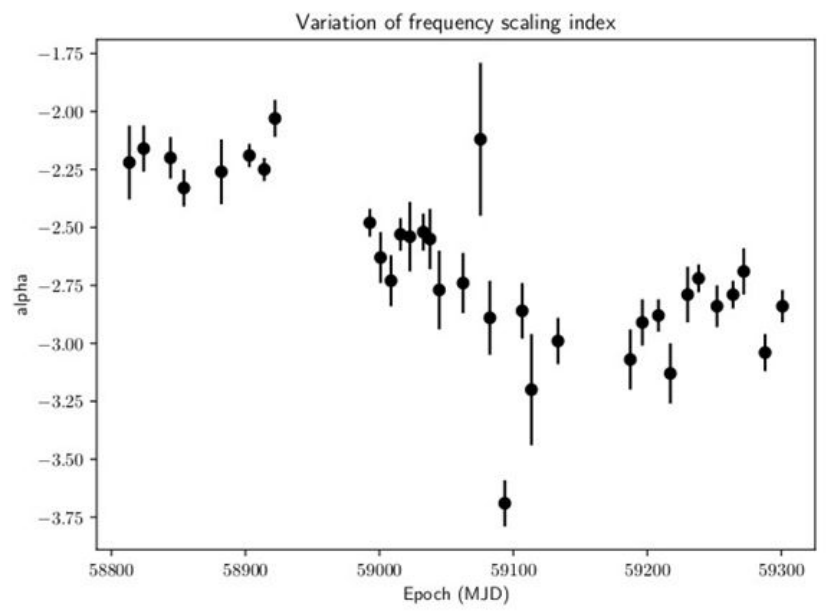
  (*Krishnakumar et al, 2021; Nobleson et al, 2022; Tarafdar et al, 2022*)

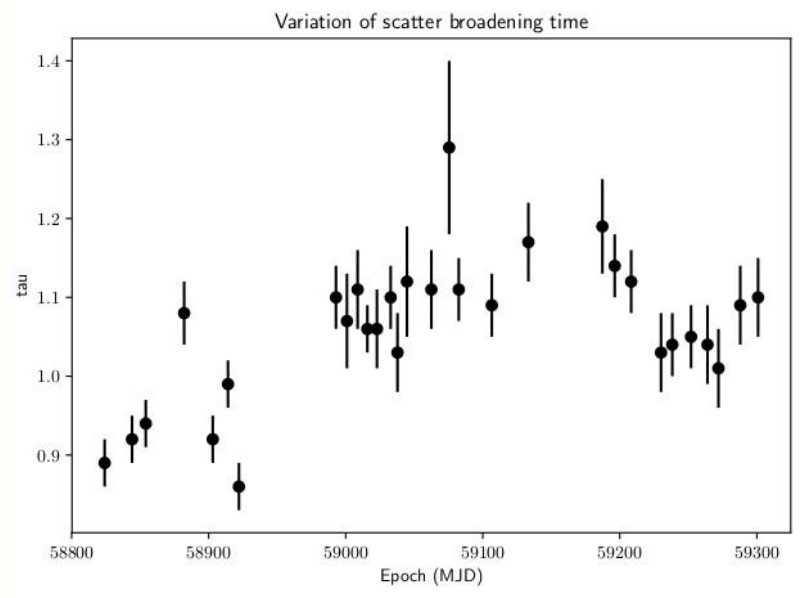
- DMs measured for PSRs J1643-1224 and J1939+2134 showed a systematic bias compared to trends from previously published DM

Could this bias be due to pulse broadening affecting the DM measurements ?

Variation in scatter broadening with observed epoch

- Frequency scaling index, α, varies from epoch to epoch for J1643-1224 **(Joshi et al., *in preparation*)**
- Possibly due to HII region Sh2-27 **(Harvey-Smith et al. 2011, ApJ, 736, 83)**





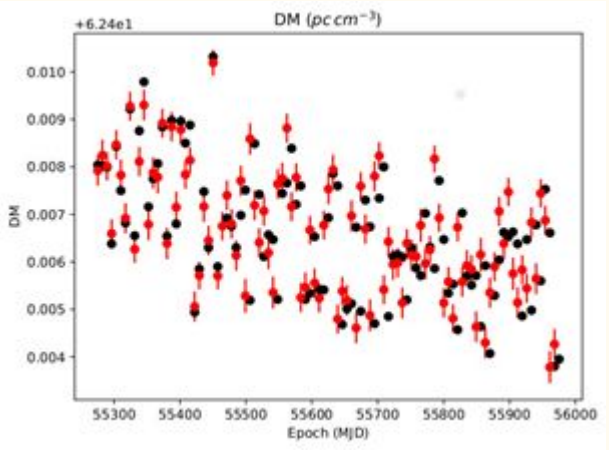
A time variation in systematic bias and hence DM, introducing a source of low frequency noise in the ToAs.

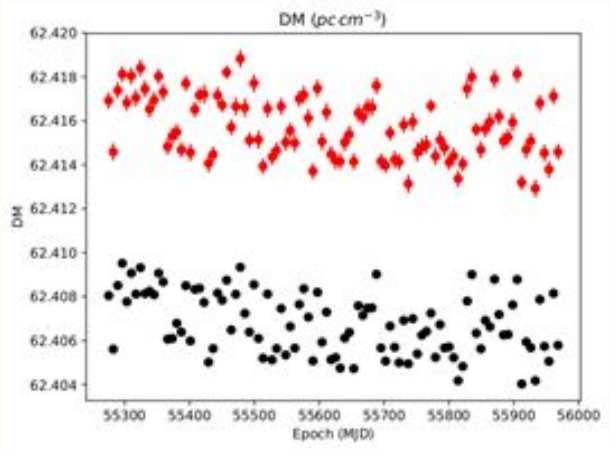
Simulations

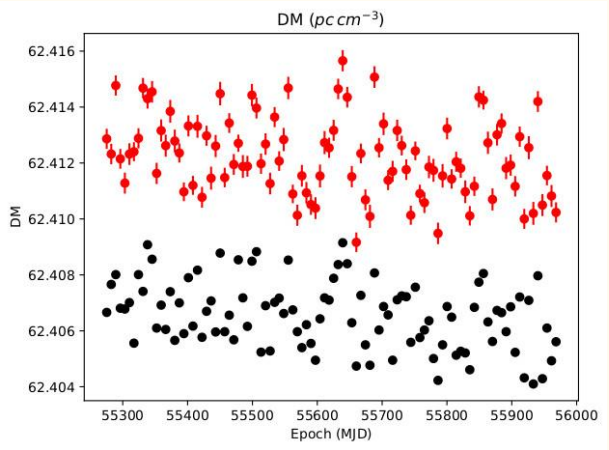
- DM variations were modeled for PSR J1643-1224 using NG12.5 and IPTA DR2 data sets
- Monte-Carlo DM time series was generated spanning 10 years
- PulPS - **Pul**sar **P**rofile **S**imulator : archive/PSRFITS files
- This was used to simulate fake pulsar data with weekly cadence over 10 years
- Three data sets were generated
  - Data set with only DM variations assumed from simulated DM time series
  - Data set with simulated DM variations and constant scatter broadening with Kolmogorov turbulence
  - Data set with simulated DM variations and variable scatter broadening

Results

- DM bias seen in data sets with constant and variable scatter broadening







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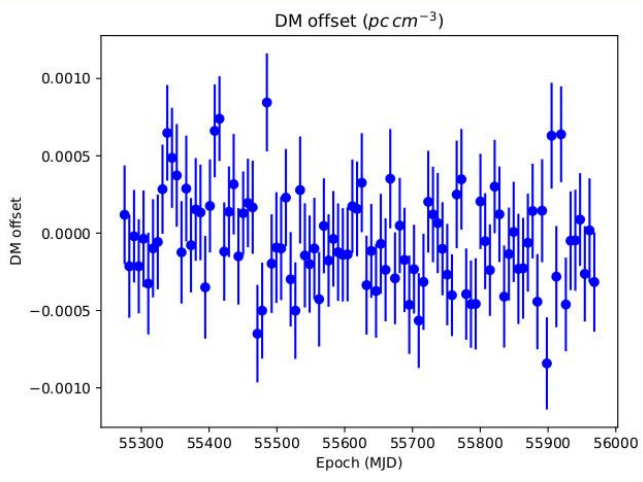
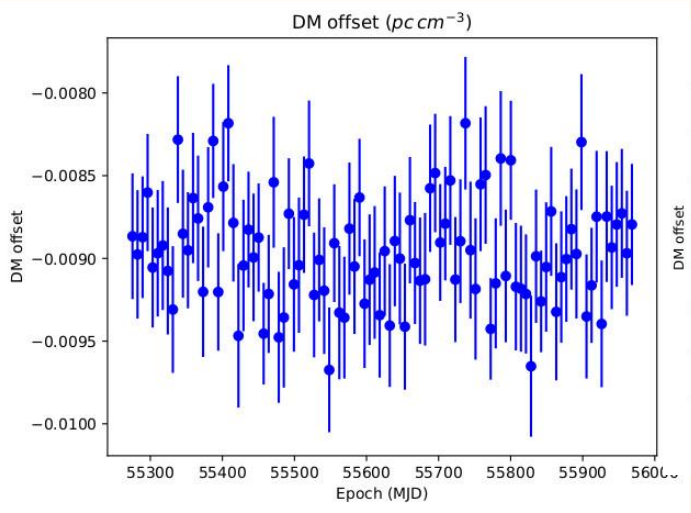
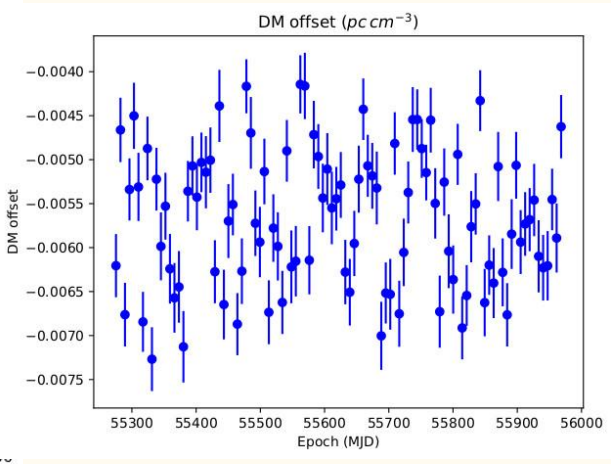






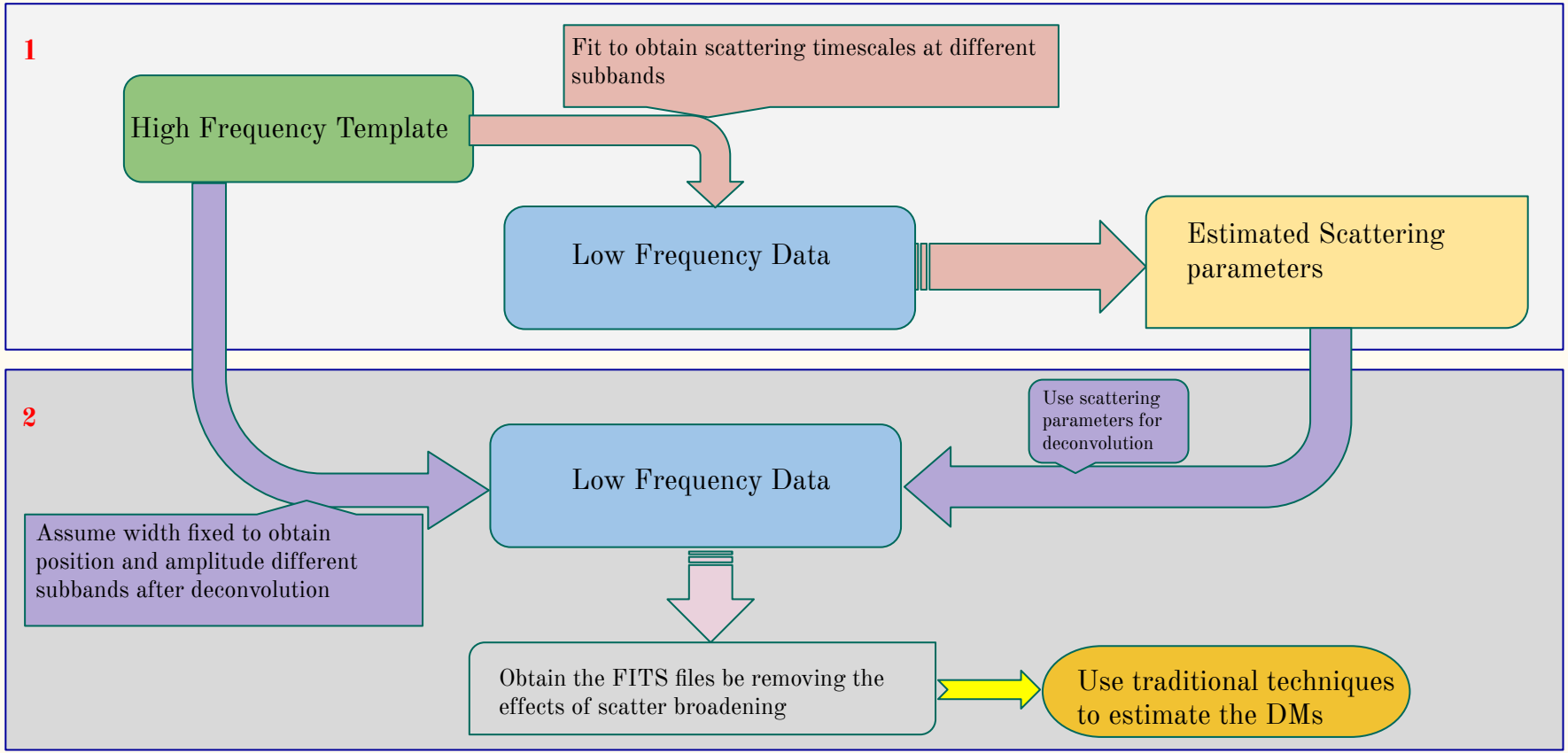
Mean = 4e-5, rms=3e-4 **Mean=9e-3, rms=3e-4** **mean=6e-3, rms=8e-4**

The rms is double for epoch variant pulse broadening than that for fixed broadening

New method for measuring DMs in presence of scattering

- τ_{sc} is estimated from low frequency measurements (Band3)
- Broadened pulse at low frequency is fitted to unscattered high frequency template convolved with τ_{sc} to obtain the phase of the pulse at each frequency (ToA)
- DMs are measured from these frequency resolved ToAs using tempo2

Summary


1
Fit to obtain scattering timescales at different subbands
High Frequency Template
Low Frequency Data
Estimated Scattering parameters
2
Use scattering parameters for deconvolution
Low Frequency Data
Assume width fixed to obtain position and amplitude different subbands after deconvolution
Obtain the FITS files be removing the effects of scatter broadening
Use traditional techniques to estimate the DMs

Summary

- DM bias can be introduced in dual frequency DM measurements if pulse broadening is not taken into account
- DM may vary with epoch for line of sight with disturbed ISM introducing a new red noise source for GW analysis
- A variation of frequency scaling index, α is seen in our data on J1643-1224
- A new method to account for variable α is developed
- DM measurements with a new method compensating for variable pulse broadening to be implemented on PSR J1643-1224 InPTA data

The InPTA Family

Faculty Members

Postdoctoral Fellows

Graduate Students

Undergraduate Students

Thank You.