Dispersion Measure Variations in NANOGrav Pulsars

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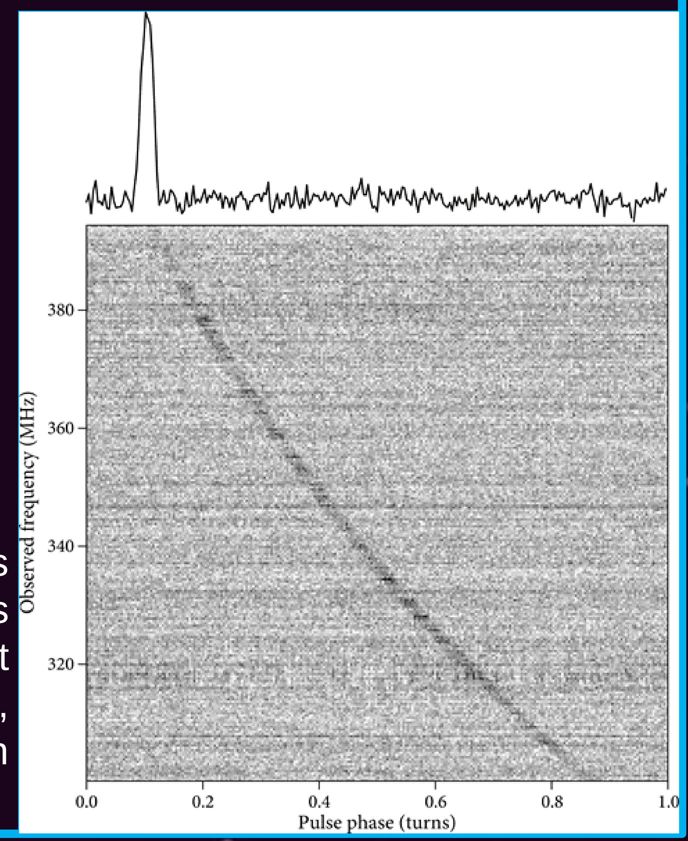
What is Dispersion Measure?

- Pulsars (rapidly spinning neutron stars) act as cosmic clocks which emit regular pulses.
- This project analyzed the radio waves that are emitted by pulsars, in order to calculate temporal dispersion measure.
- Dispersion measure (DM) is the integrated column density of free electrons along the line of sight to a pulsar.
- Equations used to calculate DM:

$$DM = \int_0^d n_e(l)dl$$

$$\Delta t \simeq 4.15 \times 10^6 \text{ms} \times (f_1^{-2} - f_2^{-2}) \times \text{DM}$$

- DM variations need to be understood to improve pulsar timing array sensitivity to nanohertz gravitational waves.
- These variations reduce the precision of the data if left uncorrected.



With observation frequency on the y-axis versus pulse phase on the x-axis, this figure shows how frequency and dispersion measure affect the arrival time of a pulse. At lower frequencies, the signal is delayed relative to high frequencies.

Why is this Important?

- Our results will be important for NANOGrav, which is a pulsar timing array (PTA) experiment using millisecond pulsars.
- NANOGrav needs very precise measurements in order to detect gravitational waves[1].
- Dispersion measure variations can give us important information about the properties of the interstellar medium.

Why CHIME?

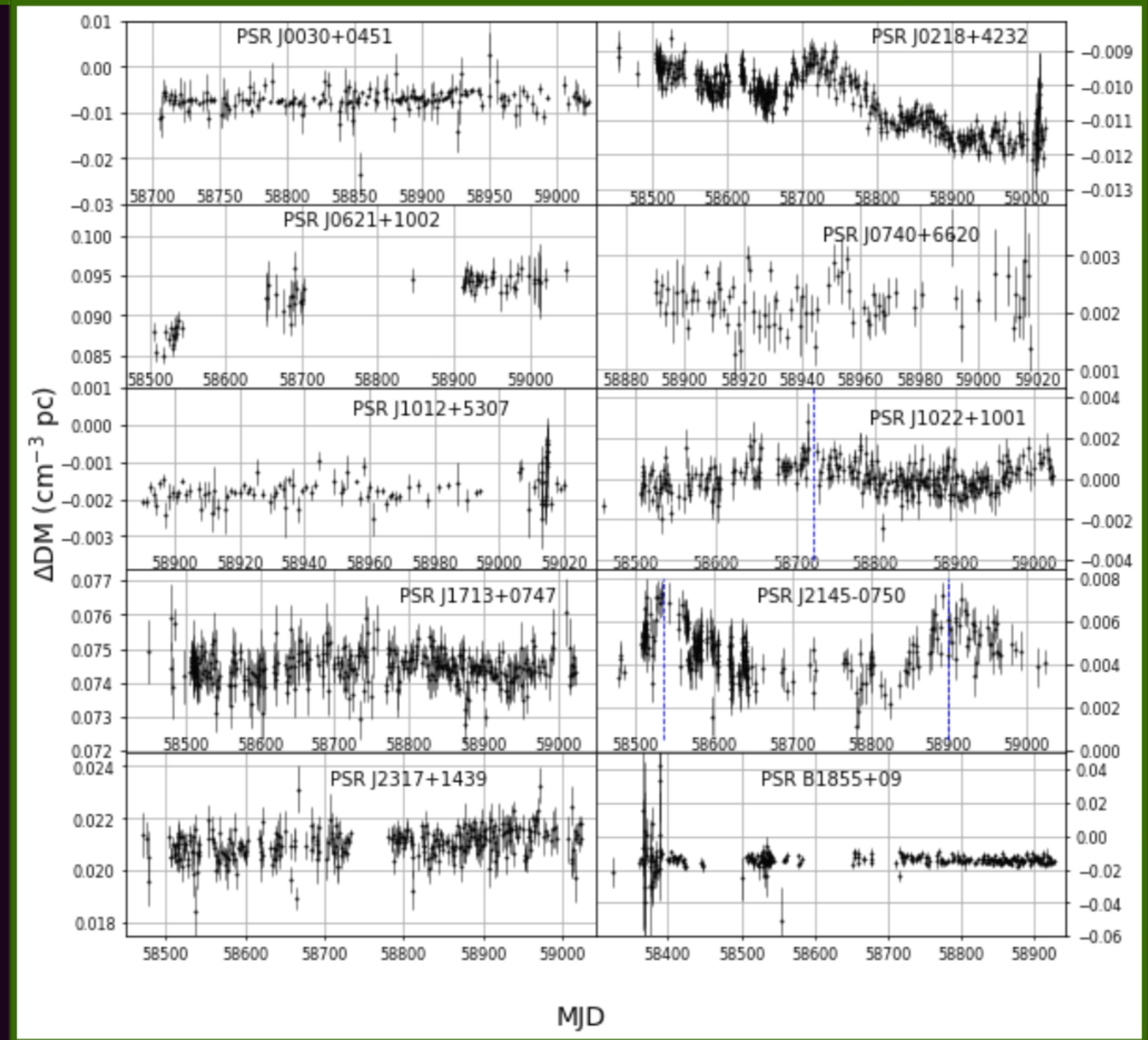
- CHIME has a large fractional bandwidth which makes it well suited to detect frequency dependent effects.
- High observing cadence[2,3].
- CHIME Observations:
  Every day for most pulsars
- NANOGrav Observations:
  Every 3-4 weeks

Results:

- 13 High quality templates for PTA pulsars.
- DM variation plots for each.
- Measured variations consistent with solar wind and plasma lensing.
- Although the CHIME telescope has not been active for very long (about 1.5 years), we are already able to see trends consistent with patterns in DM variation from other telescopes. This can be seen in pulsars PSR J2145-0750[4], PSR J1022+1001[4], PSR J0621+1002[5].

Pulsar name	DM (cm^{-3} pc)	Median DM Uncertainty (10^{-4} cm^{-3} pc)	Type of Variation
B1855+09	13.31	19.31	Flat
J0030+0451	4.34	12.65	Flat
J0218+4232	61.25	2.67	Linear+Lensing
J0340+4130	49.59	8.22	Flat
J0613-0200	38.78	3.69	Flat
J0621+1002	36.47	11.24	Linear
J0740+6620	14.96	2.66	Flat
J1012+5307	9.02	2.15	Flat
J1022+1001	10.25	4.88	Solar
J1713+0747	15.92	4.13	Flat
J1918-0642	26.46	74.76	Flat
J2145-0750	8.99	7.41	Solar
J2317+1439	21.88	4.39	Flat

The figure to the right shows 10 of the most interesting DM variations. Of note, PSR J1022+1001 and PSR J2145-0750 show evidence of solar wind signature (their closest approach to the sun is marked by the dotted blue line). PSR J0218+4232 seems to show evidence for plasma lensing.



How did we do it?

- Chose pulsars used by NANOGrav or other PTAs depending on their brightness and previously known variations.
- Measured variation from pulsar timing by matching observations to a template.
- Measured the shift of the channels relative to the template then fit for a change in DM.

1. Template Creation

Find top SNR observations
10 brightest observations
RFI (radio frequency interference) cleaning
Add observations to create template

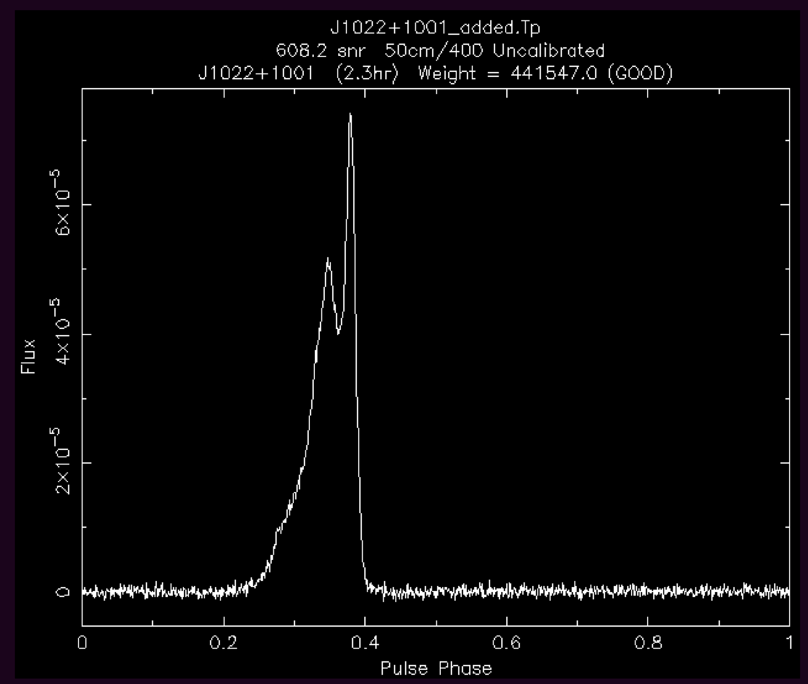
2. Data Processing Pipeline

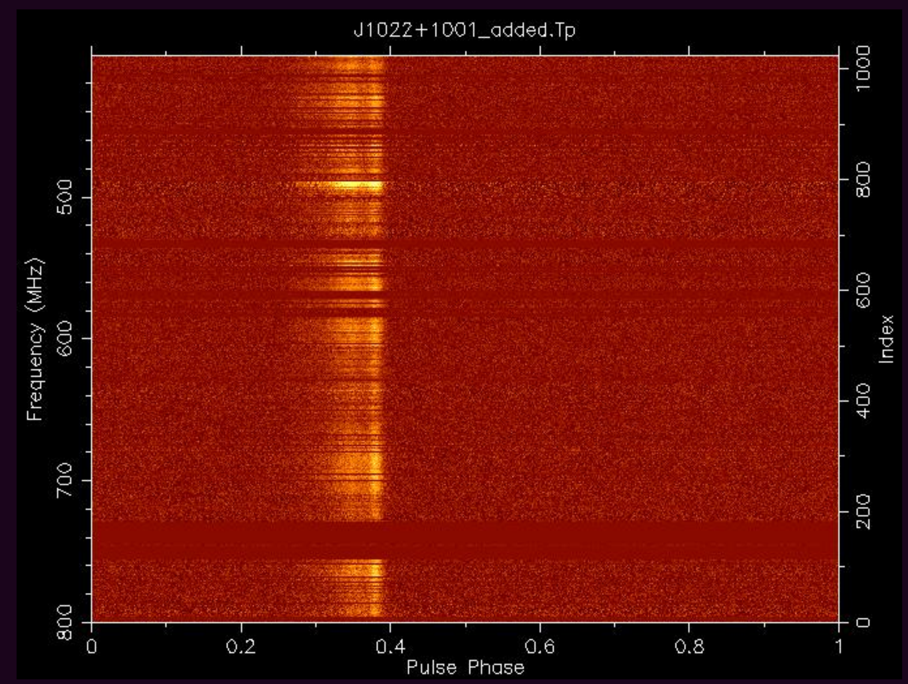
Creating 2D templates so we need to include time and frequency

3. Deriving Timing Residuals

Added files are smoothed to create noise-free profile
Measure TOAs (Times of Arrival) through template matching
Remove outliers

The two figures below show a typical example of a template. The plot to the left shows the pulse profile. The plot to the right shows the frequency versus pulse phase.





References:

1. Jones, M. L. et al. 2017, ApJ, 841 125
2. CHIME/Pulsar Collaboration et al. 2018, ApJ, 863 48
3. CHIME/Pulsar Collaboration et al. 2020, ApJ, submitted.
4. Tiburzi, C. et al. 2016, MNRAS, 455 4339
5. Desvignes, G. et al. 2016, MNRAS, 458 3341

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