The Influence of HII Regions on DM Variations for PSRs J1614-2230 & J1643-1224

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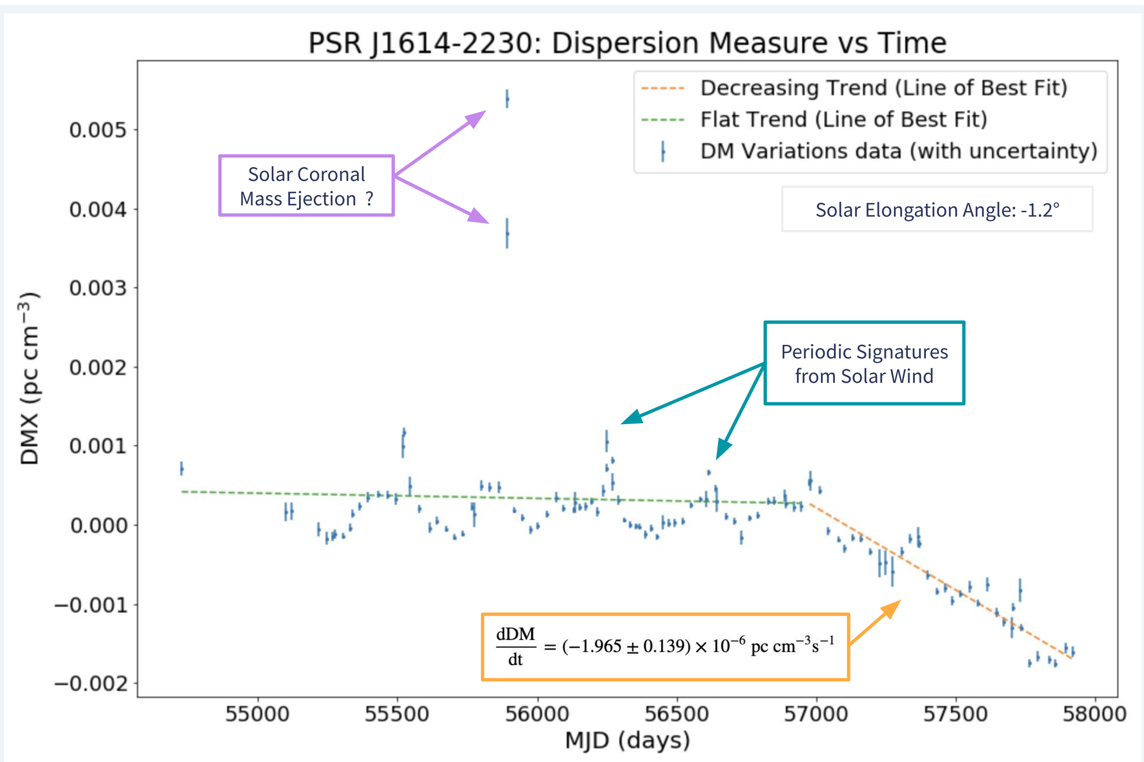
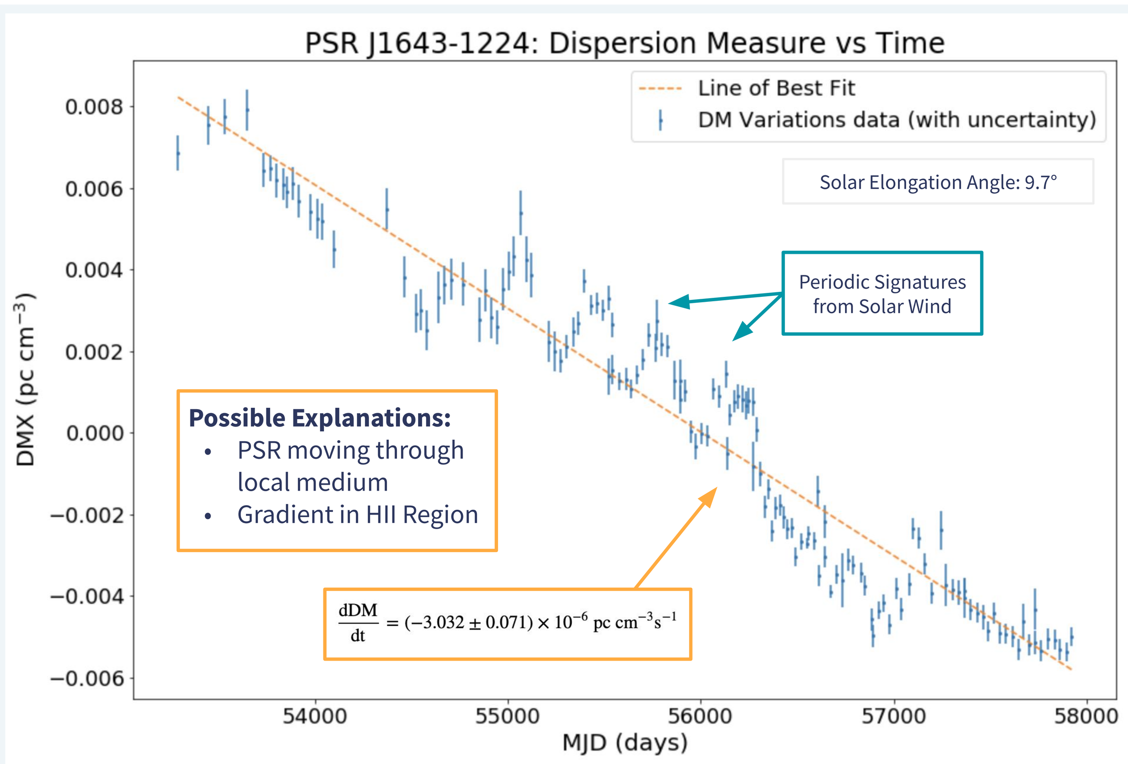
Main Results

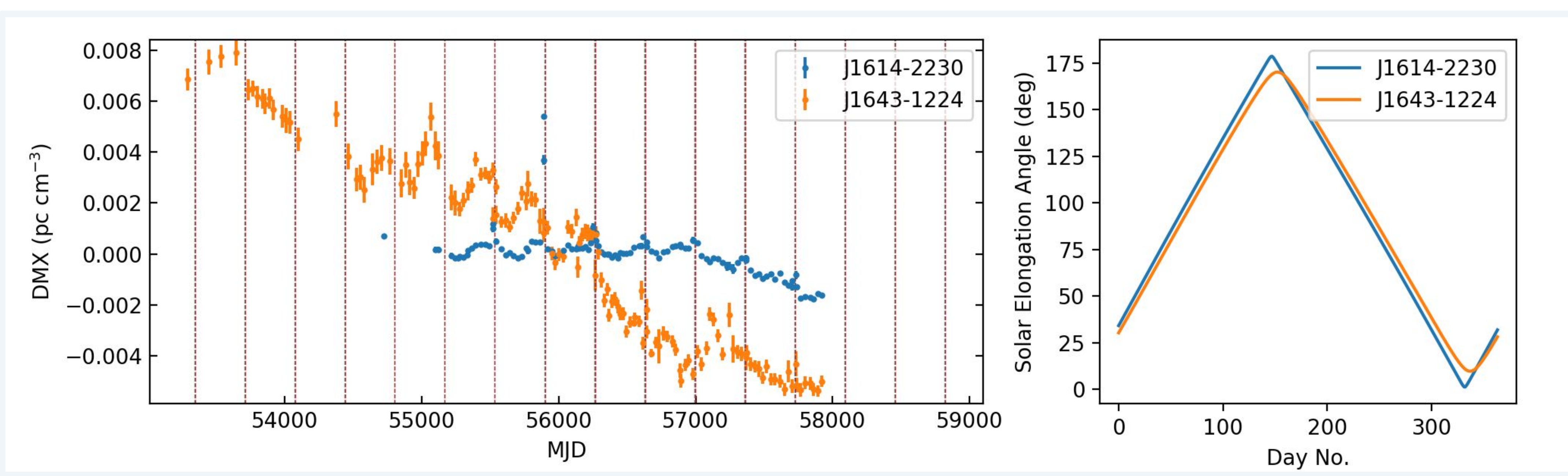
- NANOGrav has observed DM variations over 12.5 years for 42-millisecond pulsars.
- PSRs J1614-2230 and J1643-1224 trace density fluctuations in two HII regions on scales of AU or less.
- These two pulsars show evidence of DM variations induced by an interstellar plasma structure that obstructs the line of sight to the two pulsars.

Pulsar Dispersion Measure Variations Over Time





Plots of the **dispersion measure variations** (DMX) as a function of time (Modified Julian Date or MJD) for each pulsar (left: PSR J1614-2230, right: PSR J1643-1224).



DM variations vs. time for J1614-2230 and J1643-1224 (left) and solar elongation angle vs. time (right). The dashed lines show the days of closest solar approach for both pulsars.

Table 1. Data used in calculations.

- Proper motions at screen calculated from PSR proper motions.
- Translational velocities at screen calculated using proper motions at screen and HII region distances.

Pulsar Name	DM [6]	Location (degrees) [5]		PSR Distance (pc) [5]	PSR Proper Motion (mas/yr) [2]		Solar Elongation Angle (degrees) [4]	HII Region Name	HII Region Distance (pc) [7]	Proper Motion at Screen (mas/yr)		Transverse Velocity at Screen (AU/yr)	
	(pc cm-3)	gal *l*	gal *b*		RA	Dec				gal *l*	gal *b*	gal *l*	gal *b*
J1614-2230	34.5	352.64	20.192	770	3.8	-32	-1.2	Sh 2-7	170	-20.935	-24.498	-3.5566	-4.1619
J1643-1224	62.4	5.669	21.218	455	6.2	4.5	9.7	Sh 2-27	112	7.2806	-2.384	0.81488	-0.26683

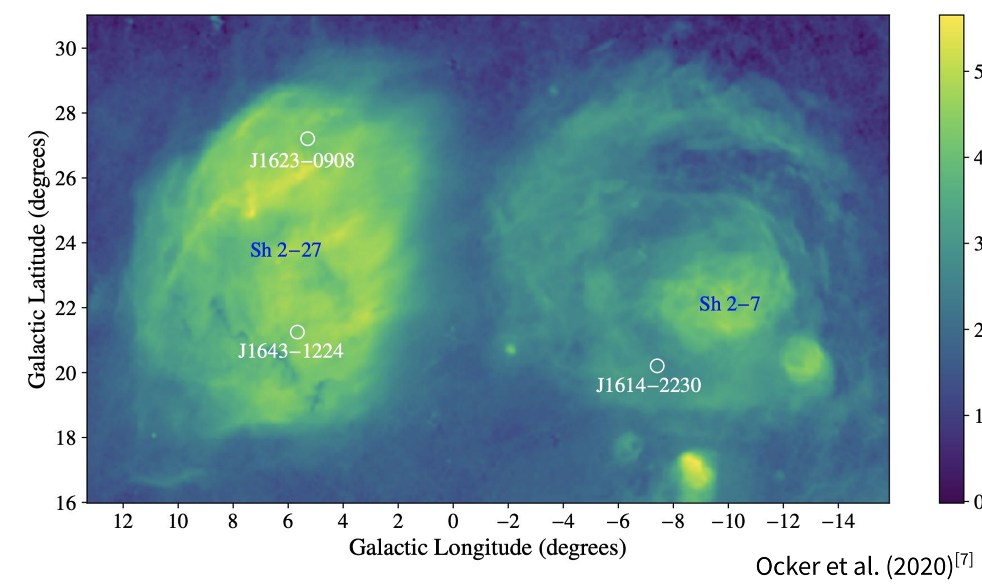
Background

- Pulsars: rapidly rotating and highly-magnetic neutron stars that emit radio frequencies
- NANOGrav: uses pulsar timing arrays to detect gravitational waves (GWs)[6]
  - Understanding and correcting DM in pulsar timing arrays is crucial in searching for GWs[3]
- Dispersion Measure (DM): integrated electron column density along the LOS to the pulsar[2]

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

- DM Structure Function (DM SF): probability density function useful for statistical analysis of ISM turbulence

HII Regions Sh 2-27 & Sh 2-7



Ocker et al. (2020)[7]

Discussion

Project Goals:

- To find any special phenomena we can associate with the HII regions.
- Analyze effects in DM time series to see what may be different to what is expected
  - Are LOS's of PSRs J1614-2230 and J1643-1224 different (worse/better) than those of other MSPs?

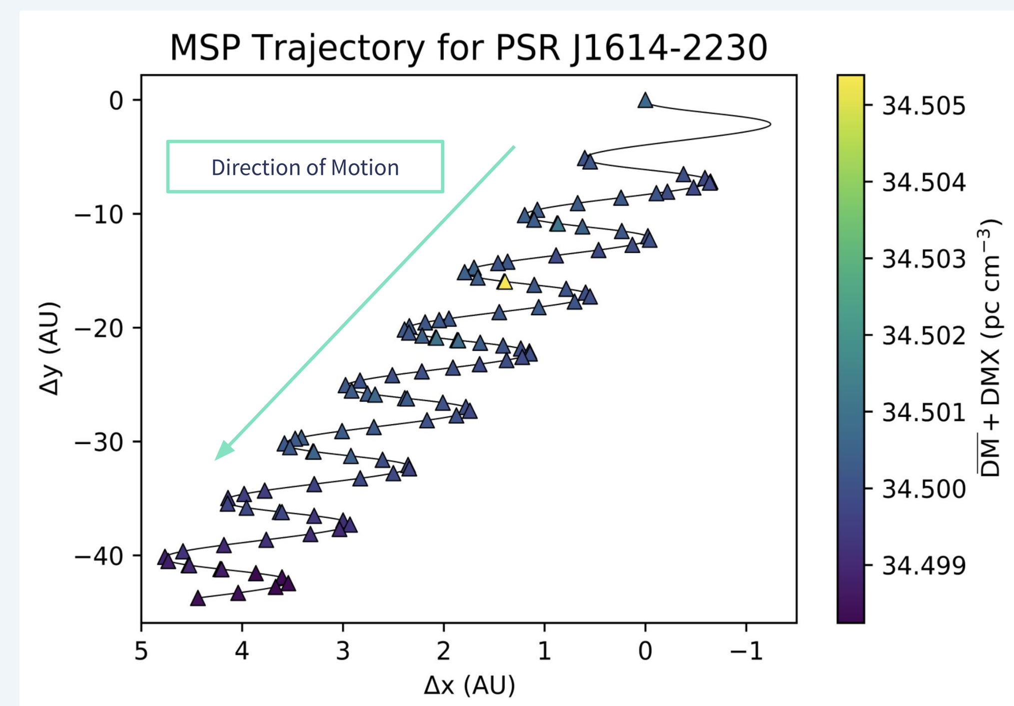
Results:

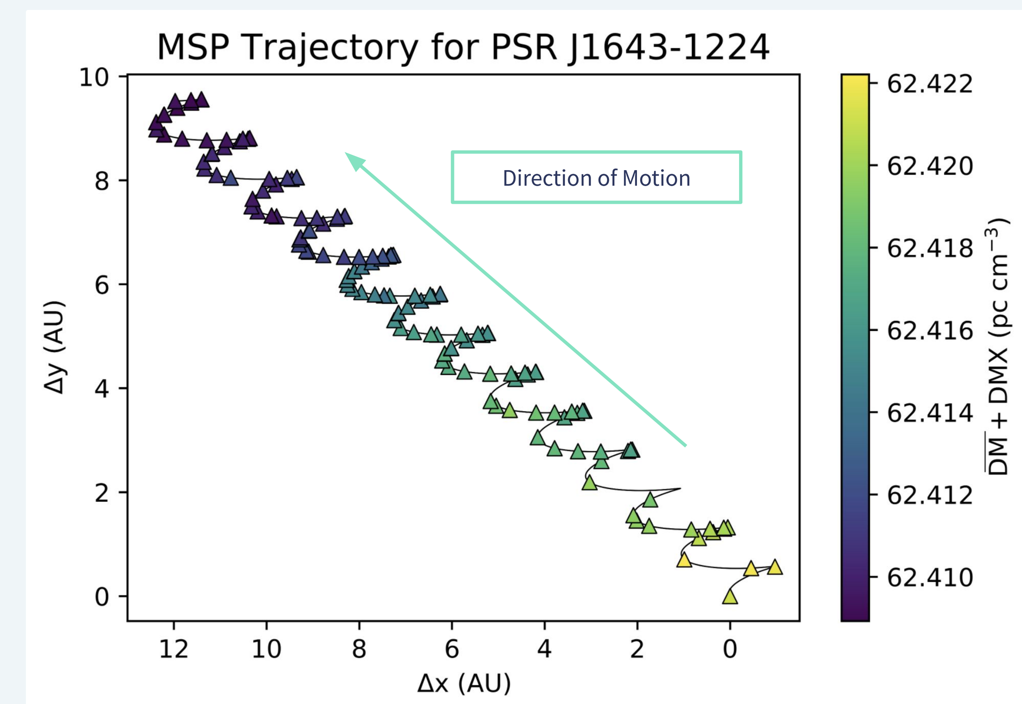
The observed DM variations show a much smaller effect from the internal density fluctuations of the HII regions than that of solar wind activity, and they show a periodic structure that is out of phase with the expected solar wind induced variations.

Future work:

- Continued analysis on DM statistical properties and how the HII regions may affect it.
- Compare results to more pulsars to see how they differ from expectations.
- Explore physical models to explain the observed DM variations.

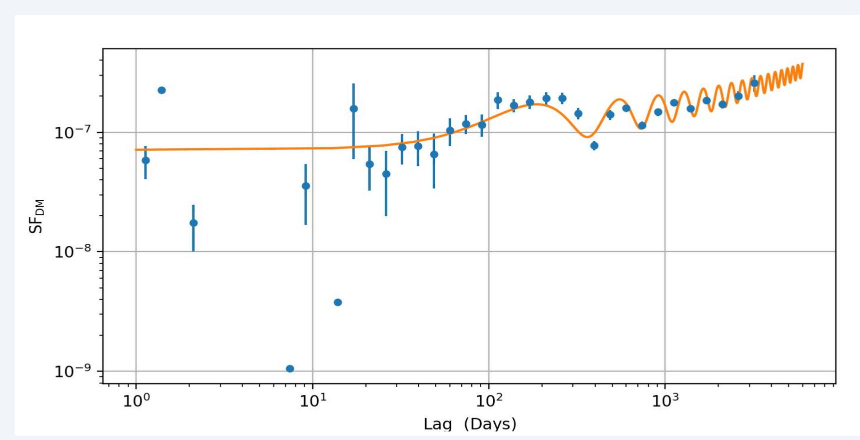
Pulsar Trajectories



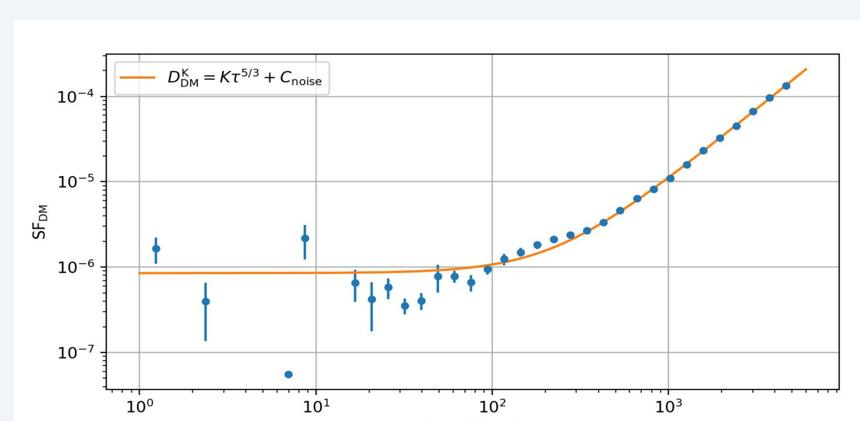


The **millisecond pulsars' trajectories** for PSRs J1614-2230 (left) and J1643-1224 (right) plotted as their projected motions in R. A. (x) and dec. (y) coordinates (with distances in AU) along the phase screen at the distance of the HII region.

The DM Structure Function and Models:



The DM structure function vs. lag for **J1614-2230** (blue). The orange line shows a model based on periodic DM variations with a period of one year added to a Kolmogorov power-law model.



The DM structure function vs. lag for **J1643-1224** (blue) and a Kolmogorov power-law model fit to the observed structure function (orange).

SF Part 1: Observed

Theoretical formula[2]

$$D_{DM}(\tau) = \langle [DM(t+\tau) - DM(t)]^2 \rangle$$

Estimation[1]

$$\widehat{D}_{DM}(\tau) = \sum_{i,j} \sum_{\Delta t \in [\tau \pm \Delta\tau]} [DM_i - DM_j]^2$$

SF Part 2: Models

(1) HII Region Model

$$D_{DM}(\tau) \propto d_{PSR} \langle C_n^2 \rangle (v_\perp \tau)^{5/3}$$

General form for Kolmogorov-based model of the HII regions

- Power spectrum $\beta = 11/3$

$$\langle C_n^2 \rangle \propto L_{HII}^{-8/3} DM_{HII}^2$$

(2) Stochastic Model

$$D_{\rm DM}^{\rm sto}(\tau) = (A_\nu \nu)^2 (\tau/\tau_D)^{\beta-2}$$

(3) Periodic Solar Wind Model

$$D_{\rm DM}^{\rm per}(\tau) = C^2[1 - \cos(\omega\tau)]$$

Expected yearly periodic contribution of solar wind-dominated SF

References

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