Scattering Study of Pulsars Below 100 MHz

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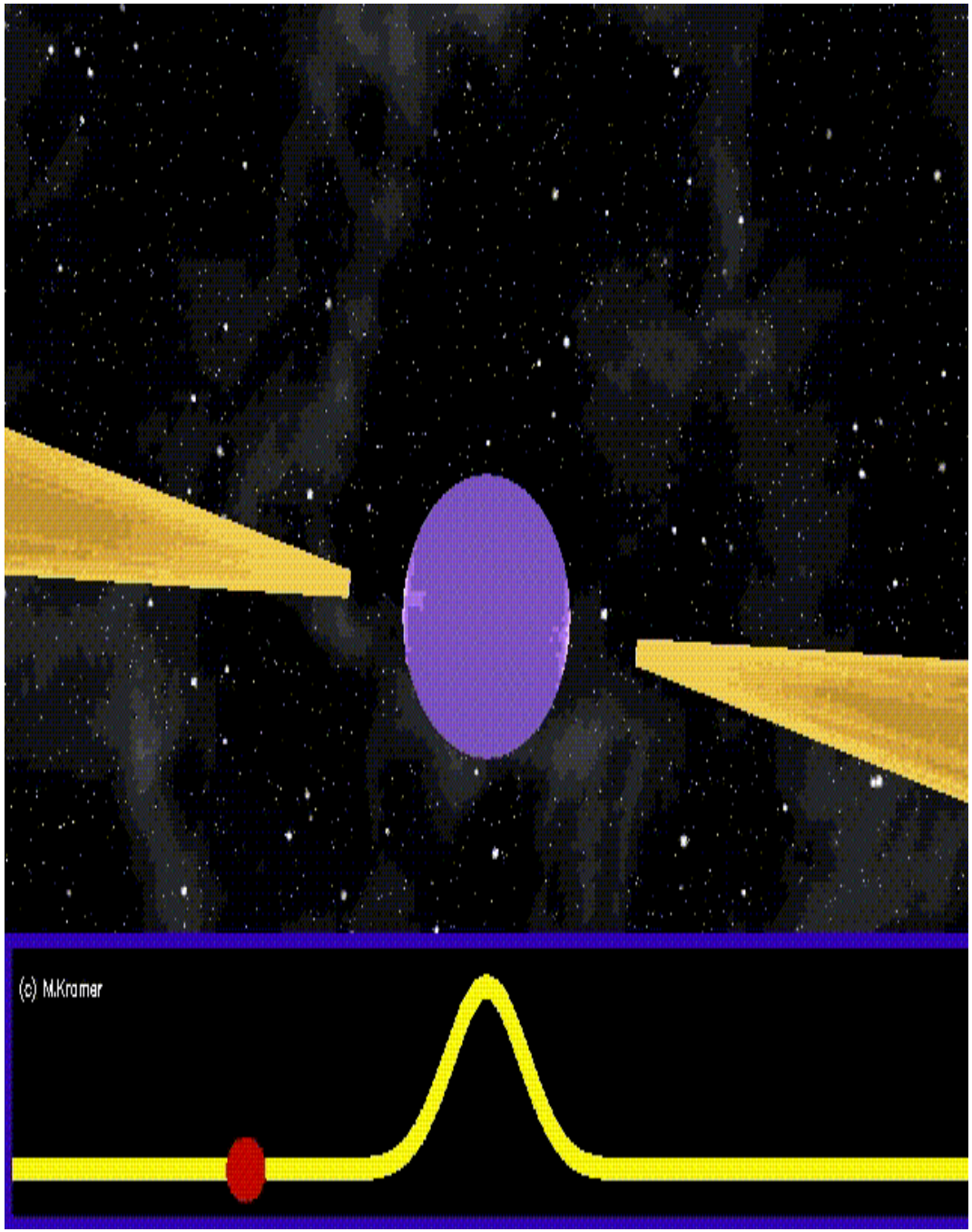
Pulsars

- Rotating Neutron Stars
- Highly dense
- Misaligned Rotation and Magnetic axis
- Beamed emission
- Highly periodic ranges from milliseconds to 24.5 seconds



Interstellar Medium

- Ionized plasma
- Magnetic field
- Inhomogeneous electron density
- Fluctuations in electron density
- Random irregularity of refractive index
- Observable Effects: Dispersion, Angular Broadening, Scattering, & Scintillation

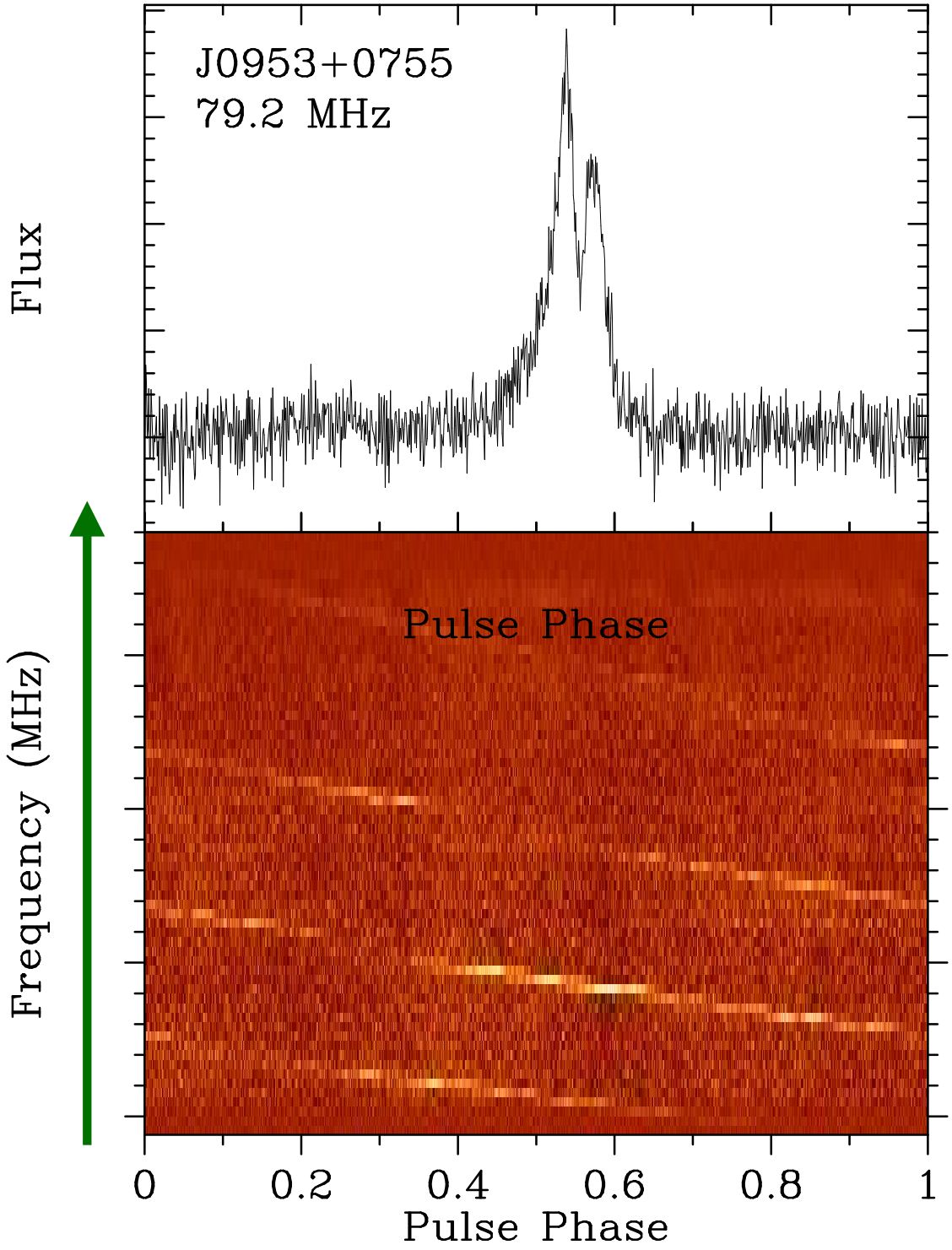
Dispersion Time Delay

$$t \propto DM\nu^{-2}$$

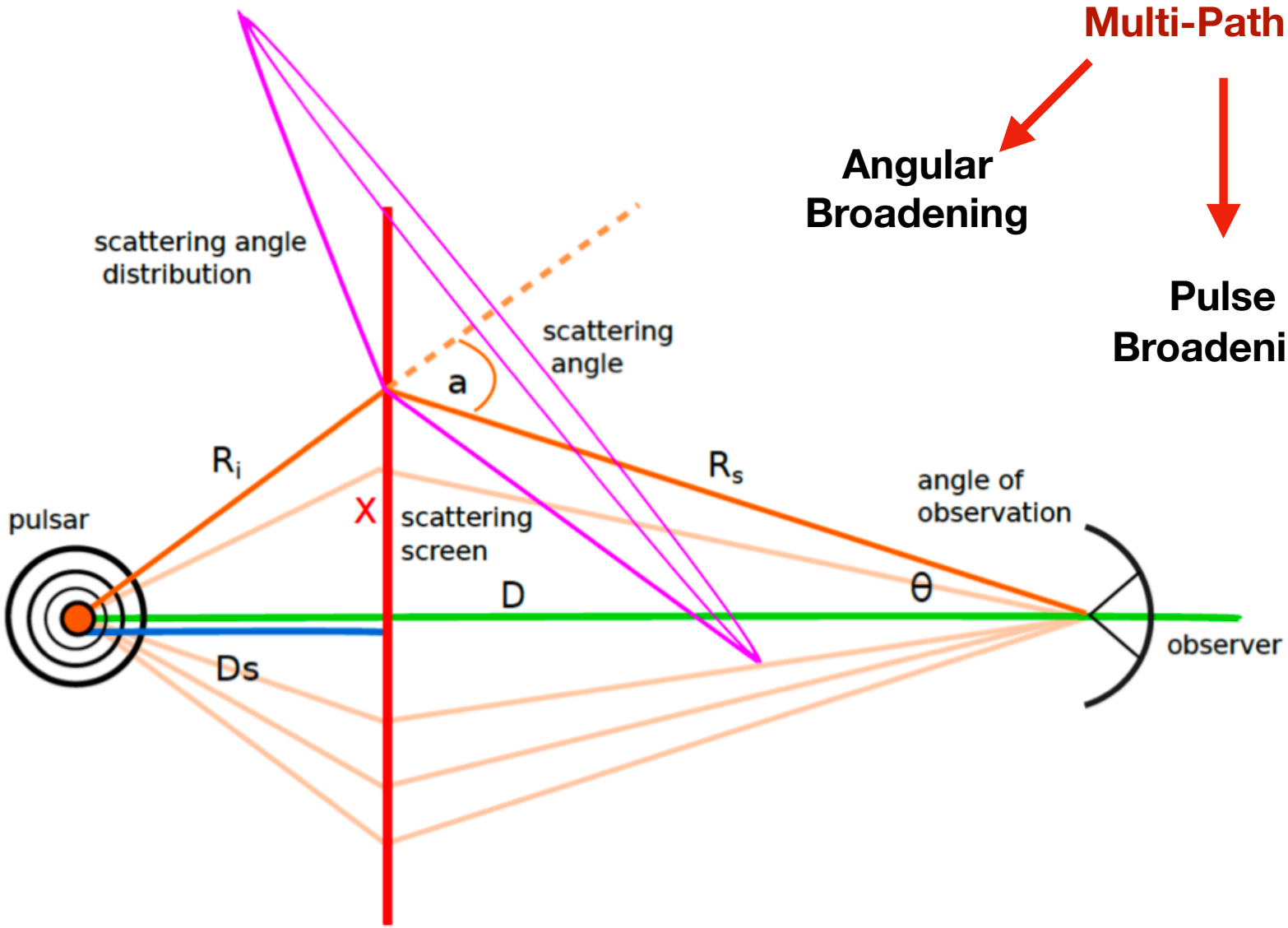
Dispersion measure

$$DM = \int_0^D n_e dl$$

Caused due to average electron density!



Interaction with inhomogeneous ISM



Multi-Path Scattering

Angular Broadening

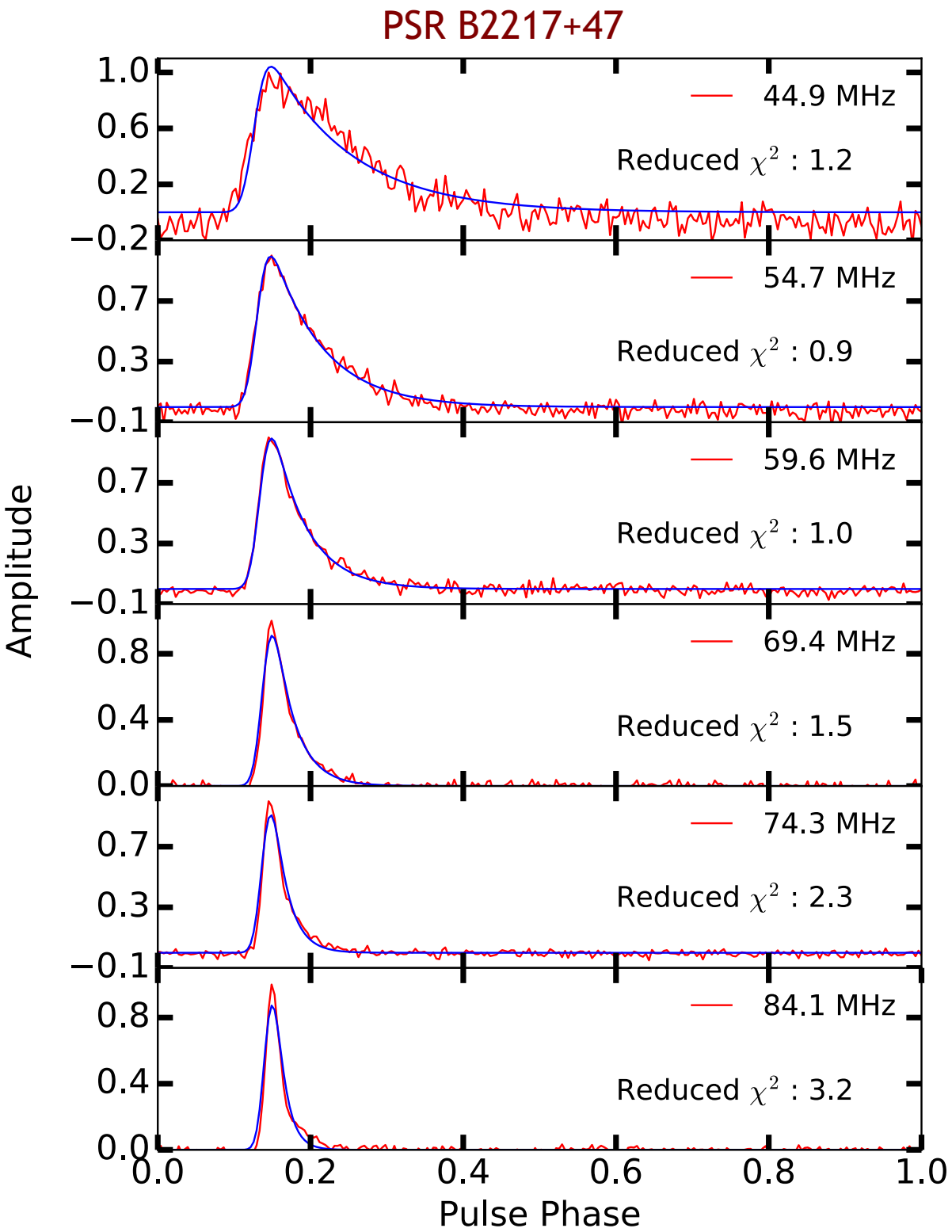
Pulse Broadening

Scintillation (Variation in flux)

Geyer et al. (2017)

Measuring the effects of ISM

- Very strong at low frequencies
- Long Wavelength Array!
- Operates between 10-88 MHz
- Simultaneous observation of multi-frequency
- Studied Scattering Broadening in 7 pulsars.



Scattering Model

Pulse Model

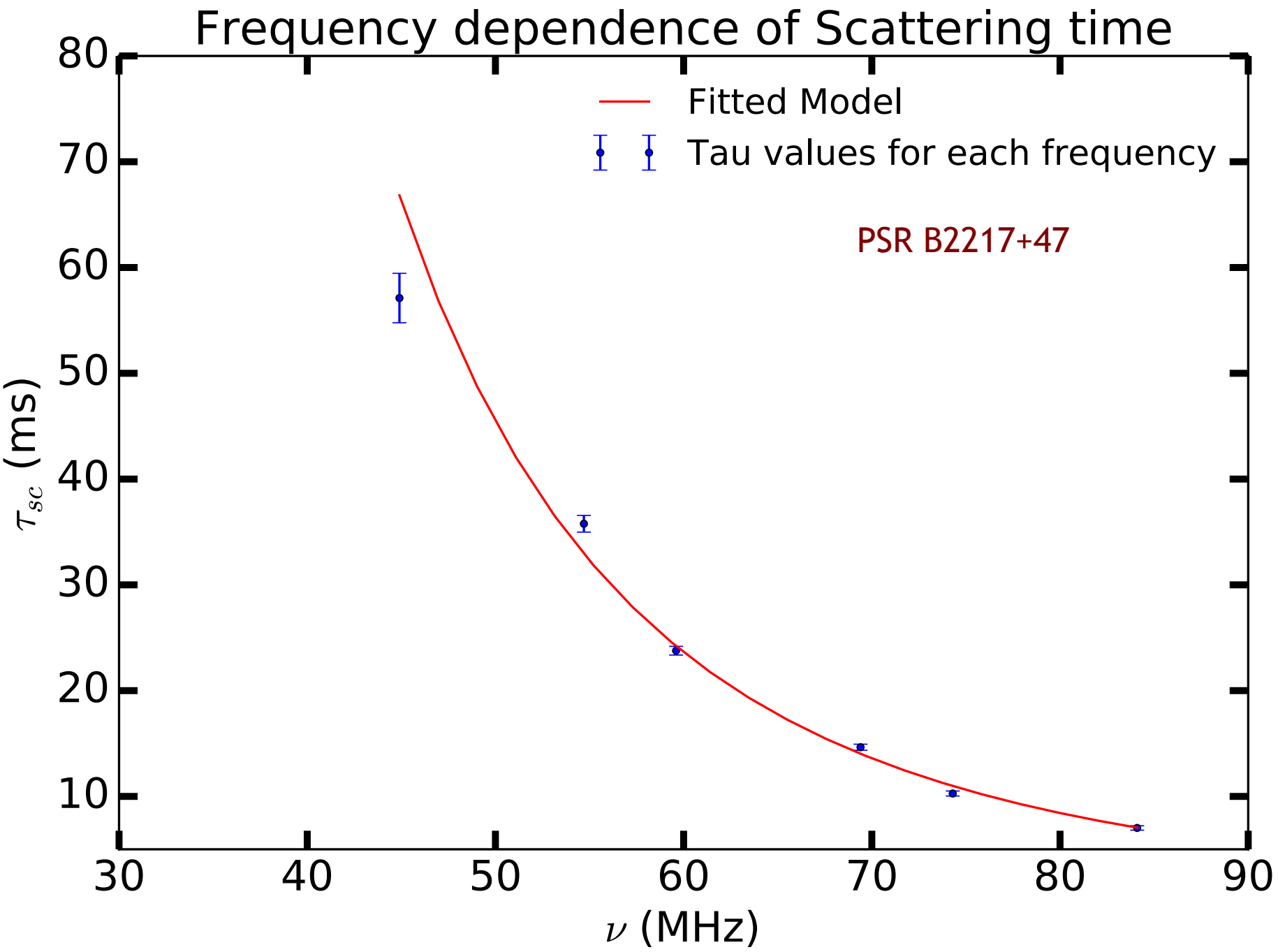
$$P(t) = P_i(t) * s(t) * D(t) * I(t)$$

Scattering Function

$$s(t) = exp(-t/\tau_{sc})$$

Scattering Time

Bansal et al. (2019)



Bansal et al. (2019)

Theoretical Models of ISM inhomogeneity

Circularly Symmetric Gaussian Distribution:

$$\tau \propto \nu^{-4} DM^2$$

Kolmogorov Distribution:

$$\tau \propto \nu^{-4.4} DM^{2.2}$$

Results

Pulsar	Scattering Index Value (α)	Scattering Index Slope (year^{-1})
B0329+54	4.05 ± 0.14	0.13 ± 0.11
B0823+26	1.55 ± 0.09	-0.16 ± 0.13
B0919+06	2.83 ± 0.18	-0.28 ± 0.15
B1822-09	4.18 ± 0.13	0.11 ± 0.25
B1839+56	2.70 ± 0.16	0.10 ± 0.05
B1842+14	3.24 ± 0.11	0.09 ± 0.12
B2217+47	3.58 ± 0.10	-0.44 ± 0.10

Deviation from theoretical models

- Limitations of Thin-Screen Model
- Truncated Screen
- B0823+26 - Limited Inner scale effects
- Anisotropic scattering

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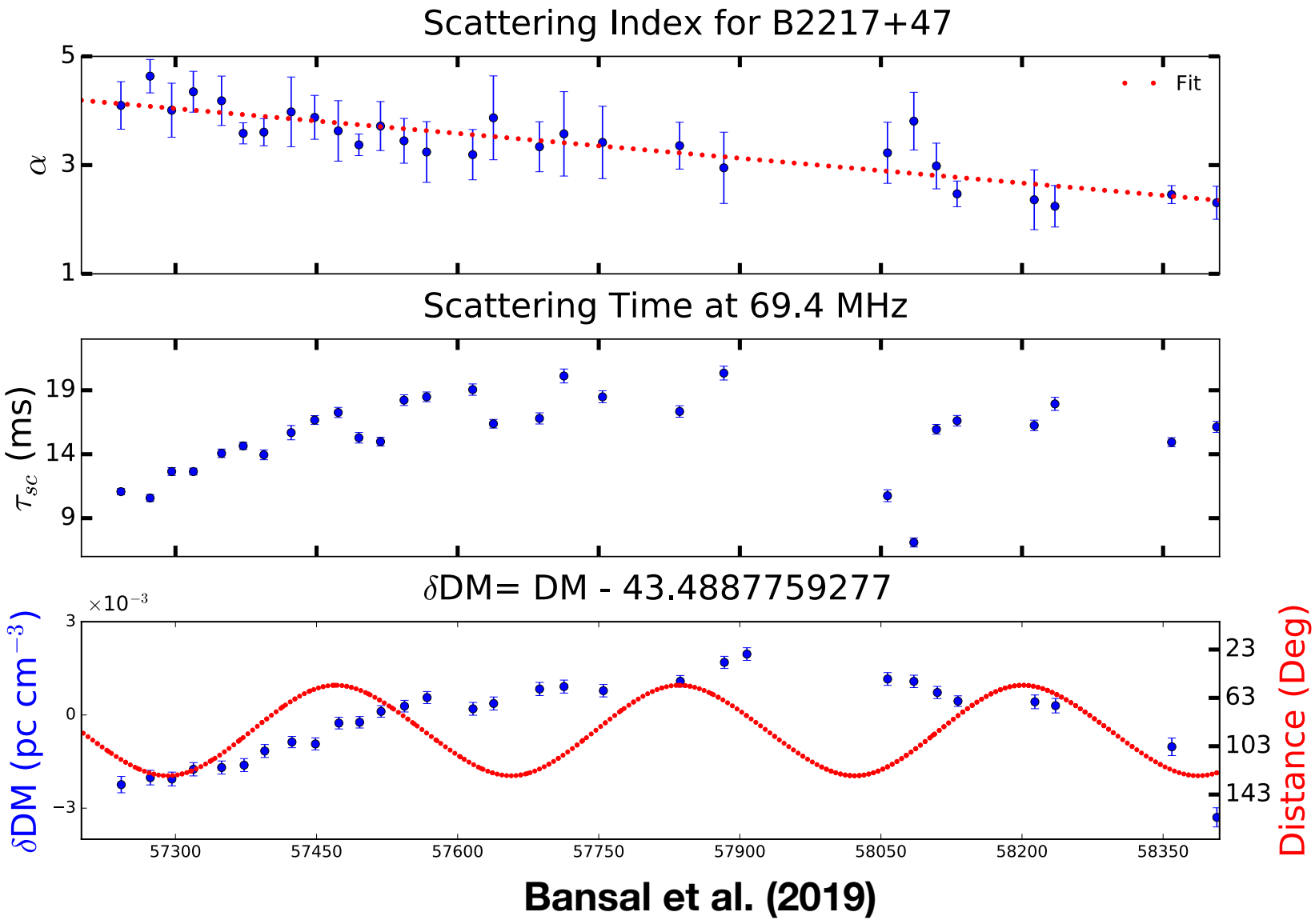


Bansal et al. (2019)

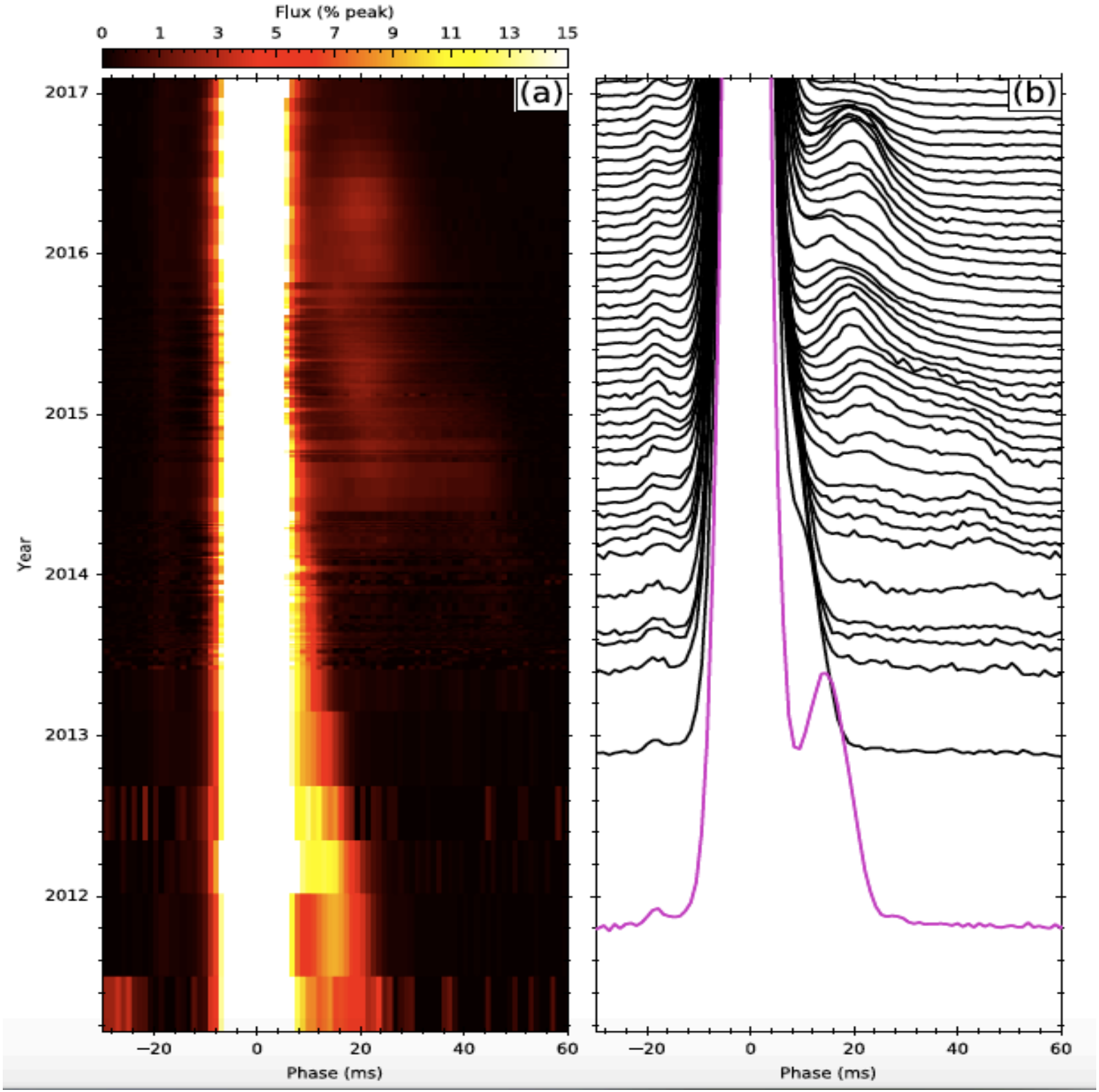
Scattering time correlates with variation with DMX

Suggests relative motion between the pulsar and a dense gas cloud

Echoes: Effect of gas clouds along the line of sight!

Varying Pulse Profiles

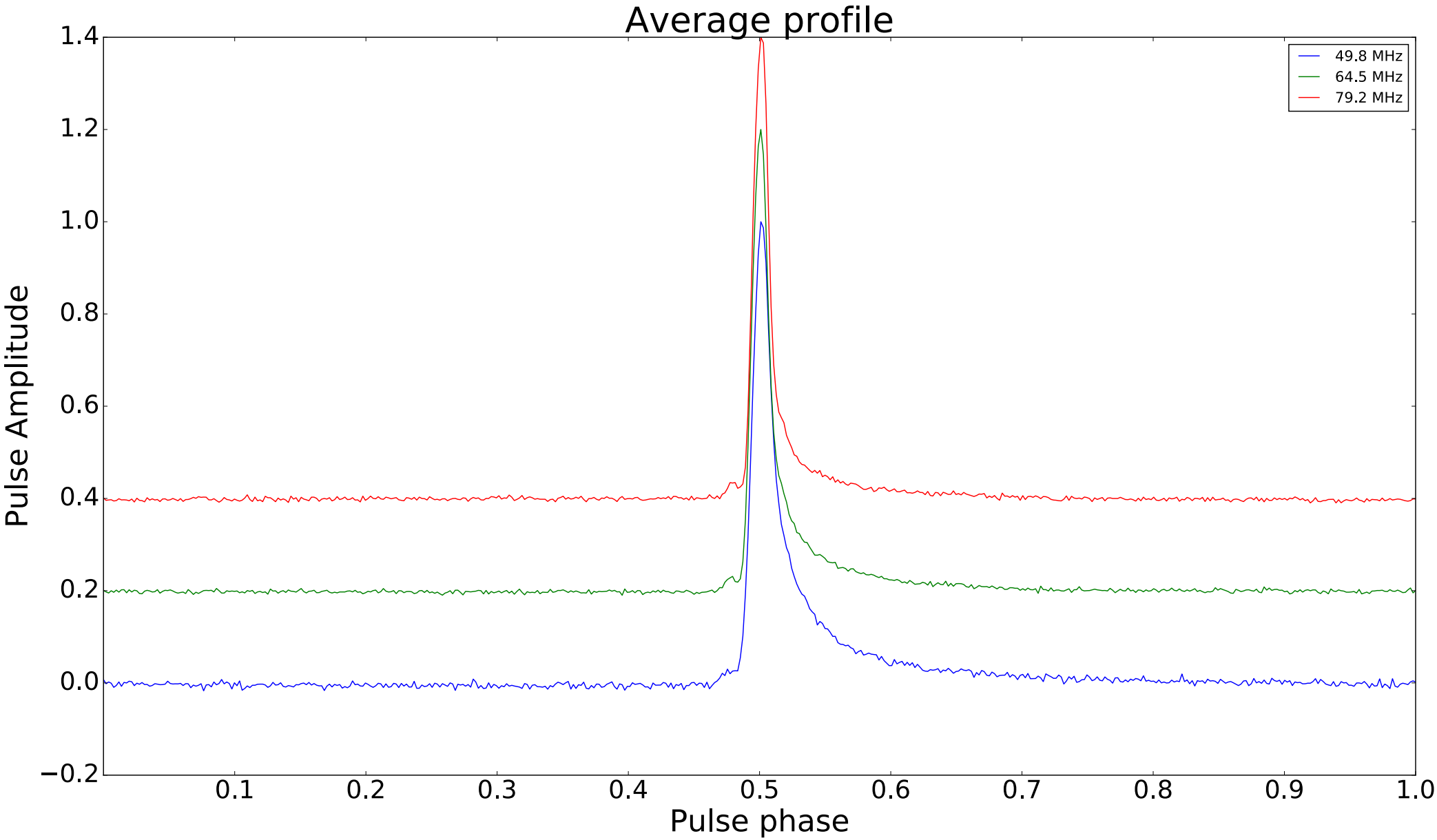
- Pulsars have stable profiles over time
- Quasi-periodic variation seen in 6 pulsars only (likely due to change in spin rate)
- B2217+47 – additional component at 150 MHz
- Typically single component above 300 MHz



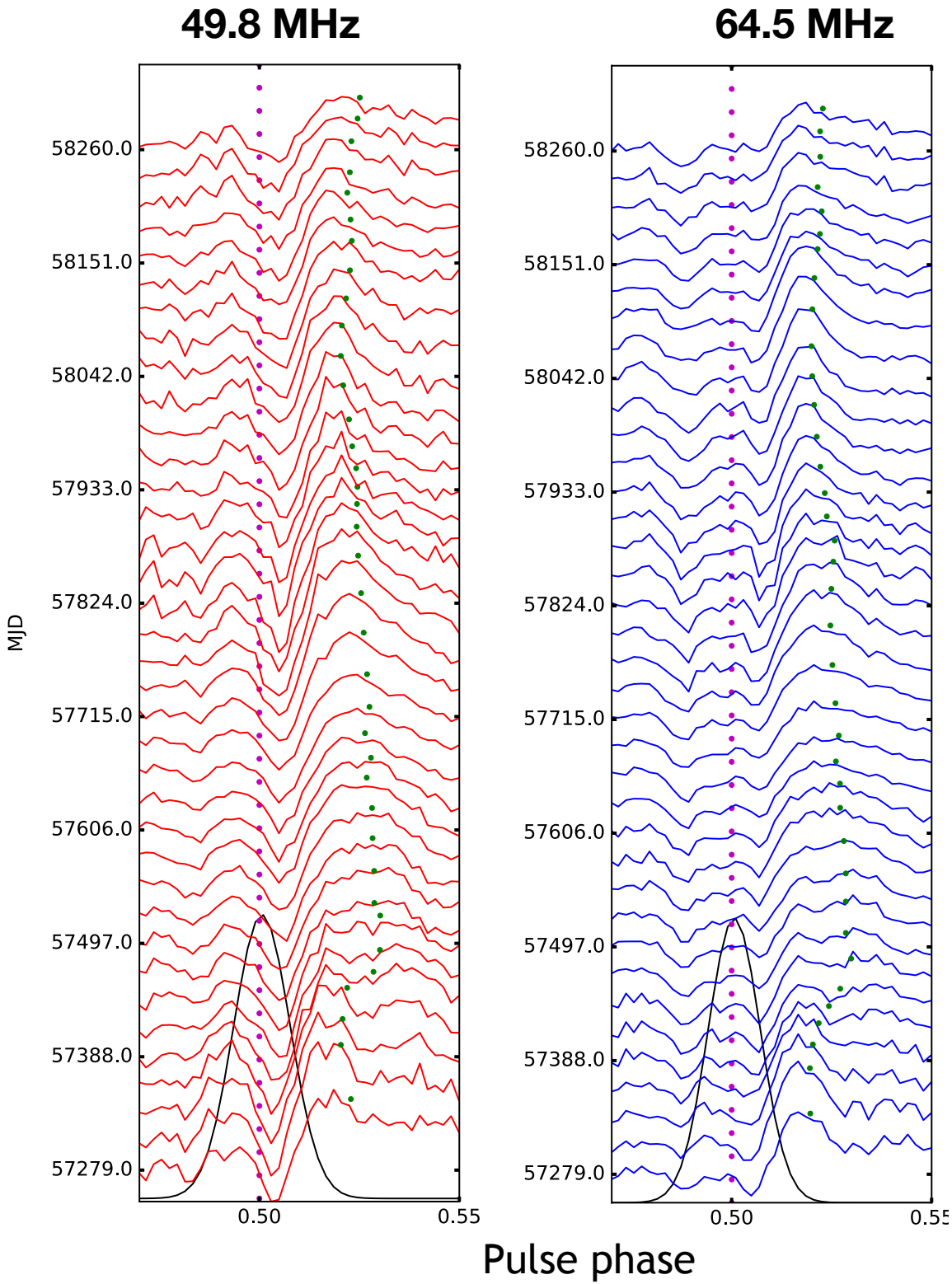
PSR B2217+47

LOFAR,
Michilli et al. (2017)

PSR B1508+55



Bansal et al., in review

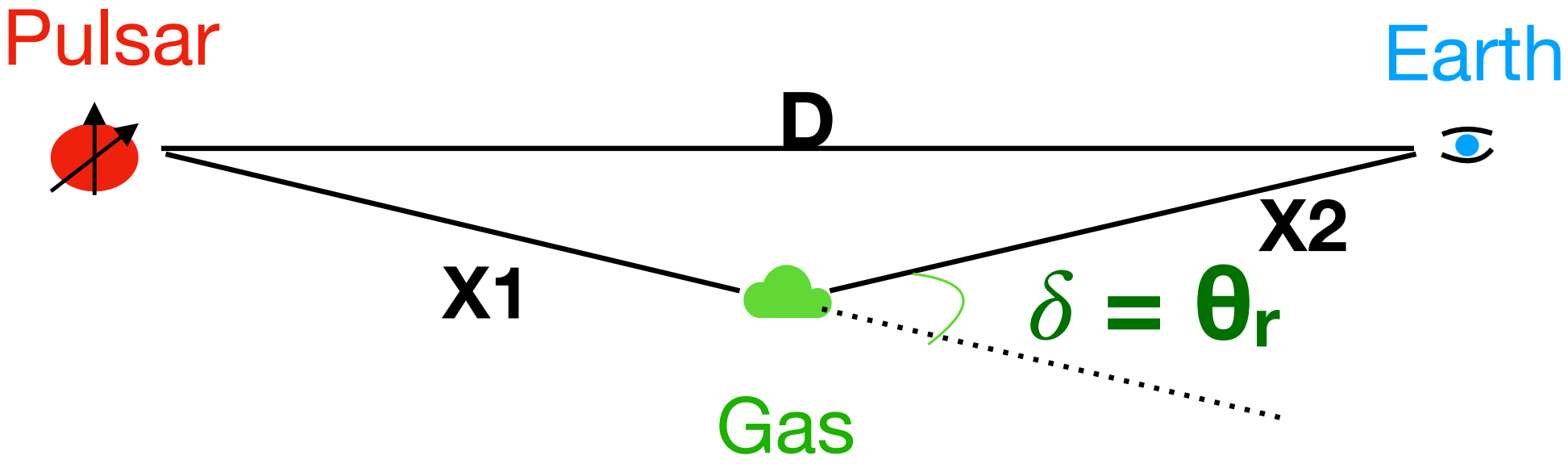


Bansal et al., in review

Possible Explanation

- Intrinsic effect of Pulsar (Spin Down rate)
- Free precision of Neutron star
- External effects – Interaction with an Asteroid
- Structures in the ISM

Mechanism of Echoes



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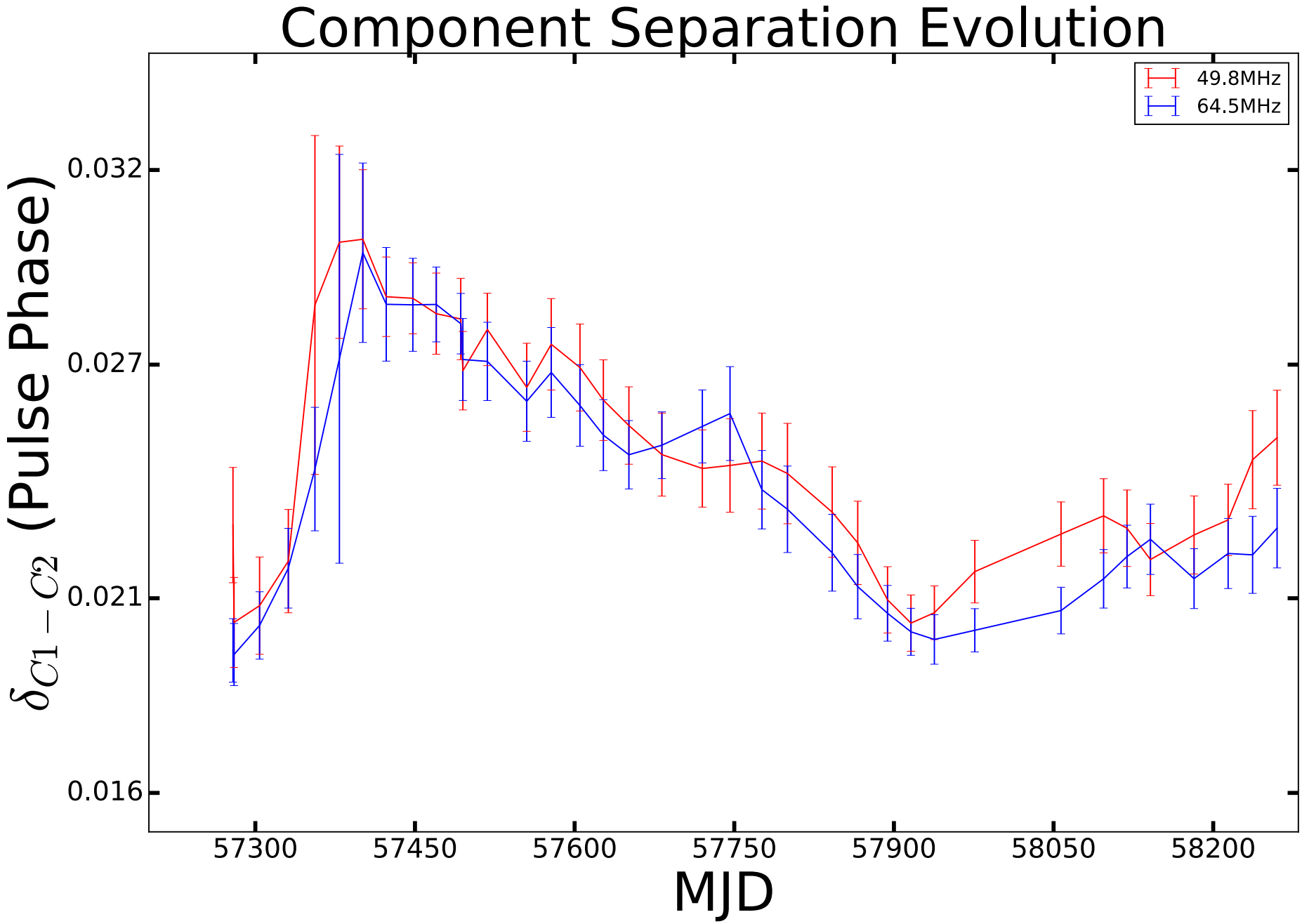
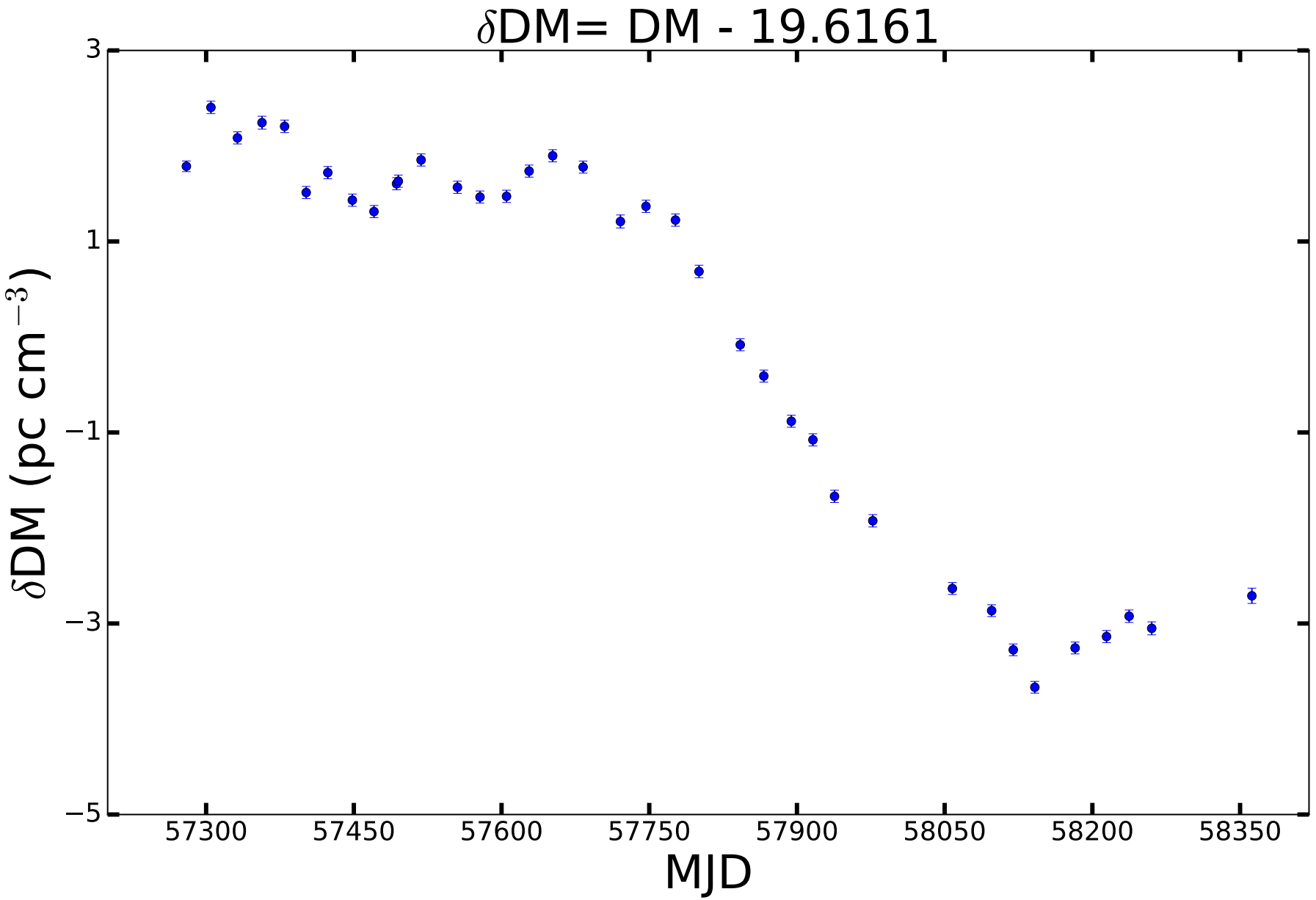


Bansal et al., in review

Dispersion Measure Variation



An offset of 250 days => Likely independent of profile change

Results

- Echoes in PSR B1508+55 below 100 MHz
- Distance to the gas structure is about 350 pc with a density of 100 cm^{-3}.
- Low Frequency study useful for probing ISM structure
- However, these are not easy to detect!

Summary

- Deviation in scattering index from theoretical models-limitation of thin screen model
- Large deviation in case of PSR B0823+26 - effects of inner scale effects.
- Variation in Scattering Index of B2217+47
- Study of echoes in pulsars at low frequency provides a tool to probe ISM structures.