Ten-Year Monitoring of PSR J0814+7429 with LOFAR

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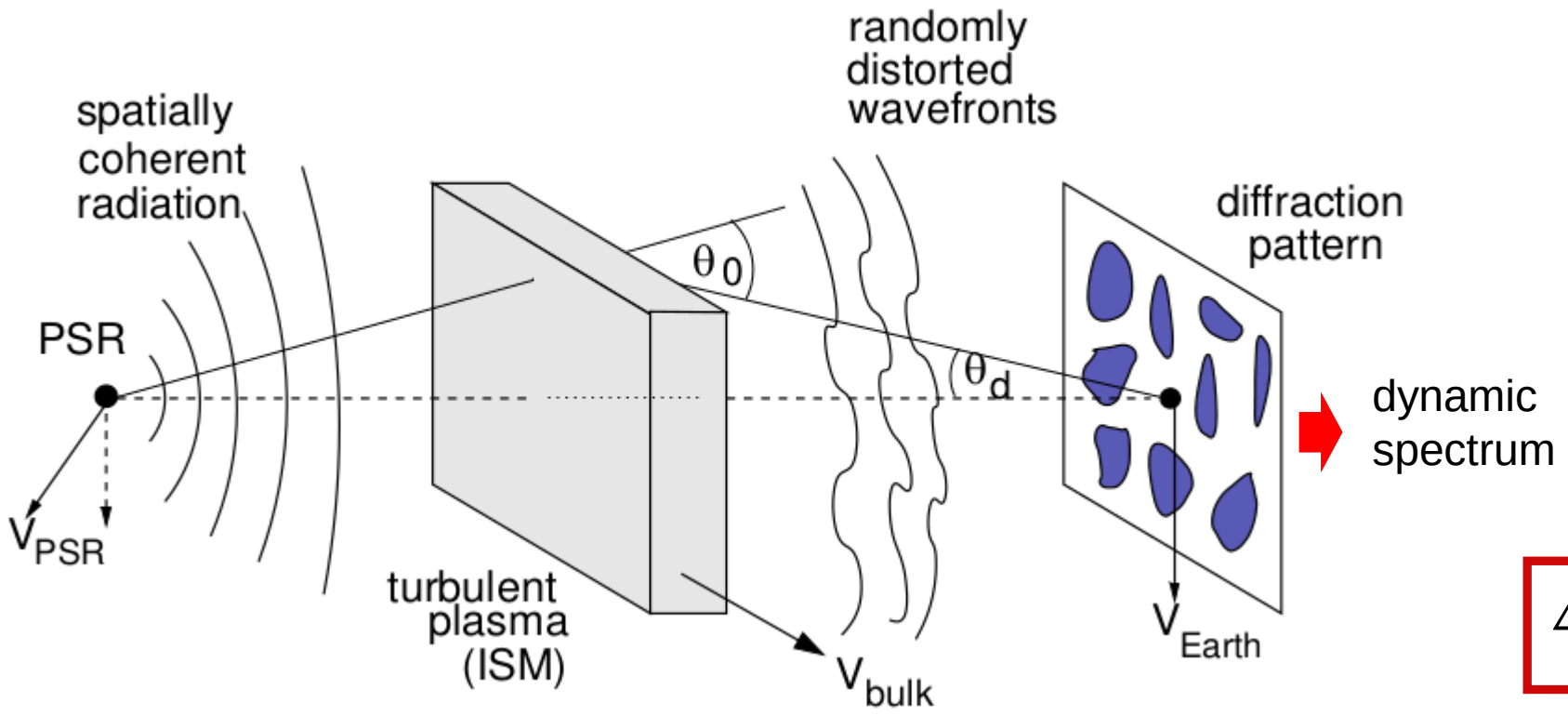
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Pulsar scintillation phenomenon



$$\Delta\tau_d = \frac{s_0}{V_{ISS}}$$

s_0: the field coherence scale
V_{ISS}: scintillation speed

For thin screen model:

$$V_{ISS} = \frac{V_{eff}}{s}$$

$$\Delta\tau_d \sim V_E, V_p, V_u, V_{IISM}$$

Figure: Sketch showing the pulsar scintillation phenomenon.

Scintillation bandwidth, $\Delta\nu_d$, a direct measure of the scintillation strength.
Scintillation timescale, $\Delta\tau_d$, related to the motion between the pulsar, the scattering medium and the observer

Observations and data processing for PSR J0814+7429

Telescopes: LOFAR

Time range: 2013~2023

Frequency range: 120~170 MHz

Frequency resolution: ~0.195 MHz

Time resolution: ~60 seconds

Each observation > 30 minutes

Table 1: LOFAR HBAs observational campaign for PSR J0814+7429.

Station	Data range (year)	Count	Length (hours)
DE601	2013–2018	70	94.58
DE602	2016–2017	18	43.26
DE603	2014–2020	42	46.20
DE604	2016–2017	58	139.95
DE605	2014–2019	254	436.82
DE609	2017–2023	862	1827.12

Notes: Given are the LOFAR stations used and their observation date range, along with the number and the total length of observations for each station.

Using psrflux to create dynamic spectrum

Using the 2DACF to measure the scintillation parameters

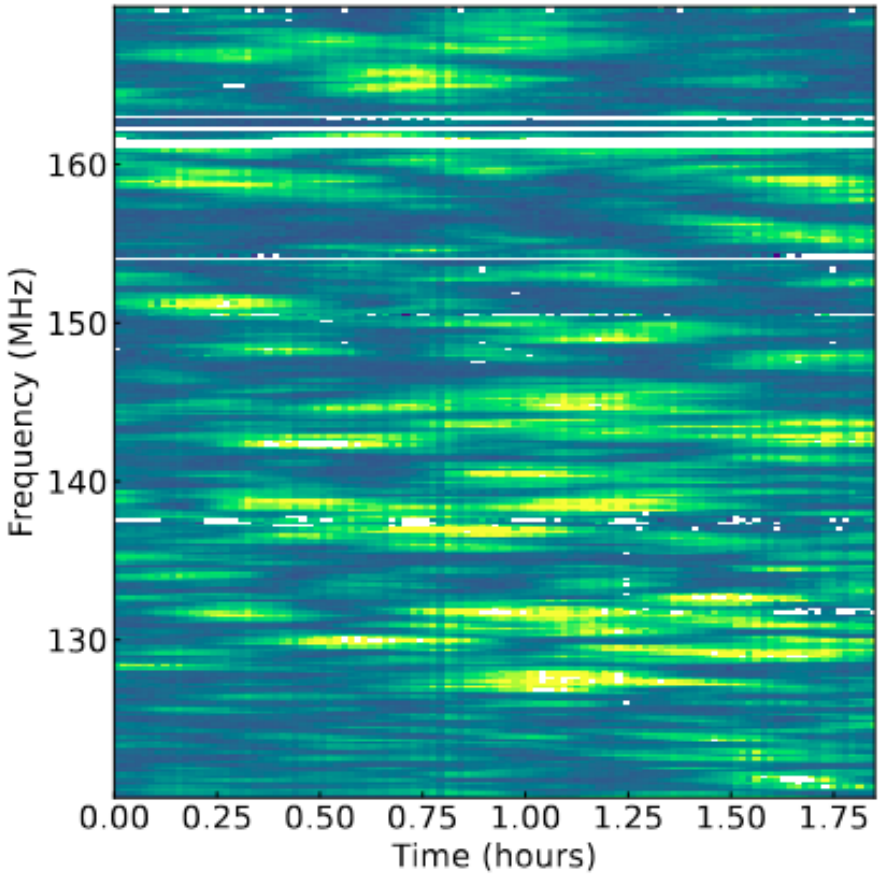


Figure: The dynamic spectrum of PSR J0814+7429 taken on MJD 57361.

The annual variation is clear in the long time series of $\Delta\tau_d$

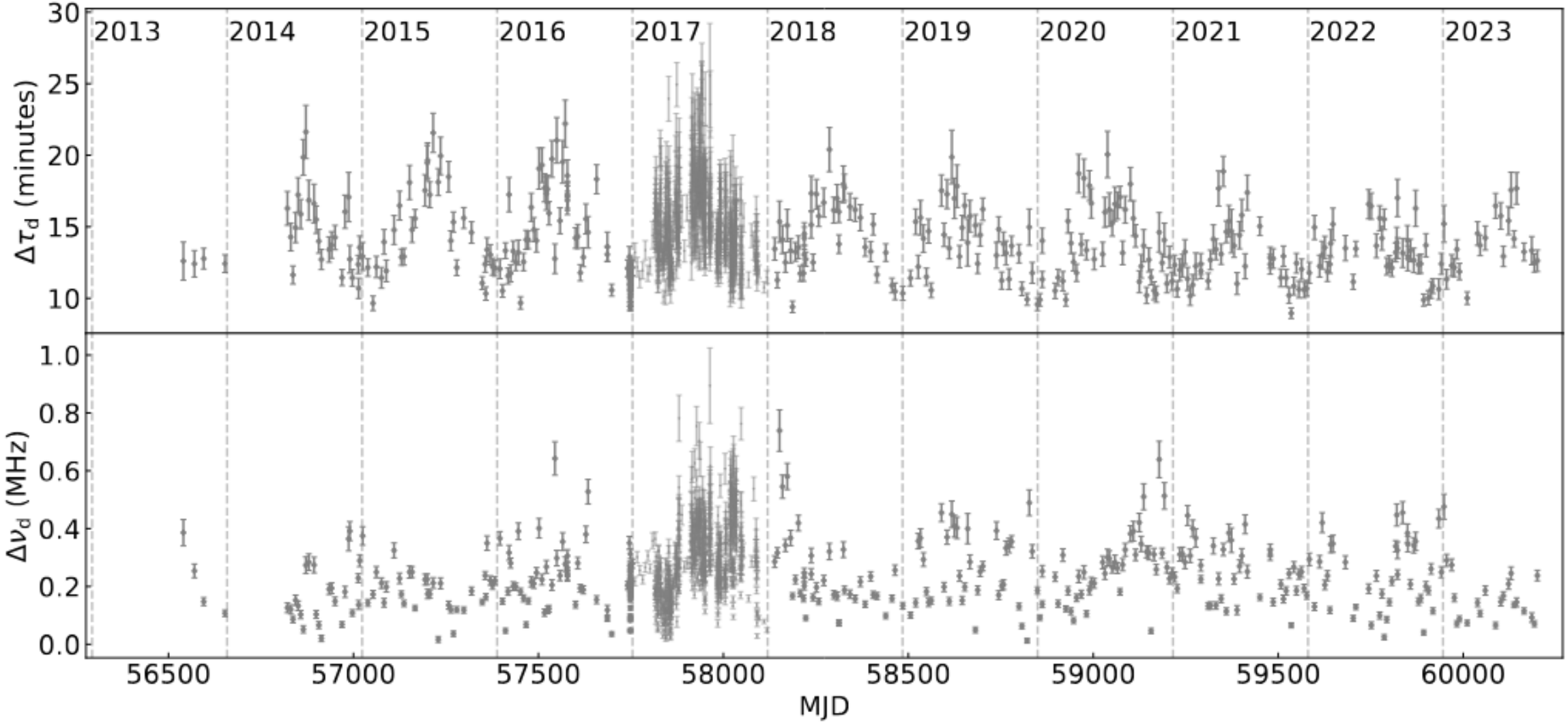
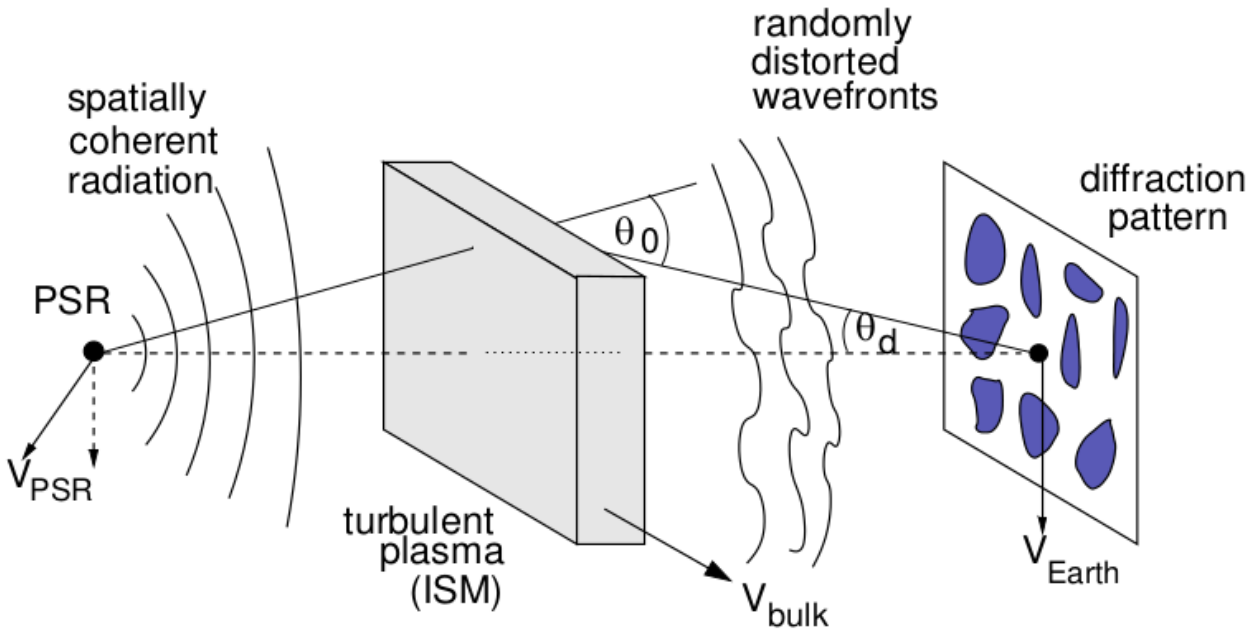


Figure: Scintillation parameters $\Delta\nu_d$ and $\Delta\tau_d$ of PSR J0814+7429.

Scintillation model



According to formula (1) and formula (2):

$$\frac{\sqrt{\Delta\nu_d}}{f\Delta\tau_d} \equiv Y = \frac{|V_{eff}|}{A_{ISS}}\frac{\sqrt{D}}{D-D_s}$$

$$V_{eff} = \frac{D-D_S}{D}V_E + \frac{D_s}{D}V_p - V_{IISM}$$

$$|V_{eff}| = \sqrt{aV_{eff,\alpha}^2 + bV_{eff,\delta}^2 + cV_{eff,\alpha}^2 V_{eff,\delta}^2}$$

$$V_{eff,\alpha} = \frac{D-D_s}{D}V_{E,\alpha} + \frac{D_s}{D}V_{P,\alpha} - V_{IISM,\alpha}$$

$$V_{eff,\delta} = \frac{D-D_s}{D}V_{E,\delta} + \frac{D_s}{D}V_{P,\delta} - V_{IISM,\delta}$$

Thin screen + kolmogorov spectrum + midly anisotropic scattering

$$V_{ISS} = A_{ISS}\frac{\sqrt{D\Delta\nu_d}}{f\Delta\tau_d} \quad (1)$$

For thin screen model:

$$V_{ISS} = |V_{eff}|\frac{D}{D-D_s} \quad (2)$$

$$A_{ISS} = 2.78\times10^4\sqrt{(A_r + 1/A_r)/2}\sqrt{2D_s/(D-D_s)}$$

$$a = [1 - R\cos(2\varphi)]/\sqrt{1-R^2}$$

$$b = [1 + R\cos(2\varphi)]/\sqrt{1-R^2}$$

$$c = -2R\sin(2\varphi)/\sqrt{1-R^2}$$

$$R = (A_r^2 - 1)/(A_r^2 - 1)$$

Unkown parameters:

$V_{IISM,\alpha}$, $V_{IISM,\delta}$, A_r, φ, D_s

Results

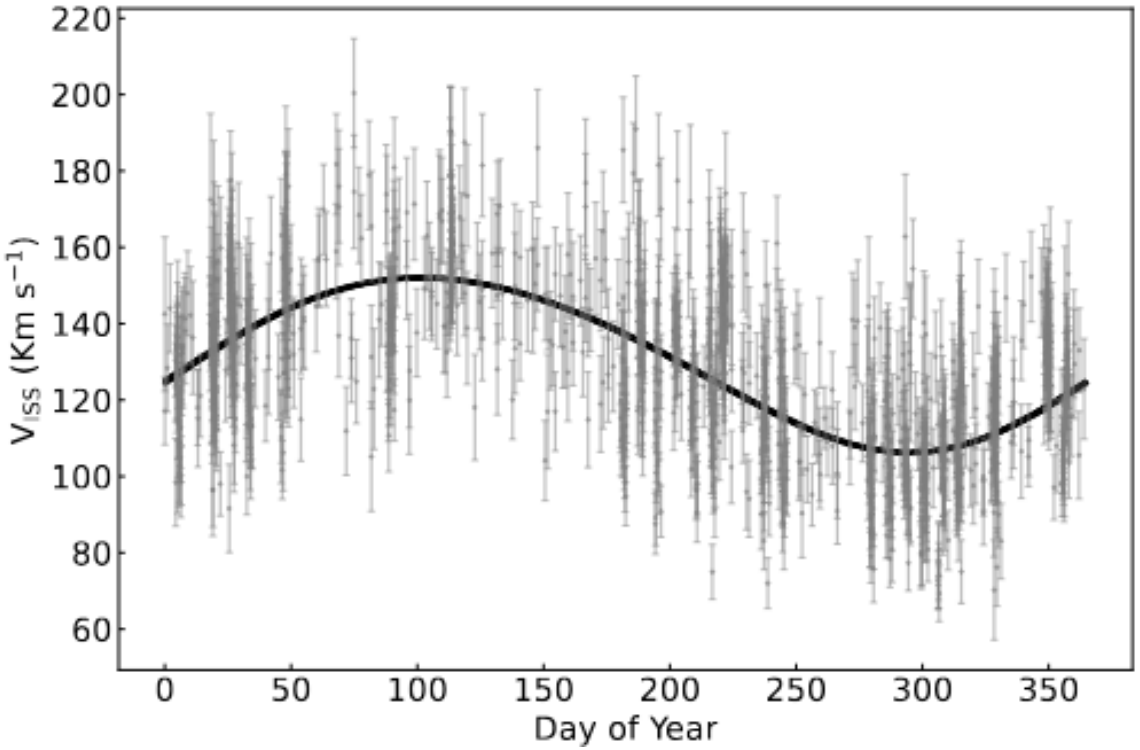
MCMC method

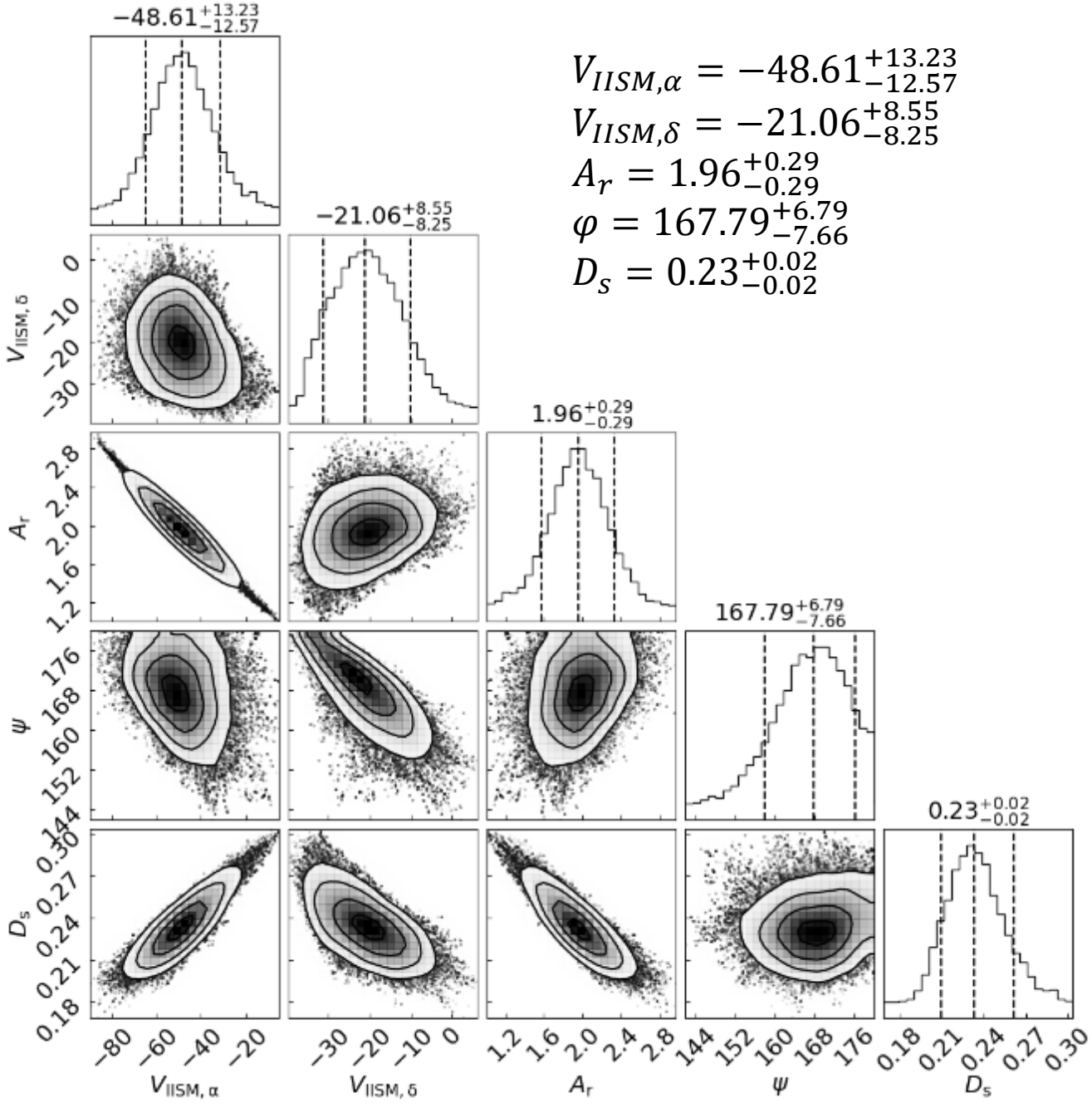
Uniform prior for each parameter

$$V_{IISM,\alpha}, V_{IISM,\delta} \sim [-100,100]\ (km/s)$$

$$D_s \sim [0,0.432]\ (kpc)$$

$A_r \sim [1,100]$, $\varphi \sim [0^{\circ}, 180^{\circ}]$

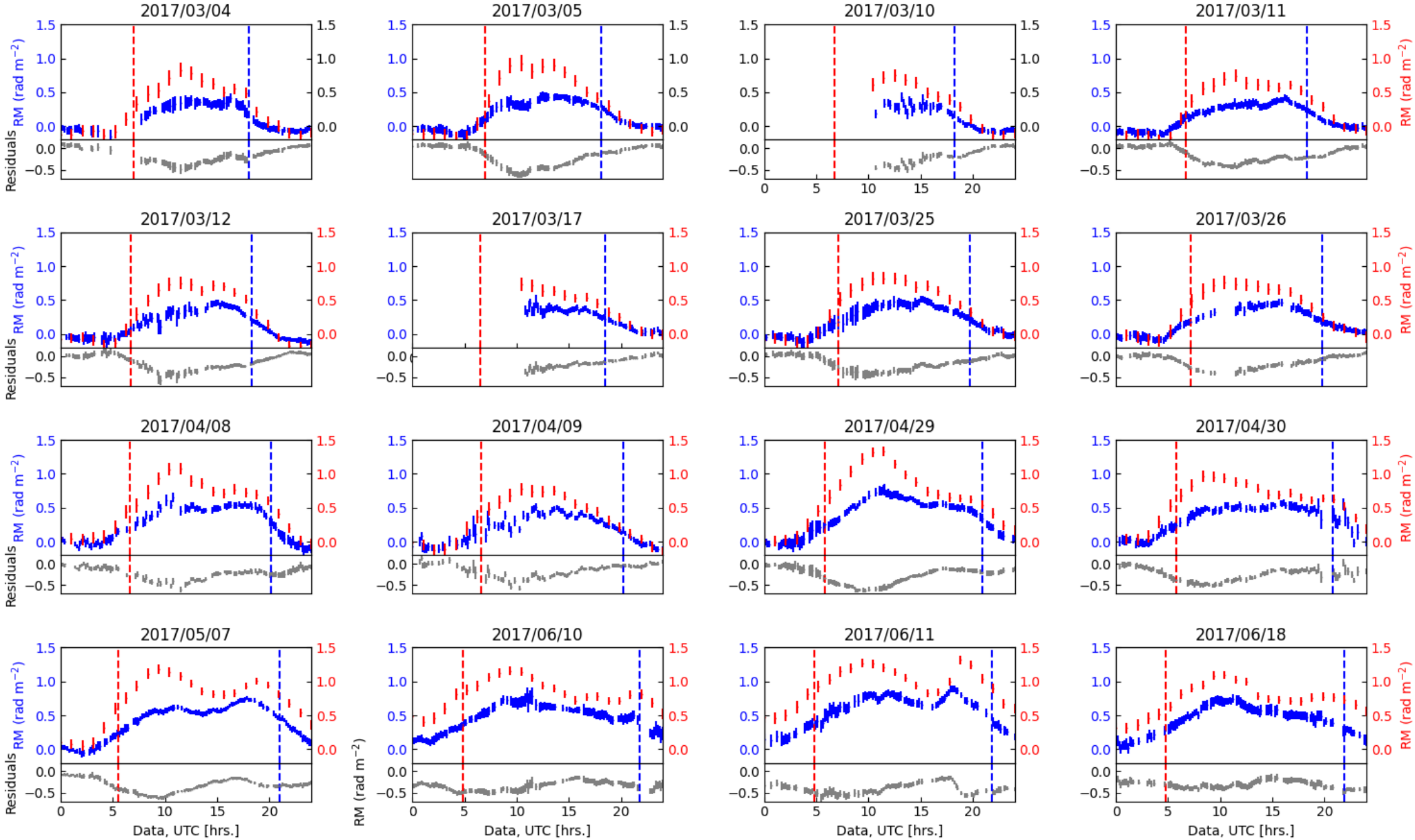


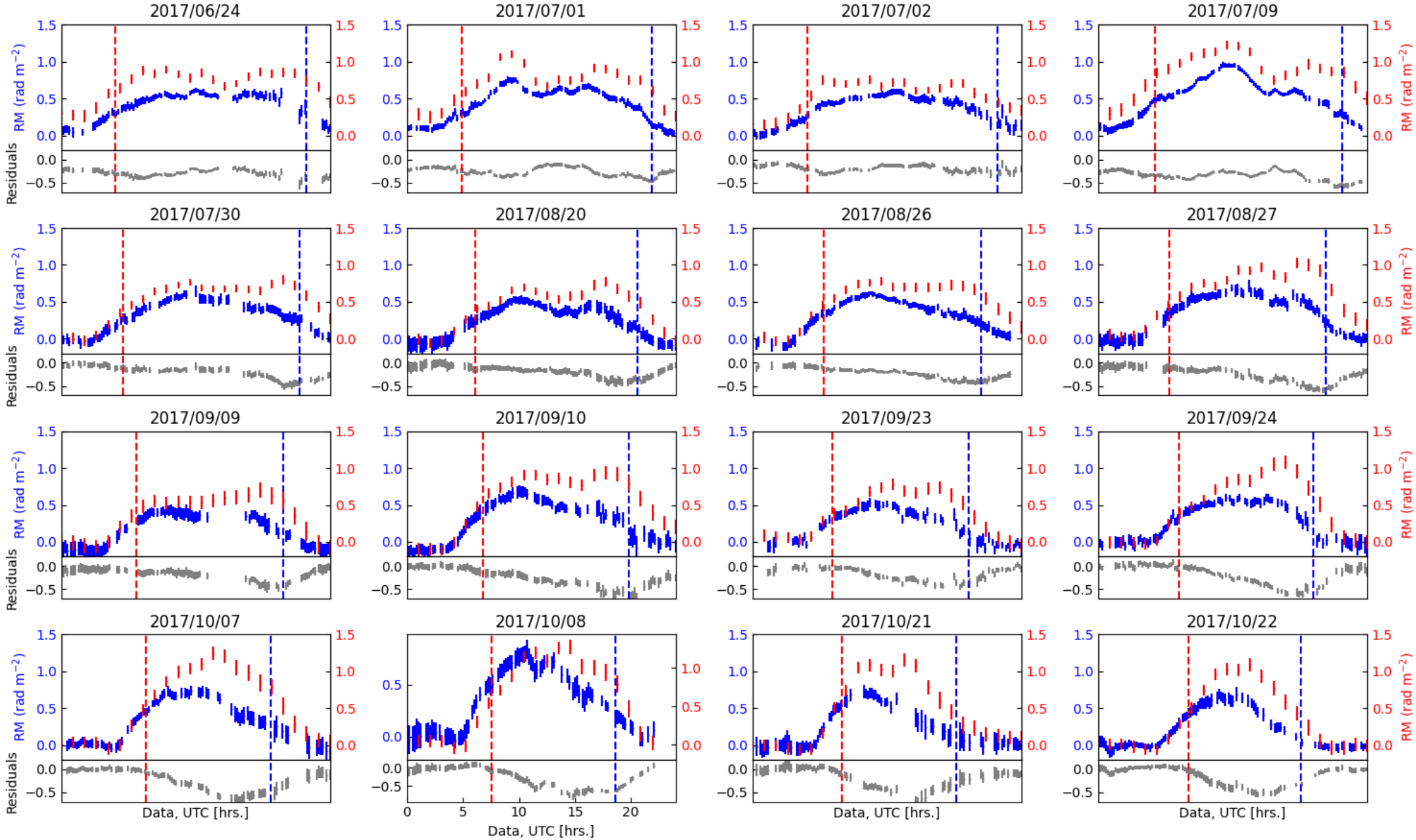


$$V_{IISM,\alpha} = -48.61^{+13.23}_{-12.57}$$
$$V_{IISM,\delta} = -21.06^{+8.55}_{-8.25}$$
$$A_r = 1.96^{+0.29}_{-0.29}$$
$$\varphi = 167.79^{+6.79}_{-7.66}$$
$$D_s = 0.23^{+0.02}_{-0.02}$$

The RM variation of PSR J0814+7429 during a day due to the change of the ionosphere.

The predicted RM values of PSR J0814+7429 contributed by the ionosphere are obtained from the ionFR model (A&A, 2013, 552: A58).


2017/03/04
2017/03/05
2017/03/10
2017/03/11
2017/03/12
2017/03/17
2017/03/25
2017/03/26
2017/04/08
2017/04/09
2017/04/29
2017/04/30
2017/05/07
2017/06/10
2017/06/11
2017/06/18
RM (rad m^{-2})
Residuals
Data, UTC [hrs.]


2017/06/24
2017/07/01
2017/07/02
2017/07/09
2017/07/30
2017/08/20
2017/08/26
2017/08/27
2017/09/09
2017/09/10
2017/09/23
2017/09/24
2017/10/07
2017/10/08
2017/10/21
2017/10/22
RM (rad m^{-2})
Residuals
Data, UTC [hrs.]

Conclusion

- The annual variation in the long time series of $\Delta\tau_d$ is clear.
- The distance of the thin scattering screen of PSR J0814+7429 from the Earth is about 0.23 kpc.
- The scattering of the signals from PSR J0814+7429 is midly anisotropic.
- The scintillation phenomenon of PSR J0814+7429 could be related to the boundary of the local bubble shell.
- The RM values of PSR J0814+7429 have a significant variation during a day due to the change of the ionosphere.

Thanks for listening and communicating