Pulsar Pulse Broadening in L-band Observed by FAST

WeiCong Jing (景威聪)

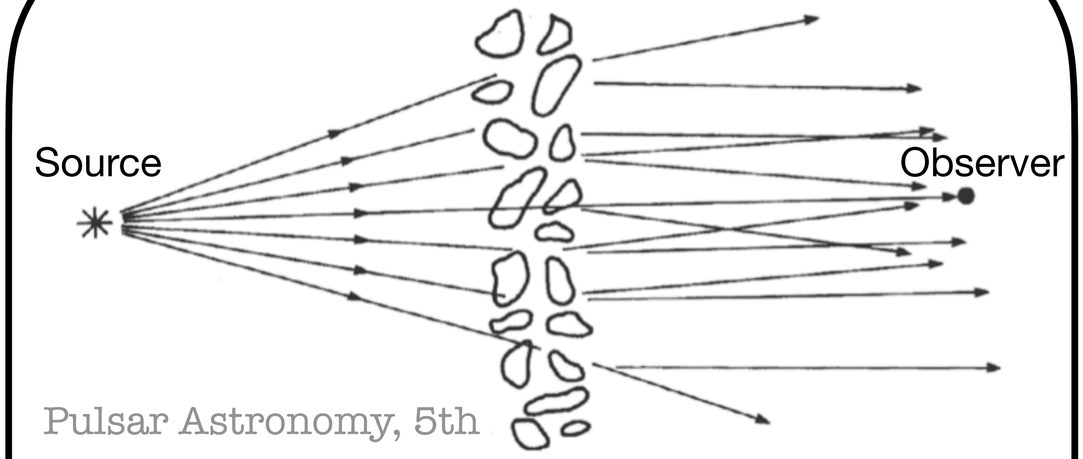
Supervisor: JinLin Han & Chen Wang

National Astronomical Observatories, CAS (NAOC)

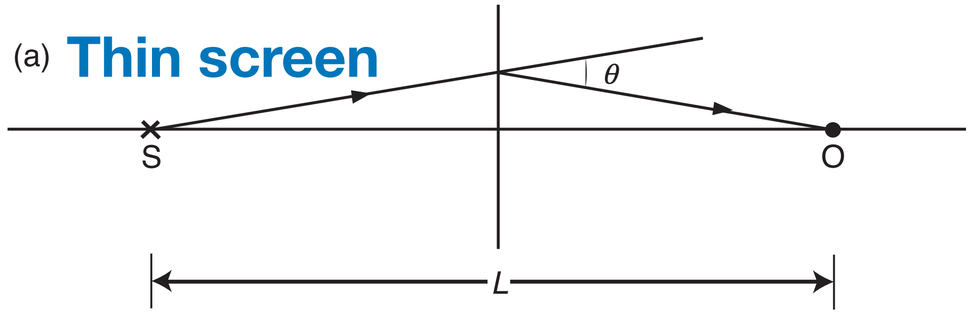
jingweicong@nao.cas.cn

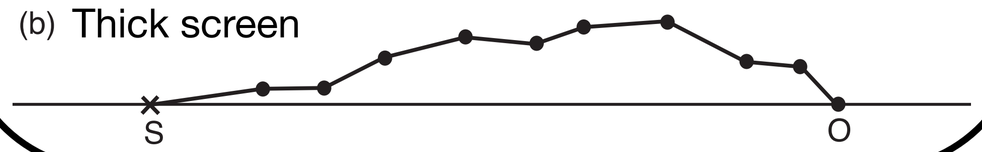
Introduction: Radio Pulse Broadening

Picture of IISM scattering



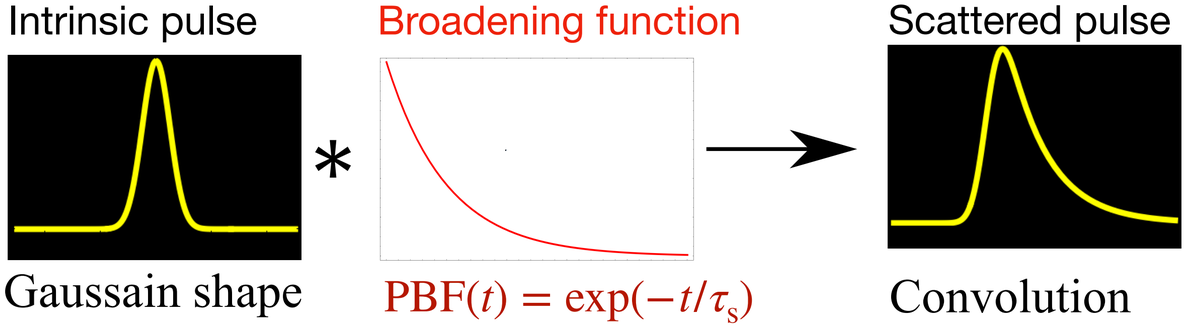
Pulsar Astronomy, 5th

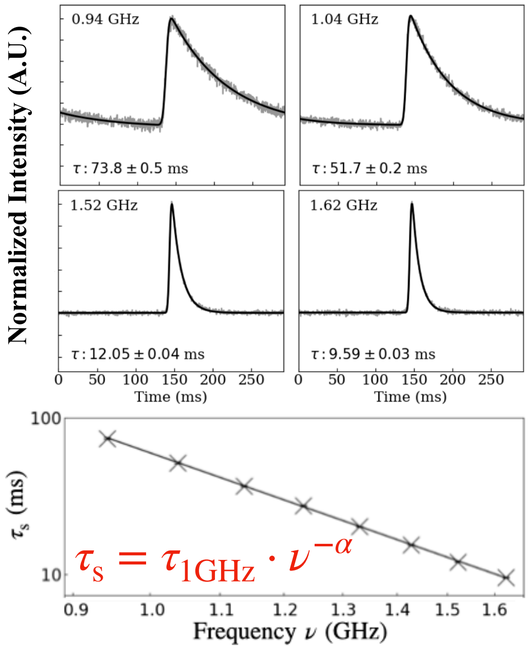




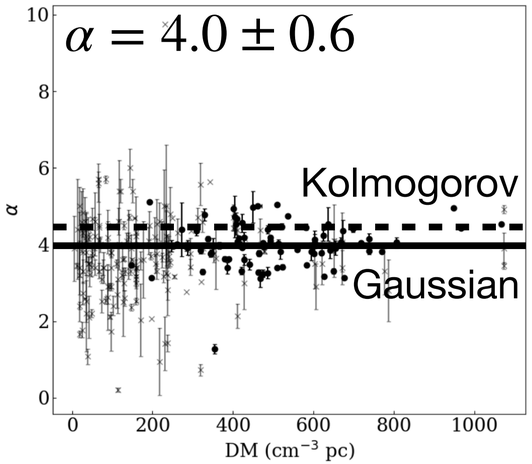
Thin-screen approximation

Geyer, 2017



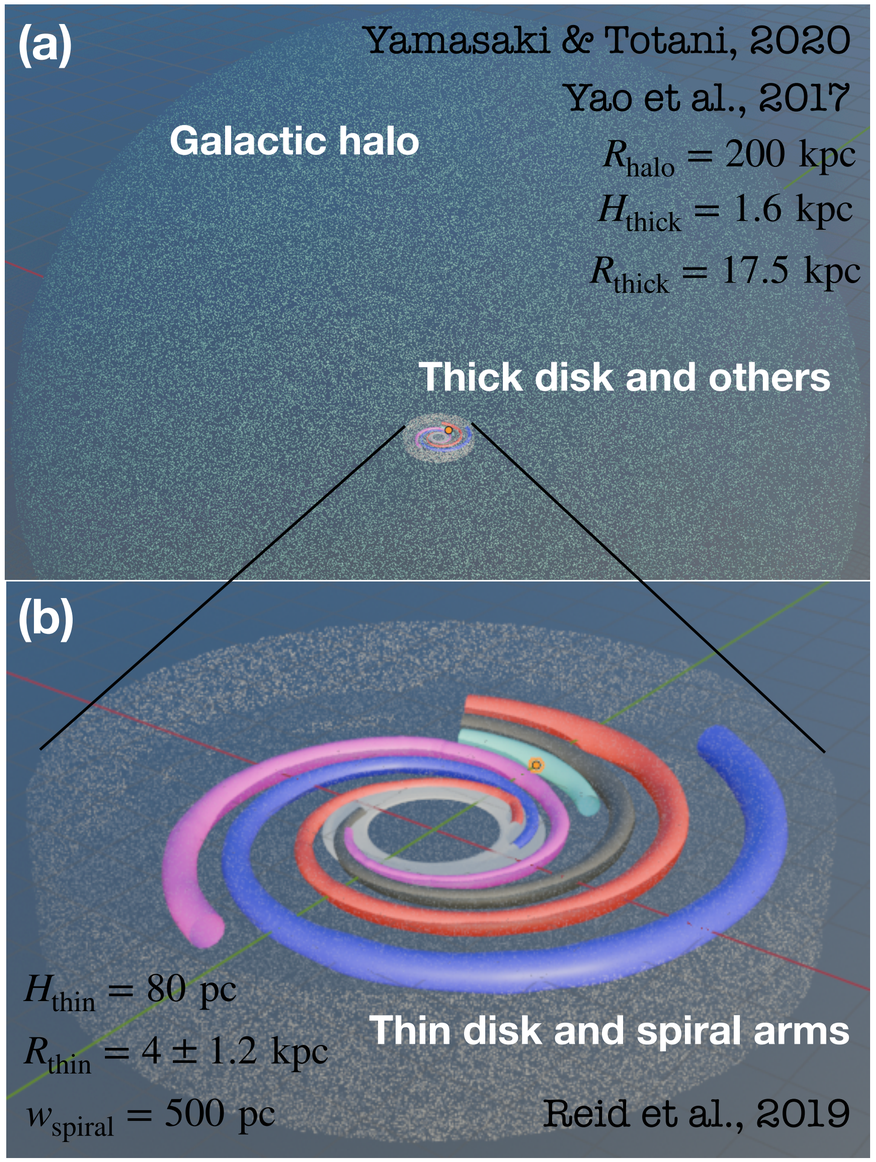


- Pulse-broadening timescale τ_s
- Scattering spectral index α



Oswald et al., 2021

Introduction: Galactic Electron Distribution Model



Large-scale mean $n_{\rm e}$:

- Dispersion measure

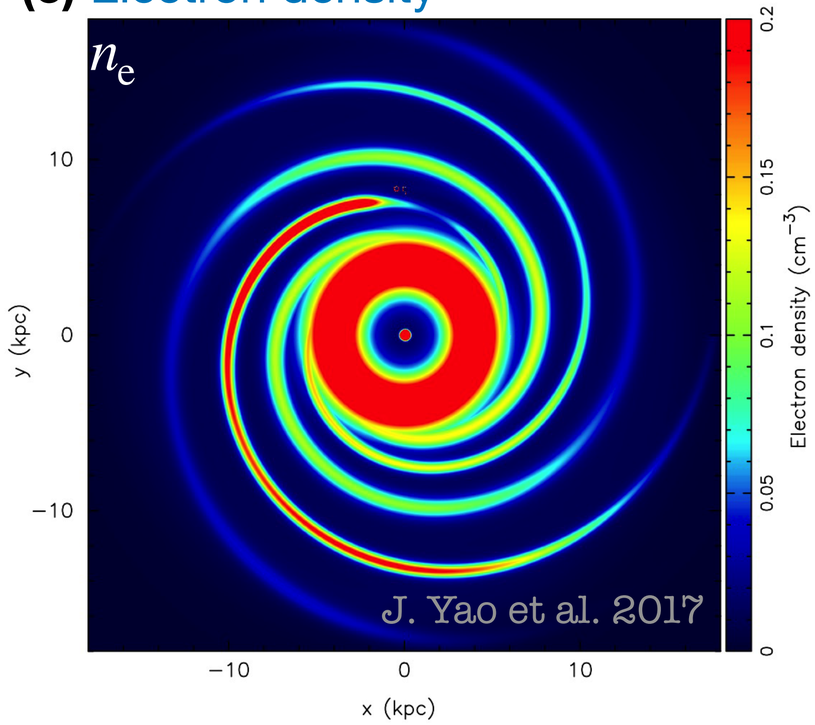
$$\mathrm{DM} \equiv \int_0^D n_{\rm e} \mathrm{d}s$$

Small-scale $n_{\rm e}$ fluctuations:

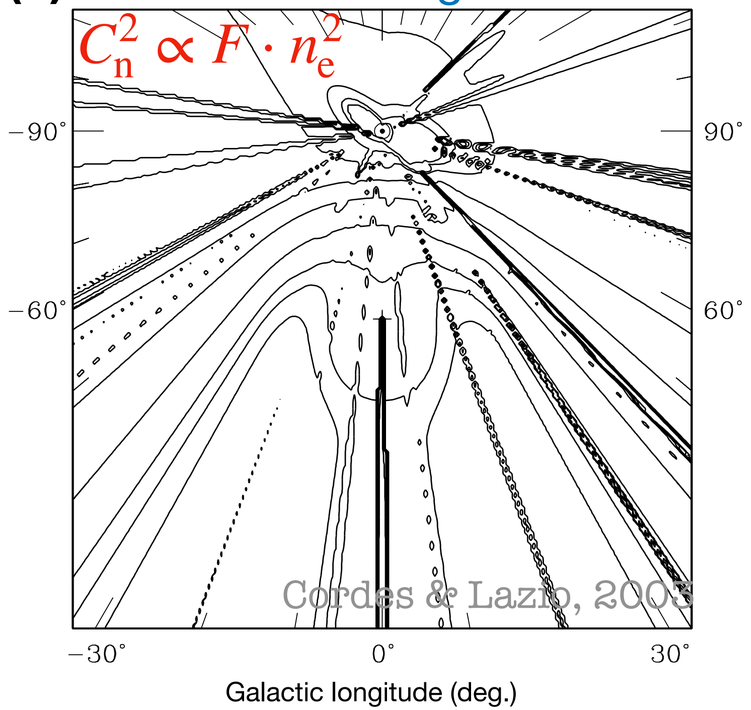
- Scattering measure

$$\mathrm{SM} \equiv \int_0^D C_{\rm n}^2 \mathrm{d}s$$

(c) Electron density



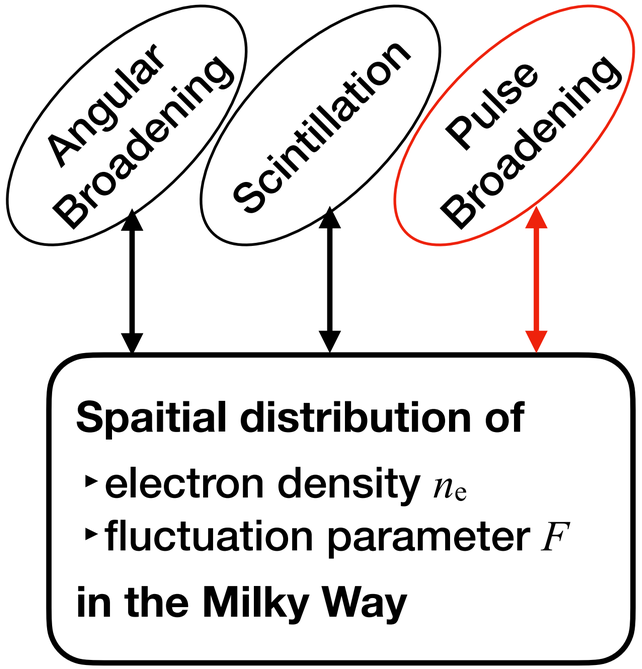
(d) Turbulence strength



Introduction: Radio Pulses Prob n_e Fluctuations

How to prob the density fluctuation?

- ISM scattering effects:



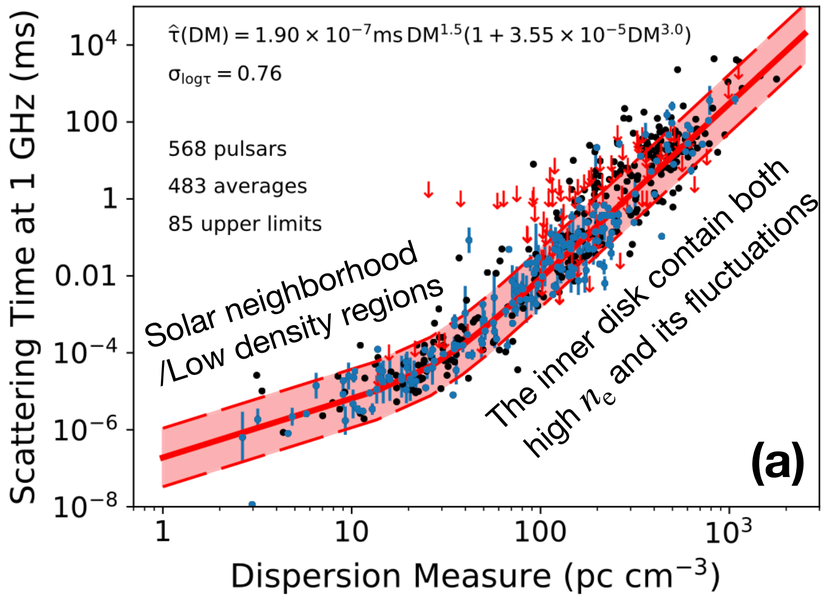
$\tilde{F}$ is LOS-weighted F.

Relation between the pulse-broadening timescale and DM

- Position-independent

Empirical formula:

$$\tau_s = \tau_{1\mathrm{GHz}}(\mathrm{DM}) \cdot \nu_{\mathrm{GHz}}^{-\alpha}$$

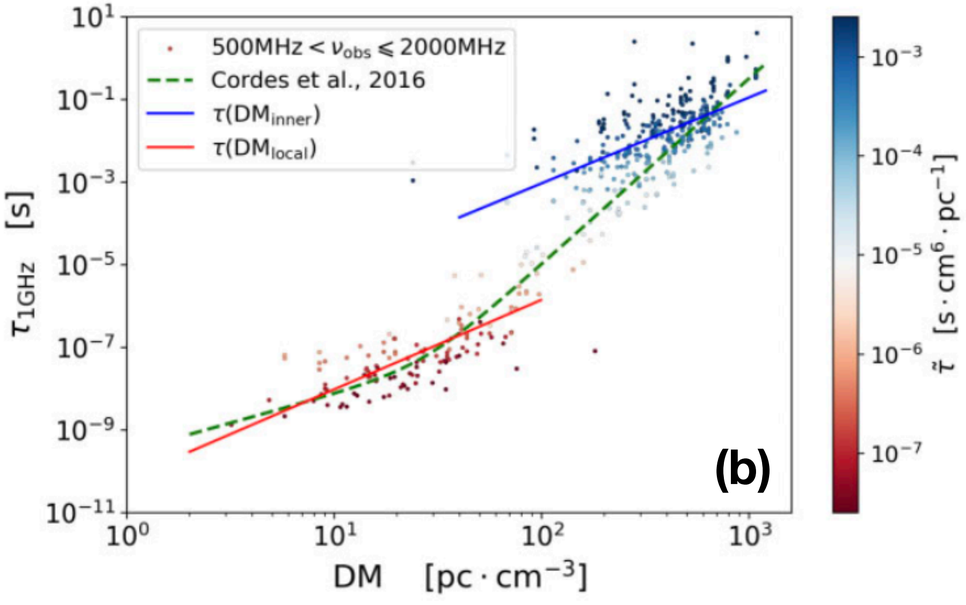


Cordes et al., 2022

- Position-dependent

Simplified-model formula:

$$\tau_s = \tilde{F}(l, b, D) \times \mathrm{DM}^2 \cdot \nu_{\mathrm{GHz}}^{-\alpha}$$

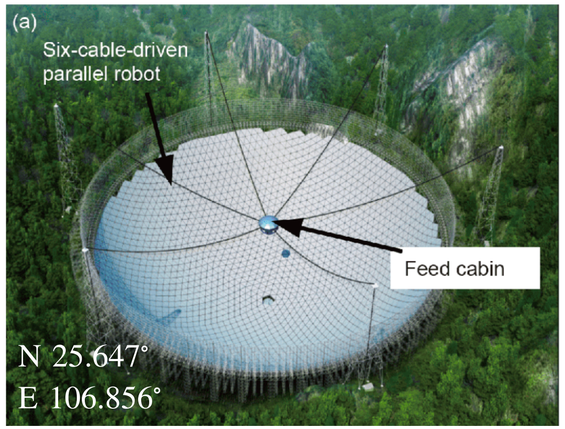


He & Shi, 2024

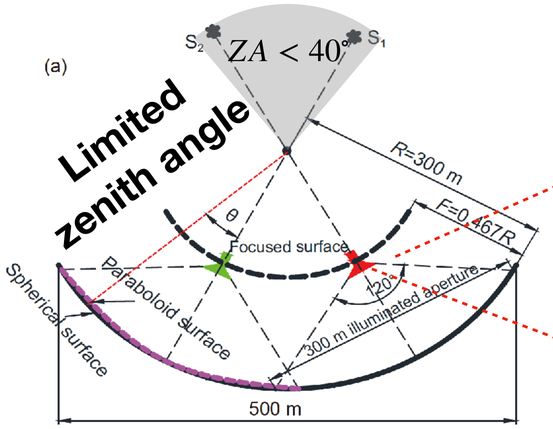
Introduction: FAST and FAST-GPPS Survey

1. FAST and its L-band 19 beam reciever

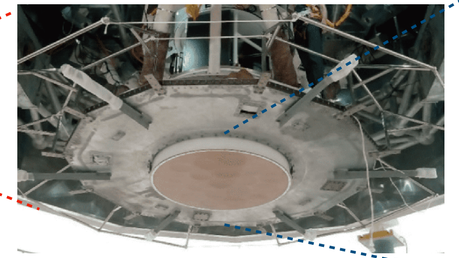
☑ FAST locates in Guizhou, China;



☑ Effective 300-m aperature;

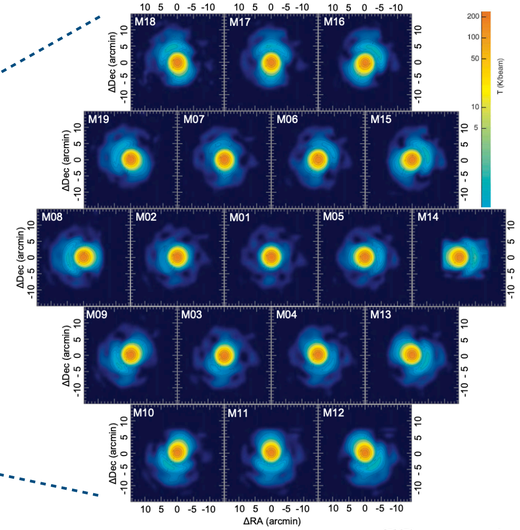


☑ 19-beam reciever;



Jiang et al., 2019

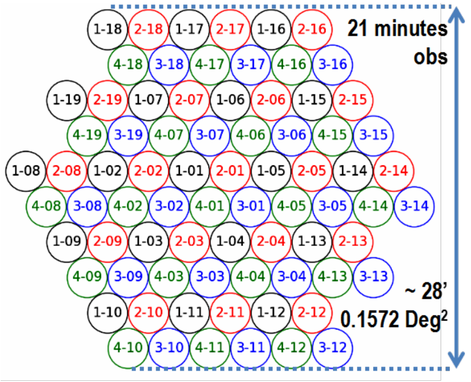
☑ Gain of each beam.



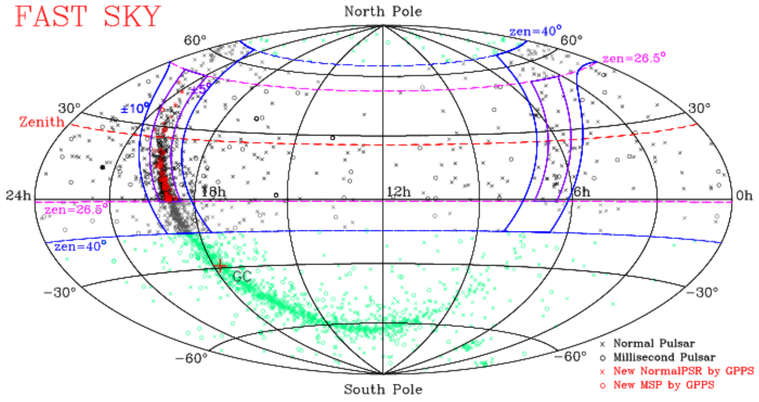
Han et al., 2021

2. FAST Galactic Plane Pulsar Snapshot (GPPS) survey

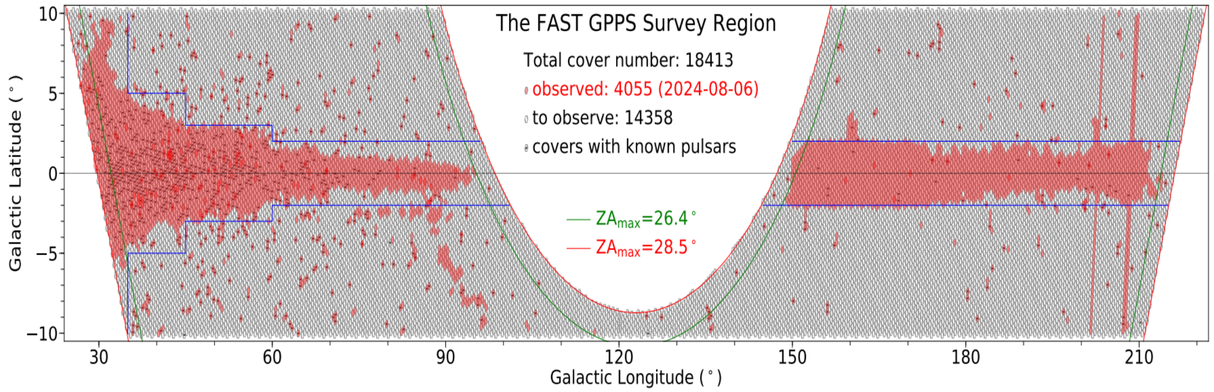
☆ Four pointings



☆ FAST-observable Galactic plane



◔ Complished GPPS sky coverage



Introduction: FAST Observational Data

Data source:

1. GPPS survey (main data source)
2. PI projects (from group members)
3. Released data (avioding conflicts)

769 GPPS-discovered PSRs and 1008 known.

FAST Pulsar Database. I. Polarization Profiles of 682 Pulsars

P. F. Wang[1,2], J. L. Han[1,2], J. Xu[1,2], C. Wang[1,2], Y. Yan[1,2], W. C. Jing[1,2], W. Q. Su[1,2], D. J. Zhou[1,2], and T. Wang[1,2]

FAST Pulsar Database: II. Scattering Profiles of 122 Pulsars

W. C. Jing[1,2], J. L. Han[1,2,3,*], C. Wang[1,2,3], P. F. Wang[1,2,3], T. Wang[1], N. N. Cai[1], J. Xu[1,3], Z. L. Yang[1,2], D. J. Zhou[1], Yi Yan[1], W. Q. Su[1,2], X. Y. Gao[1], and L. Xie[1]

The FAST Galactic Plane Pulsar Snapshot survey: I. Project design and pulsar discoveries*

J. L. Han[1,2,3], Chen Wang[1,2], P. F. Wang[1,2], Tao Wang[1,3], D. J. Zhou[1,3], Jing-Hai Sun[1,2], Yi Yan[1,3], Wei-Qi Su[1,3], Wei-Cong Jing[1,3], Xue Chen[1,3], X. Y. Gao[1,2], Li-Gang Hou[1,2], Jun Xu[1,2], K. J. Lee[1,4], Na Wang[6,7], Peng Jiang[1,2], Ren-Xin Xu[5], Jun Yan[1,2], Heng-Qian Gan[1,2], Xin Guan[1,2], Wen-Jun Huang[8], Jin-Chen Jiang[4,5], Hui Li[1,2], Yun-Peng Men[4,5], Chun Sun[1,2], Bo-Jun Wang[4,5], H. G. Wang[8], Shuang-Qiang Wang[6,7], Jin-Tao Xie[6,7], Heng Xu[4,5], Rui Yao[1,2], Xiao-Peng You[9], D. J. Yu[1,2], Jian-Ping Yuan[6,7], Rai Yuen[6,7], Chun-Feng Zhang[4,5] and Yan Zhu[1,2]

The FAST Galactic Plane Pulsar Snapshot Survey. VI. The Discovery of 473 New Pulsars*

J. L. Han[1,2], D. J. Zhou[1,2], C. Wang[1,2], W. Q. Su[1,2], Yi Yan[1,2], W. C. Jing[1,2], Z. L. Yang[1,2], P. F. Wang[1,2], T. Wang[1,2], J. Xu[1,2], N. N. Cai[1,2], J. H. Sun[1,2], Q. L. Yang[1], R. X. Xu[3,4], H. G. Wang[5], and X. P. You[6]

Status of pulsar observations:

- We processed FAST data of 1777 pulsars.
  - 122 PSRs show pulse-broadening.
    - ⋆ 60 GPPS-discovered PSRs
    - ⋆ 33 + 29 (scat-known) known PSRs

FAST Pulsar Database

No.	PSR Name	Period(s)	DM	Obs.Date	FAST obs.Mode	Beam	Prof.Plot	Prof.Data	Publication
1	J0006+1834	0.693	11.4	20210110	Tracking	P1M01	Poln.png	ILVPA	whx+23
1247	J2340+08	0.303	22.9	20210125	Tracking	P1M01	Poln.png	ILVPA	whx+23
1248	J2355+2246	1.841	23.1	20201101	Tracking	P1M01	Poln.png	ILVPA	whx+23

The FAST Galactic Plane Pulsar Snapshot survey

Table 1: Newly discovered pulsars from the GPPS survey

Name*	gppsNo. ProfData.taz	Period (s)	DM	RA J2000	DEC J2000	Discovery Obs Date	Confirm Obs Date	OnWeb Date	Notes	Ref.
J1901+0658	gpps0001	0.0757439	125.88	19:01:22.8522	+06:58:24.08	20190321	20191110; 20200420	20200928	20210122updateRA; 20230726updateP; 20230726updateDM; 20230726updateRA; 20230726updateDEC; 20230726updateName	hww+21; shy+24; why+25;
J1835-1115g	gpps0768	0.048962	204.5	18:35:41	-11:15	20250201	20250226	20250516		
J1935+2200	gpps0769	1.096485	293.9	19:35:07.00	22:00:16.0	20240408	20200430	20250516	ArchiveDataConfirm	xhy+25;

*name suffix with "g" indicates the temporary nature, since it may change slightly due to position uncertainty of about 1.5'.

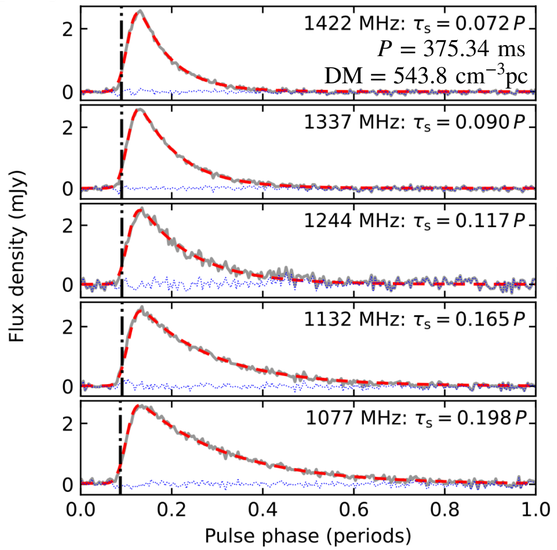
http://zmtt.bao.ac.cn/psr-fast/

http://zmtt.bao.ac.cn/GPPS/GPPSnewPSR.html

Method: Parameters of Scattered Profiles

1. DM deviation

(a1) PSR J2052+4421g



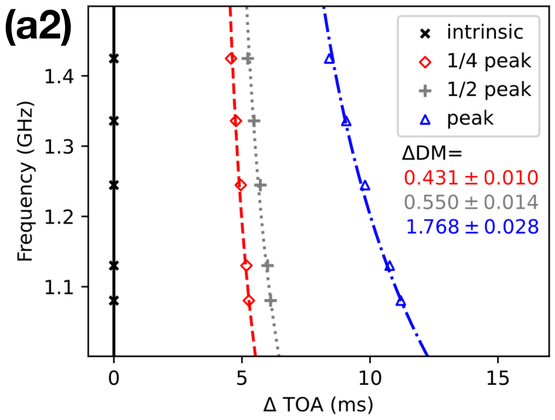
a. TOAs from

- Peak
- Leading-edge@1/4Peak
- Model fitting

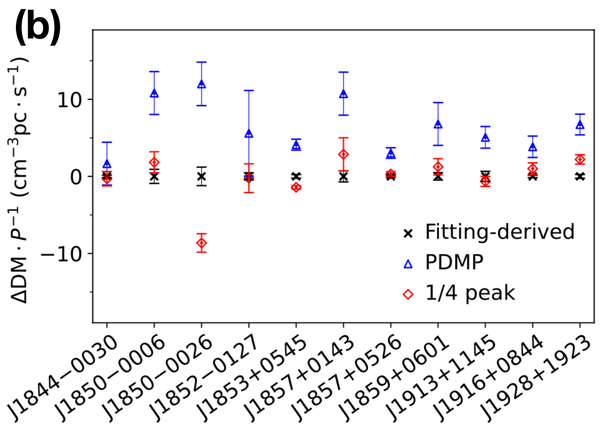
b. DM comparison

- Unbiased model DM
- 1/4-lead DM is effective
- DM bias from peak TOA

(a2)



(b)



2. Fitting of Scattering parameters

By assuming:

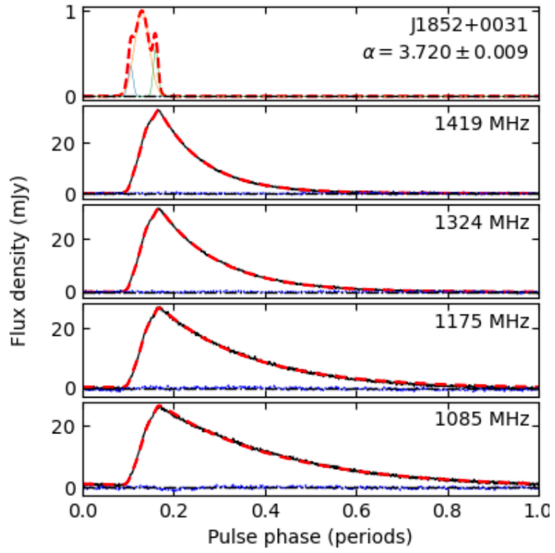
- Frequency-independent intrinsic profile

$$\Sigma G(t, f) = \Sigma G(t)$$

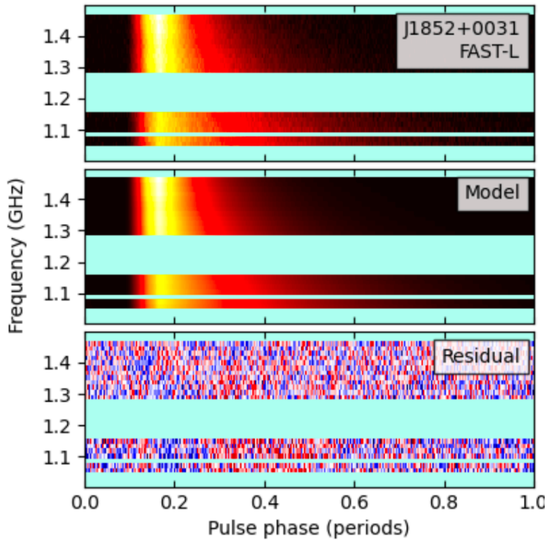
- Pulse broadening fuction is $\mathrm{PBF}(t) = \exp(-t/\tau_s)$
- Powerlaw frequency scaling of $\tau_s = \tau_{1\mathrm{GHz}} \cdot \nu_{\mathrm{GHz}}^{-\alpha}$

Simultaneously fit DM, $\tau_{1\mathrm{GHz}}$, α and Gaussians

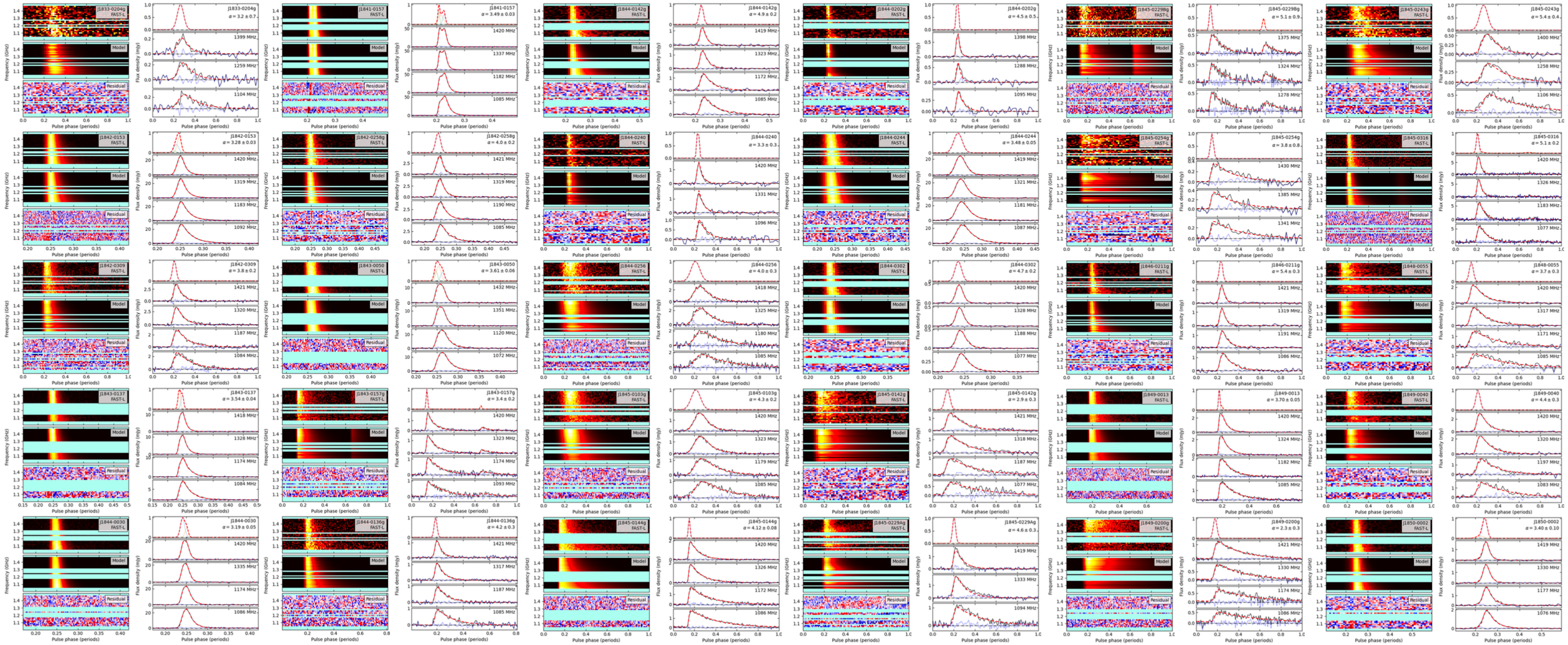
(c1) Jointly fitting profiles



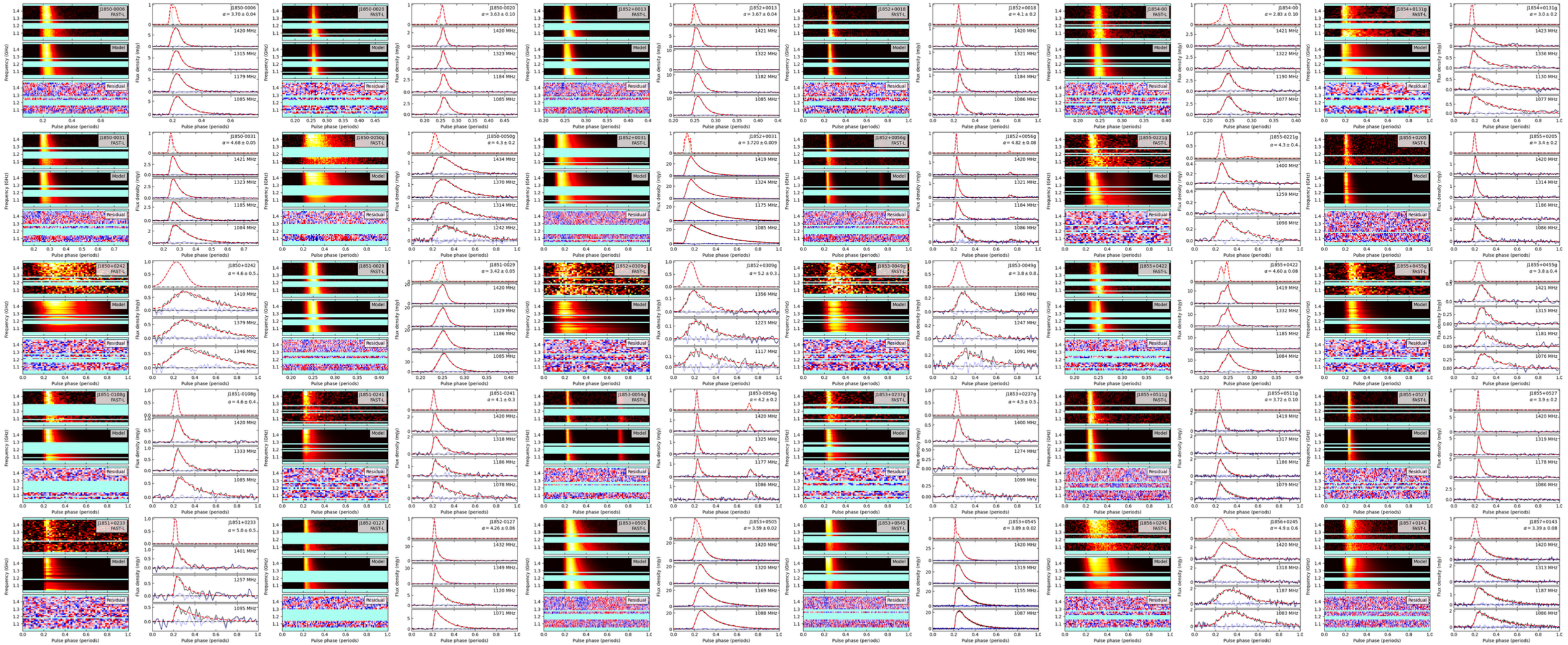
(c2) Validation of results



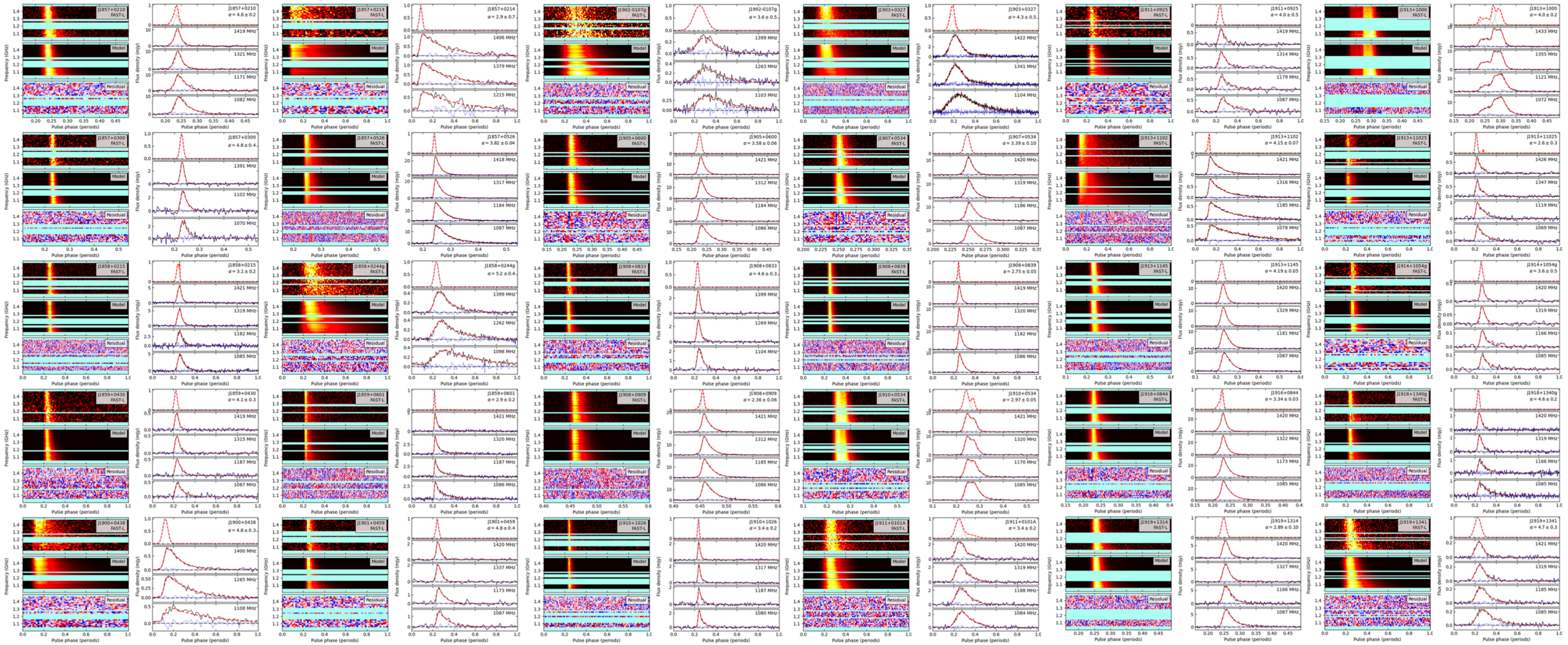
Results: Fitted Scatted Profiles (Page 1)



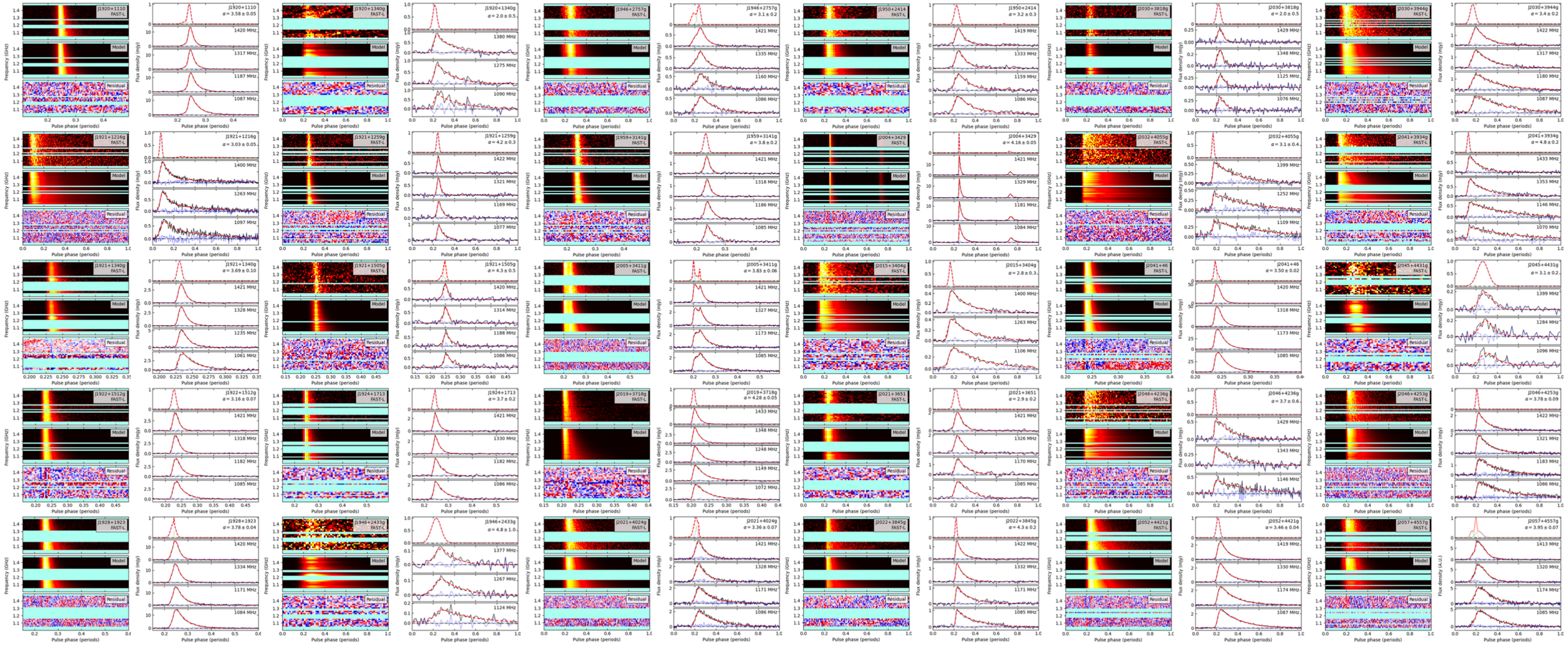
Results: Fitted Scatted Profiles (Page 2)



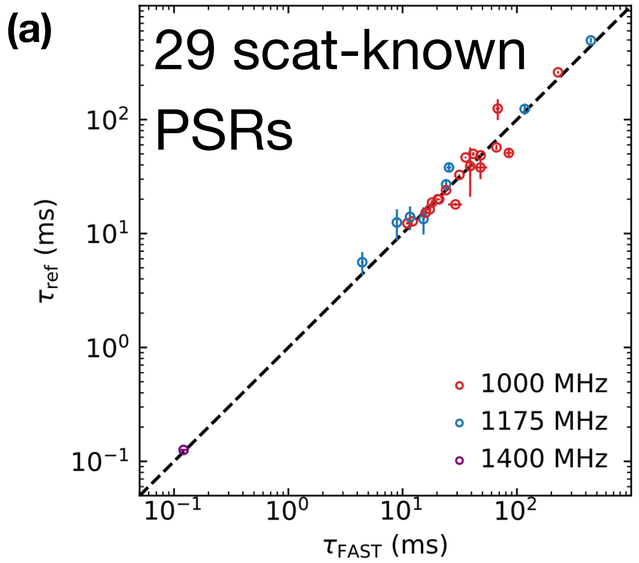
Results: Fitted Scatted Profiles (Page 3)



Results: Fitted Scatted Profiles (Page 4)



Discussion: Statistics on Measured Parameters

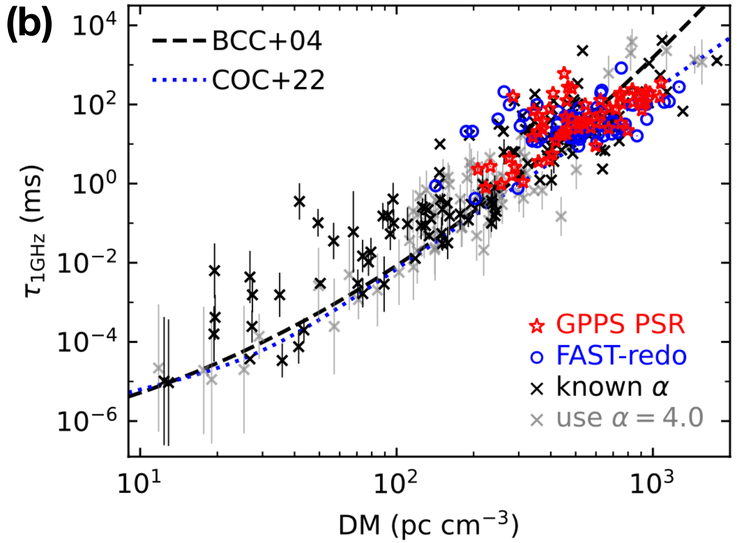


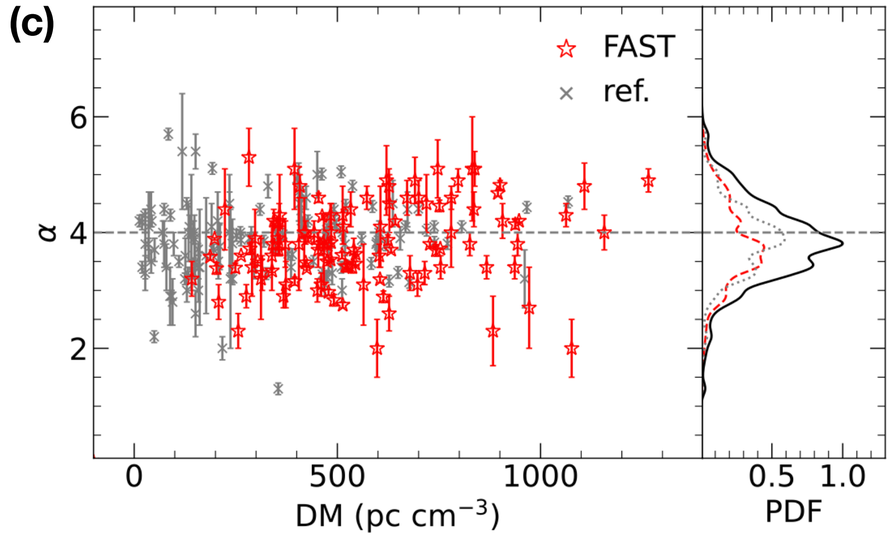
a. Consistency of FAST results and publication's τ_s

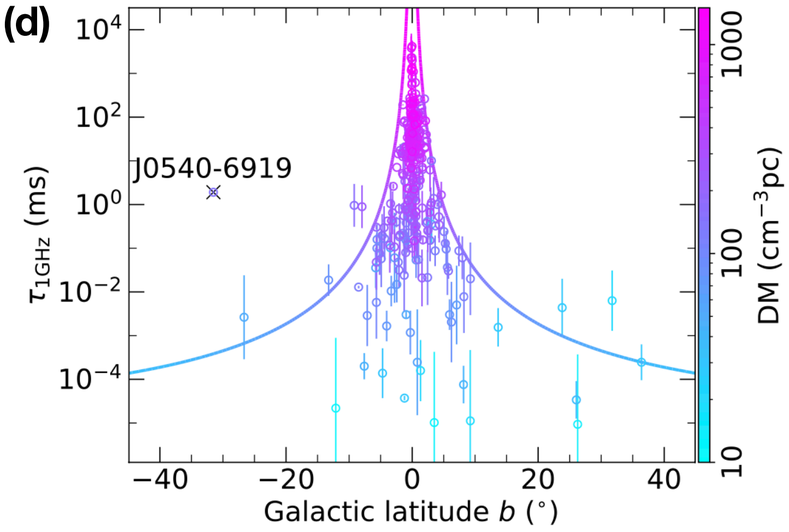
b. Measurements follow the τ_s-DM empirical formula

c. Scattering spectral indexes α are around 4.0

d. Upper limit of the Galactic τ_s along Gal. latitude





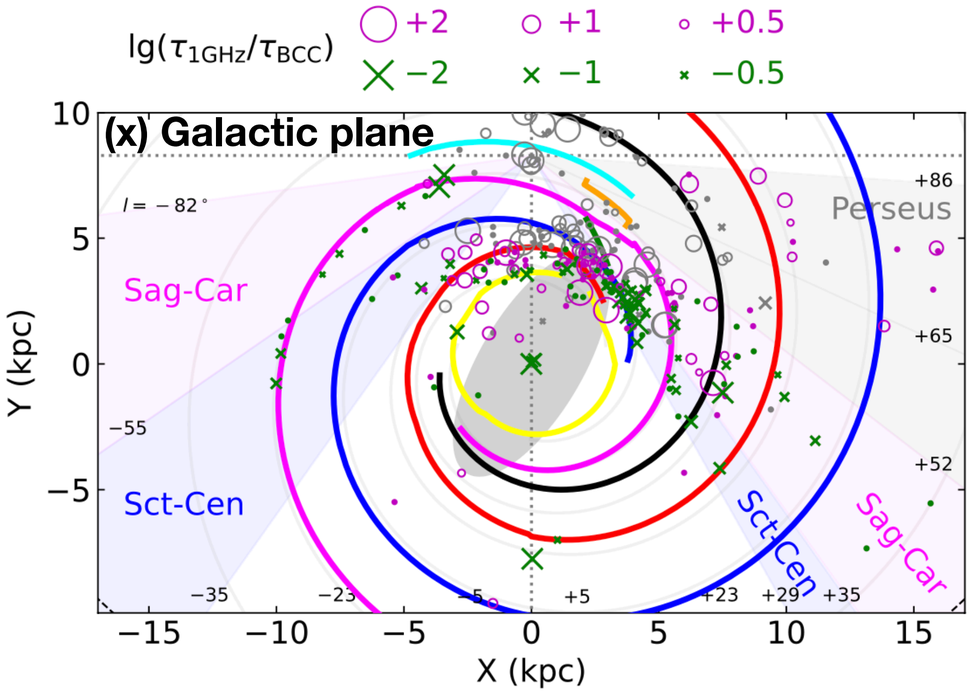


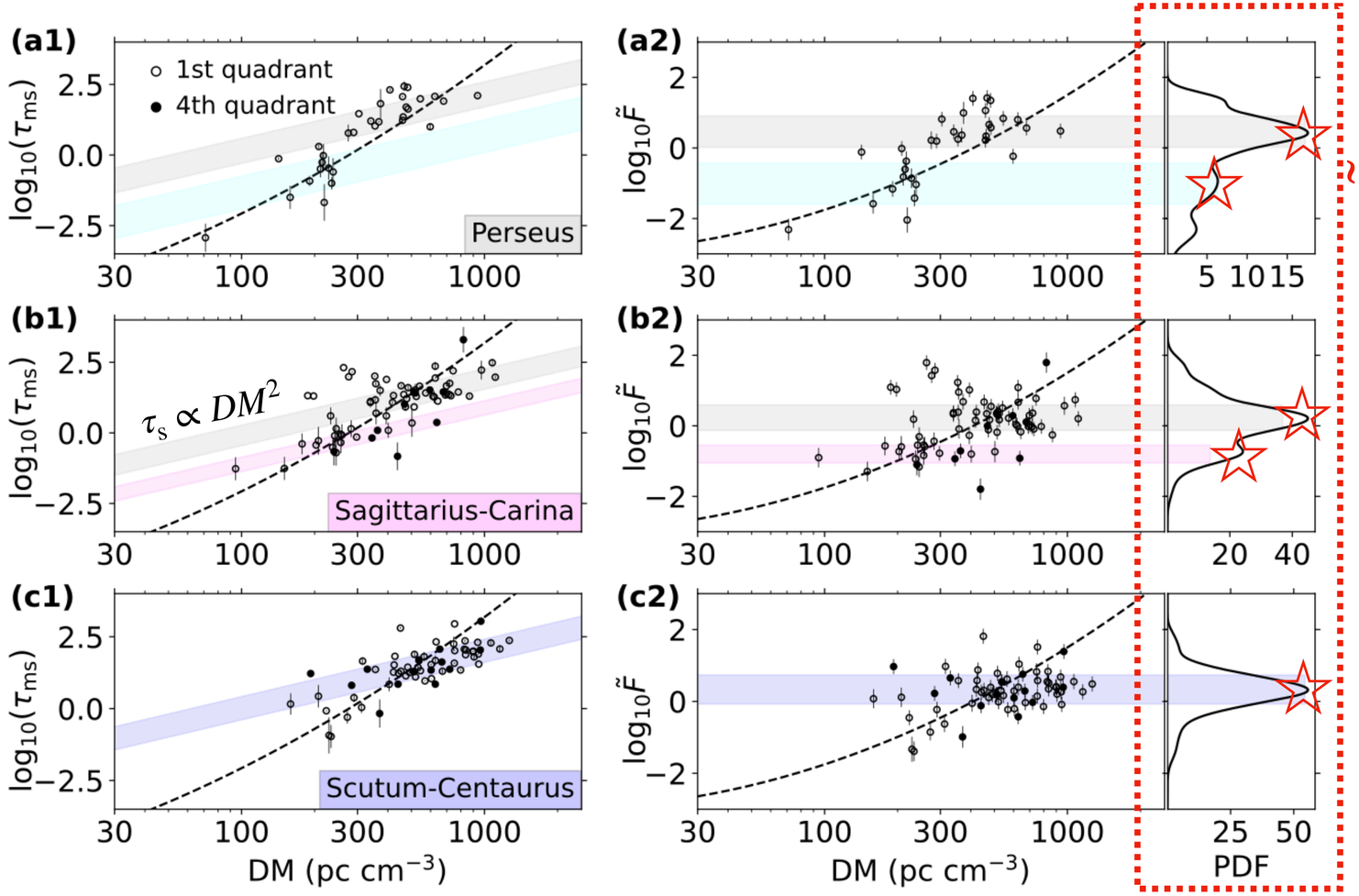
Discussion: Scattering toward different spiral arms

Specific arms dominate electrons in each constrained longitude range.

Weighted fluctuation parameter

$$\tilde{F} = (\tau_{1\mathrm{GHz}}/0.48\mathrm{ms})(DM/100\mathrm{cm}^{-3}\mathrm{pc})^{-2}$$





Summary

- In FAST L-band view, there are 122 pulsars with scattering features.
- 93 Pulsars filrstly show their scattering parameters, including 60 GPPS-discovered pulsars.
- The degree of density fluctuations $\tilde{F}$ depnends on spiral arms.

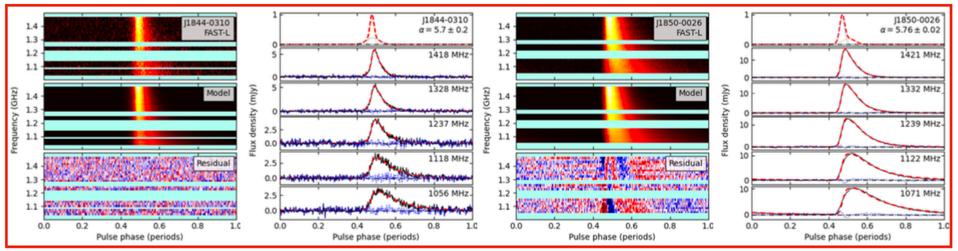
Thanks!

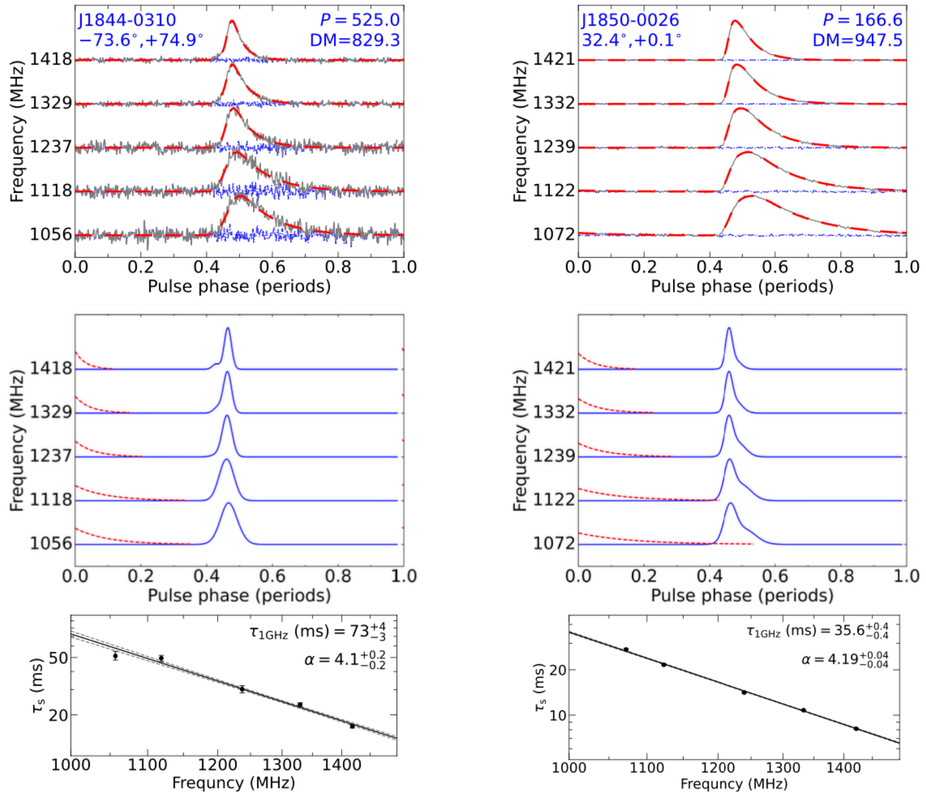
Feel free to discuss with me. Email: *jingweicong@nao.cas.cn*

Supplimentary Material

Two PSRs with evolution of intrinsic profiles?

Noticiable residuals ! ! !





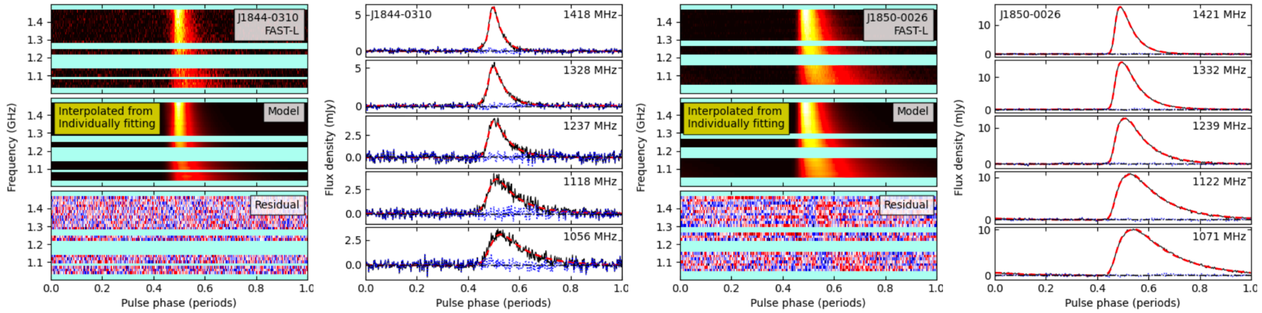
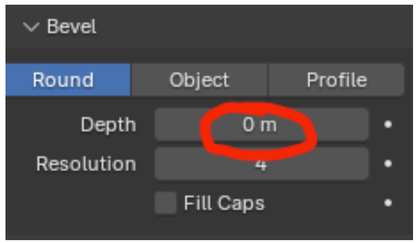


Figure A 3: The validation plot of two unusual pulsars, PSR J1844-0310 and J1850-0026, with the interpolated intrinsic profile from the individual fitting. Their residuals reach the noise level.

Blender绘制银河系旋臂

- 旋臂：Object Mode下add一个 Curve下面的path；按g平移path到合适的位置，点击左键固定path的位置；进入Edit Mode，按g平移5个标准点，使它们顺序沿着旋臂排列，彼此离得近一点；是有ctrl+鼠标右键，追加线段





Depth统一设置管道直径

Edit Mode下，curve的 transform的radius可以细致调节每个点位的半径。Mac的快捷键是option+s。点击点位，然后看快捷键



新建一个

