凡十一日沒三年
南方大中祥符四
年正月丁丑見南斗
四月丙辰出軒轅
前星西北大如桃
星入太微垣掩右執
法犯次將歷屛
日入濁沒明道元
年六月乙巳出東北方近濁有芒孛至丁巳凡十
日沒至和元年五月己丑出天關東南可數寸歲餘
稍沒熙寧二年六月丙辰出箕度中至七月丁
箕乃散三年十一月丁未出天囷元祐六年十
辛亥出參度中犯掩側星壬子犯九游星十二
酉入奎至七年三月辛亥乃散紹興八年五月
宋史志卷九

Chinese pulsar timing array (CPTA) progress

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@ 南阳 2023

2023

Current core team

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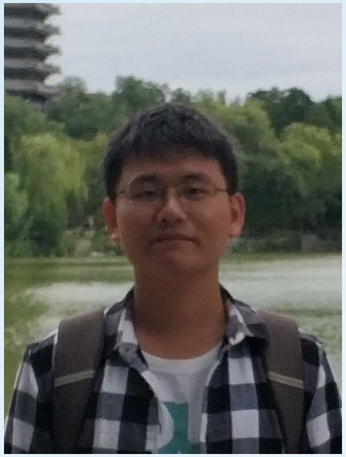
PhD



Jiangwei Xu
PhD

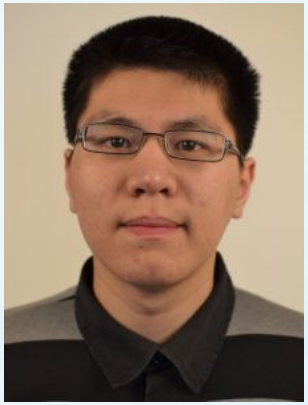
Bojun Wang
Post-Doc

Jinchen Jiang
Post-Doc

Nicolas
Caballero Post-Doc

Yanjun Guo
Post-Doc

Heng Xu
Post-Doc



Siyuan Chen
Post-Doc

Yonghua Xu
Facalty

Kejia Lee
Technician

北京大學
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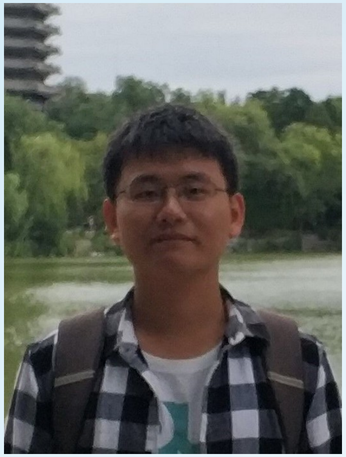
Current core team

Single source
and axion



Cosmic string and
dark matter

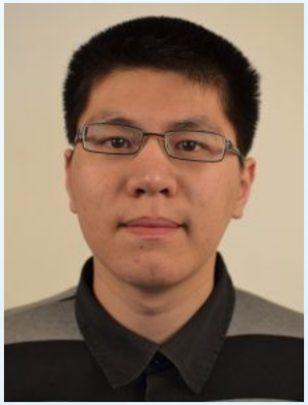
Single pulse
and jitter

Polarisation and
interferometry
and designed
CPTA logo

Nicolas Caballero
Targeted source

Noise analysis
GW background

Observation
timing and
noise analysis



Noise analysis
GW background

Scintillation

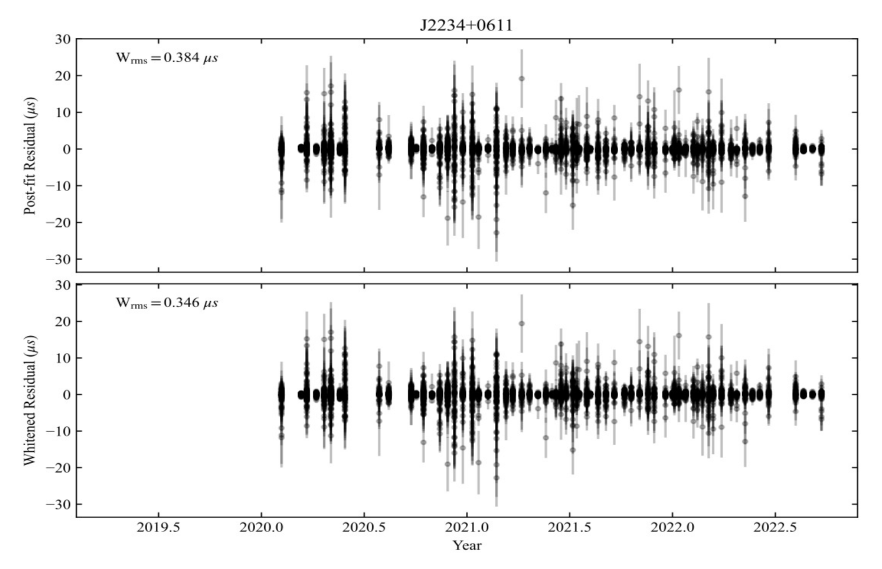
Technical and
educational supp

CPTA-DR1

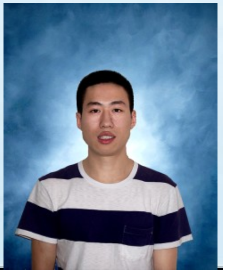
~2.5 years length

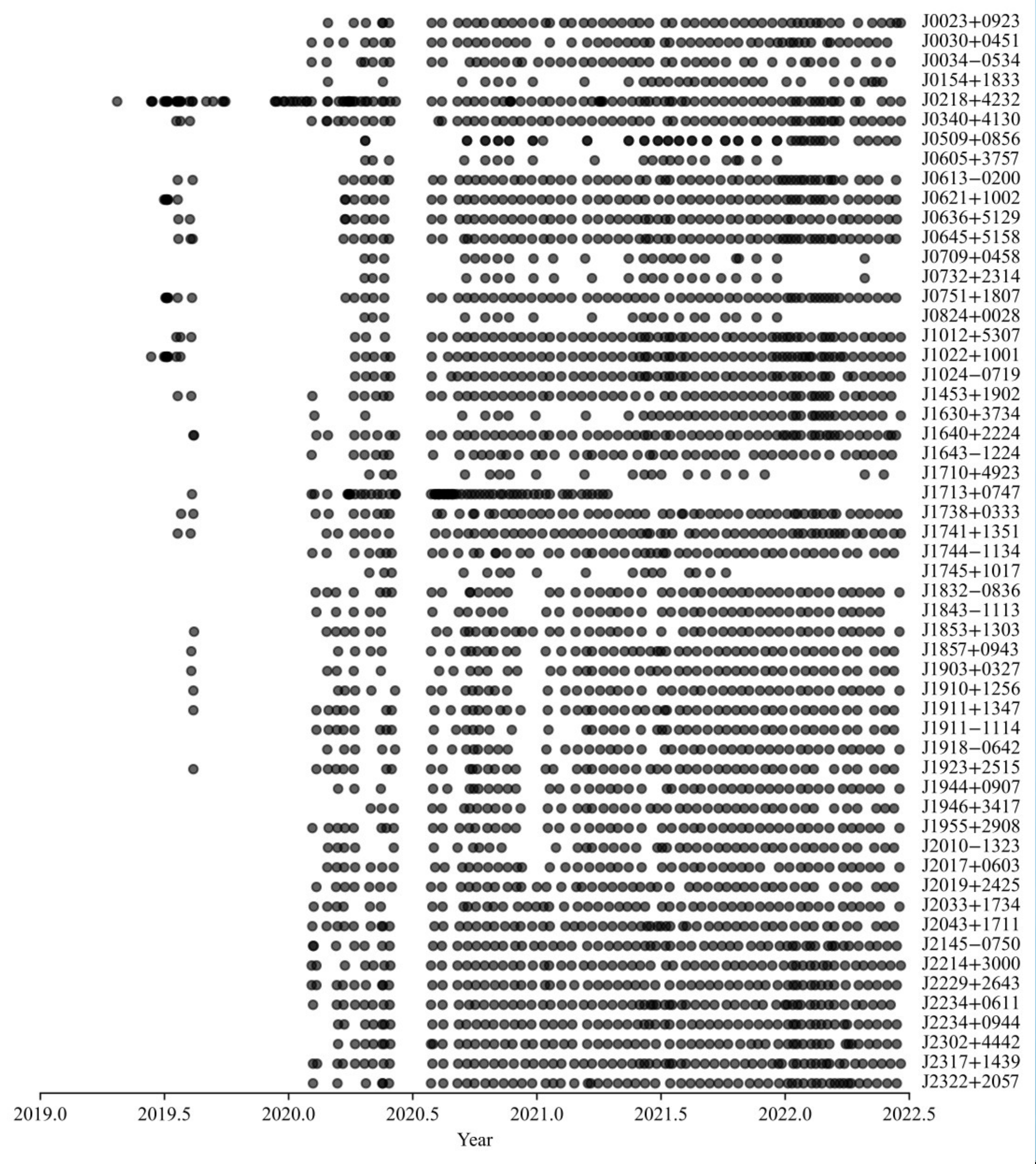
100ns for ~35 pulsars, and
200ns for ~55 pulsars.

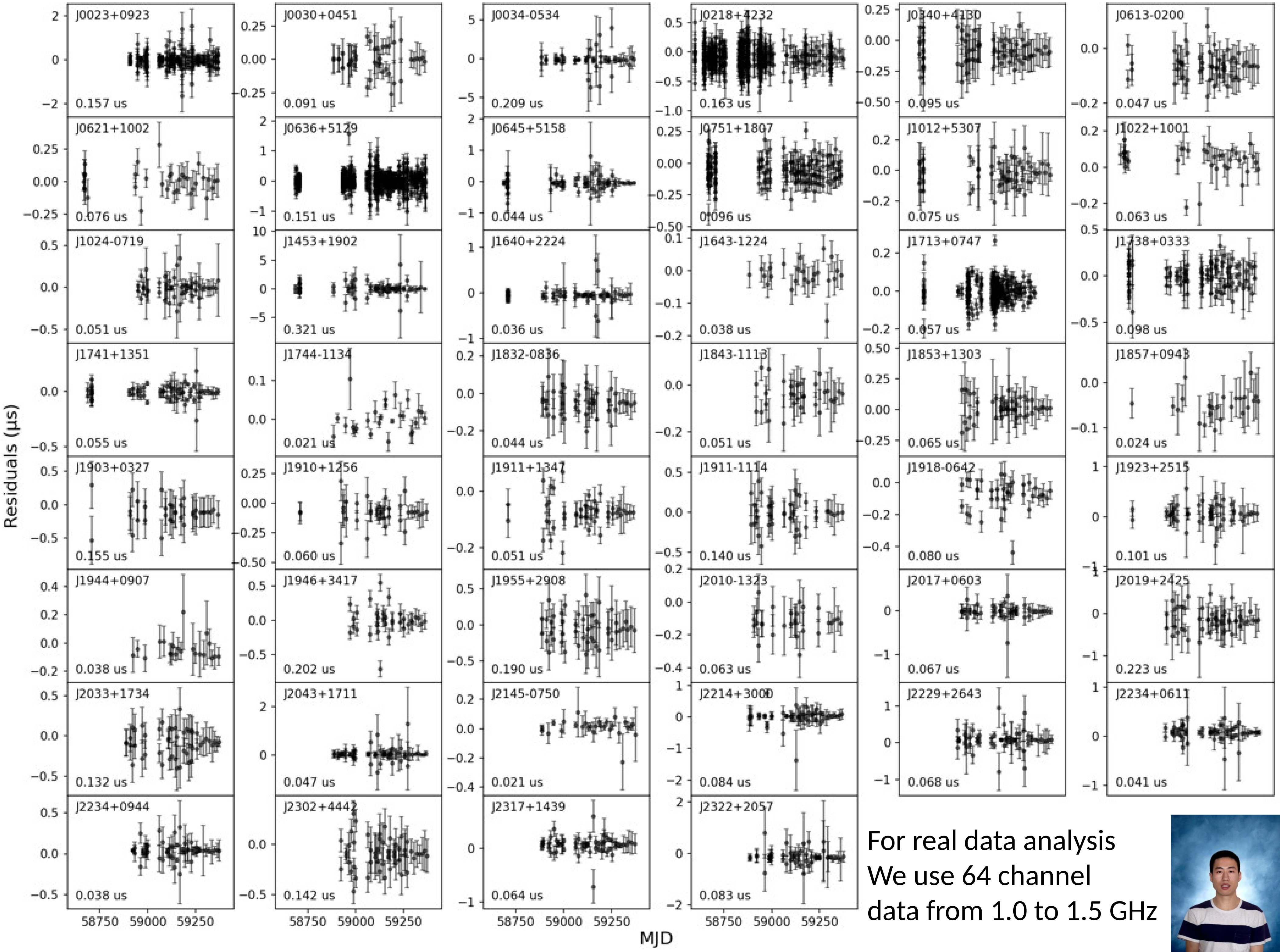
Noise analysis



Pulsar J2000	EQUAD	ECORR	DMNoise	RedNoise
J0023+0923		√	√	√
J0030+0923		√	√	√
J0034+0923			√	√
J0154+0923		√		√







For real data analysis
We use 64 channel
data from 1.0 to 1.5 GHz

CPTA achive facotr of 4 to 50 improvement of precision for 2-year observation compare to best internation data set.

CPTA polarimetry

FAST polarimetry

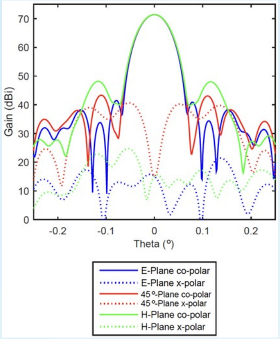
Low feed leakage

easy to calibrate

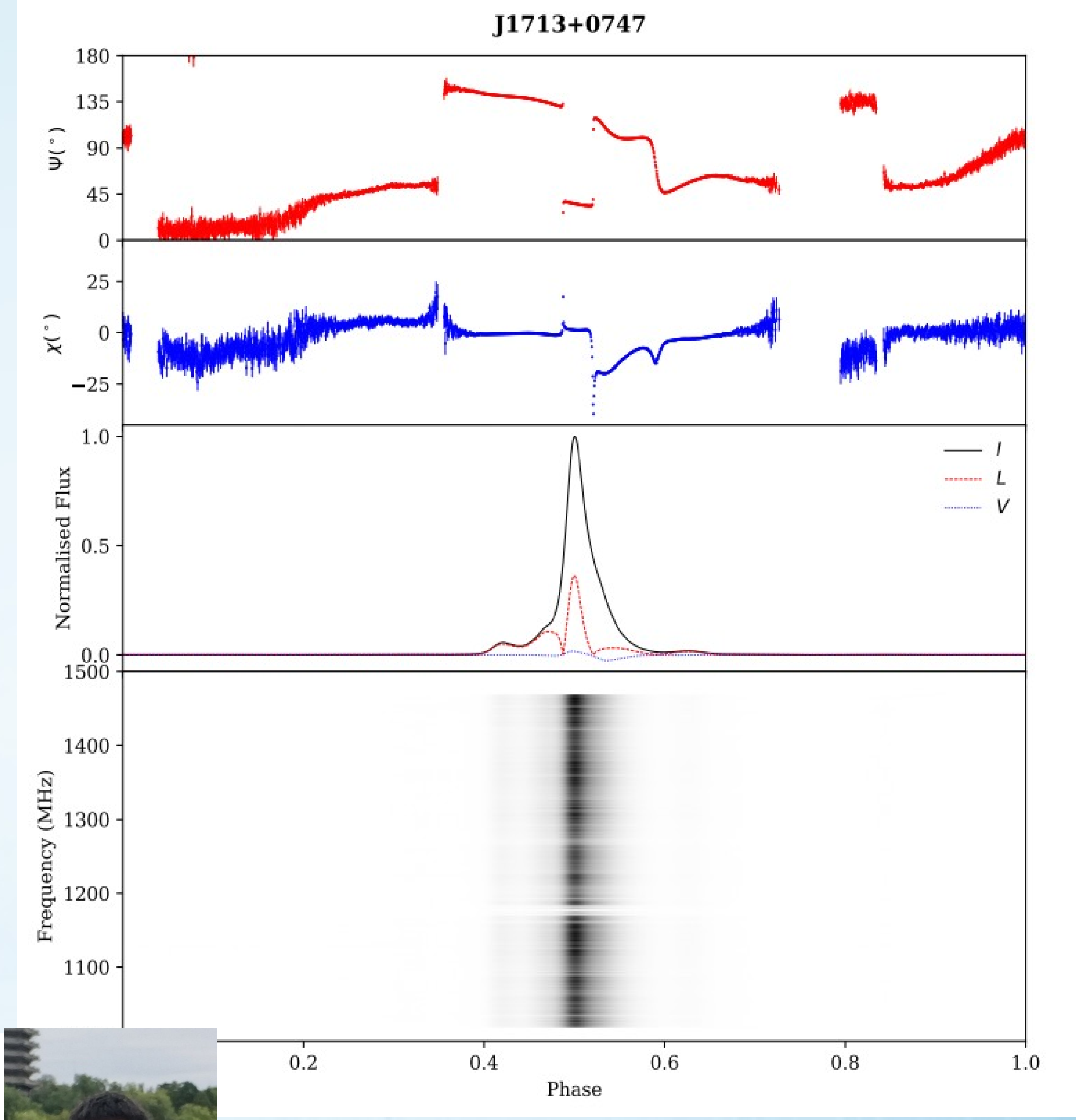
Fitting RM

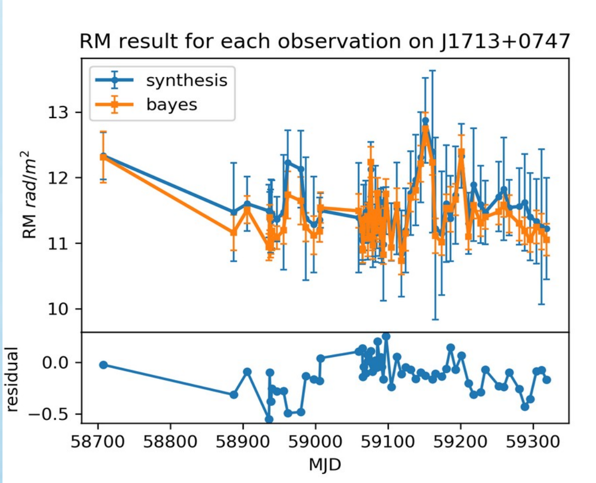
RM synthesis

Bayesian method



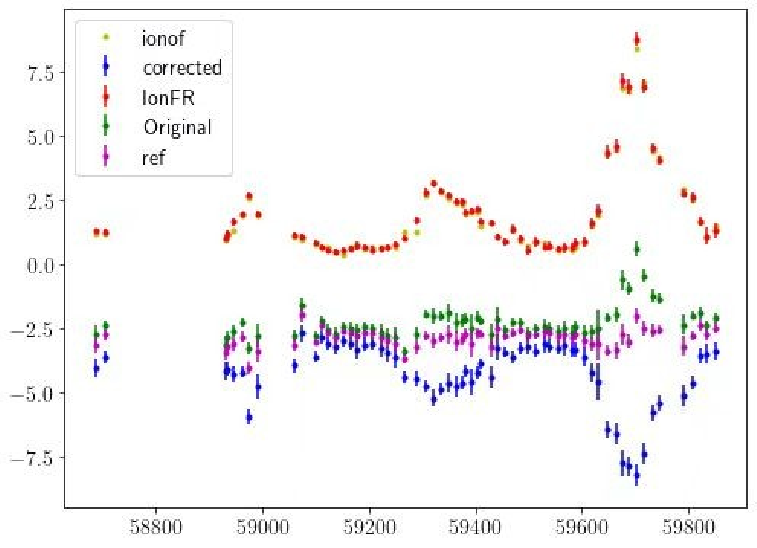
(Dunning et al. 2017)

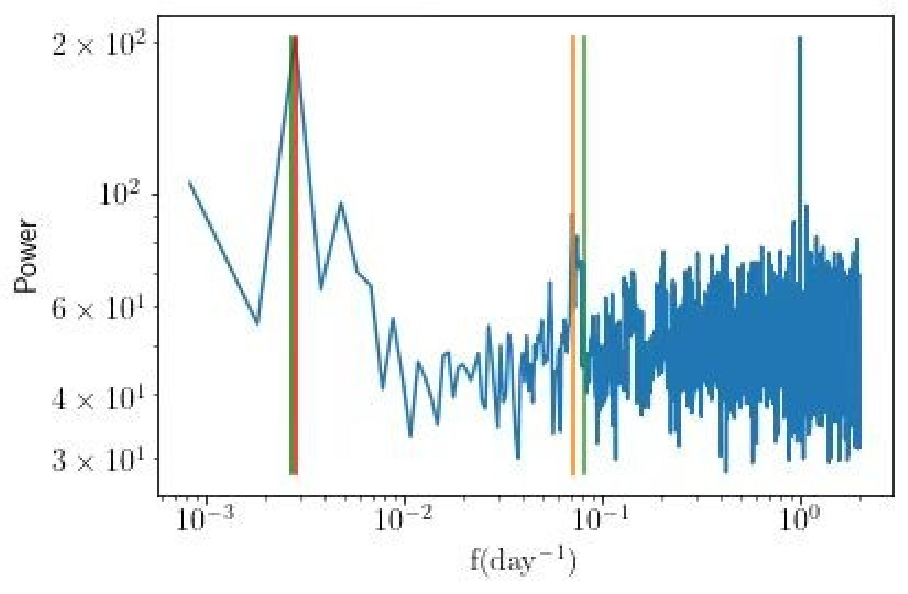


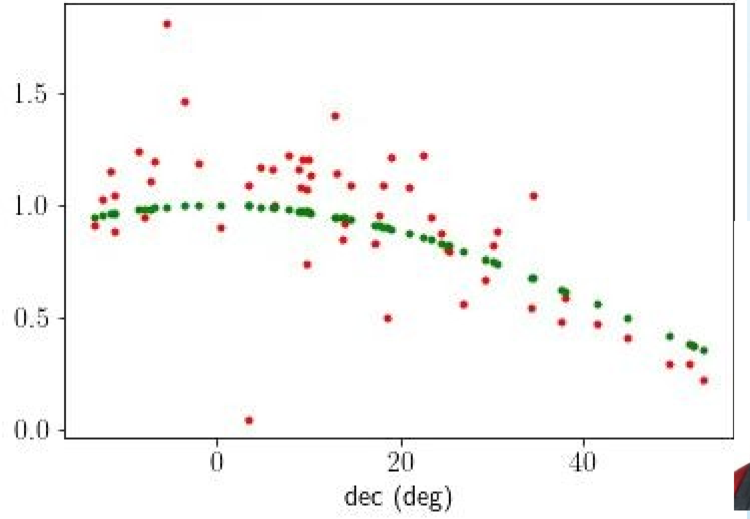


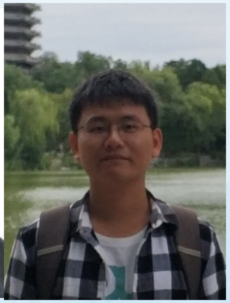
CPTA probing the ionosphere

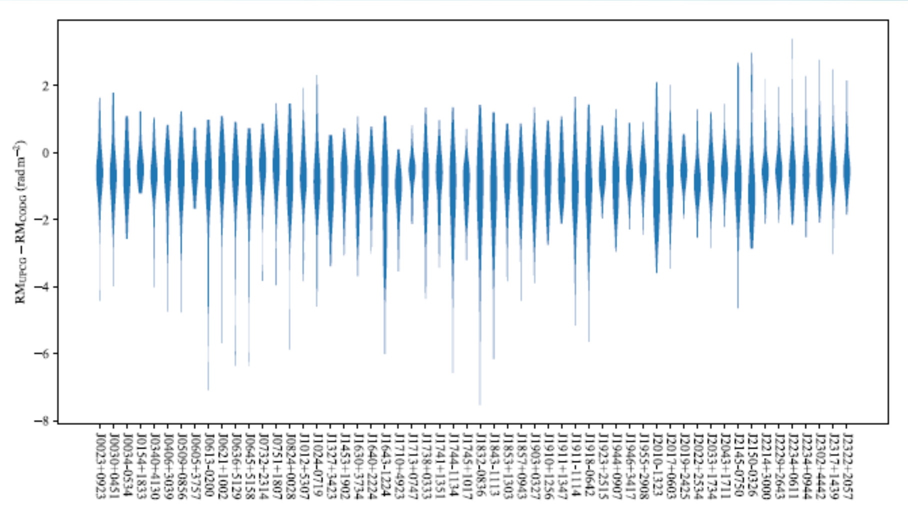
- IonFR over estimates the RM variation by a factor of 2-3 for high dec sources.
- IonFR is not wrong, we implement the ionof, it produces nearly the same answers.
- TEC is problematic, different TEC model differs by more than factor of 2.
- We saw 1-year and 28-days RM variation. Indication solar wind –earth magnetosphere interaction is important for sub 1 Rad/m^2 RM precision



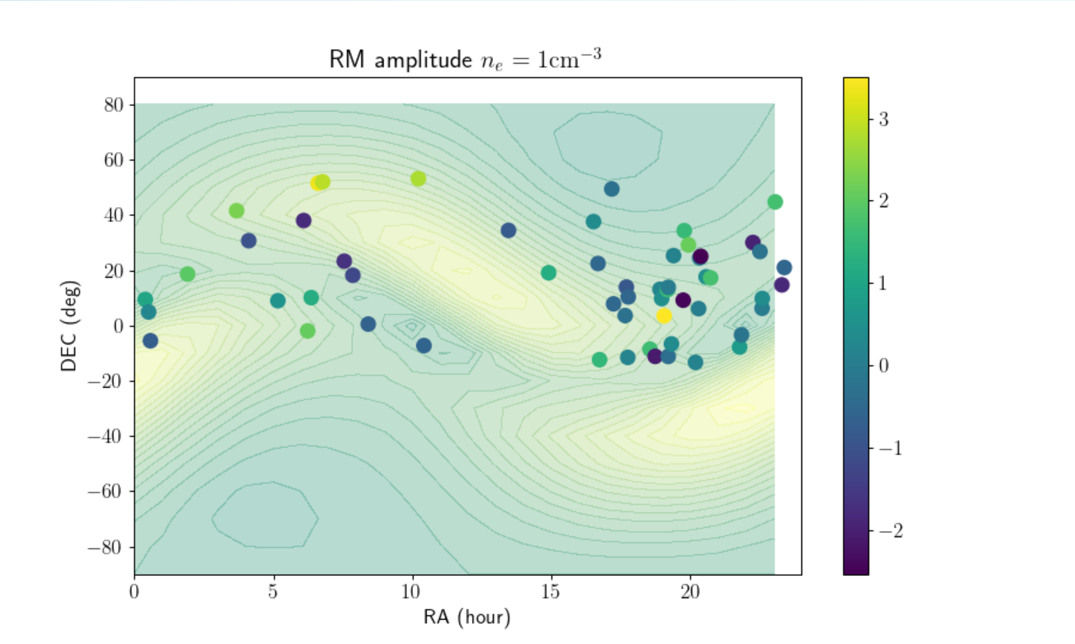


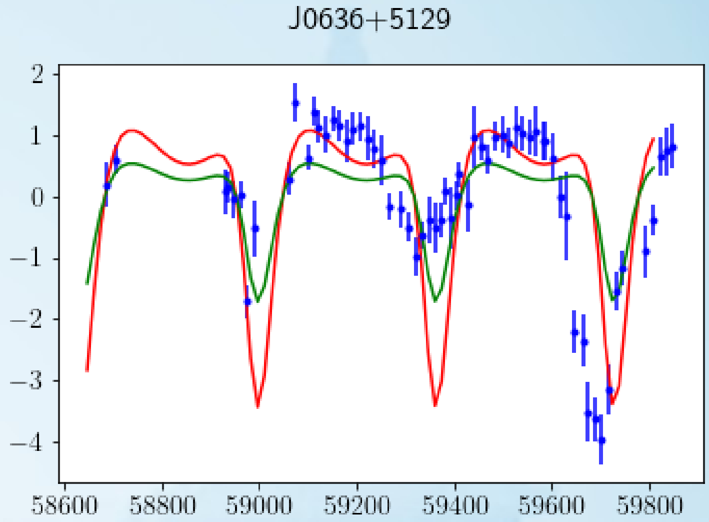


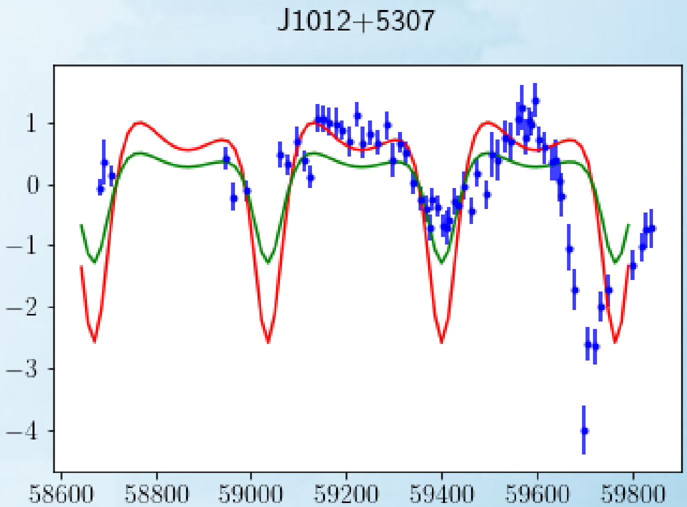


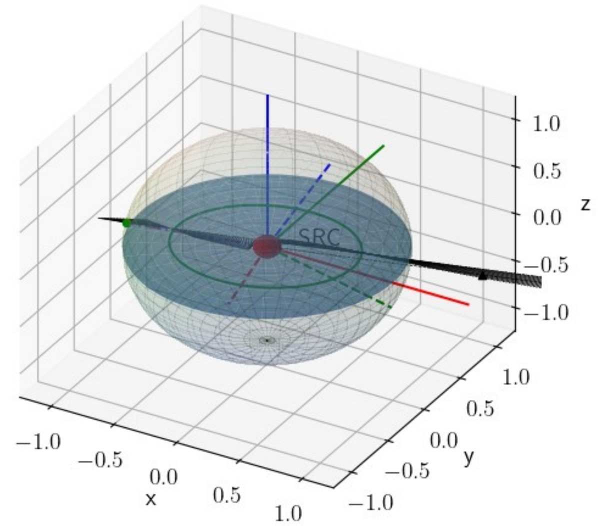


Solar system RM modeling







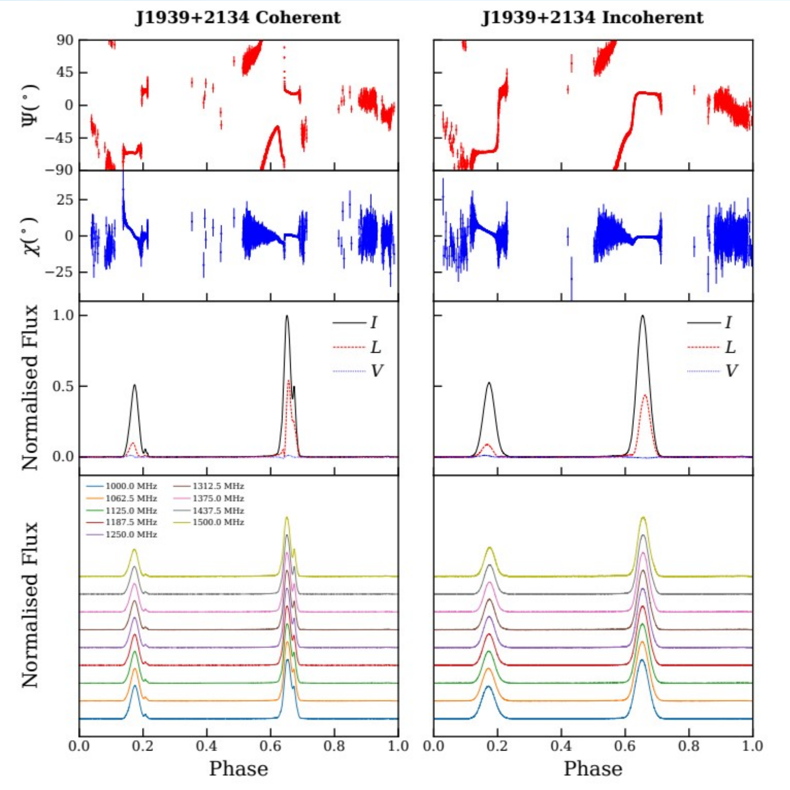


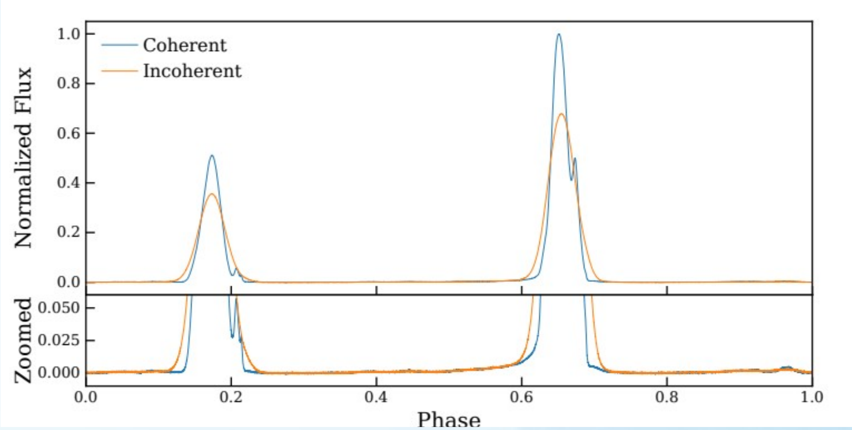
The naïve model can fit observation. However, one artificially require 100-1000 times higher electron density in solar wind. It seems that we need consider the solar-wind-earth magnetosphere interaction.

High time resolution for pulse structures

B1937+21

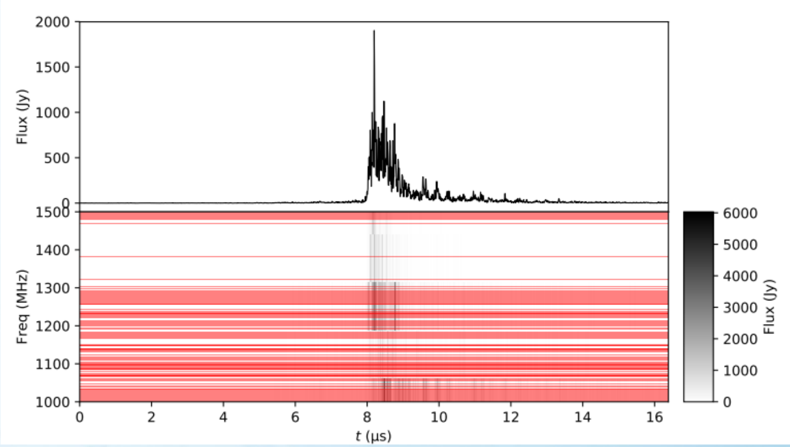
- Integrated profile





8192 bin

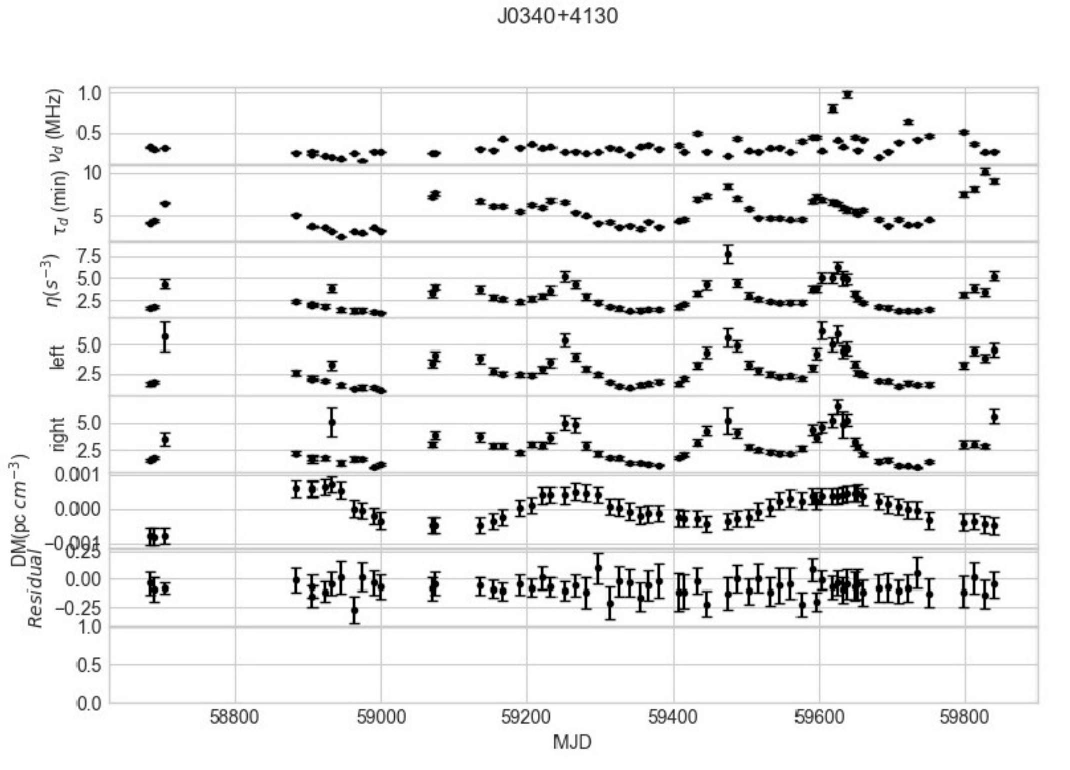
Giant pulse

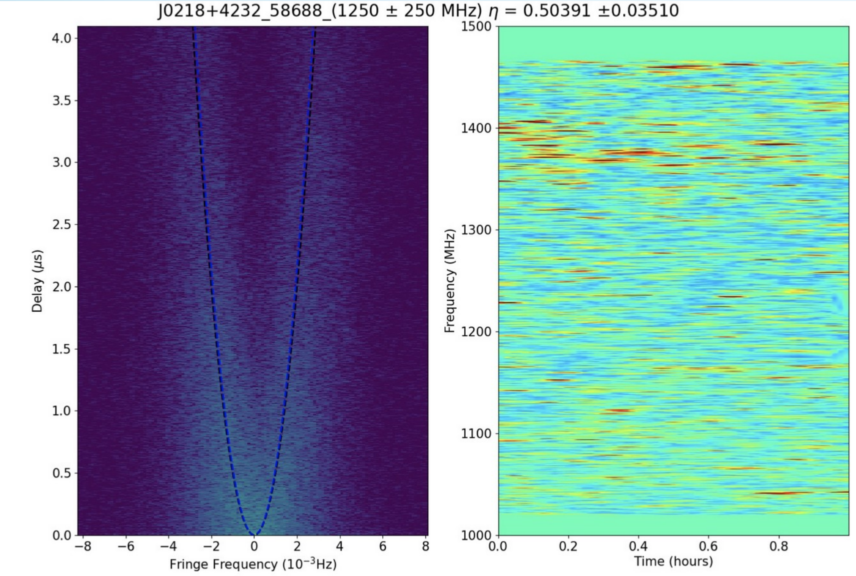


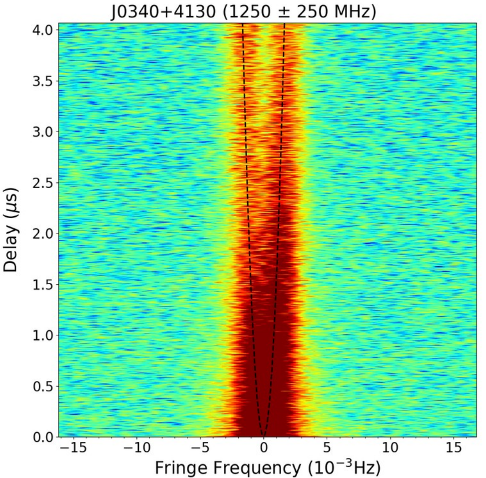
8 ns/sample

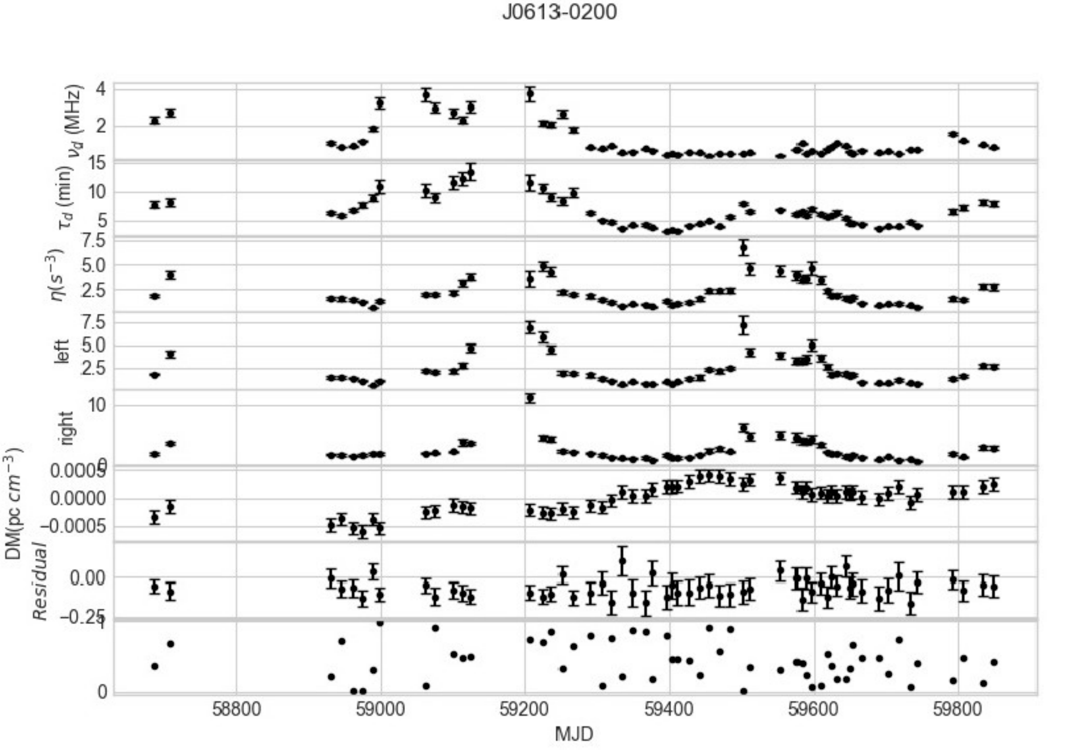
Scintillation

We tried to measure the scintillation effects for all pulsar we monitored. For a sub fraction of pulsars, we can see clear variation in scintillation effects including 2nd spectra arc curvature.

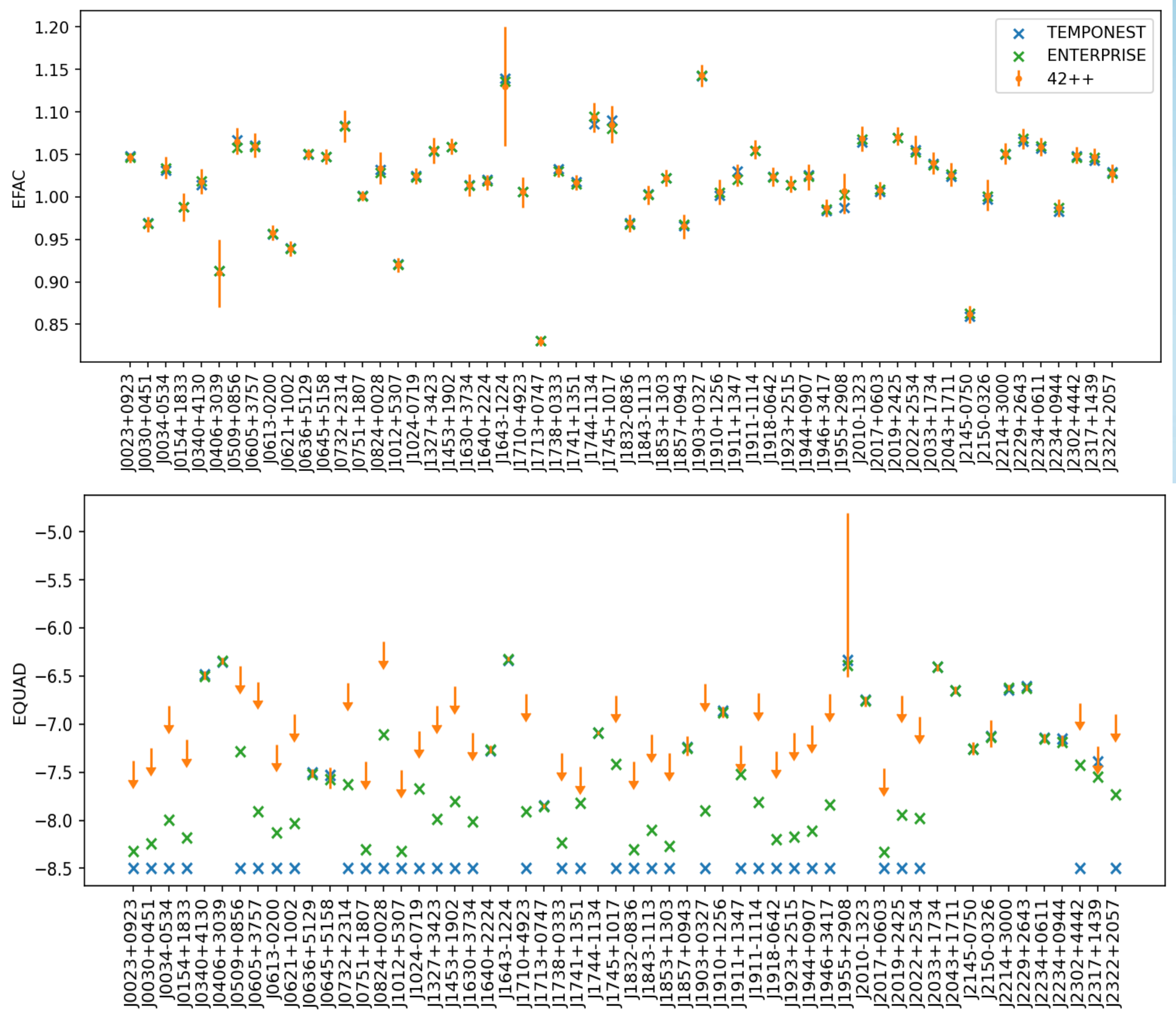




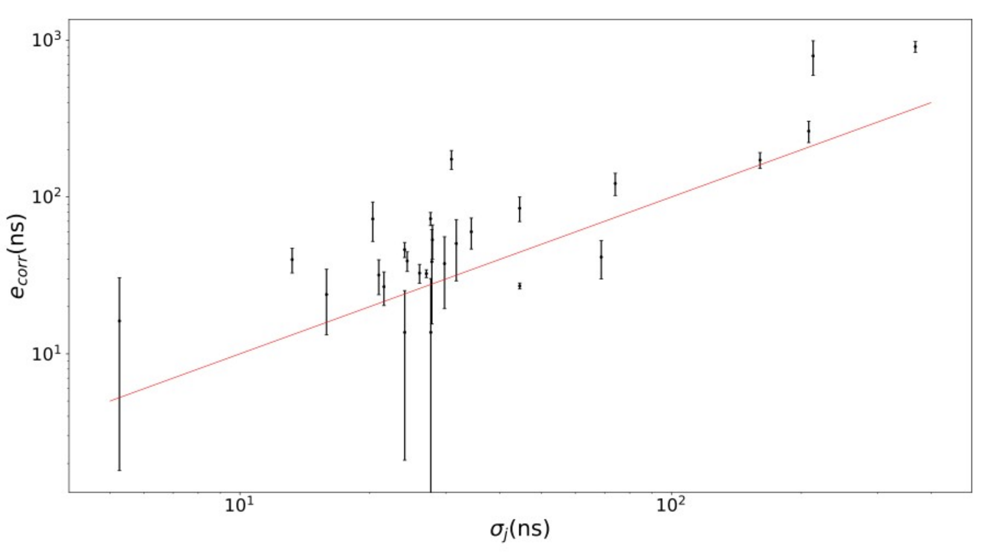


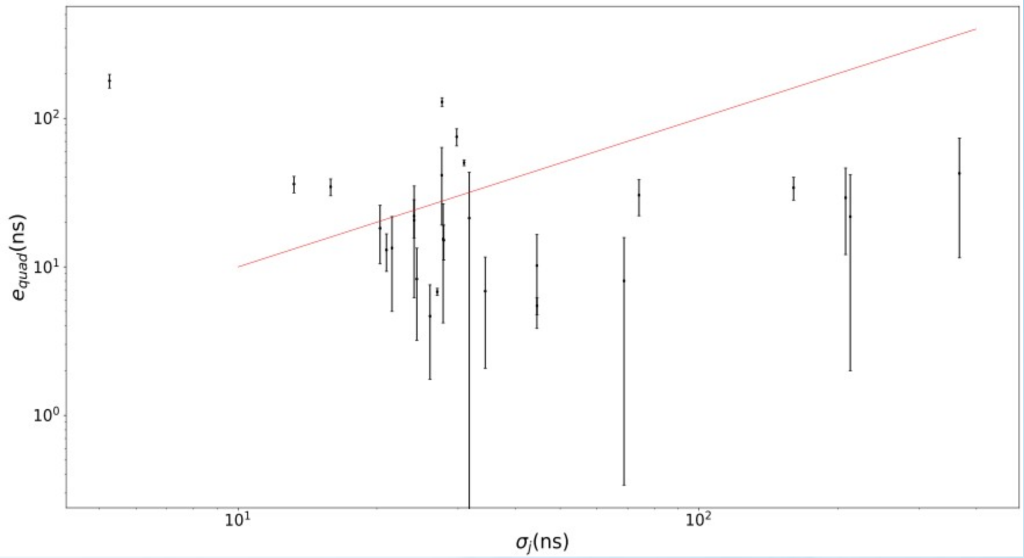


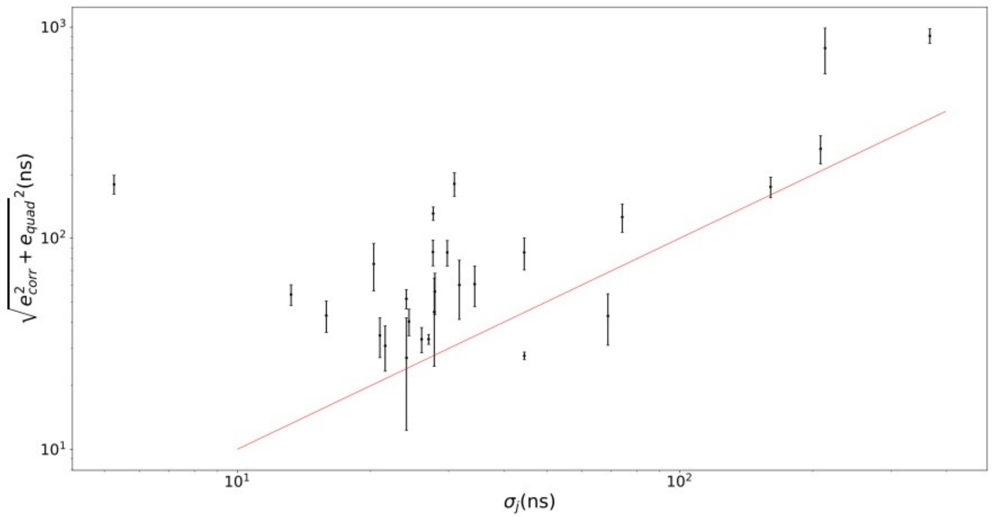
White noise analysis



Compare jitter modeled in timing and single pulse domain



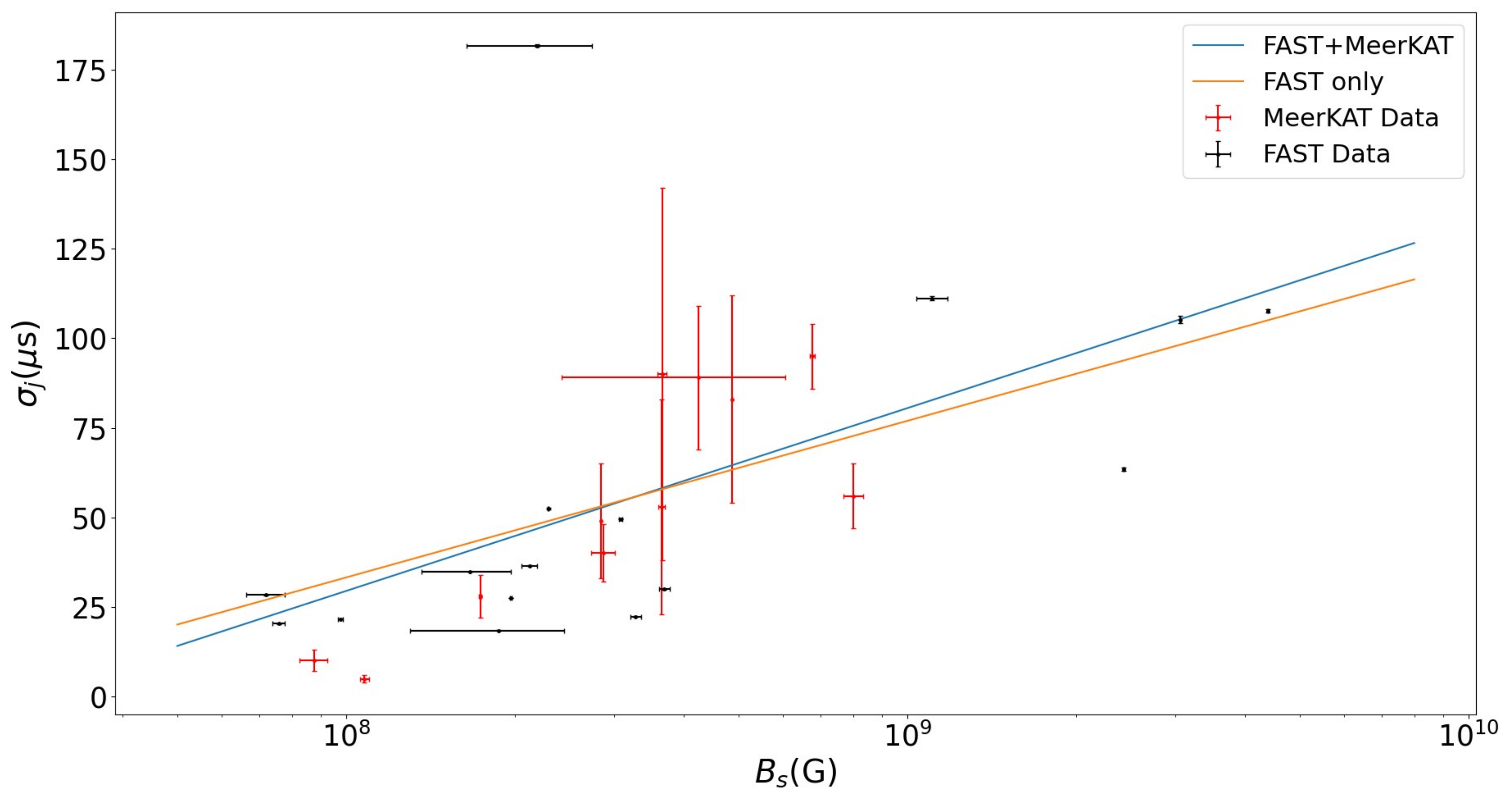




In general, the jitter parameter Ecorr agrees with single pulse domain modeling. It is not clear where the EQ comes from yet.

For some pulsars, short timescale RM variation affect the Ecorr measurement.

Jitter modeling with single pulse domain analysis



Jitter amplitude depends on pulsar dynamical parameters.

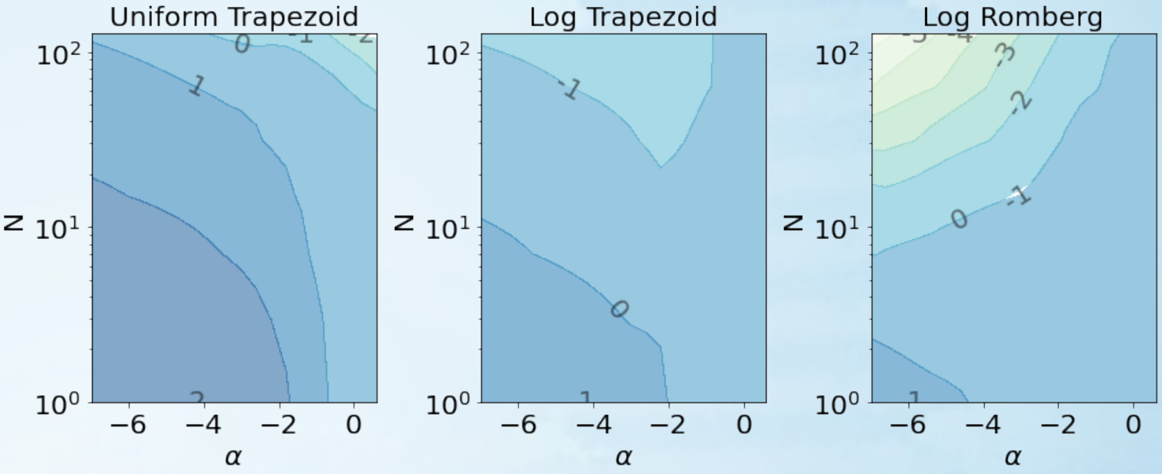
Difference between 42++ and enterprise implementation

1. 42++ using C++17, seems to be better memory efficiency than python.

2. Using Romberg weight to improve covariance matrix computation precision

$$C_r = F^T S F$$

$$C_r = \int_{fl}^{fh} s[f] \, \mathrm{Cos}[2\pi f (t_1 - t_2)] \, df = \sum s_i w_i \, \mathrm{Cos}[2\pi f_i (t_1 - t_2)]$$



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3. Split pulsar noise updater and correlated signal up dater to speed up (a lot).

$$C = C_W + F_r^T S_r F_r + F_C^T S_C F_C$$

$$C_W + F_{All}^T S_{All} F_{All}$$

$$Cw + C_r + F^T S_C F$$

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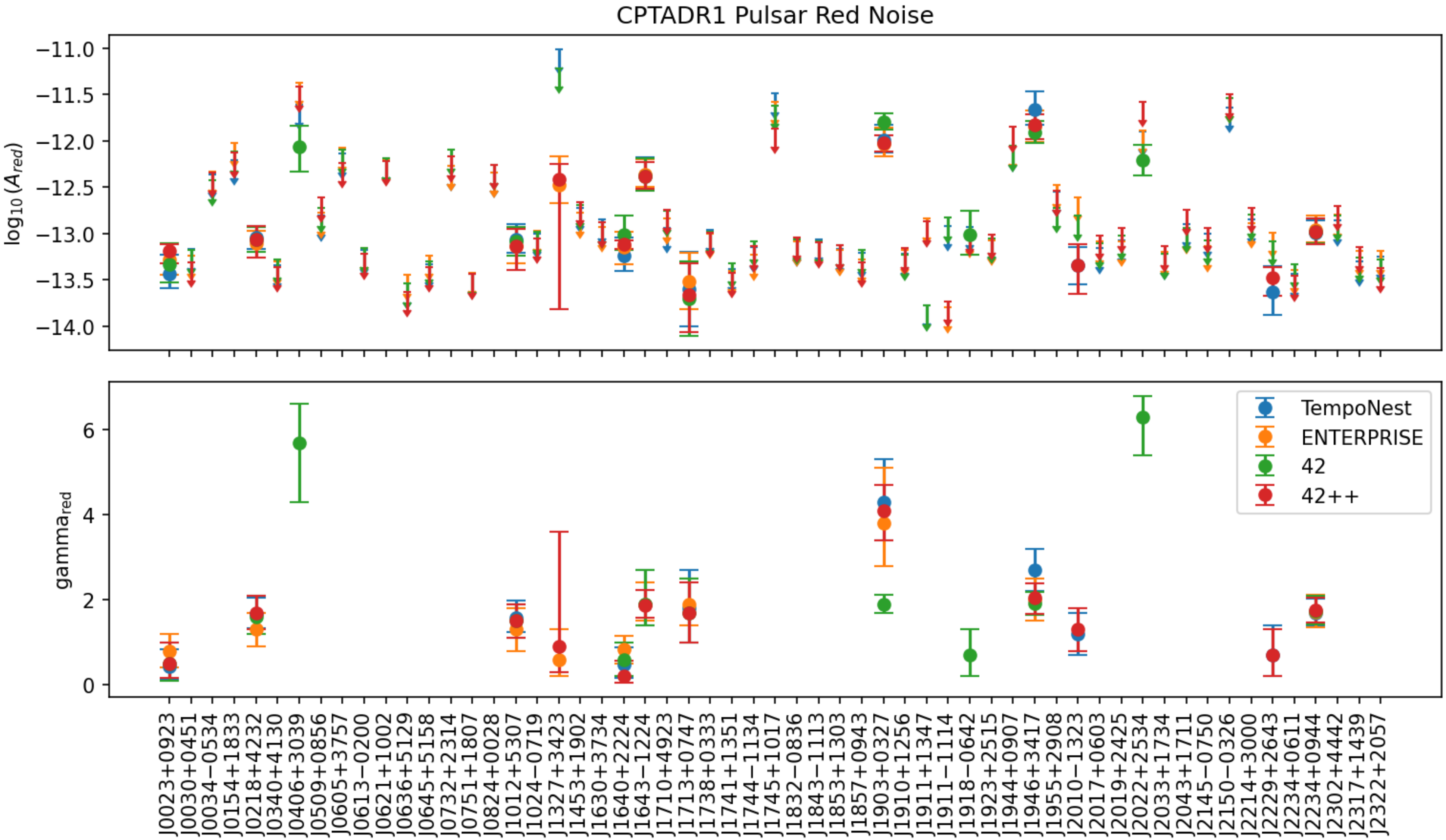
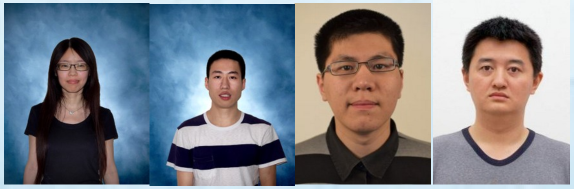
We are marginalizing all the white, red, DM noise in later inference.

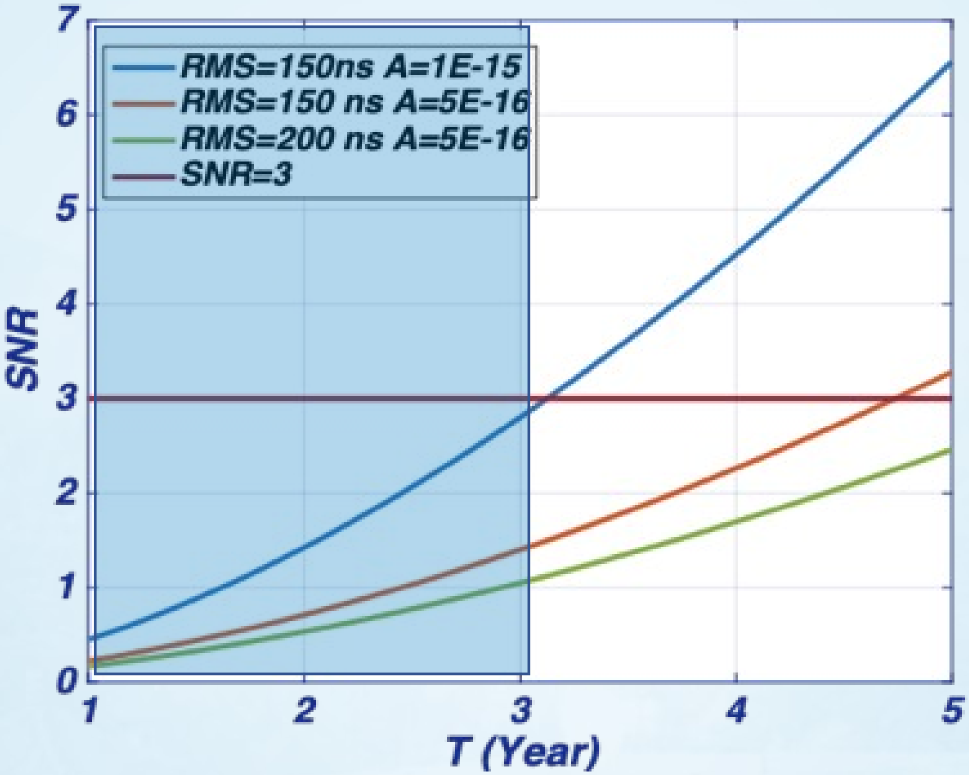
Noise analysis





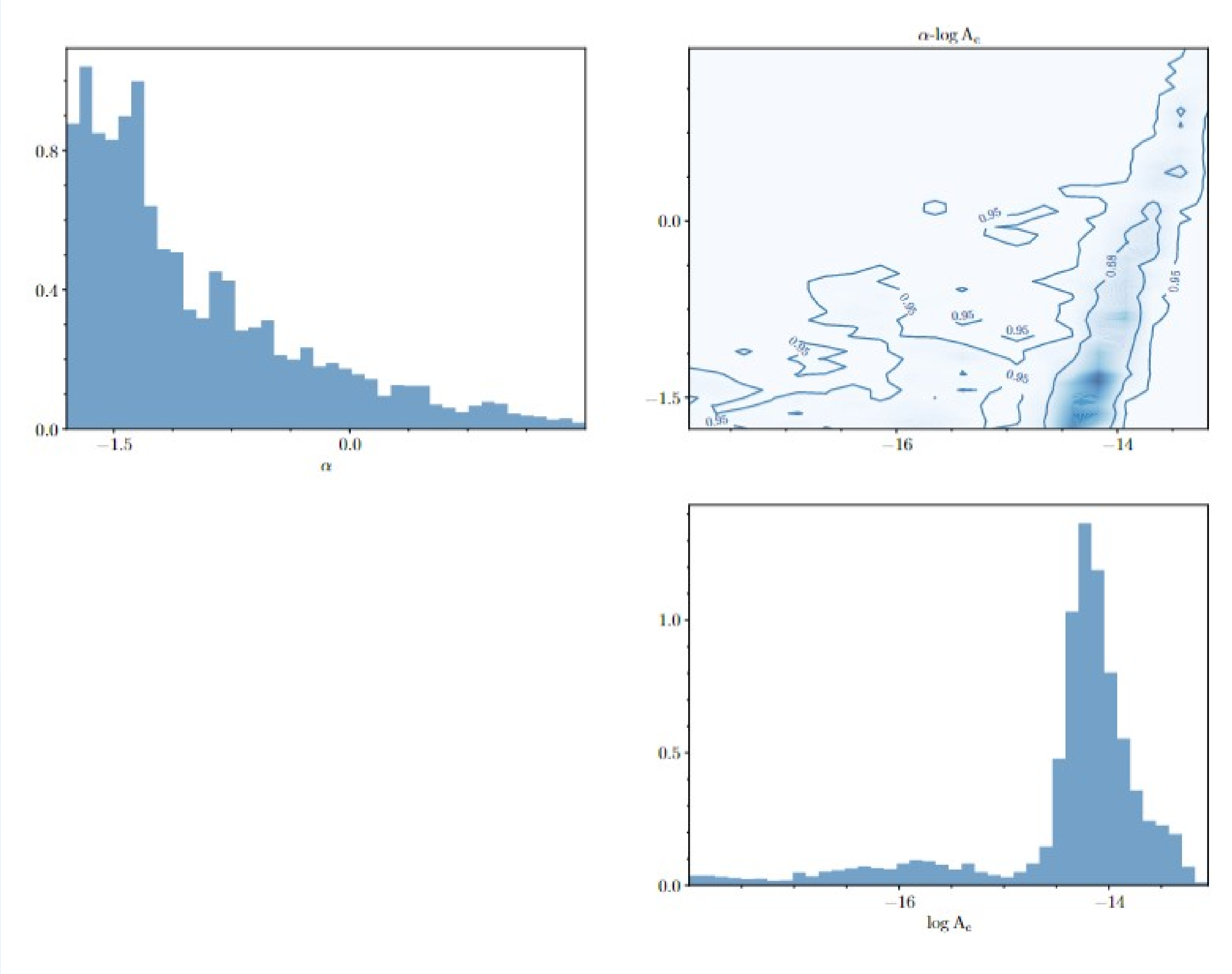
Stochastic background

- In 2019, when we start CPTA observation with FAST. I put my hand on Landaufshitz and claim that we will get something in 5 years (Yes, it is always 5 year away). If lucky, we will get something in 3 years.



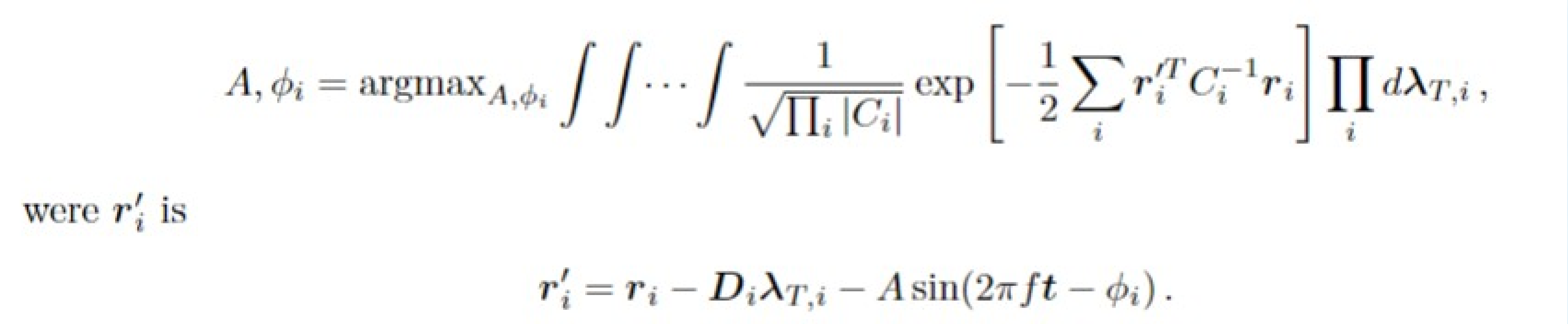
Estimation using CRB: DR1.0 should show some indication if A>2e-15.

Parameter inference



HD curve inference

Due to the limit data length, we can not do power-law modeling well. We need to focus on the part of signal with minimal error in correlation curve inference. The lowest frequency bin is a good guess, but not exactly.

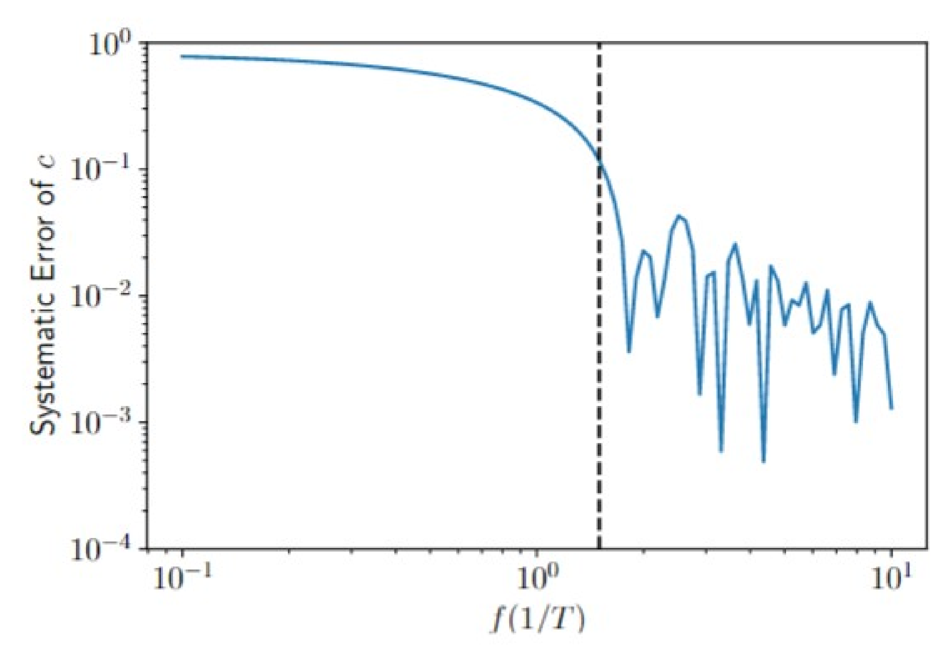


$$A, \phi_i = \mathrm{argmax}_{A,\phi_i} \int\int\cdots\int \frac{1}{\sqrt{\prod_i |C_i|}} \exp\left[-\frac{1}{2}\sum_i \boldsymbol{r}_i'^T C_i^{-1} \boldsymbol{r}_i\right] \prod_i d\boldsymbol{\lambda}_{T,i}\,,$$

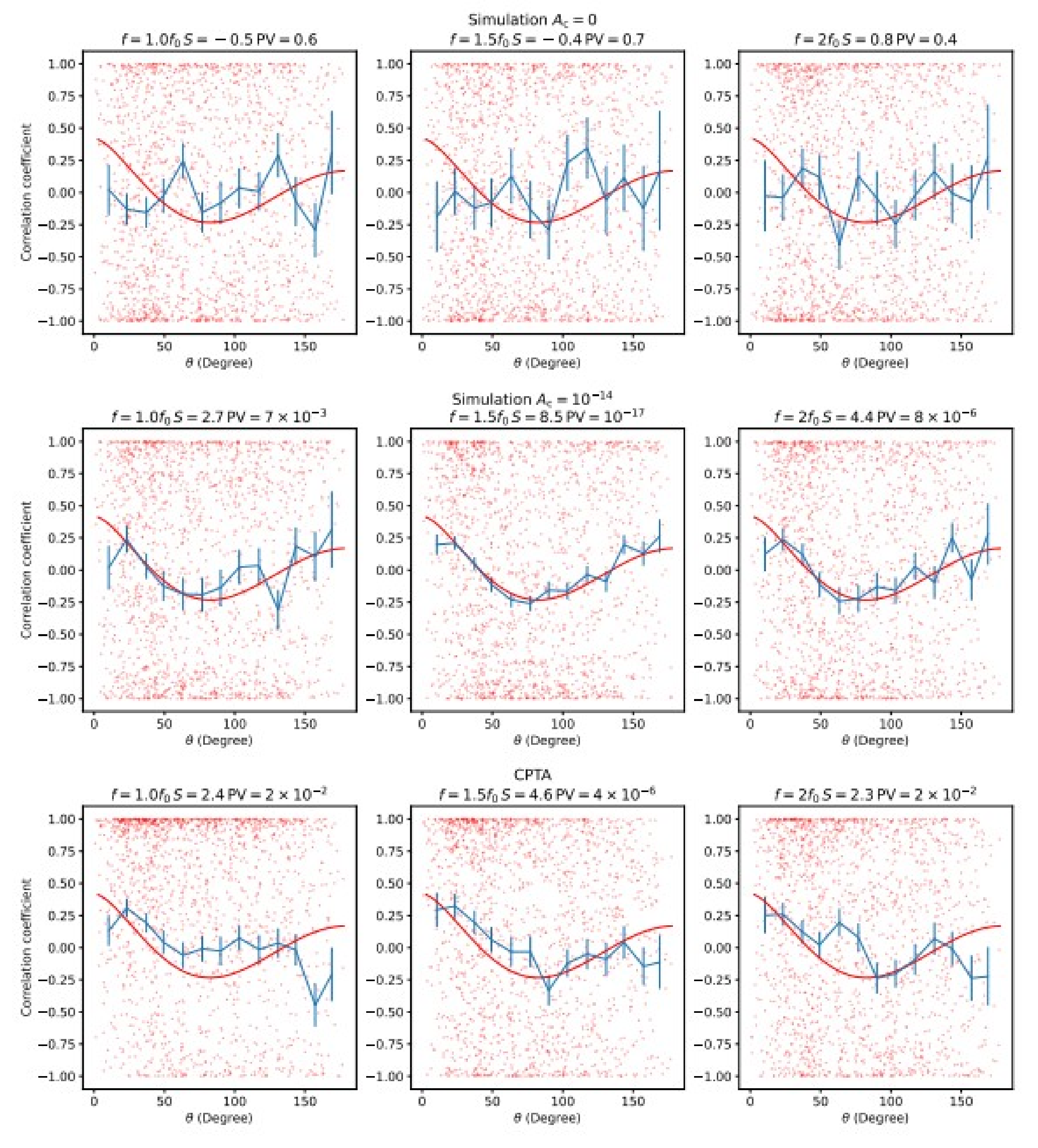
were $\boldsymbol{r}_i'$ is

$$\boldsymbol{r}_i' = \boldsymbol{r}_i - \boldsymbol{D}_i \boldsymbol{\lambda}_{T,i} - A\sin(2\pi f \boldsymbol{t} - \phi_i)\,.$$

The sweat spot for short data set is to look for correlation at f~1.5/T.



HD curve



Simulation $A_c = 0$

$f = 1.0 f_0$ $S = -0.5$ PV = 0.6

$f = 1.5 f_0$ $S = -0.4$ PV = 0.7

$f = 2 f_0$ $S = 0.8$ PV = 0.4

Simulation $A_c = 10^{-14}$

$f = 1.0 f_0$ $S = 2.7$ PV = 7×10^{-3}

$f = 1.5 f_0$ $S = 8.5$ PV = 10^{-17}

$f = 2 f_0$ $S = 4.4$ PV = 8×10^{-6}

CPTA

$f = 1.0 f_0$ $S = 2.4$ PV = 2×10^{-2}

$f = 1.5 f_0$ $S = 4.6$ PV = 4×10^{-6}

$f = 2 f_0$ $S = 2.3$ PV = 2×10^{-2}

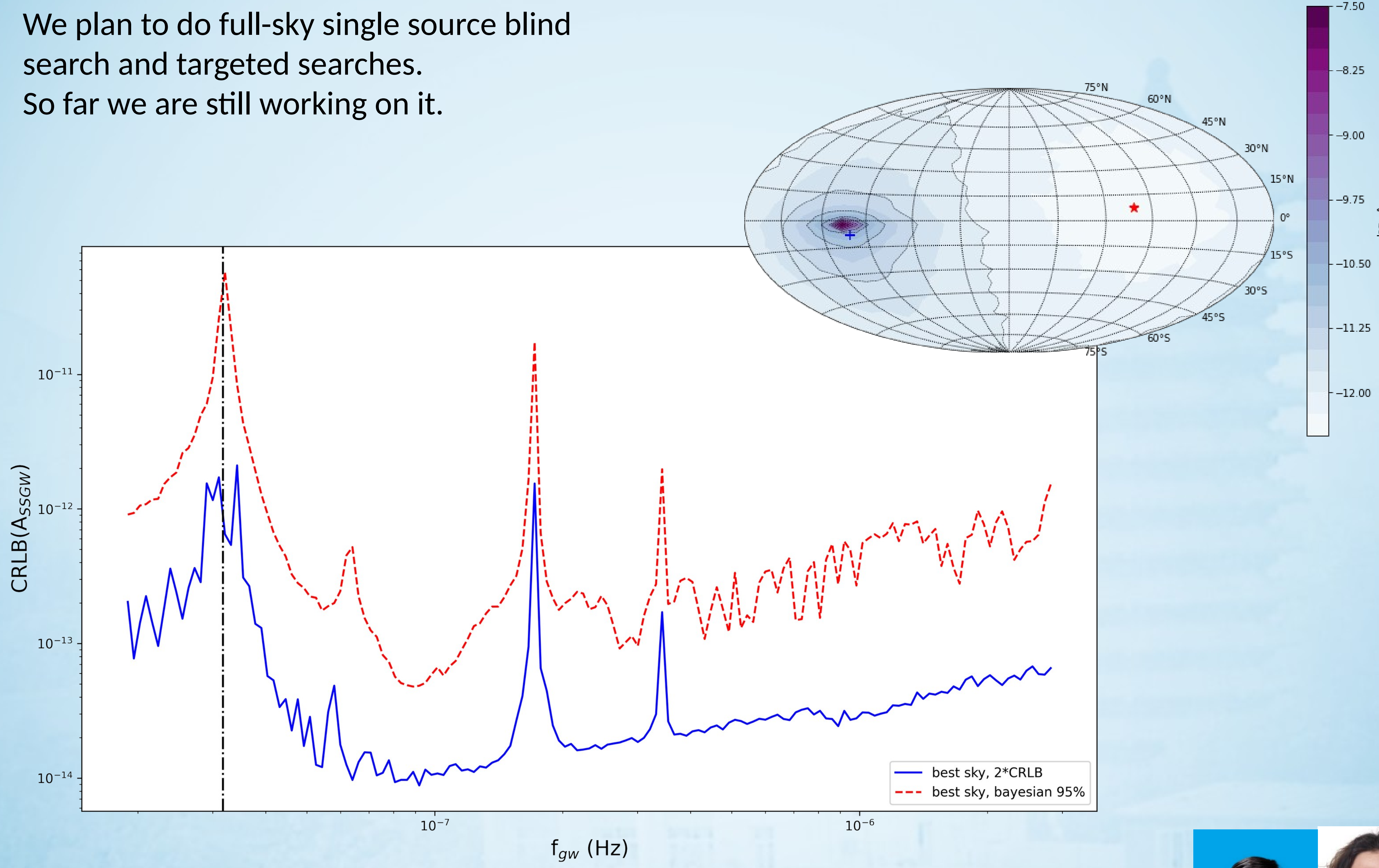
Null control group

Positive control group

Real data

Single pulsar bounds for single GW sources

We plan to do full-sky single source blind search and targeted searches.
So far we are still working on it.



Summary of IPTA

Claim 1: “Nanograv carefully use several methods analyzed data get S/N~3-4 claimed that PTAs detected the first evidence of nHz GW, where PPTA had started the community 2003, EPTA aquited the longest dataset of 30 years for S/N~3 and new CPTA get the highest SNR of 4.6 sigma within very rigorous probability framework. “

Claim 2“ In March, CPTA claimed something with 4.6 sigma, data is so short that they do not know what it is, and they can just push for nice HD curve. The thing is, however, not shown in most historical PPTA dataset. EPTA needs to throw historical data to see the thing at 3-sigma. But, Nanograv believed strongly this is the first evidence for nHz GW, after they try different methods, which reports different S/Ns and they could not select one but report all. “

Both claim1 and 2 are true.

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No time for the details

1. The current paper is only the table of contents. Real papers are still in pipeline.
2. CPTA HD curve is independent of power law modeling.
3. CPTA p-value is computed both analytically and numerically. The value matches. There is only one single p-value for CPTA.
4. We do not use Bayesian factor, we show it is not rigorous to use it in the current problem.
5. We show some methods described in the "checklist" is wrong. We reported to IPTA, it will be revised.

Conclusion

We are getting there.