Single pulsar analysis on PSR J1909-3744 : Limits on the low-frequency stochastic gravitational wave background

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Assemblée Générale GdR Ondes gravitationnelles
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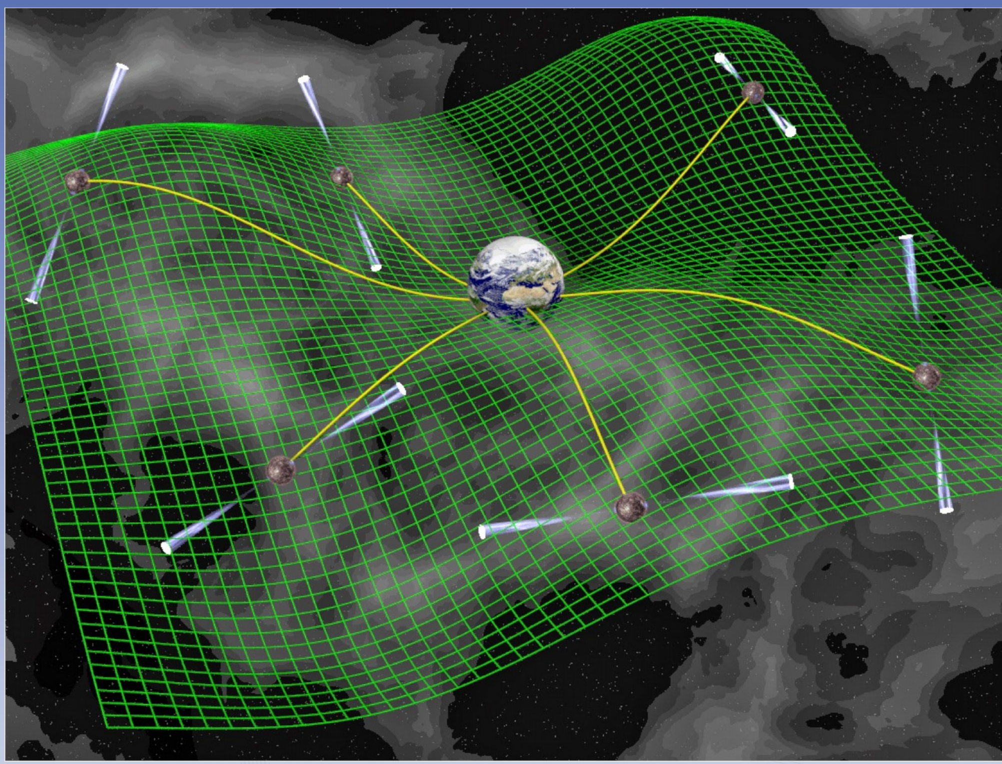
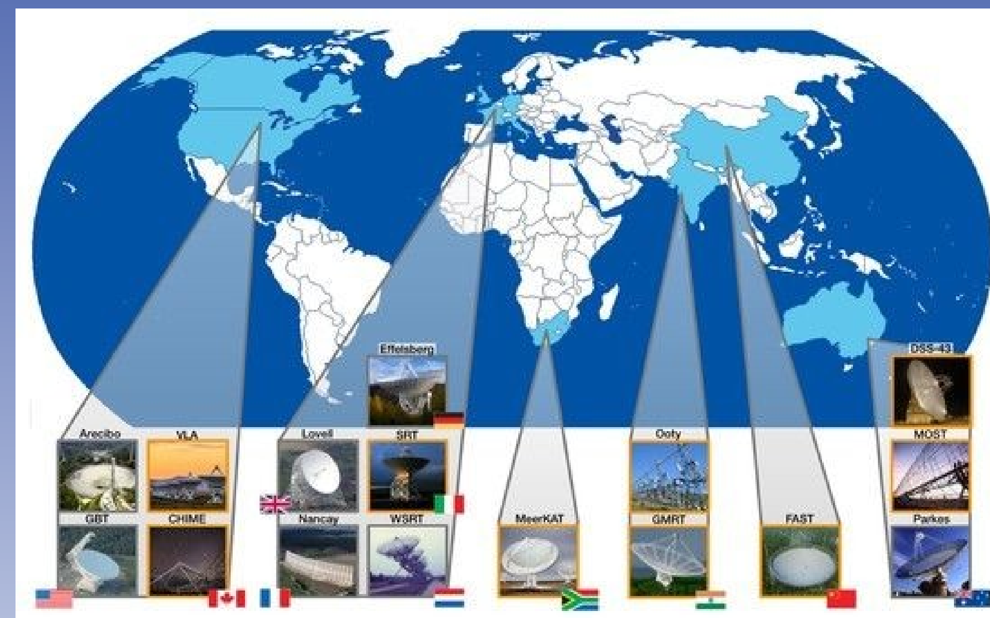
Pulsar Timing Arrays - Principle

Probe very low-frequency gravitational waves effects on pulses' arrival times in a full array of pulsars!



Credit : D. Champion



NANOGrav

EPTA

PPTA

SMBHB (stochastic background + single sources)

Cosmic strings, primordial GWs, ...

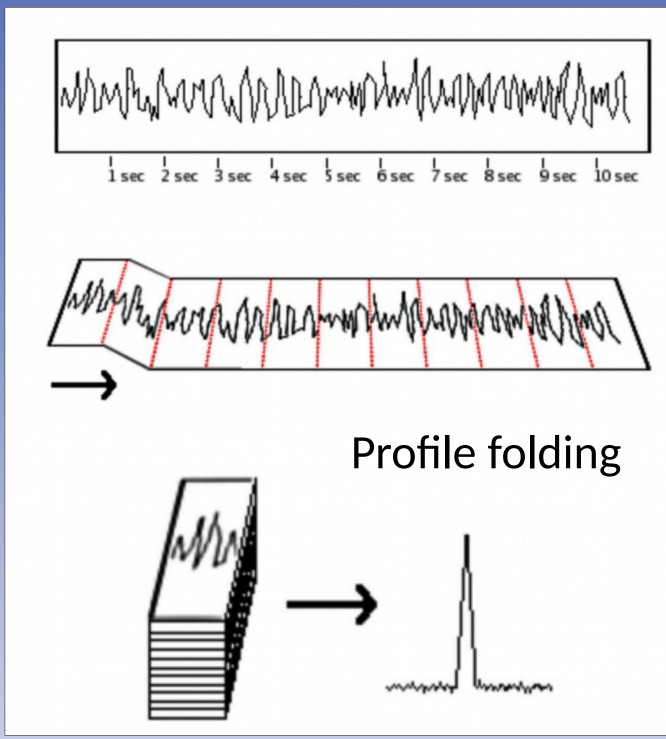
INTERNATIONAL PULSAR TIMING ARRAY — IPTA

= 65 Millisecond PSRs [Perera et al. 2019]

Pulsar timing procedure(s)

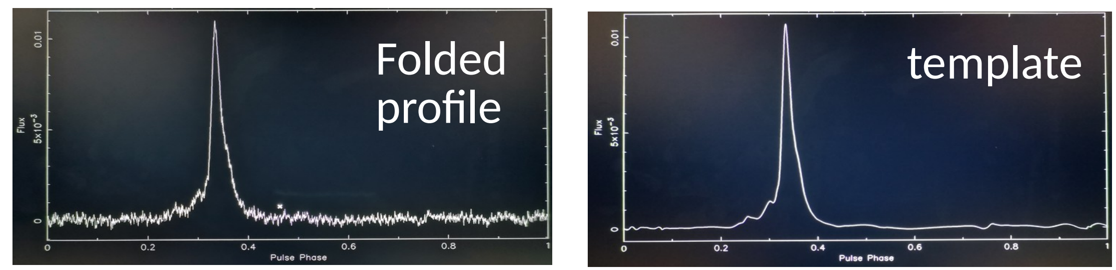
Determinate times of arrival (TOAs)

Observation



cf. McKee

TOA creation



folded profile cross-correlated with a noise-free **template** (« template matching »)

Observe ...

$$\sigma_{\mathrm{TOA}} \propto \frac{S_{\mathrm{sys}}}{\sqrt{t_{\mathrm{obs}}\Delta f}} \times \frac{P\delta^{3/2}}{S_{\mathrm{mean}}}$$

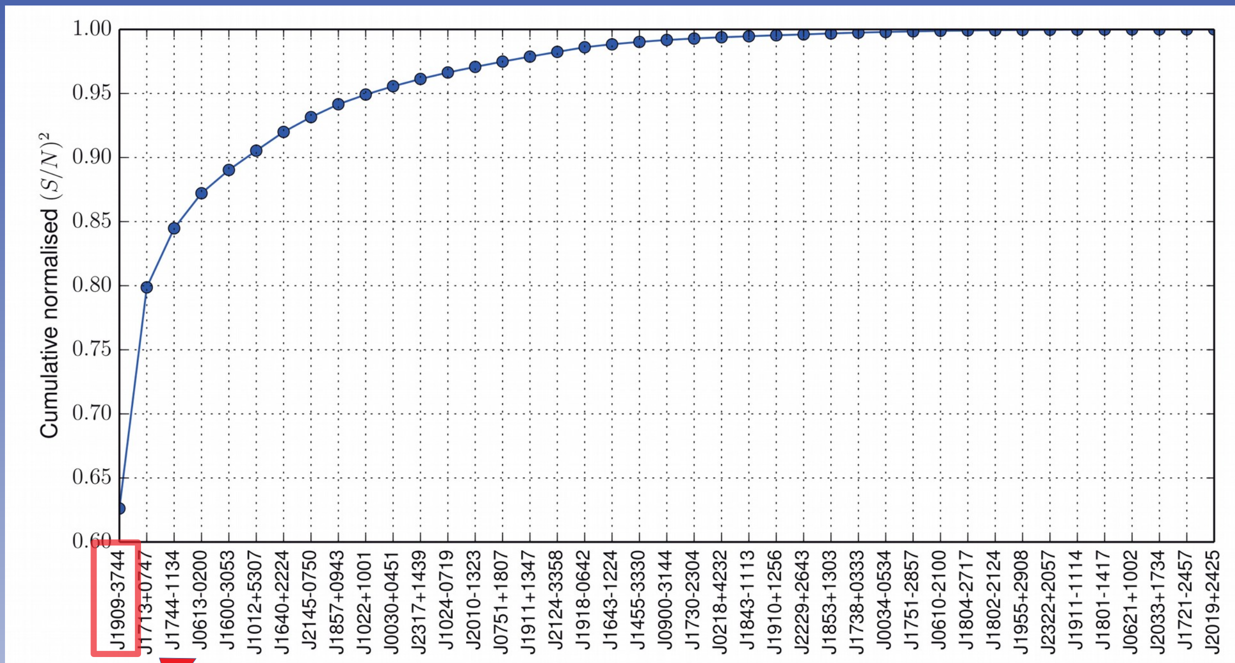
... choosing good pulsars

... with a good receiver

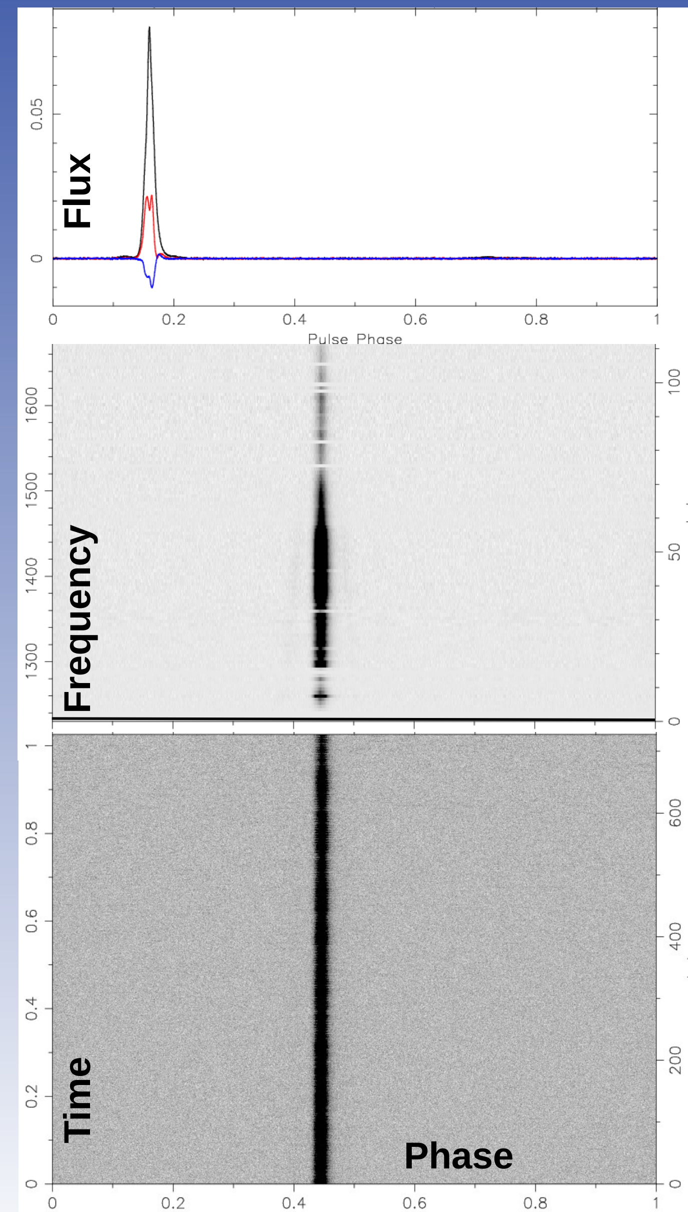
σ_{TOA} ~ 100 ns

PSR J1909-3744 – ID card

Discovered in **2003** and observed **weekly** with Nançay Radio Telescope since **2004**



[Babak et al. 2015]



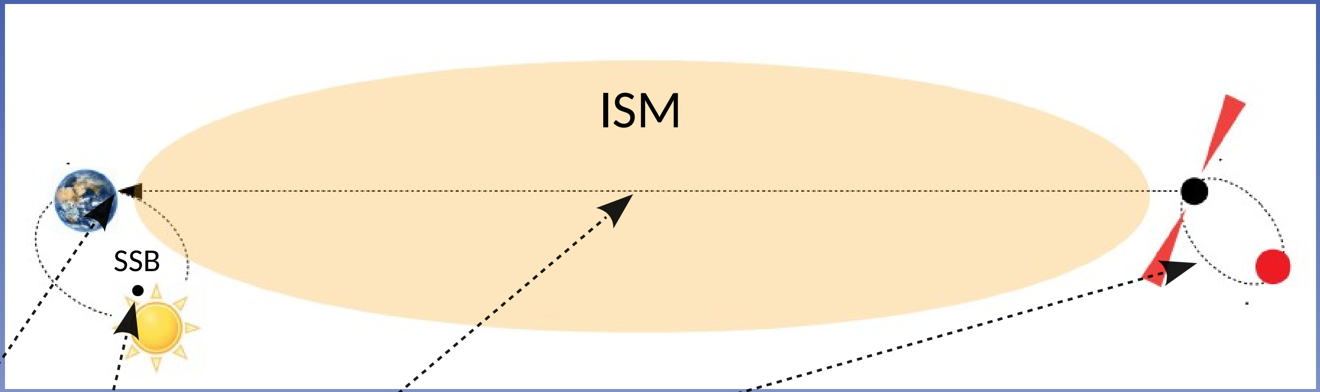
J1909 → Our best timer !

- **Short pulse period : ~2.95 ms**
- **Single narrow sharp peak : FWHM ~ 43 µs** (<1.5%)
- **Low dispersion measure (DM) : ~10.4 pc.cm^{-3}**

- Relatively close MSP (~1 kpc)
- Timed (until now) **only with NRT** in Europe (low dec.)

Timing model procedure

Build a timing model and get residuals



$$t_e^{psr} = t_a^{obs} - \Delta_\odot - \Delta_{\rm ISM} - \Delta_{\rm B}$$

t_e^{psr} : Time of emission from the center of the pulsar

t_a^{obs} : TOA at observatory time after clock correction

$\Delta_\odot$: Transformation to the solar system barycenter (SSB)

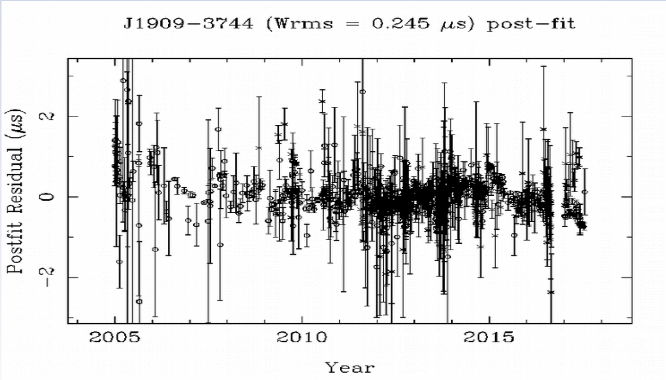
Δ_{ISM} : Transformation to the binary barycenter (dispersion from the ISM)

Δ_B : Transformation to the pulsar proper time of emission

Timing model

- Rotational params
- Astrometric params
- Orbital params
- ISM effects
- Clock correction
- Transformation to the SSB

TOAs – predicted TOAs = Timing residuals



Single pulsar noise analysis procedure

Build a model describing remnant noise in residuals

- **white noise** $\hat{\sigma}^2 = (\mathrm{EFAC} \times \sigma_{TOA})^2 + \mathrm{EQUAD}^2$
- Using correlations :
  - **Red noise** (psr spin noise,...) (PL)
  - **DM variation** (chromatic) (PL)

MCMC sampling in Bayesian frame

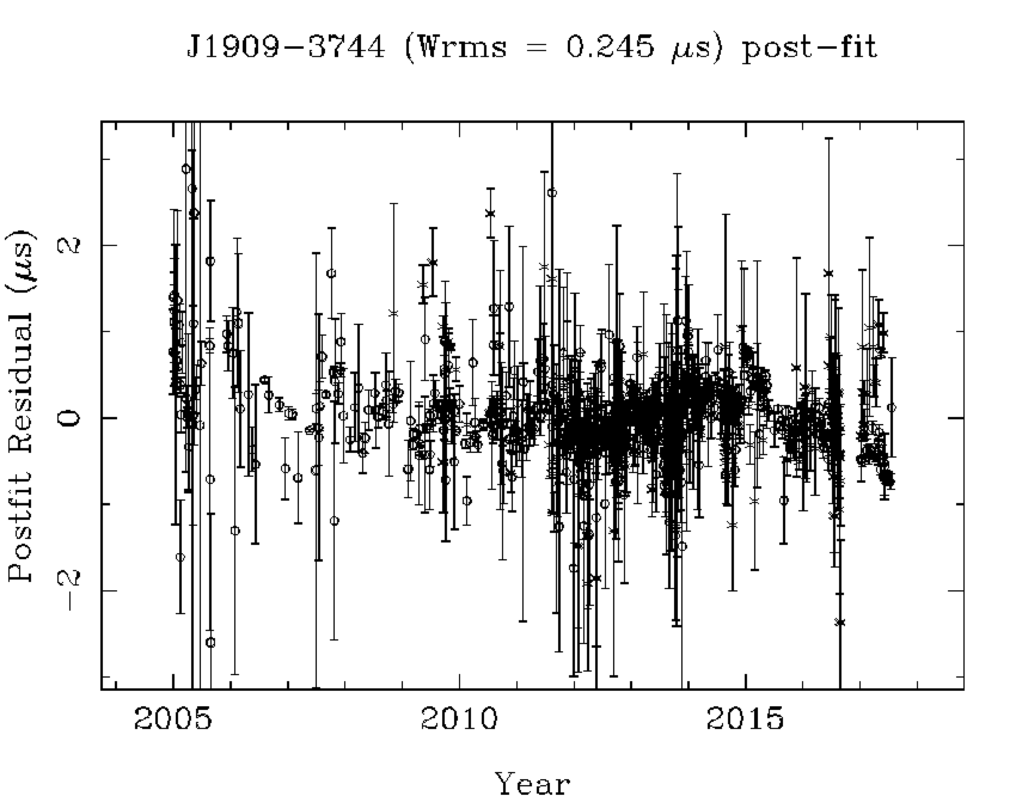
- **Study intrinsic & extrinsic noises**
- **Measure white & red noises**

PSR J1909-3744 – residuals

2 Backends combination

Datasets

- **BON backend data** (Δf : 64 & 128 MHz)
  - ➔ 425 TOAs
  - ➔ 1400, 1600, 2000 MHz
  - ➔ 2004-2014
- **NUPPI backend data** (Δf 512 MHz)
  - ➔ 631 TOAs
  - ➔ 1484, 2154, 2539 MHz
  - 2011-2017

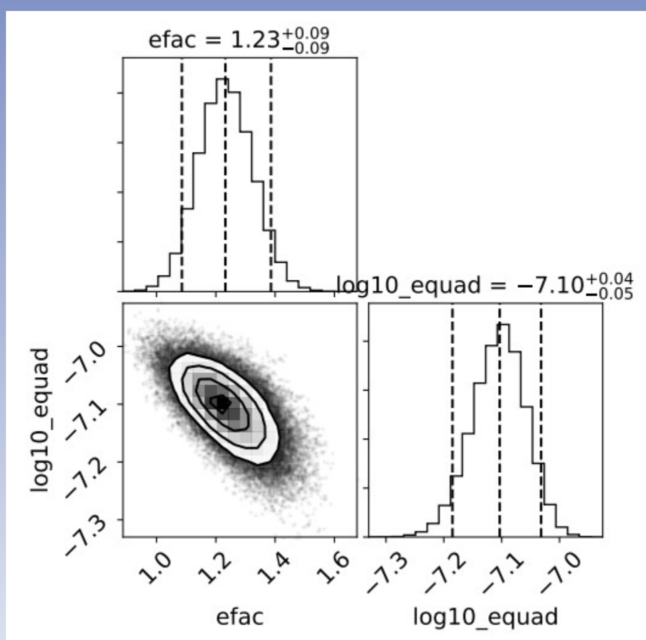


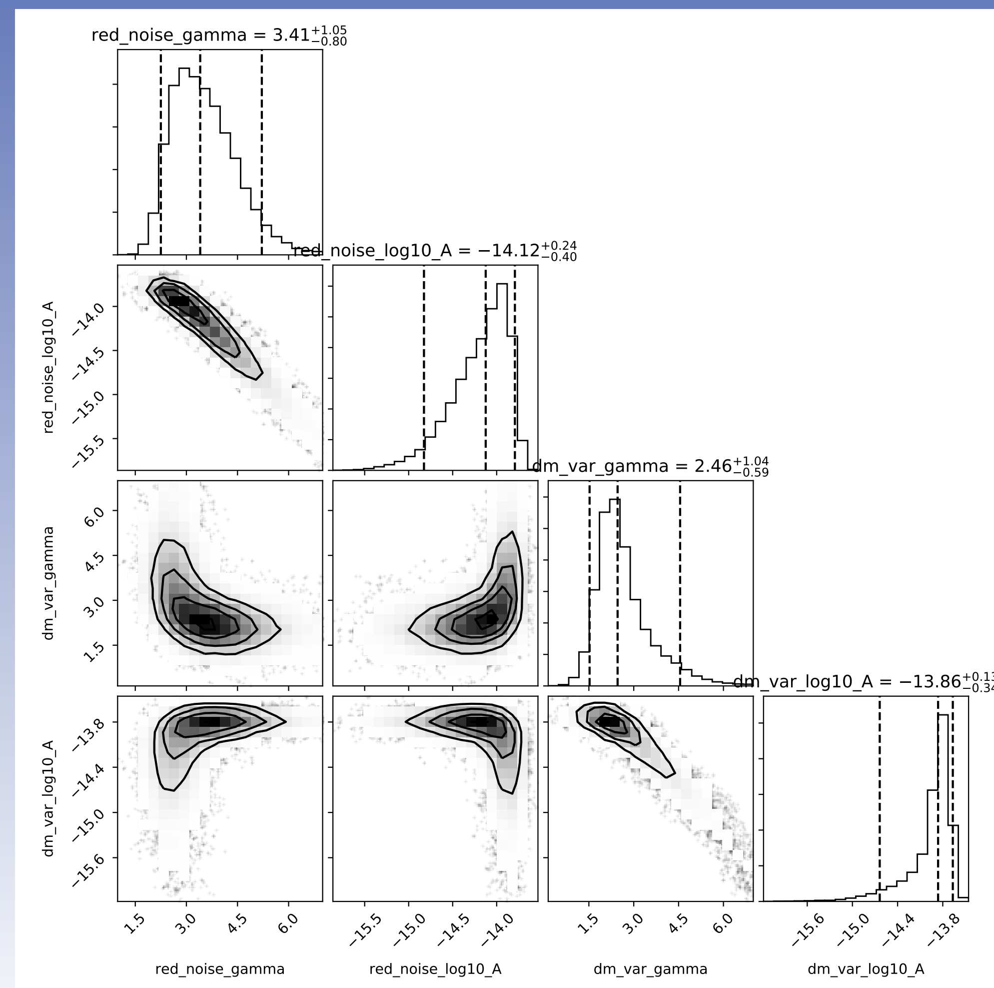
PSR J1909-3744 – Noise analysis

Combined ***NUPPI + BON*** *datasets – PRELIMINARY !*

red noise & **DM variation**

NUPPI 1400 MHz **white noise**

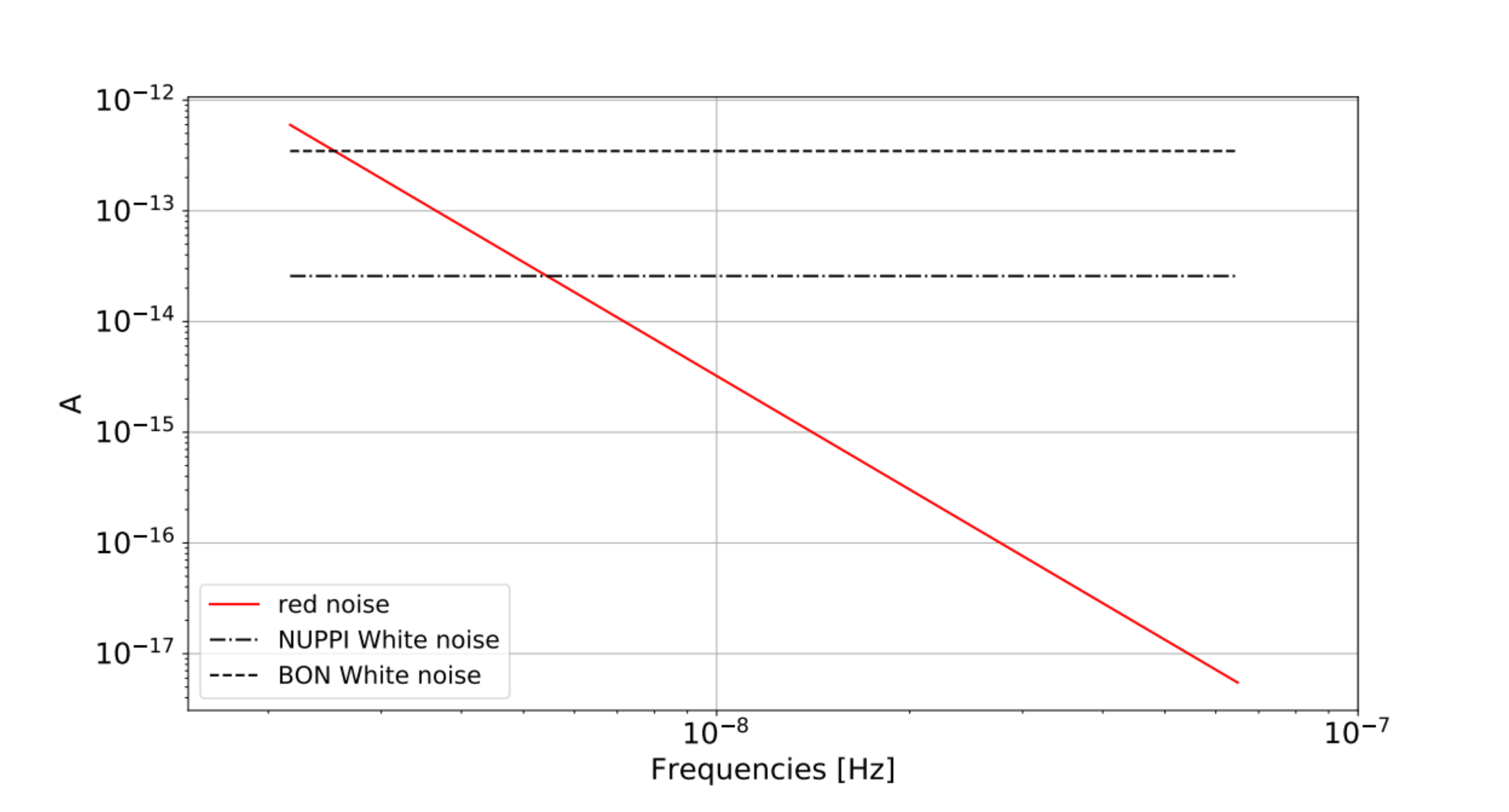




PSR J1909-3744 – Noise analysis

*Combined **NUPPI + BON** datasets – PRELIMINARY !*

Red noise vs. white noise



Conclusions

- Single PSR analysis primordial to understand noises
- Our preliminary result : $A_{RN} \sim 7.15 \times 10^{-15}$
- But TOAs require more attention

- Next steps :
  - → Investigate Wideband template method
  - → Check other models for DM variation

Thank you !