Search for Continuous Gravitational Wave signal with Pulsar Timing Array

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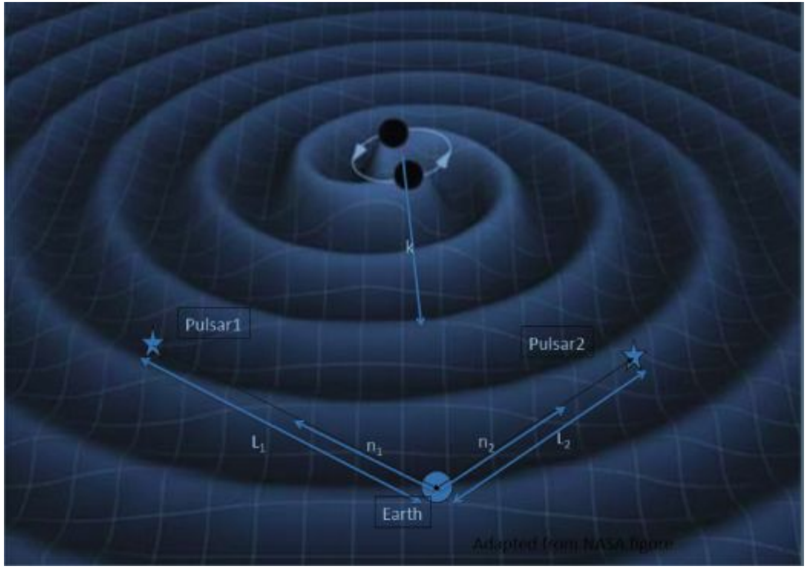
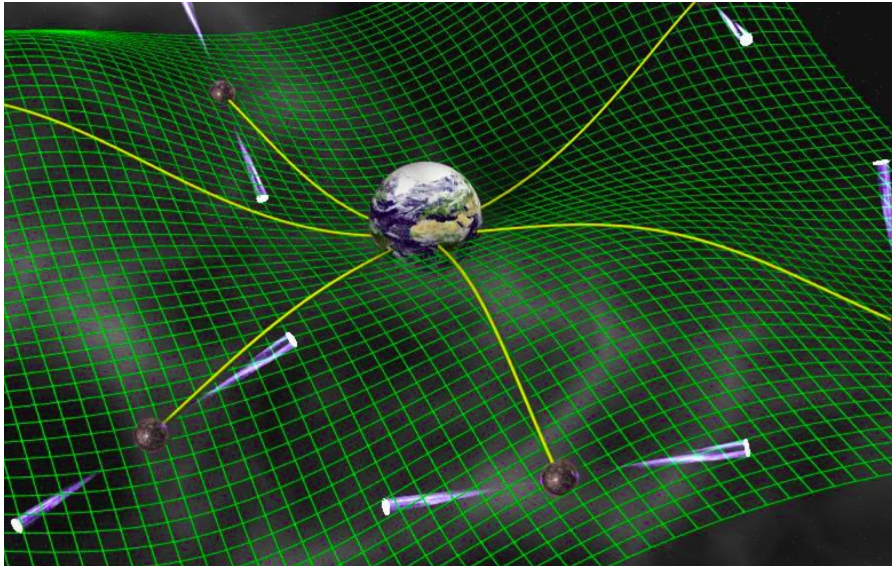
The Pulsar Timing Array (PTA)

- **Millisecond pulsars** (MSP) are very **stable**
- Used as **clocks** to measure **gravitational wave** signals
- Observed in **radio frequency band**

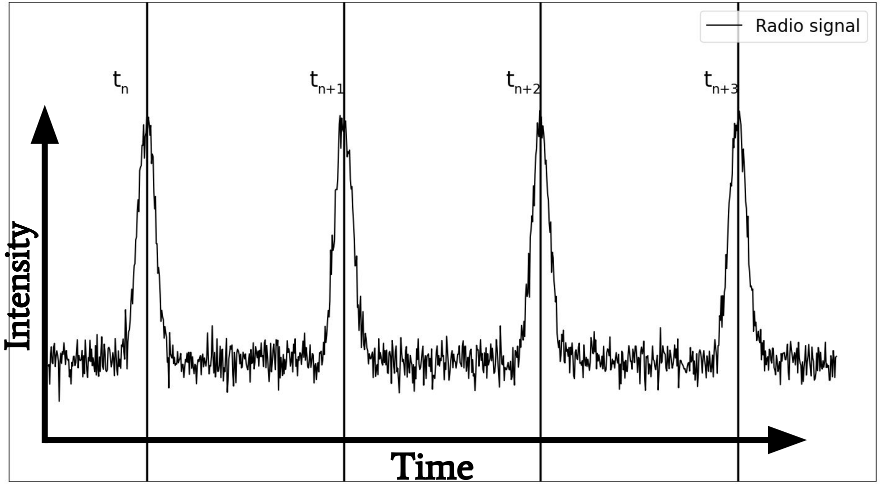




Credits : *Andrea N. Lommen, 2011, arXiv:1112.2158v2*

The Pulsar Timing Array (PTA)

The gravitational wave signal modulates the **time of arrivals** of pulses...



...the measured quantities are the **timing residuals**

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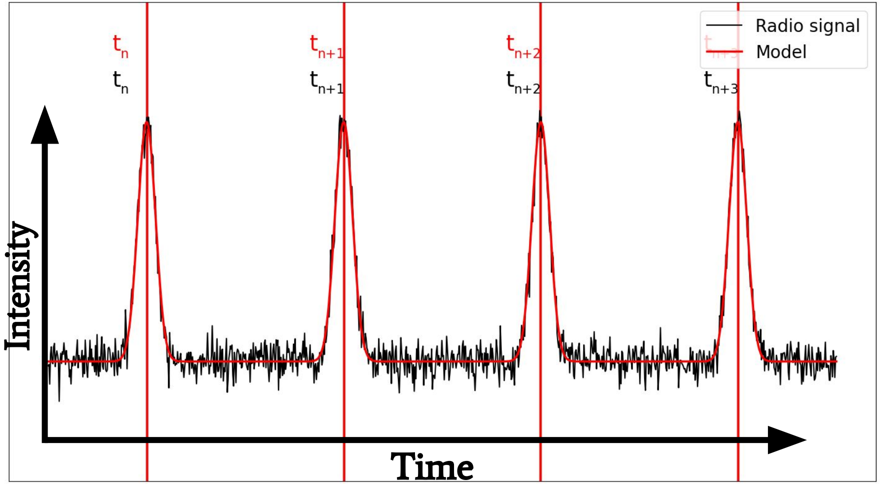

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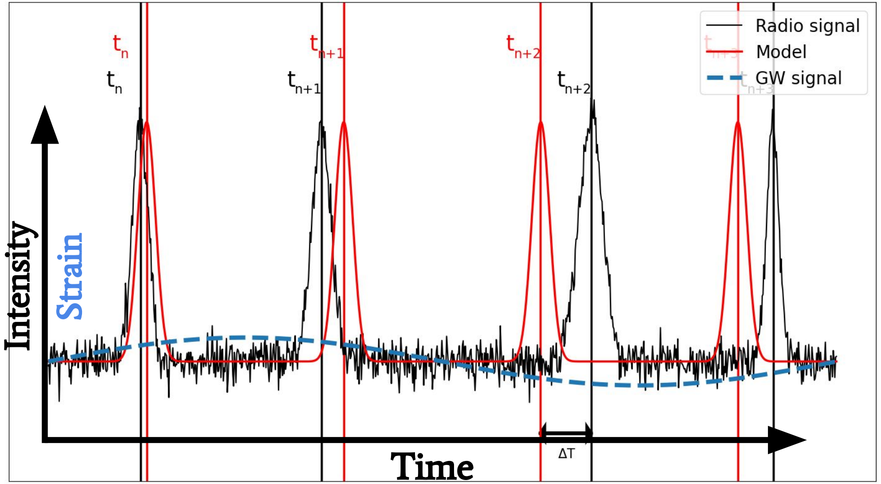

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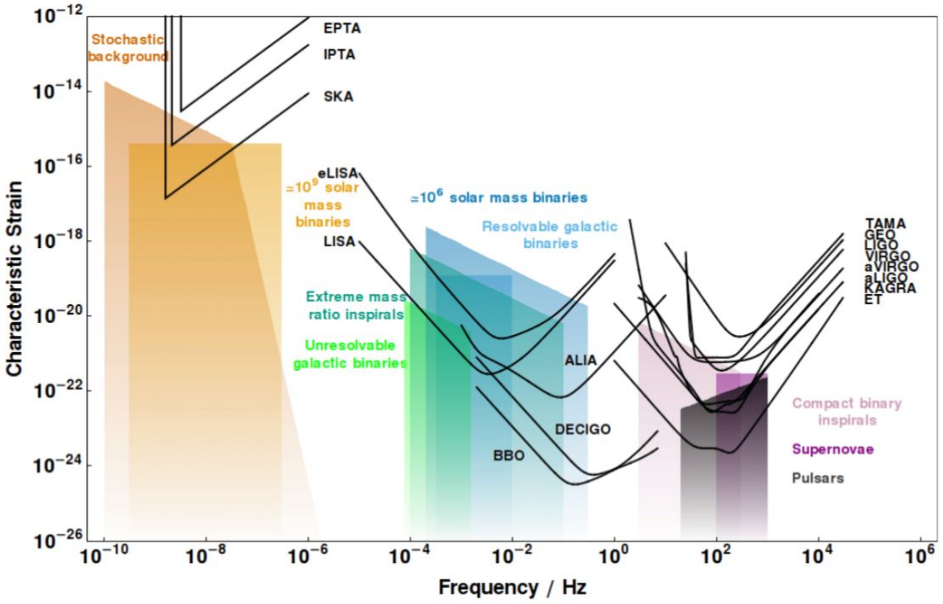
The Pulsar Timing Array (PTA)

Two main categories of signals:

- **Gravitational wave background** (GWB)
- **<u>Continuous waves</u>** (CW)

↳ **Data analysis** for CW detection



Credits : Gravitational-wave sensitivity curves, C J Moore et al., 2014

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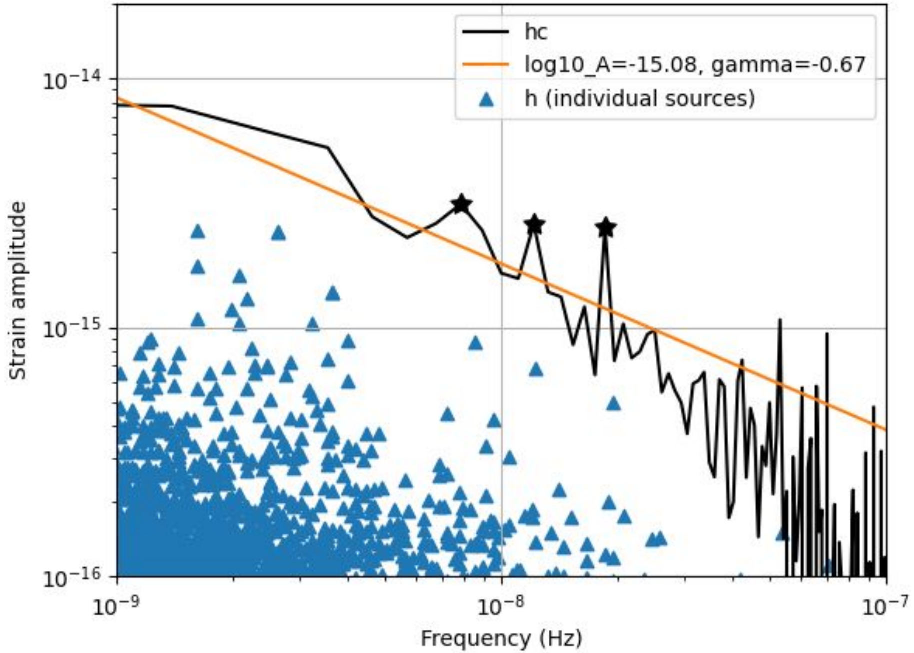

Data analysis

- Build a **model** that takes into account all possible **noise components**
- Main **noise** components: **white** noise, **red** noise, **dispersion variation** noise
- Modelled as **gaussian process**, encoded in the **covariance matrix Σ**
- **Bayesian** analysis

Likelihood:

$$p(\delta t|\vec{\phi}) = \frac{1}{\sqrt{\det(2\pi\Sigma)}} \exp\left(-\frac{1}{2}\delta t^T \Sigma^{-1} \delta t\right)$$

Residuals:

$$\delta t \rightarrow \delta t - \sum_{i=1}^{N_{\text{signals}}} s_i(\vec{\lambda}_i)$$

→ Continuous waves

Data analysis

$$\Sigma^{\alpha} = \sigma^2_{\alpha,WN}\delta_{ij} + \Sigma^{\alpha}_{RN} + \Sigma^{\alpha}_{DM}(+\Sigma^{\alpha\beta}_{GW})$$

White noise : measurement errors (radiometer noise) + systematics

$$S_{WN} = \sigma^2\delta(f - f')$$

Red noise : low frequency noise on pulsar rotation

$$S_{RN} = A_{RN} f^{-\gamma_{RN}}$$

Dispersion noise : dispersion due to propagation through interstellar medium

$$S_{DM} = (\frac{K_{DM}}{\nu^2}) A_{DM} f^{-\gamma_{DM}}$$

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Data analysis

Stochastic Gravitational Wave Background : noise term, correlated across pulsars in array

$$S_{GW} = \Gamma_{\alpha\beta} A_{GW} f^{-\gamma_{GW}}$$

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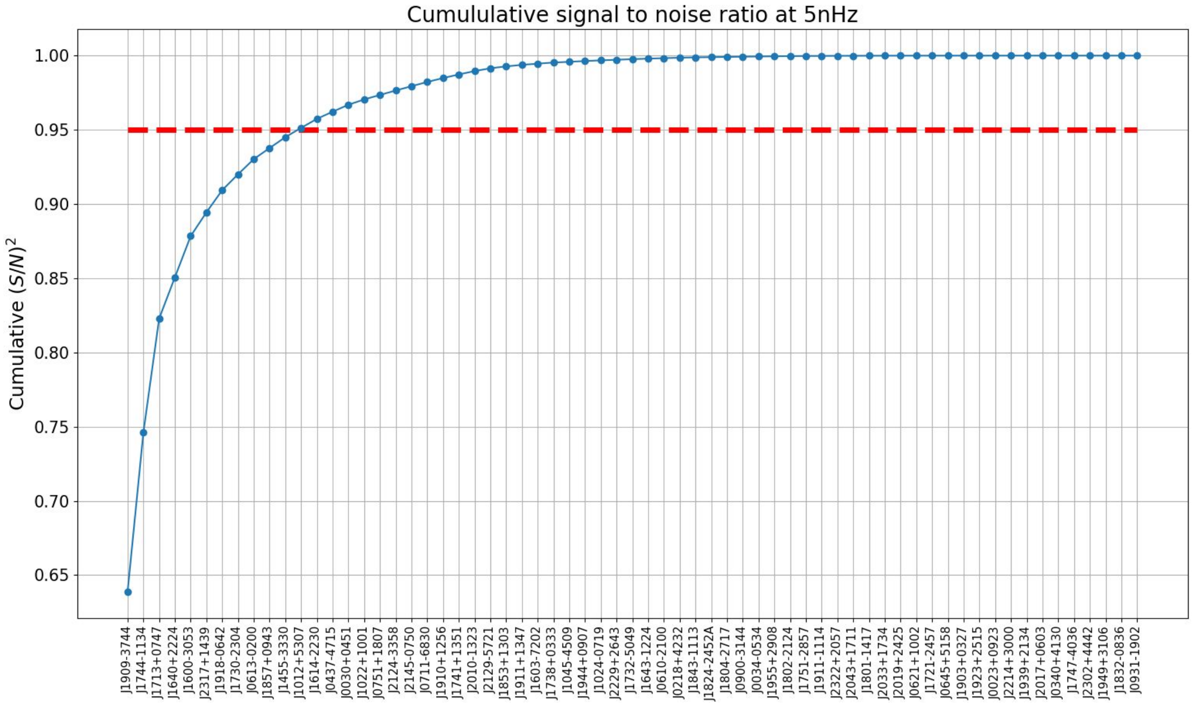
Ranking

- Study on **IPTA DR2** data, **65 pulsars**, combining data from **worldwide collaborations**
- We **inject fake GW** signal to estimate **relative contribution** of each **pulsar** to the **total SNR**



We can express the SNR as :

$$\rho^2 \propto \frac{h^2}{\pi^2 f_{gw}^2} \langle s|s \rangle_{\phi_0, i, \psi, \theta, \phi}$$

with : $\langle s|s \rangle = s^T \Sigma^{-1} s$

the **covariance matrix** is a **function** of **model parameters**, we use **maximum likelihood** parameter values for ranking

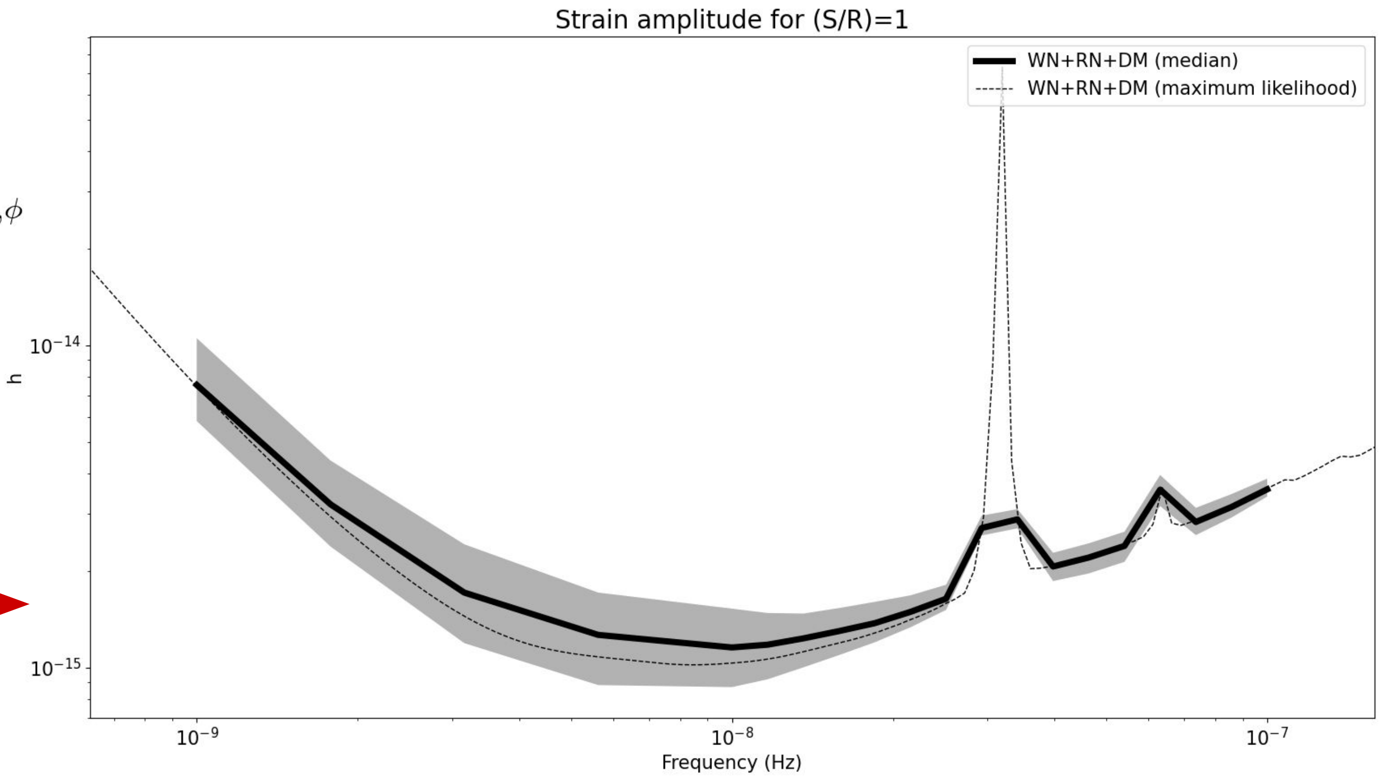
Sensitivity curves

Given the previous expression, we have :

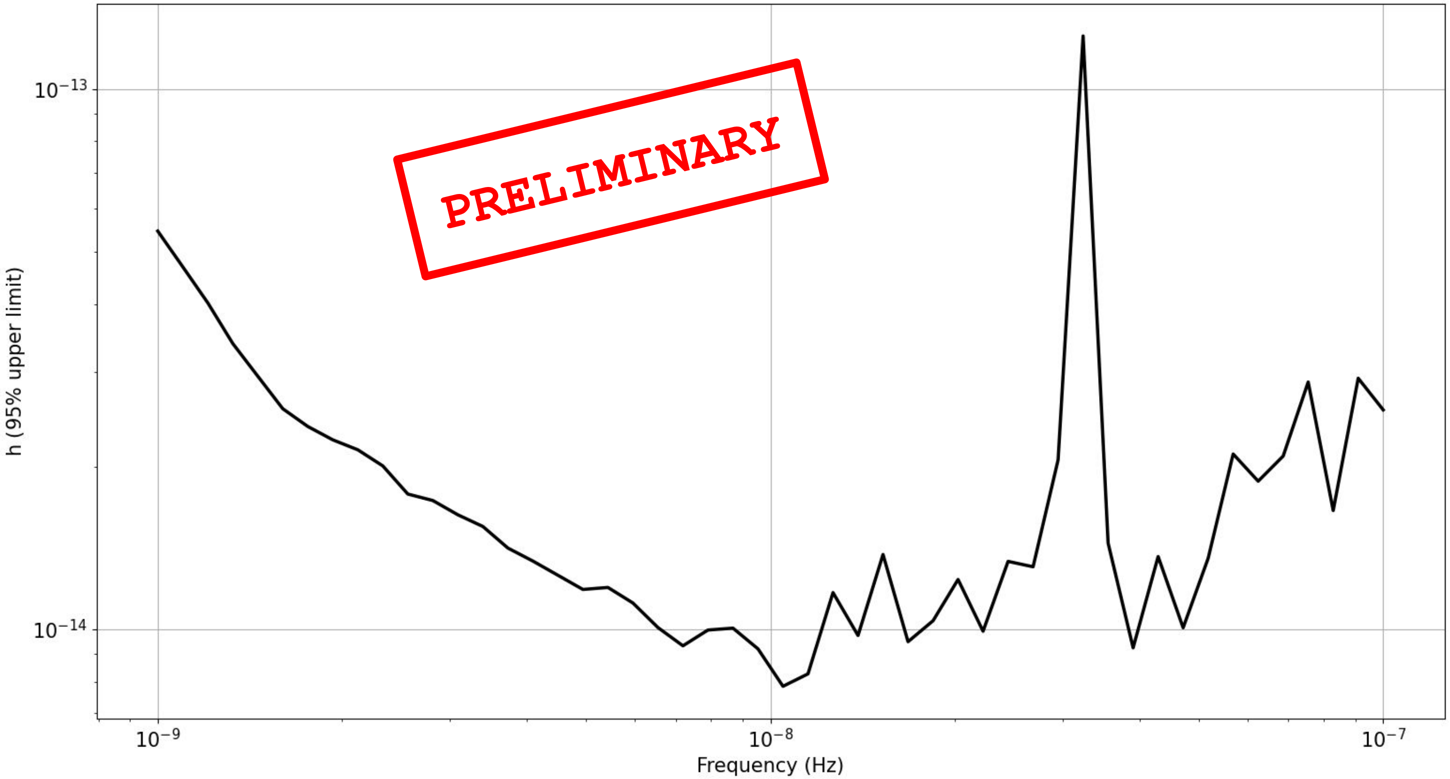
$$\rho^2 \propto \frac{h^2}{\pi^2 f_{gw}^2} \langle s|s \rangle_{\phi_0,i,\psi,\theta,\phi}$$

$$h^2 \propto \frac{\rho^2 \pi^2 f_{gw}^2}{\langle s|s \rangle_{\phi_0,i,\psi,\theta,\phi}}$$

$$\rho^2 = 1$$



95% upper limit on strain amplitude for CW



Summary

- The **PTA collaboration** aims to **detect low frequency GW** signals in the **nHz band**
- We perform **search for continuous GWs** standing **above stochastic signal** (possible **nearby SMBHB**)
- **Ranking** allows to **reduce computational cost** by selecting pulsar wich contribute **(on average) 95%** of **total SNR**: **reduction** in **number of fitting parameters without significant loss in detectability**
- Preliminary results **do not indicate presence of continuous GW** signal: setting **upper limit** on GW amplitude
- **IPTA data** is most **sensitive** around **10 nHz** where $\mathbf{h_{95\%} \sim 7.8\ 10^{-15}}$

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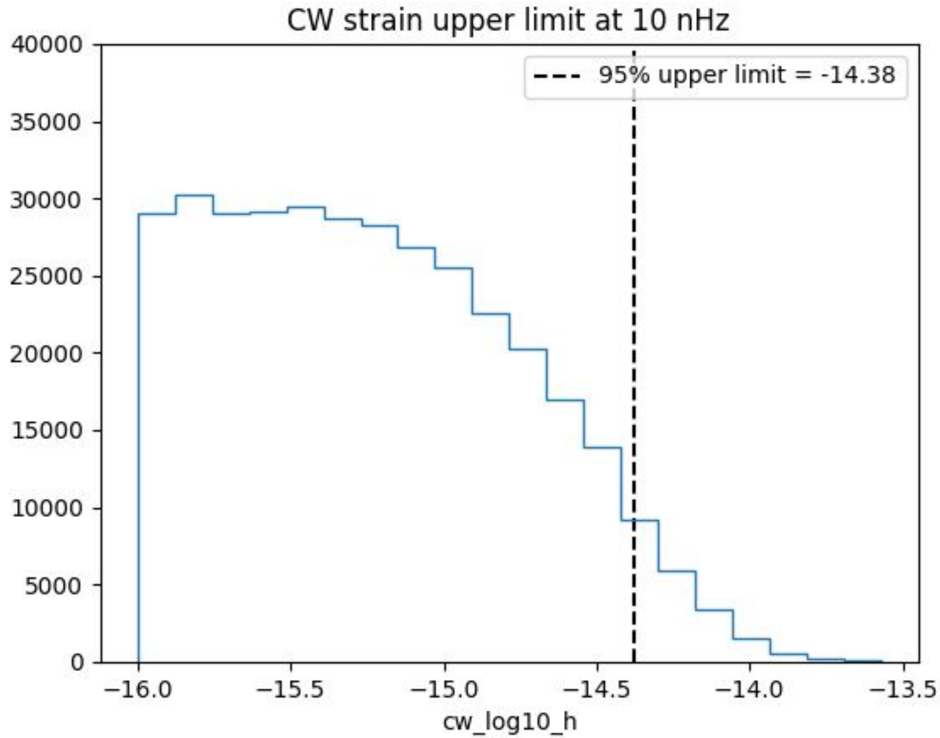

- The **95% upper limit** is computed by **integration** of the **posterior probability distribution** of our **strain amplitude** parameter
- These posterior probability distributions are obtained with **Monte Carlo Markov Chain** (MCMC) algorithms