

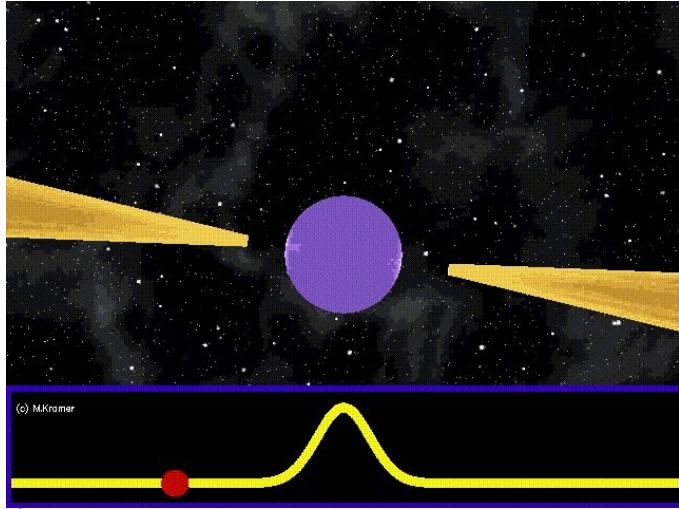


PINPOINTING PULSAR TIMING ARRAY *SINGLE SOURCES*

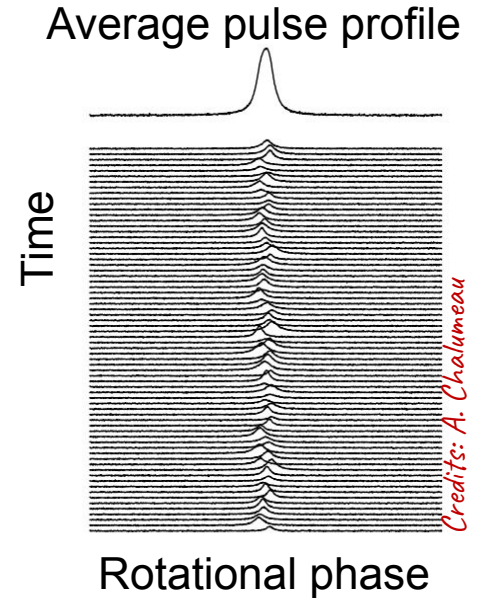
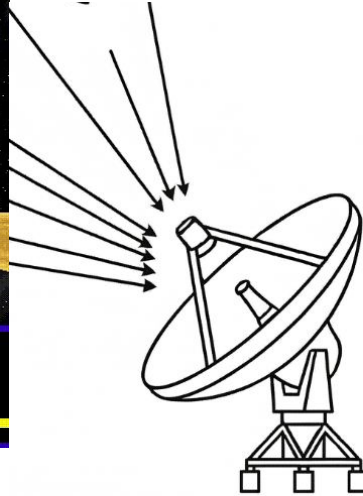
Mikel Falxa
Alberto Sesana



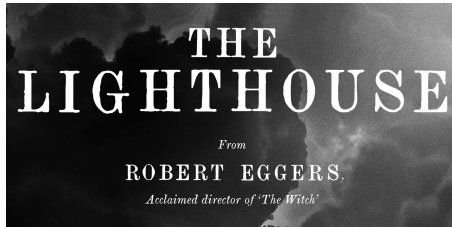
PULSAR TIMING ARRAY



Credits: M. Kramer



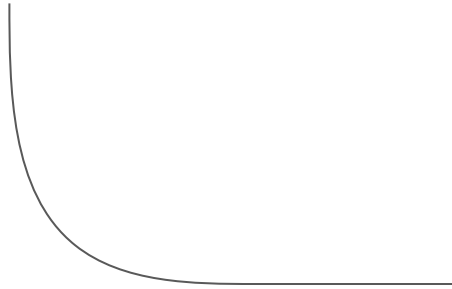
Credits: A. Chalumeau



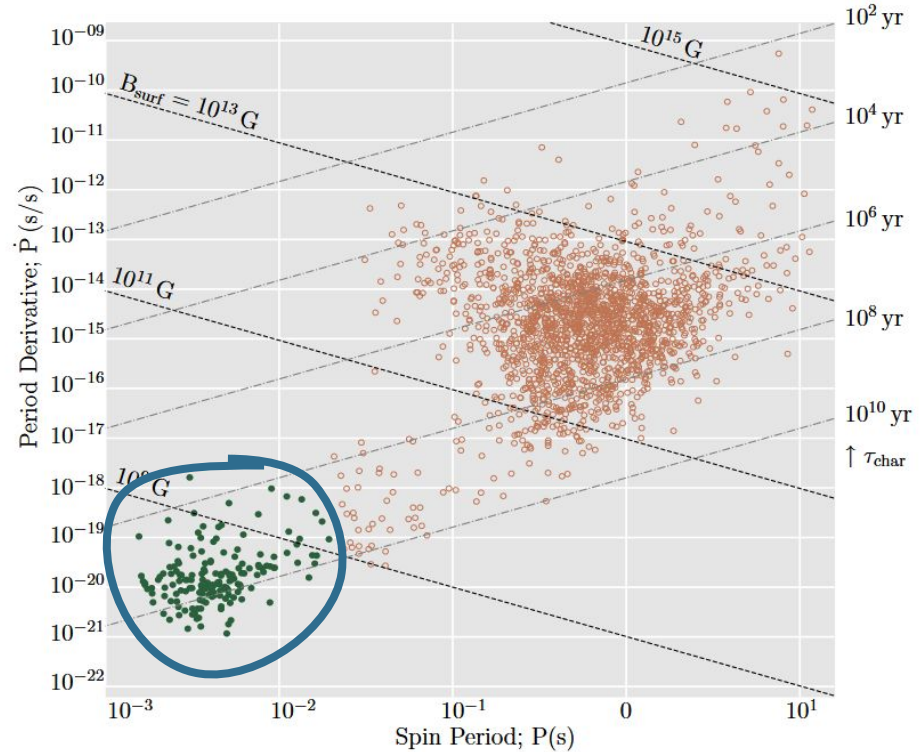
effect

PULSAR TIMING ARRAY

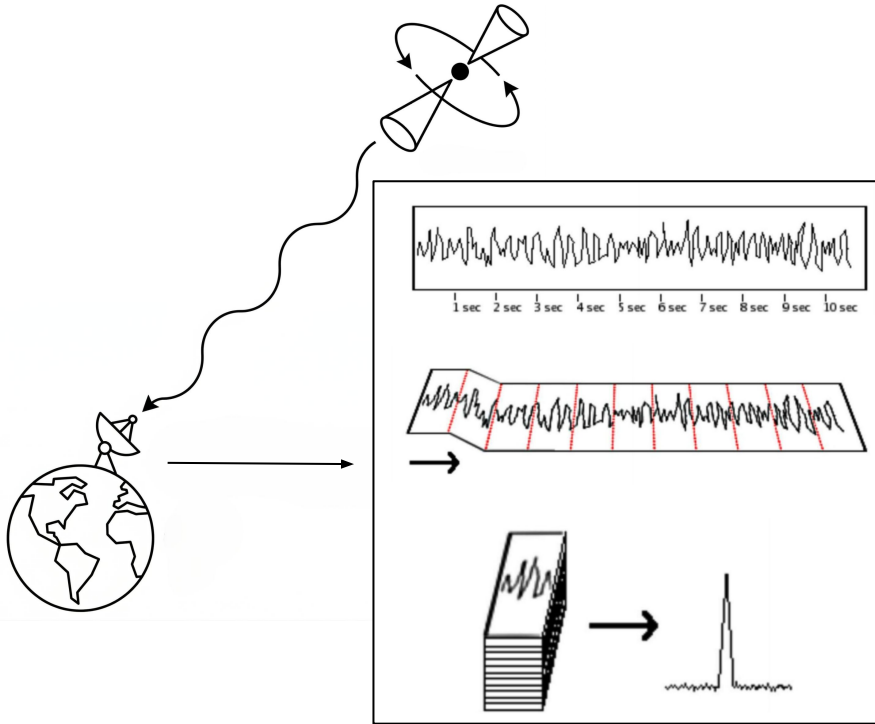
- Jocelyn Bell Burnell 1967
- Period < 30 ms
- Very stable



Verbiest and Shaifullah 2018



PULSAR TIMING ARRAY

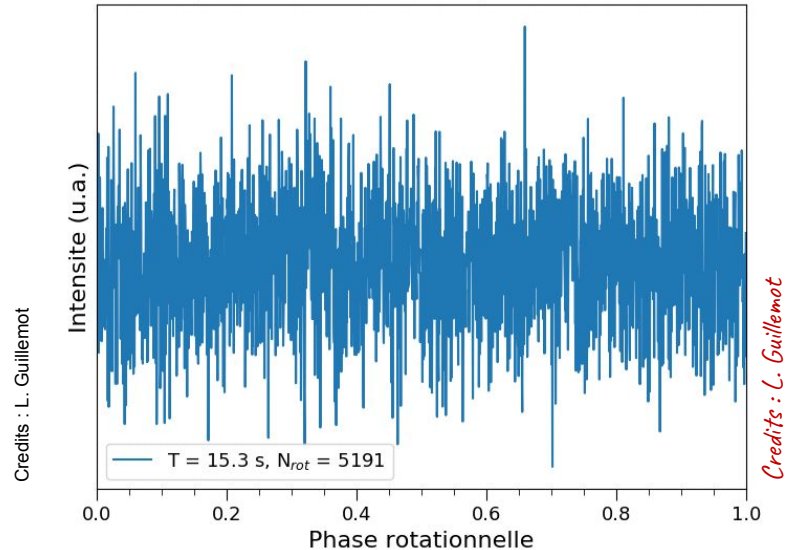


credits: McKee talk @ IPTA Student Week 2019

Pulse Folding

average pulses from ~ 1 hour
observation to get
average pulse profile

PSR J1909-3744, Nancay, frequency = 1.4 GHz



Credits : L. Guillemot

Credits : L. Guillemot

PULSAR TIMING ARRAY



Observed pulse

t_{TOA}

-

Deterministic timing model

t_{det}

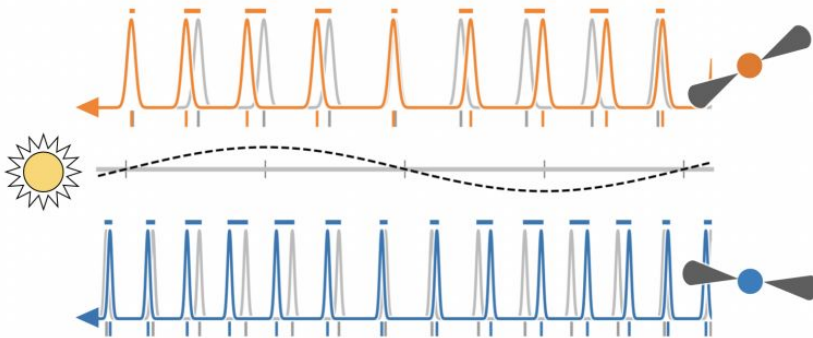
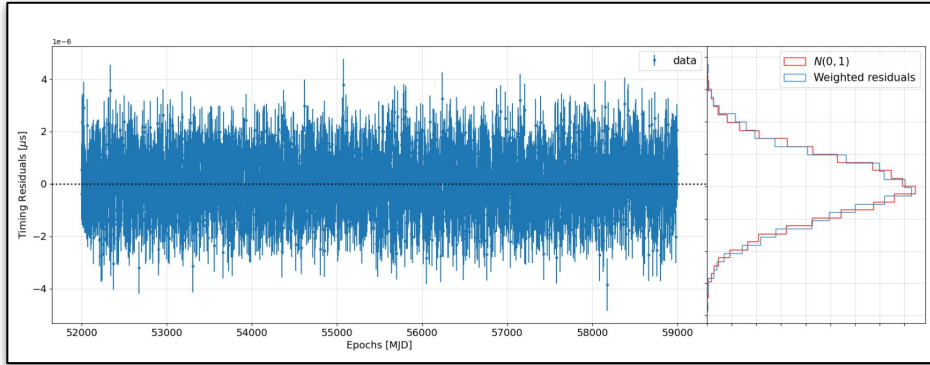
=

Timing Residuals

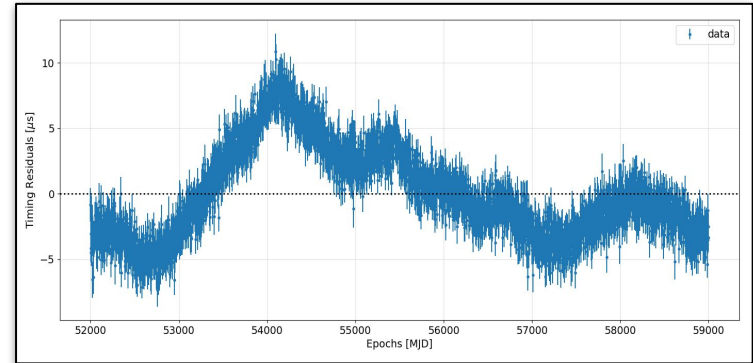
dt

RESIDUALS

if we would know perfectly what's going on



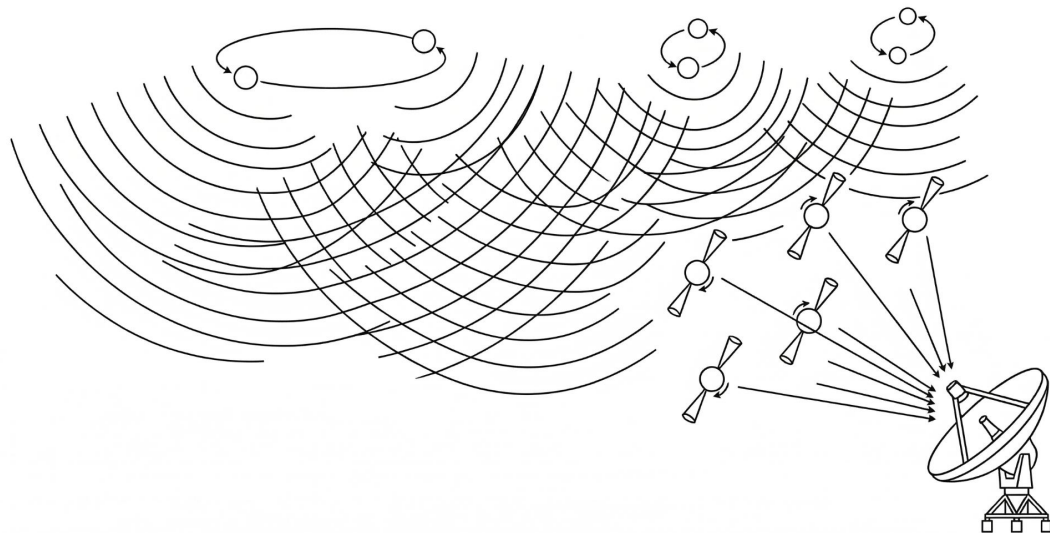
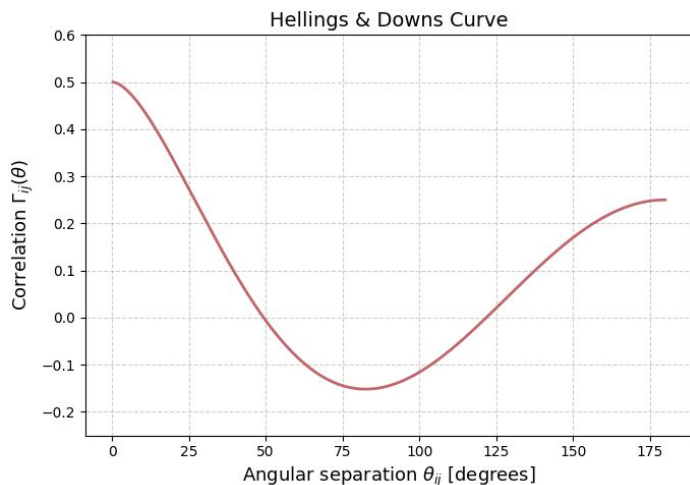
in reality



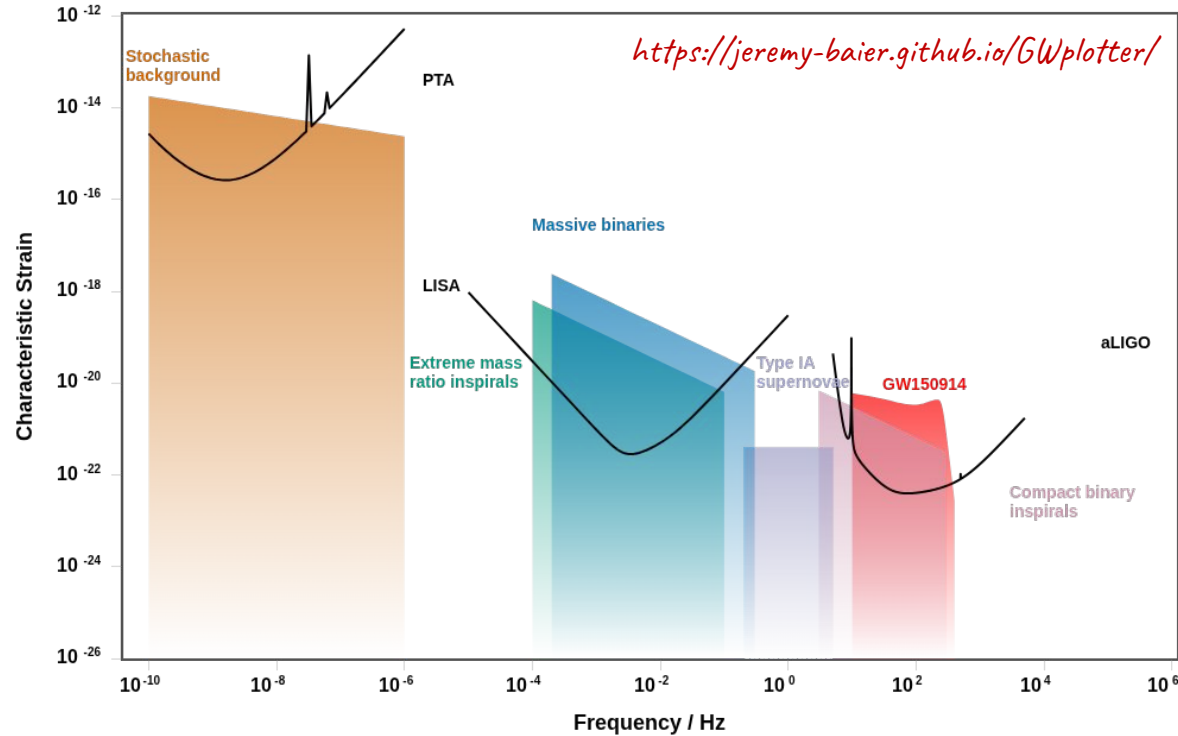
PULSAR TIMING ARRAY

$$h \ll n$$

-> correlate the residuals of an array of pulsars to be sensitive to this weak signal!



PULSAR TIMING ARRAY



THE SIGNALS

*Stochastic GW background
from the superposition of SMBHB*

$$h_c^{\text{SGWB}} \propto f^{-2/3} \text{ Phinney 2001}$$

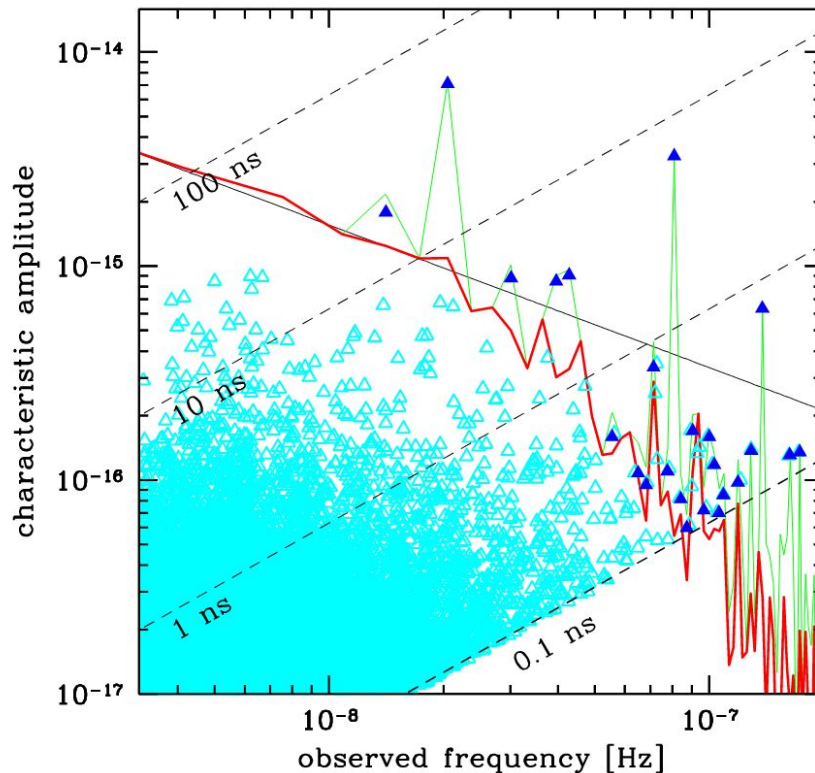
$$\frac{dN}{d \ln f} \propto f^{-8/3}$$

$$h_c \propto h \sqrt{N_{\text{cyc}}} \propto f^{2/3} \sqrt{f T} = f^{7/6}$$

Continuous GW

*seen as an excess of power, they're
bright individual SMBHB*

Credits: Alberto Sesana



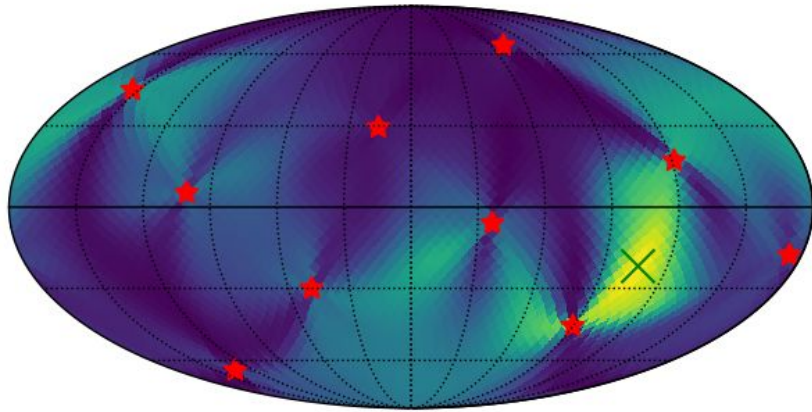
MY PROJECTS - CGWs SEARCH

The model of the CGW signal is analytic and included in the timing residual model. At a given frequency, for a pulsar \mathbf{p} , the delayed arrival rate of the TOAs can be expressed as a convolution with the antenna response function \mathcal{F} of the pulsar:

$$R_{GW,p} = \sum_{A=+,\times} \mathcal{F}_p^A \left[R_p^{\text{Earth}}(t_0) - R_p^{\text{pulsar}}(t_p) \right].$$

MY PROJECTS - CGWs SEARCH

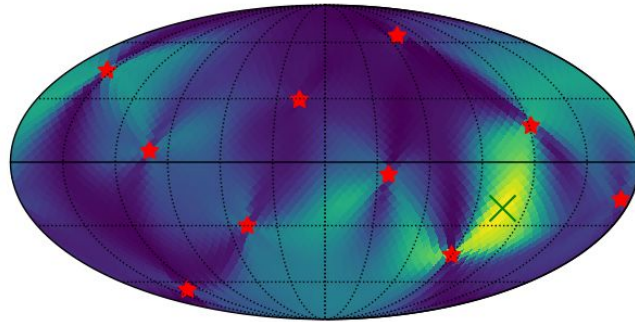
- The *Fe* statistic is a detection method for CGWs in PTA. *Babak and Sesana 2011*
- It's the analytical maximization of the likelihood, over the intrinsic signal parameters at fixed frequency.
- Then it is evaluated for a fixed sky location (θ, ϕ)



- By scanning the sky, one obtains a sky map of *Fe*, highlighting the most likely source positions



MY PROJECTS - CGWs SEARCH



PRO

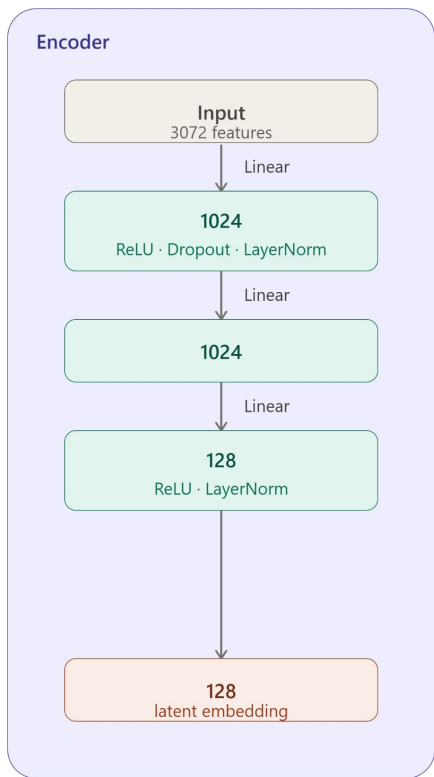
- *Fast to obtain -> now even faster with GPU based code we have 100k maps in less than 3 min*
- *A way to embed the data in a 1D array with N entries*

CONS

- *It "loose" info on the other parameters*
- *It has spurious power due to the antenna pattern functions of the PTA*

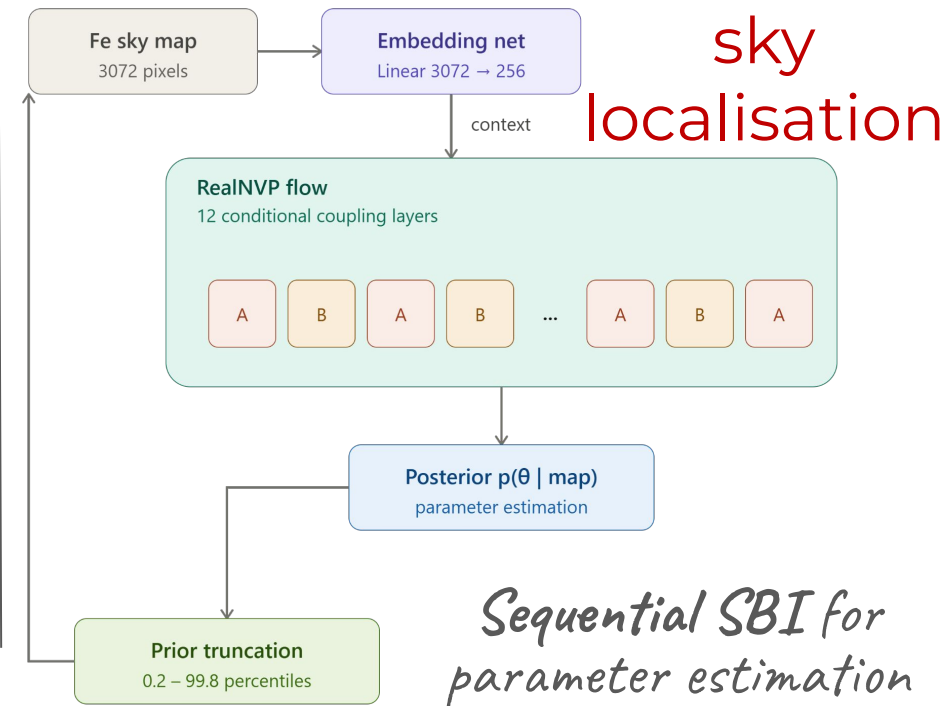
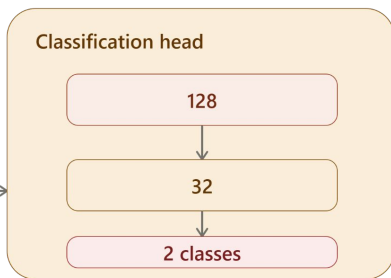
MY PROJECTS - CGWs SEARCH

SIMULATOR ✓



detection

*Classifier to show
if there is a source
and in which
frequency bin*



MY PROJECTS - DETECTOR RESULTS

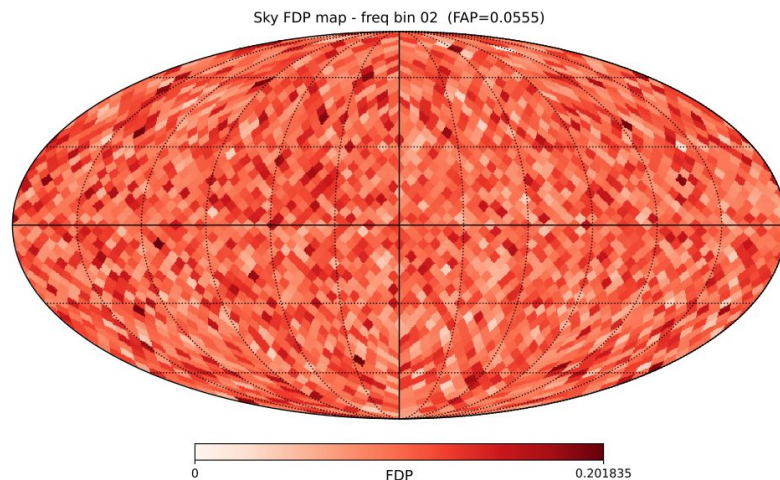
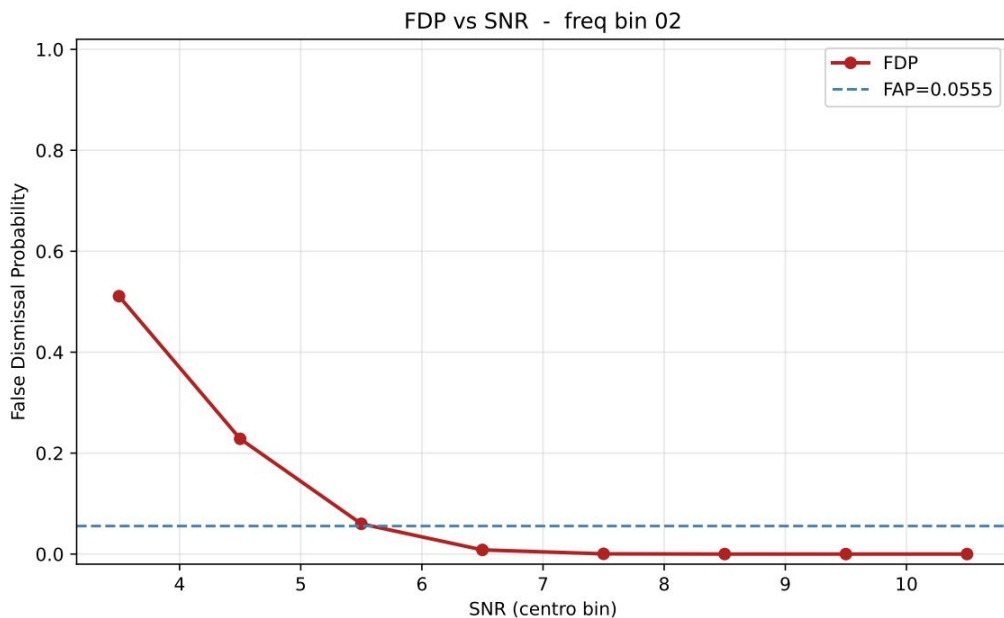
- Simulated PTA 25 pulsars
- Isotropically distributed
- sensitivity 100ns

False Dismissal Probability

$$\text{FDP} = \frac{\text{FN}}{\text{FN} + \text{TP}}$$

False Alarm Probability

$$\text{FAP} = \frac{\text{FP}}{\text{FP} + \text{TN}}$$

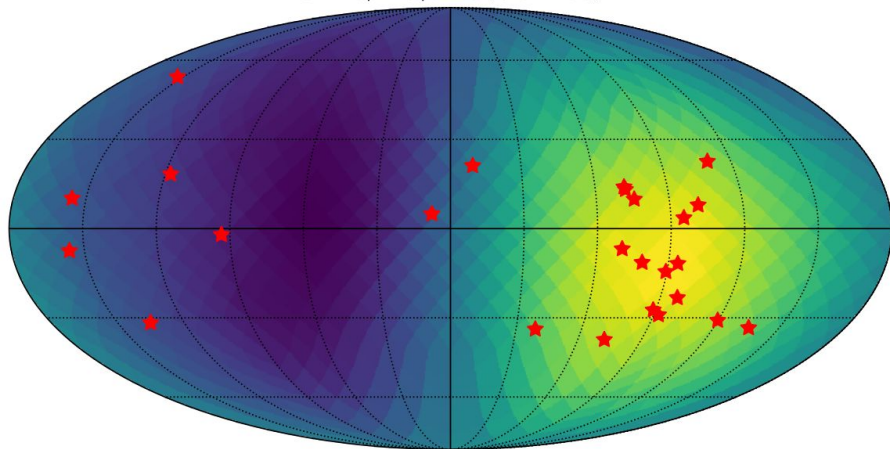


MY PROJECTS - DETECTOR RESULTS

False Dismissal Probability

$$\text{FDP} = \frac{\text{FN}}{\text{FN} + \text{TP}}$$

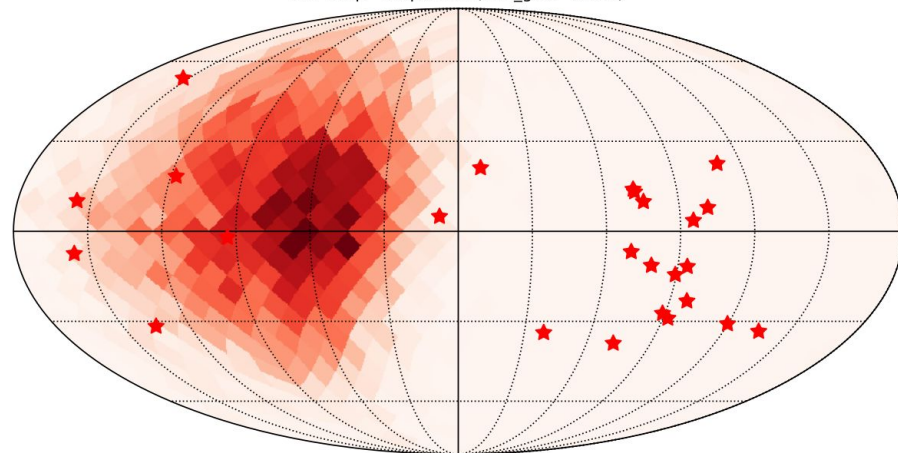
SNR map - freq bin 08 (ref SNR=5.0)



False Alarm Probability

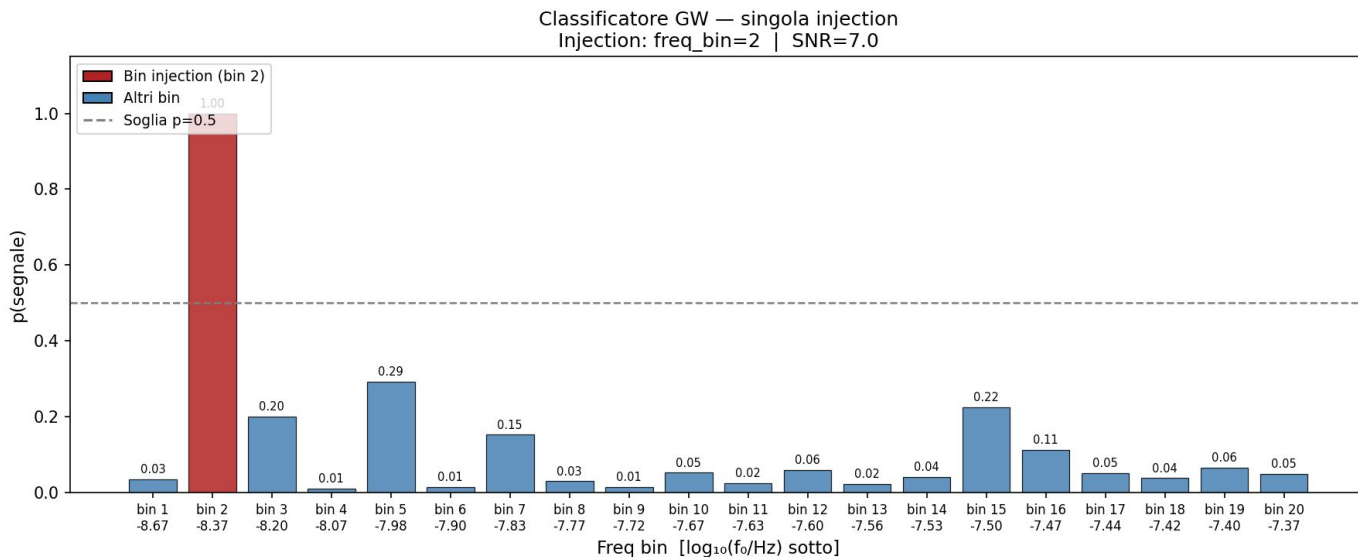
$$\text{FAP} = \frac{\text{FP}}{\text{FP} + \text{TN}}$$

FDP map - freq bin 08 (FDP_glob=0.019)



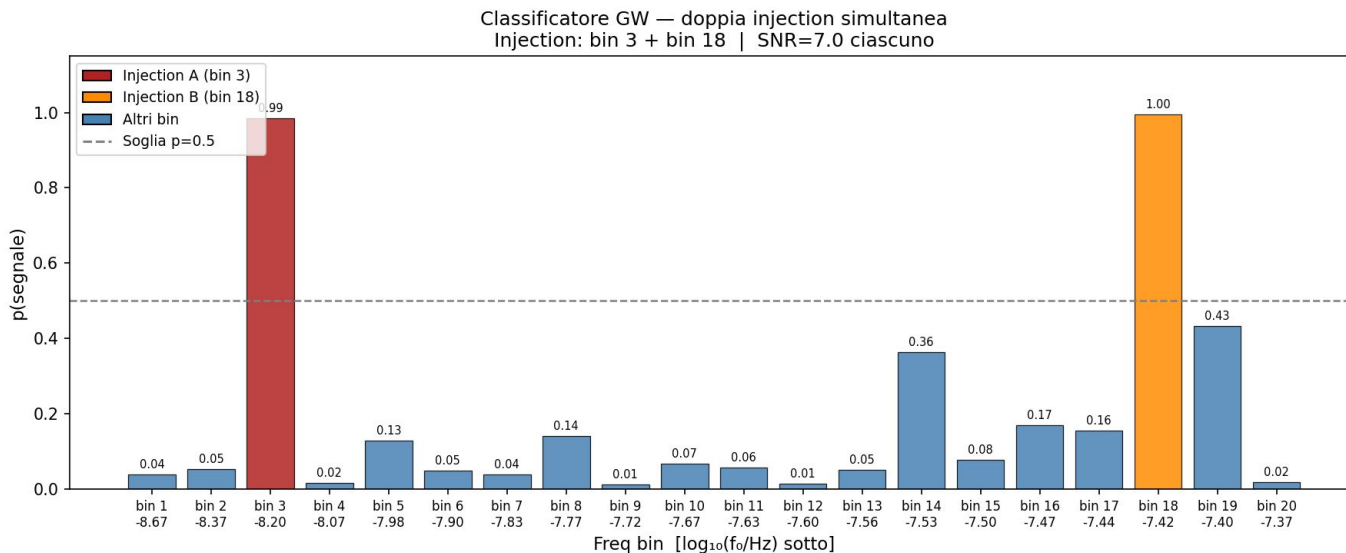
MY PROJECTS - DETECTOR RESULTS

1. You have your **PTA data**
2. You create **one map per frequency bin**
3. You **infer the probability** of having a single source in each freq. bin with the trained NN (1 min inference)



MY PROJECTS - DETECTOR RESULTS

1. You have your **PTA data**
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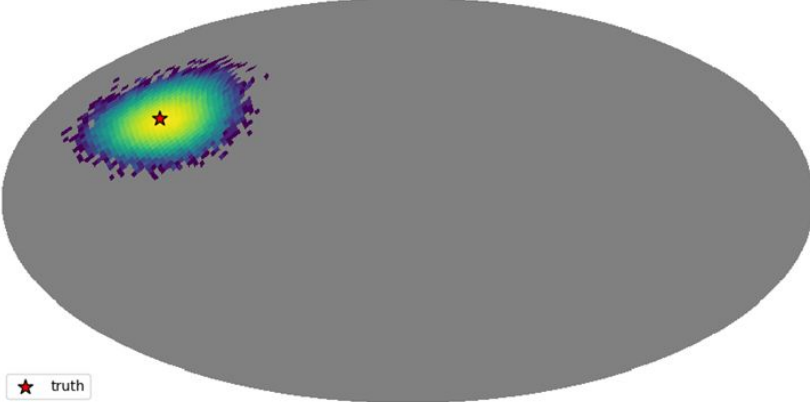
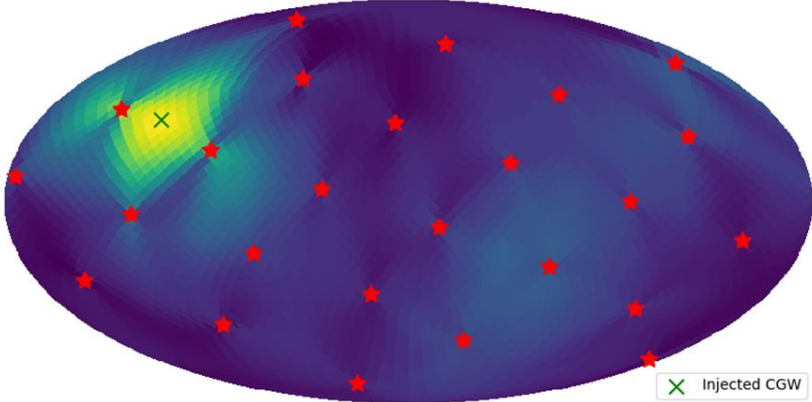


preliminary

MY PROJECTS - SBI RESULTS

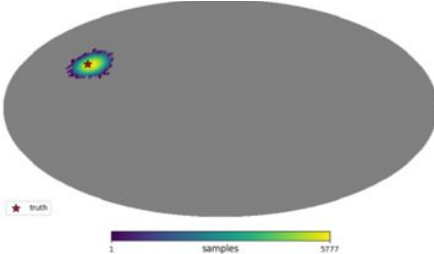
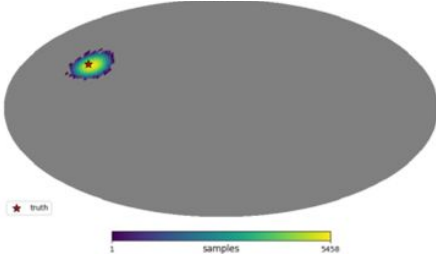
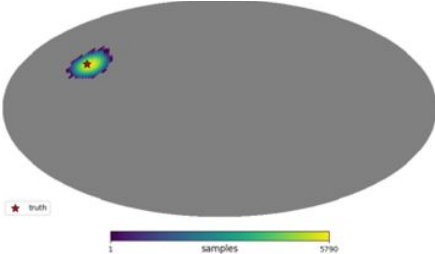
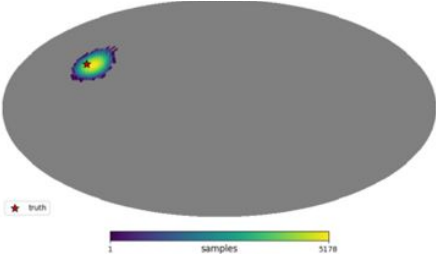
Fe-statistic

Round 1 - 95% Area: 866.67 deg²



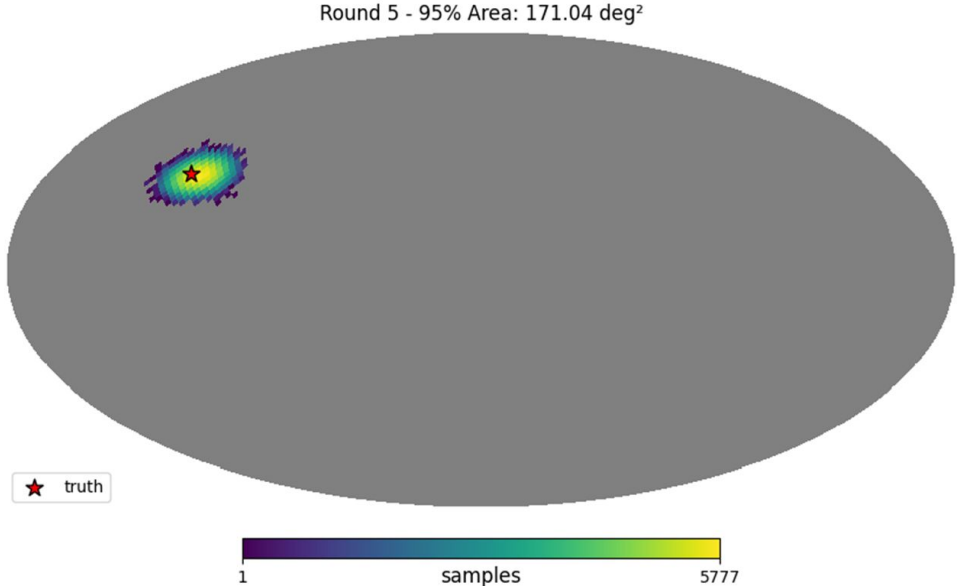
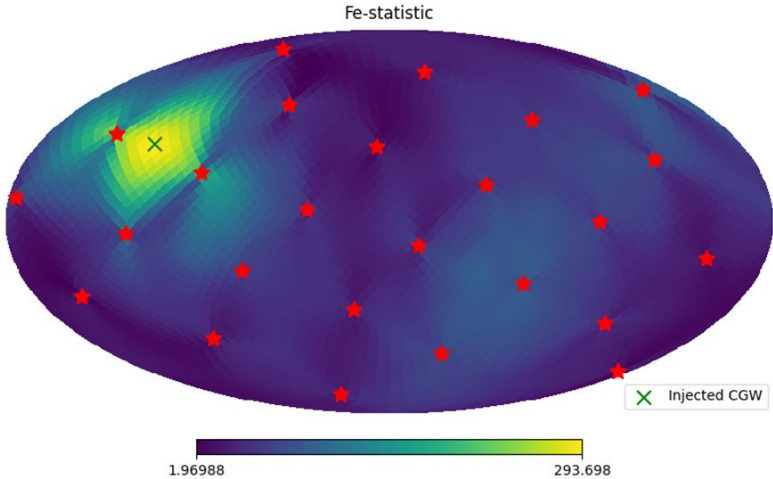
X Injected CGW

★ truth



preliminary

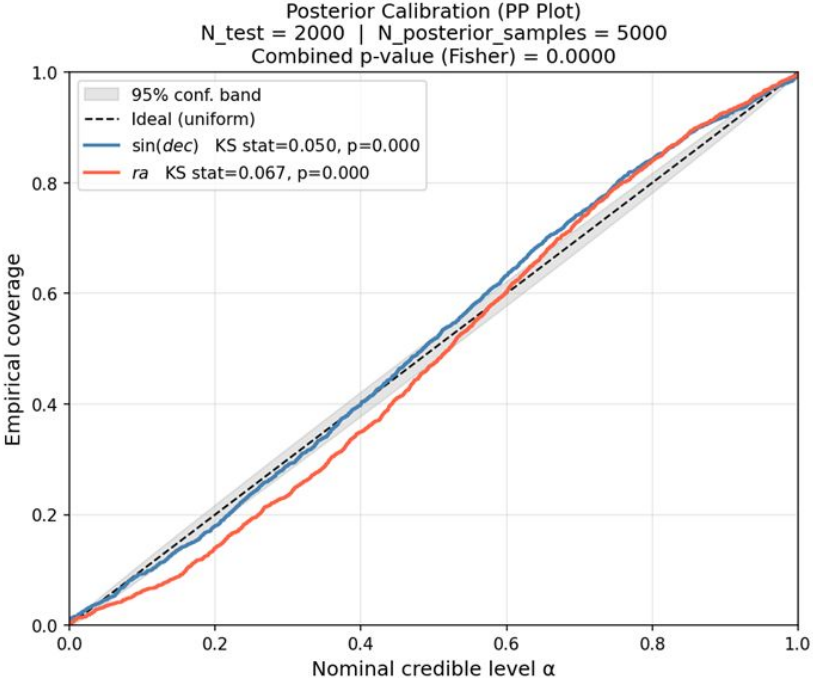
MY PROJECTS - SBI RESULTS



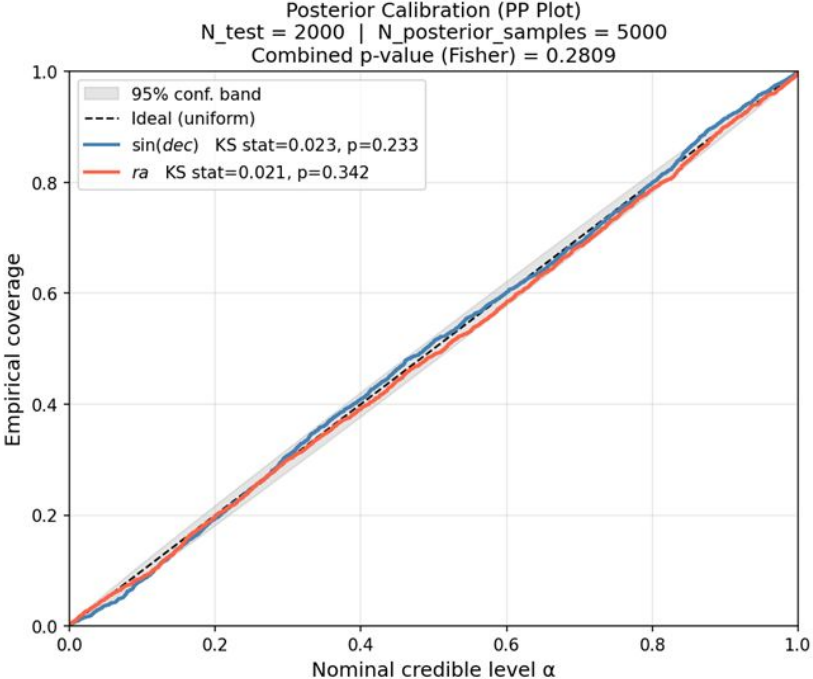


MY PROJECTS - SBI RESULTS

1st round



5th round



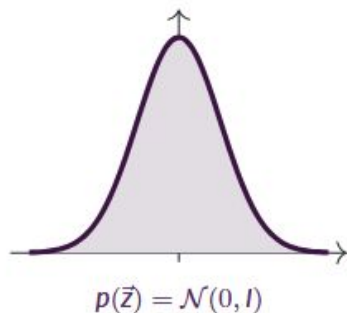
THANK YOUUU!!

Normalizing Flows

Idea

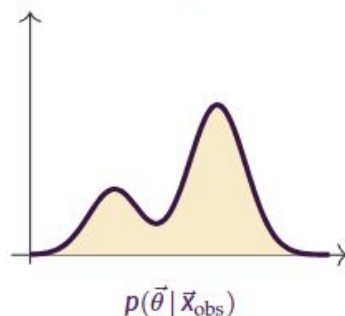
Learn an invertible map $f_\theta : \vec{z} \mapsto \vec{y}$ that transforms a simple base distribution $p(\vec{z})$ (e.g. $\mathcal{N}(0, I)$) into the target posterior $p(\vec{y}|\vec{x})$.

Base distribution



f_θ
invertible

Learned posterior



$$\ln p(\vec{y}|\vec{x}) = \ln p(f^{-1}(\vec{y})) + \ln \left| \det \frac{\partial f^{-1}}{\partial \vec{y}} \right|$$

The flow stretches and compresses the Gaussian until it matches the true posterior shape and the Jacobian determinant accounts for the volume change.

PULSAR TIMING ARRAYS

