

10th of February 2026
Multimessenger Astronomy in the Einstein Telescope Era

Pulsar Timing Arrays

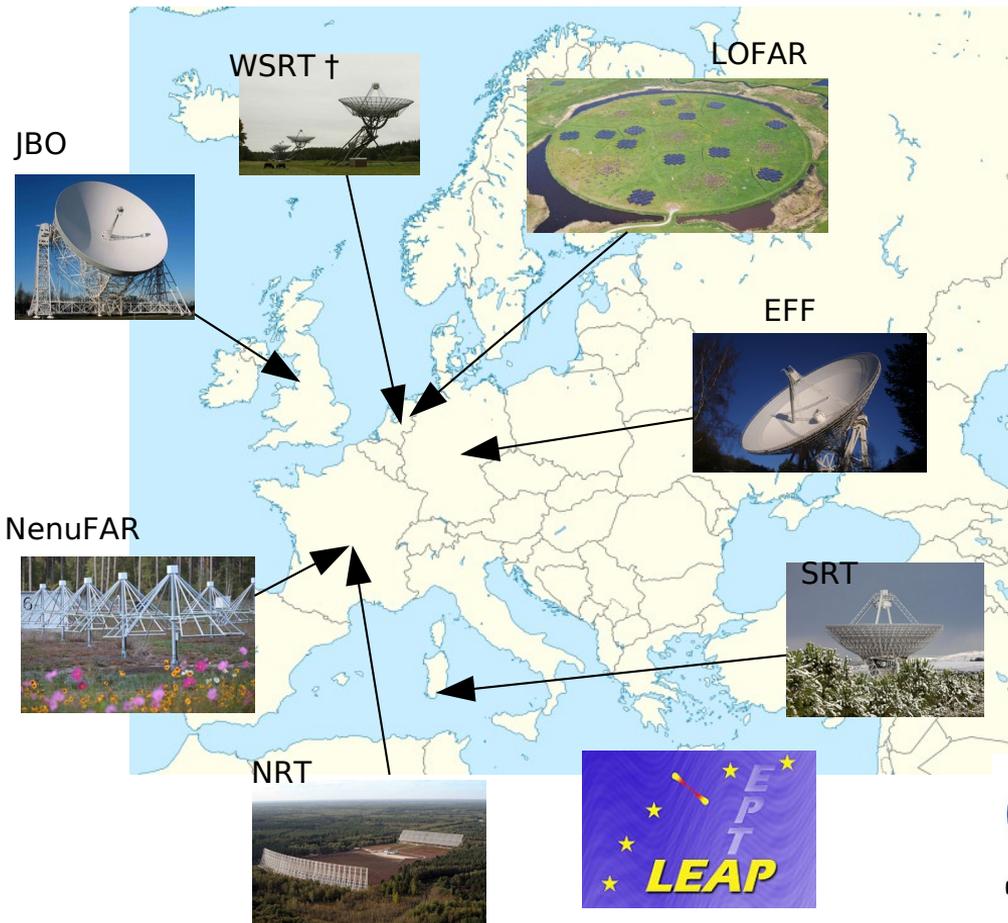
Basics and recent results

C. Tiburzi

INAF



The European Pulsar Timing Array



In Italy:



Milan-Merate



Milan

Cagliari

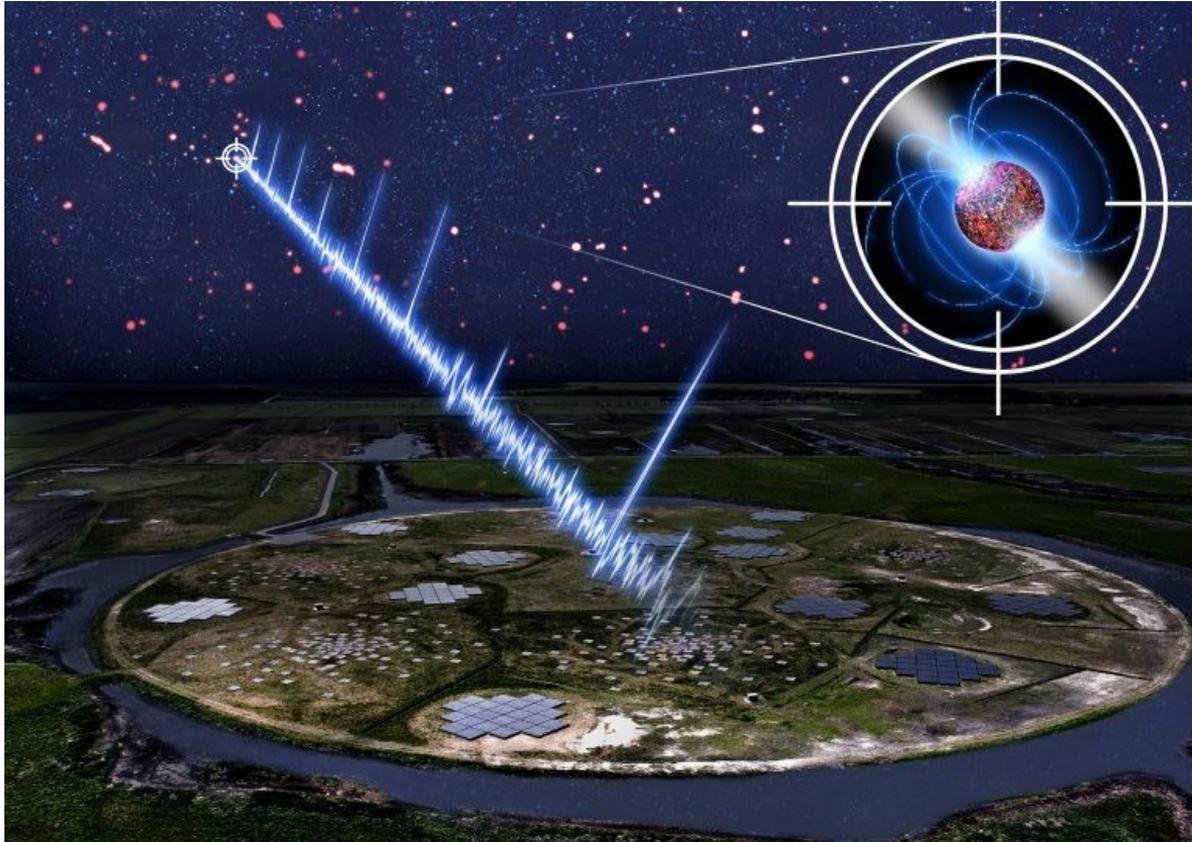


Trieste



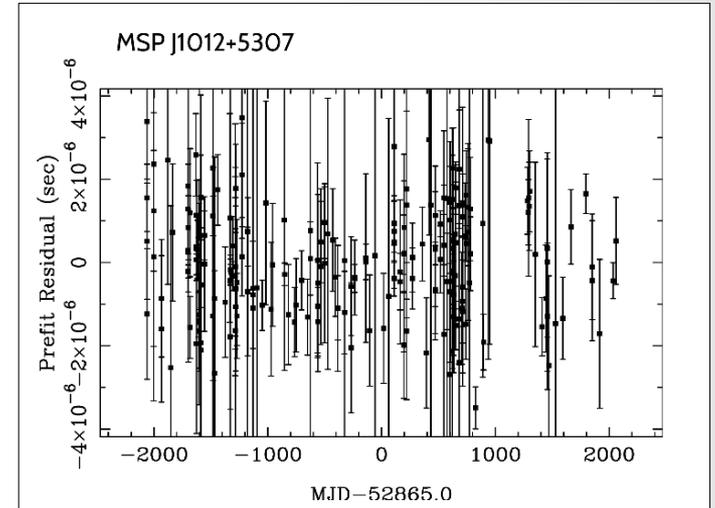
GW Perturbations

Radio pulsars as detectors



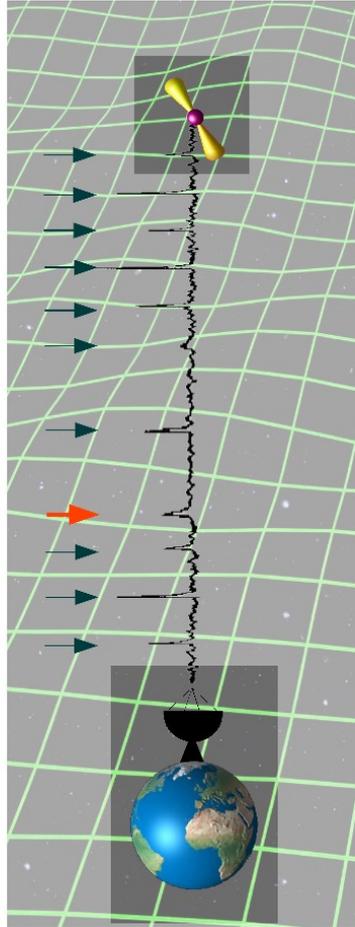
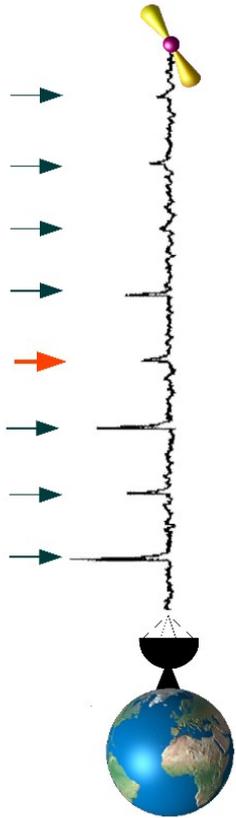
The regular times of arrival (**ToA**) from stable trains of radio pulses are modeled through **pulsar timing** to obtain the pulsar's characteristics.

The modeling yields **timing residuals** with $< 1 \mu\text{s}$ precision in rms

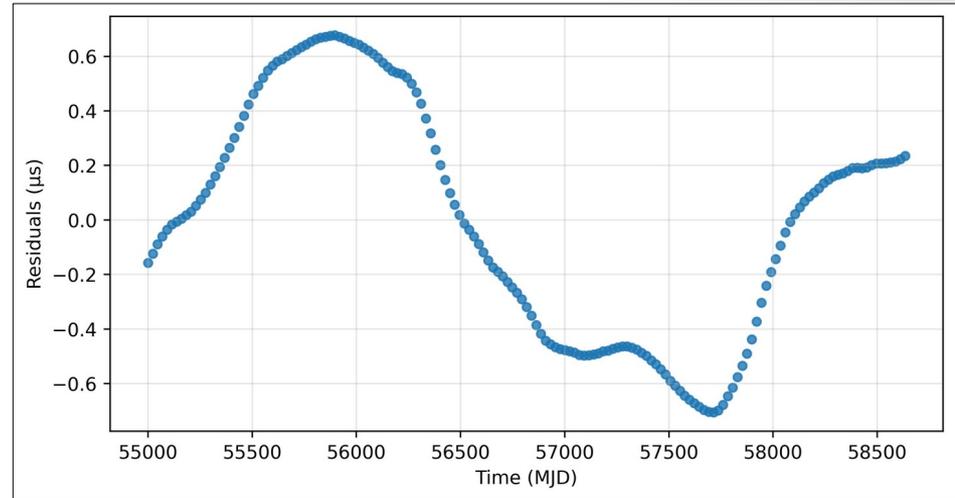


GW Perturbations

GW impact



A **nanoHertz GW background (GWB)** induces shifts in the ToAs of a specific pulsar, which exhibit a temporal correlation with a red power spectrum:



$$P_{GWB}(f) = \frac{A^2}{12\pi^2} \left(\frac{f}{\text{yr}^{-1}} \right)^{2\alpha - 3 = -13/3}$$

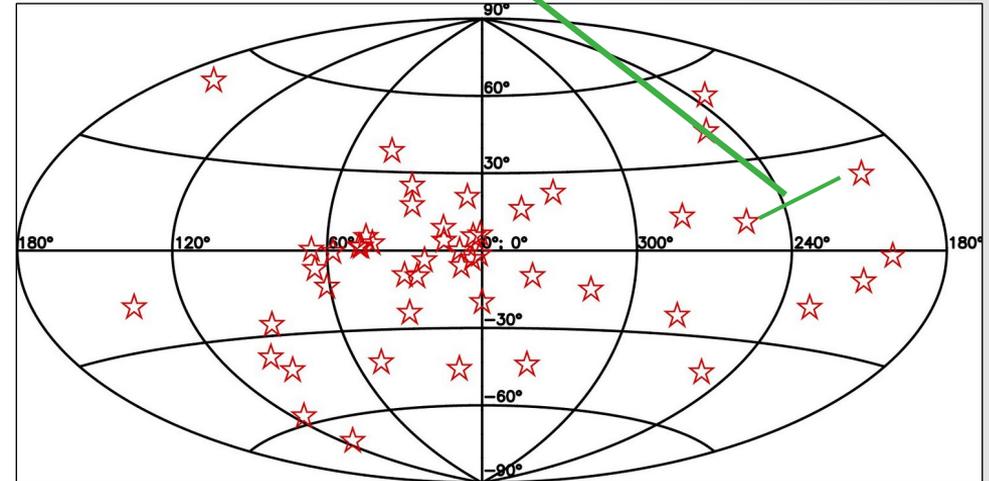
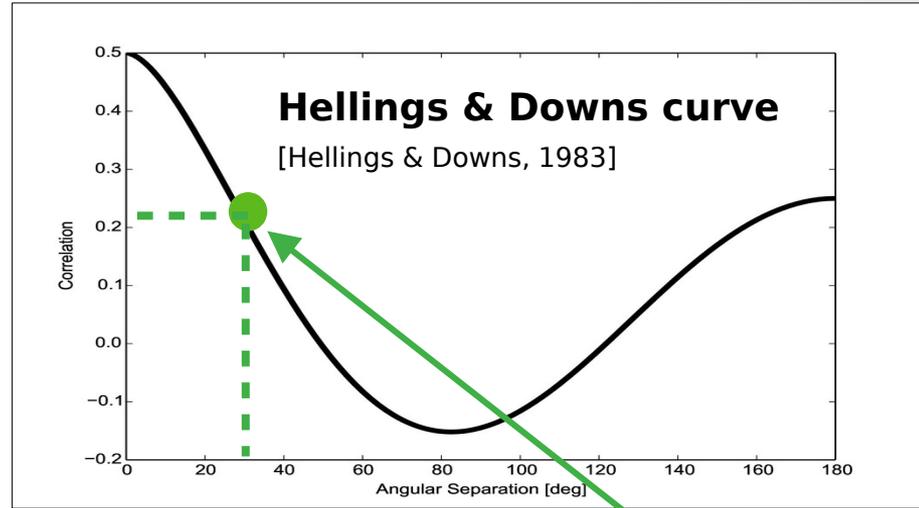
Pulsar Timing Arrays (PTAs)

Pulsar timing arrays use **arrays of pulsars** to detect these time-shifts, to:

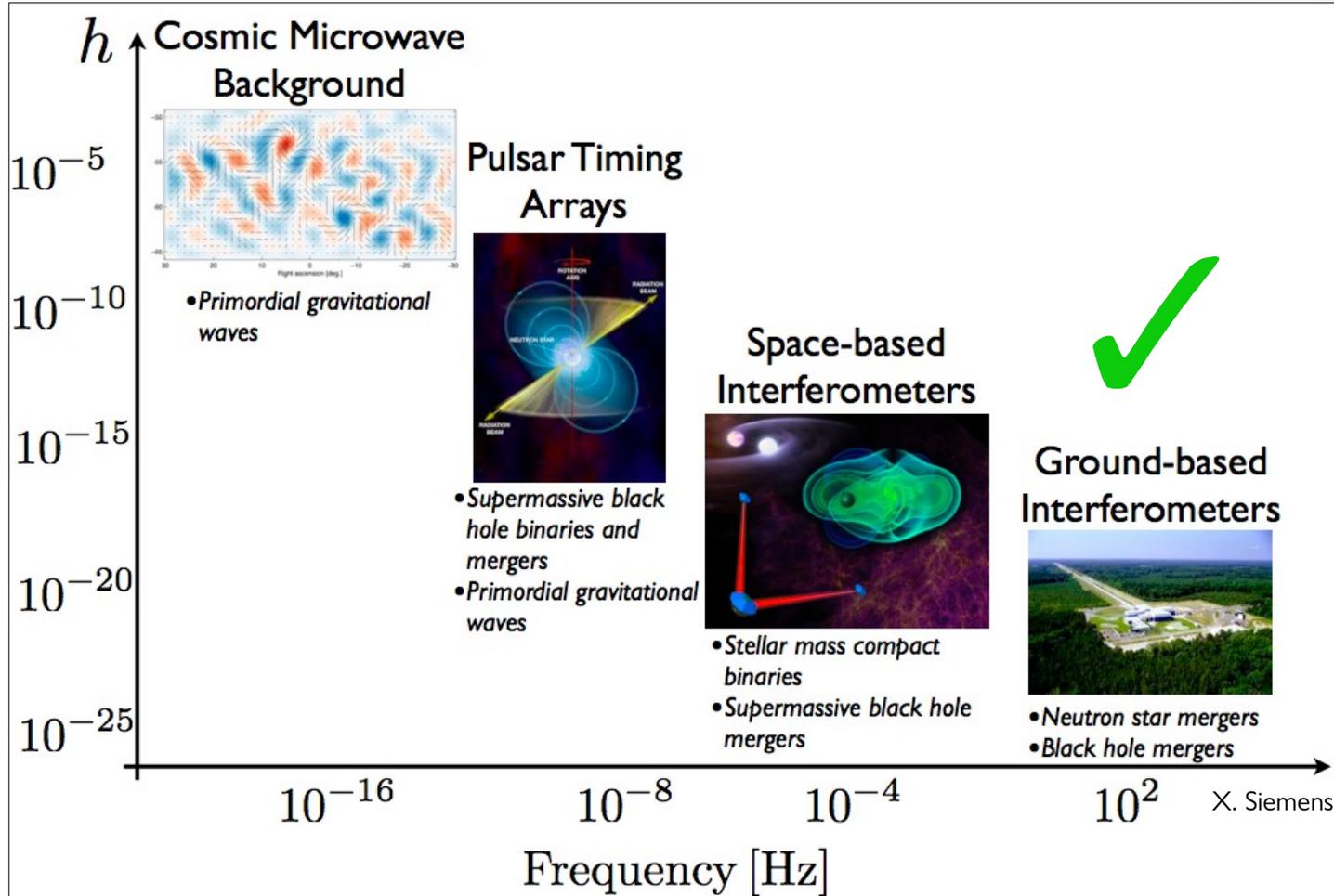
- Increase the detection sensitivity
- Exploit the **spatial correlation** that GWs introduce between the pulsar's ToAs

$$\left\{ \begin{array}{l} \zeta(\theta_{ij}) = \frac{3}{2} x \log(x) - \frac{x}{4} + \frac{1}{2} \\ x = [1 - \cos(\theta_{ij})] \end{array} \right.$$

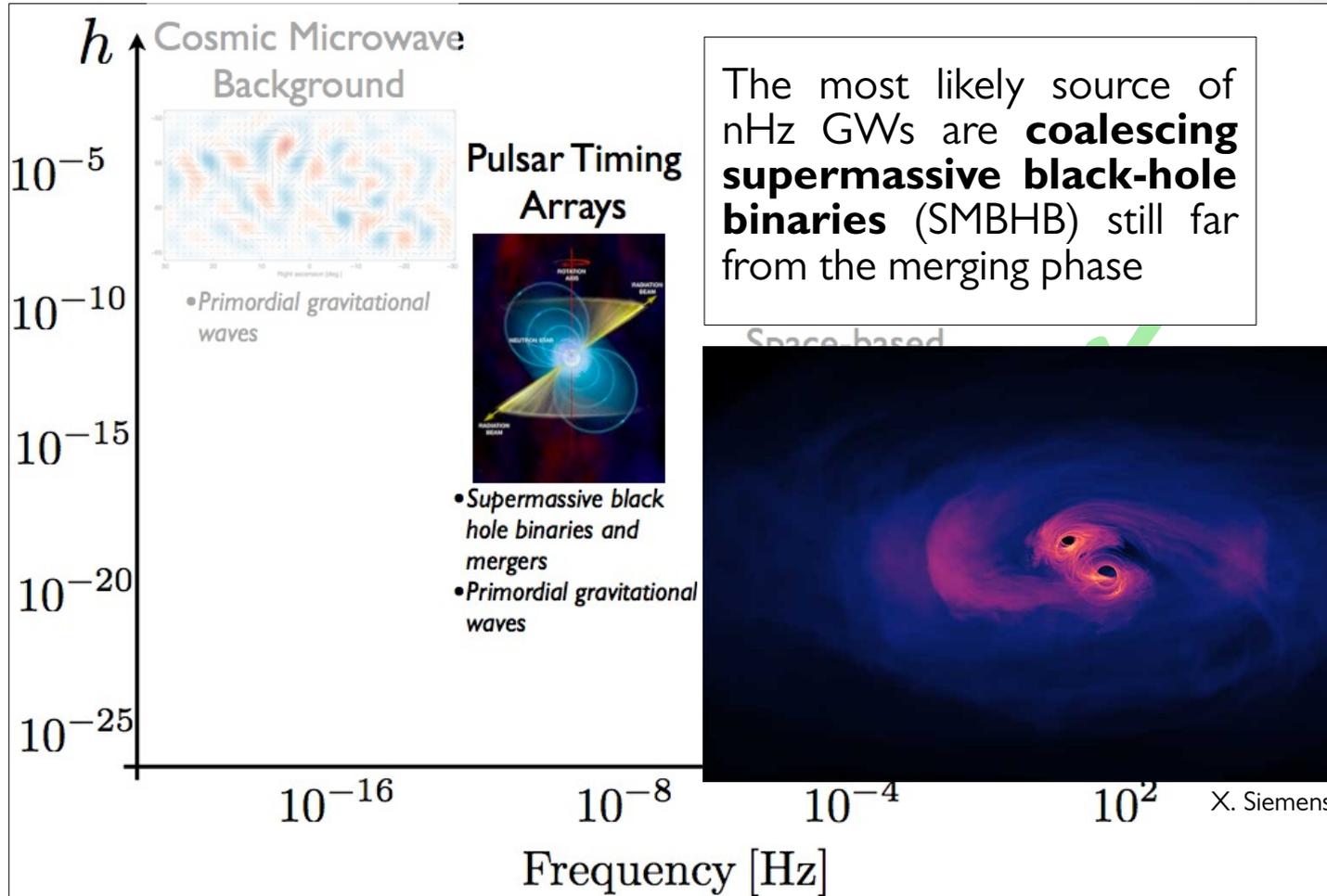
[Hellings & Downs, 1983]



The GW spectrum

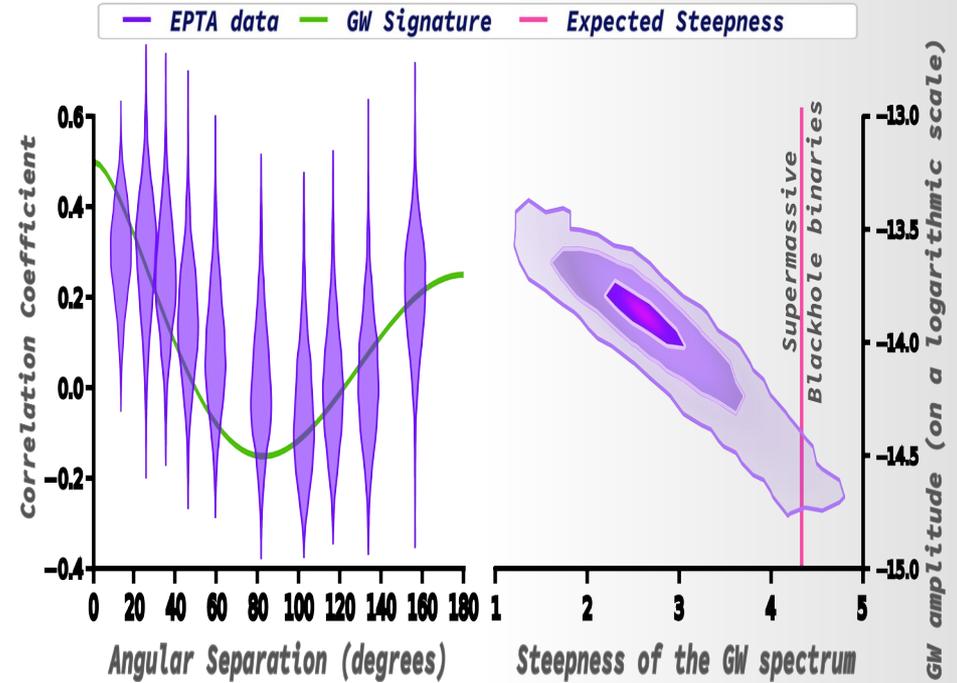
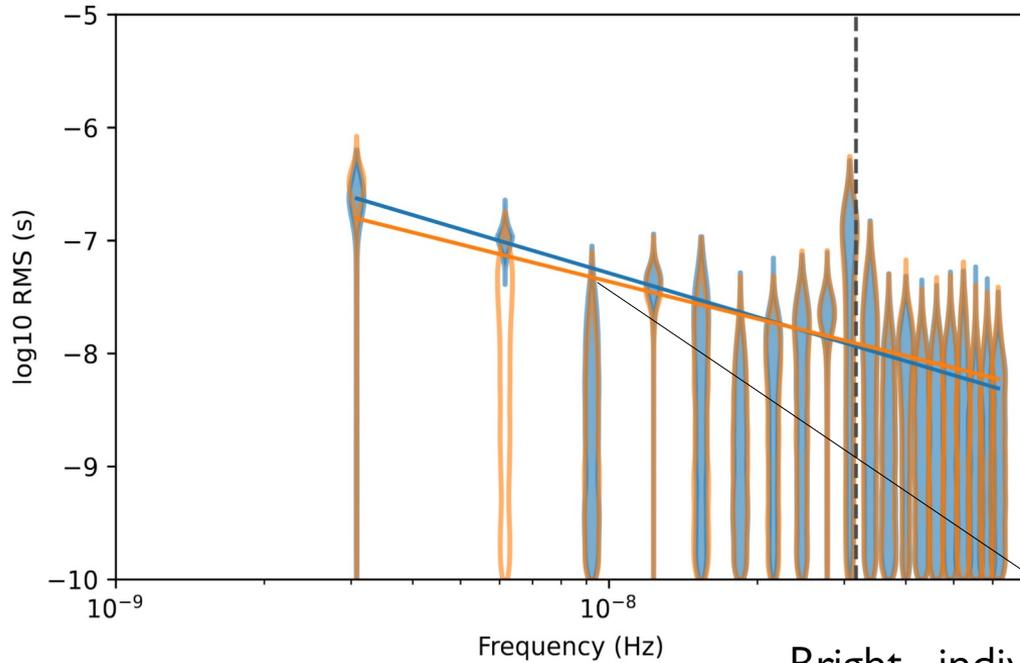


The GW spectrum



The search for individual sources

$\sim 3\sigma$ – GWB, European PTA

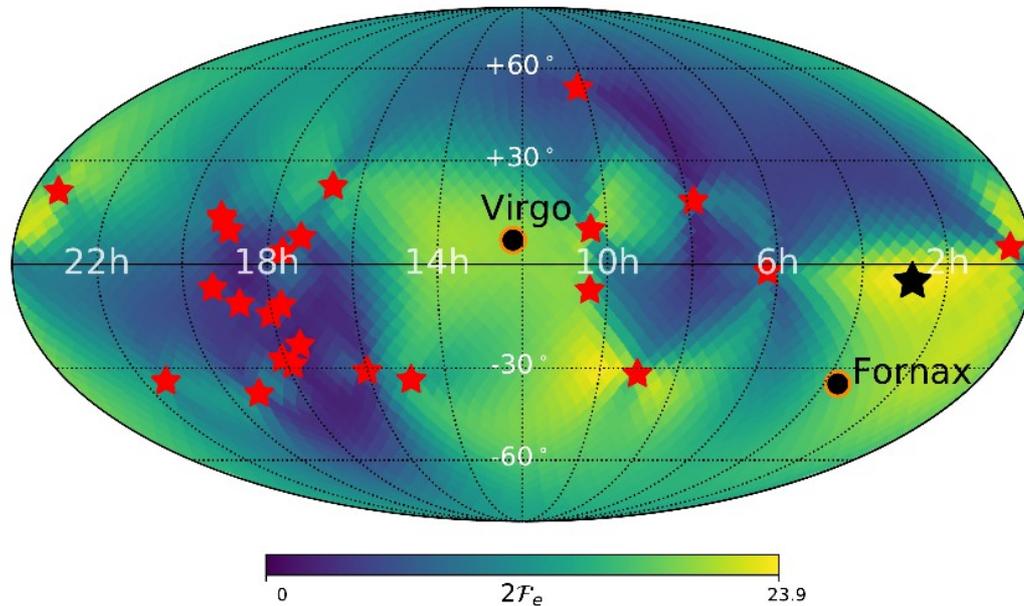


Bright, individual GW sources introduce **deviations from a powerlaw spectrum**, but the current precision is unable to identify them

Antoniadis+2023 [EPTA III]

The search for individual sources

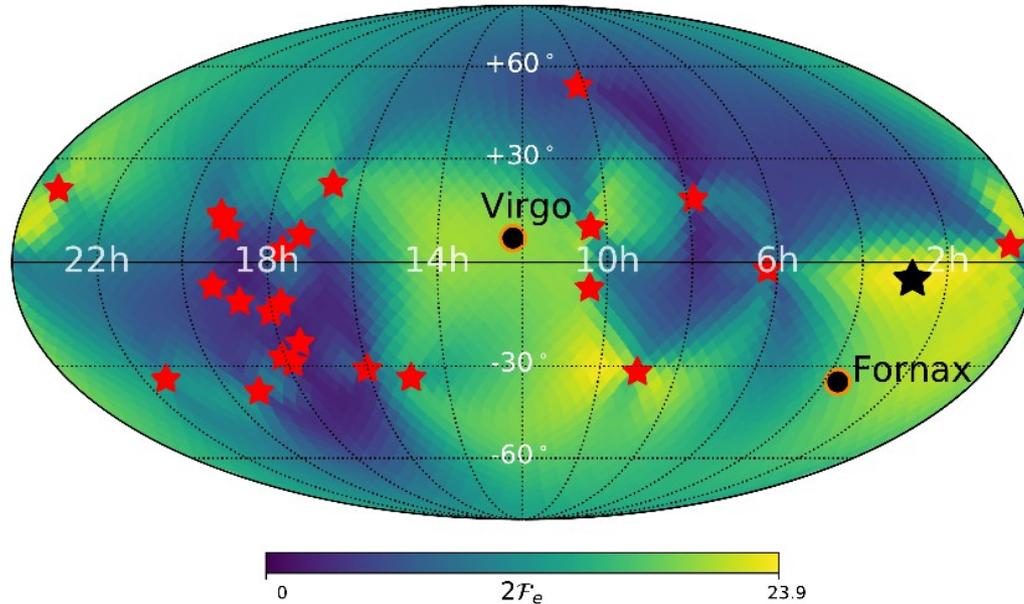
Individual sources, European PTA



- The PTA-adapted F_e statistics indicates that the most likely sky location for an individual SMBHB **is a region depleted from pulsars** at $f_{\text{gw}}=4.64$ nHz
- The Bayesian analysis carried out on the “signal” is inconclusive
- Upper limit – $h_0 < (5-8) \times 10^{-15}$ at 95% confidence level in optimal sky regions
- NanoGRAV – $h_0 < 2.66 \times 10^{-15}$
- PPTA – $h_0 < 7 \times 10^{-15}$
- MPTA – $h_0 < 2-3 \times 10^{-14}$

The search for individual sources

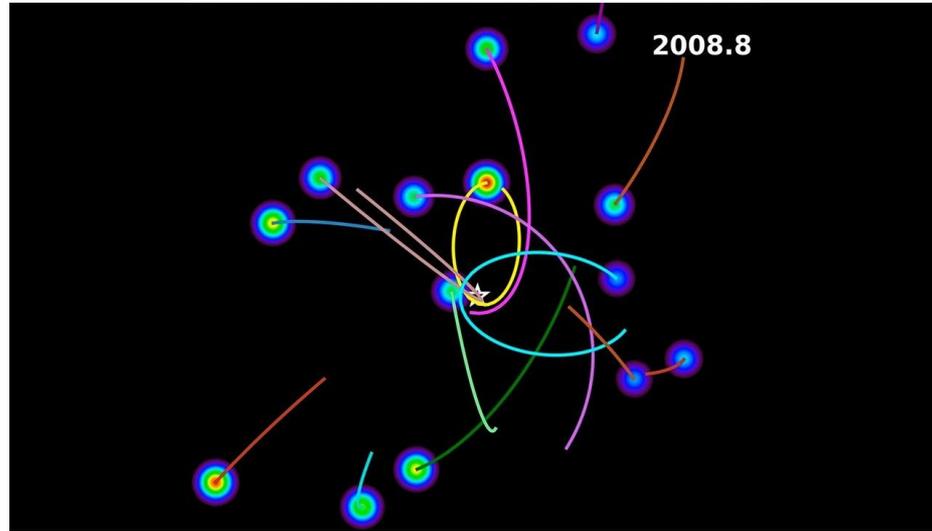
Localization



- Heavily affected by the ToA precision, and the **number of pulsars in the array**
- EPTA → The ‘best location’ (black star) is $\sim 10\text{-}20^\circ$ in angular diameter ($\sim 100\text{-}300 \text{ deg}^2$)
- NanoGRAV → $\sim 200 \text{ deg}^2$ sky-averaged, tightening to $\sim 50 \text{ deg}^2$ in high pulsar-density regions
- SKAO → 10^{-3} deg^2 expected with precise pulsar distances ($< 1 \text{ pc}$) for the nearby pulsars if a high-S/N detection is made first

Counterparts

- Given the PTA-derived f_{orbital} , we can search for optical fluctuations in galaxies within the angular uncertainty region. No need for immediate follow-ups!



Counterparts

- Direct counterparts for a SMBHB
 - Uncertain given the attempted LIGO-Virgo follow-ups, but the environment of a SMBHB is different with respect to a BHB
 - Possibility of tidal disruption-like event during the merger



Counterparts?

Thank you for your attention



Backup

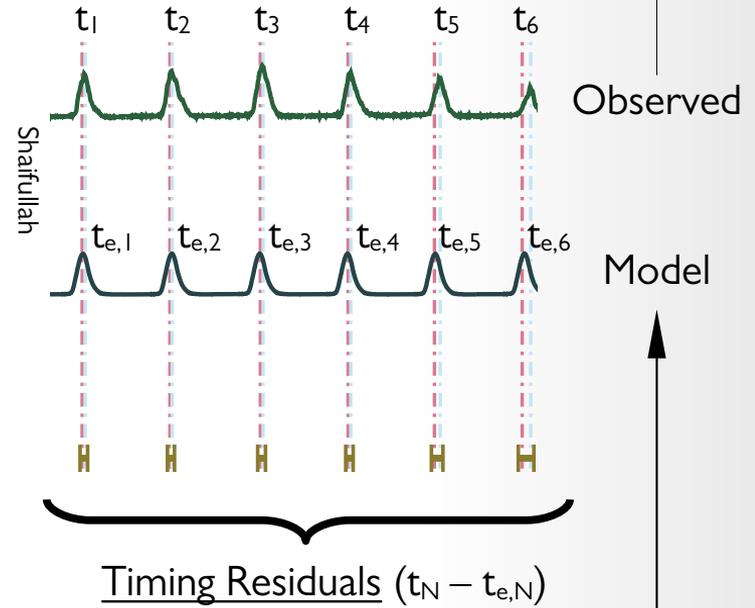


Pulsar Timing

Technique

Pulsar Ephemeris

Pulsar	J1012+5307
Right Ascension	10:12:33.437521
Declination	+53:07:02.29999
DM	9.02314
Spin frequency	190.2678376220576
Spin freq. derivative	-6.20063E-16
Proper motion RA	2.609
Proper motion DEC	-25.482
BINARY	ELL1
Orbital period	0.604672722901
Rotation Measure	2.98
Solar Wind	Spherical, $n_0 = 4$
Companion mass	0.16
Clock reference	TT(BIPM2019)
SSE	DE440
[TBC]	

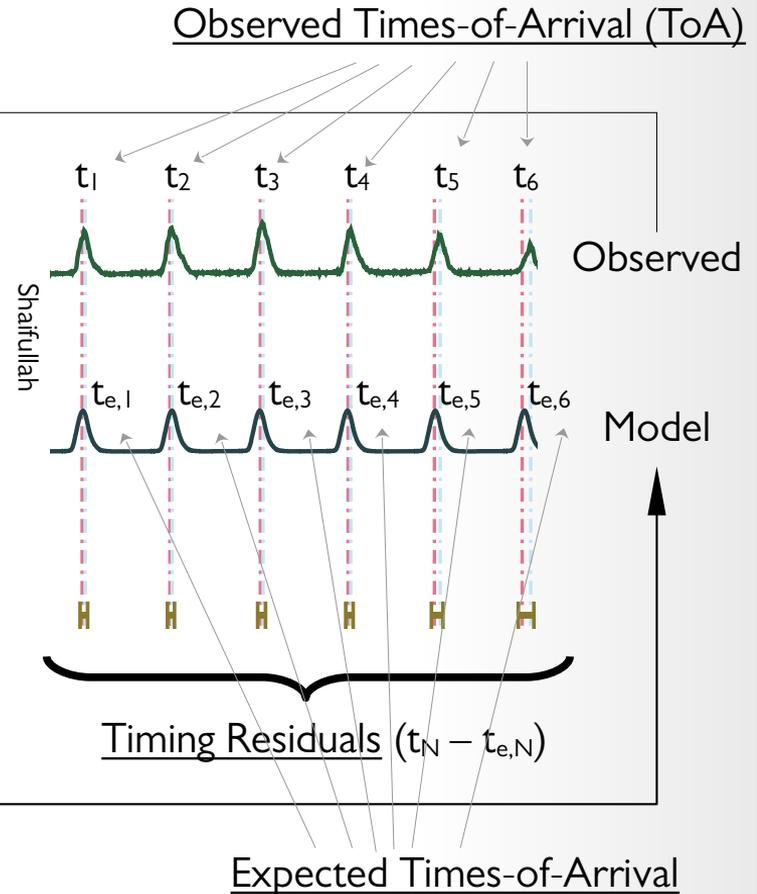


Pulsar Timing

Technique

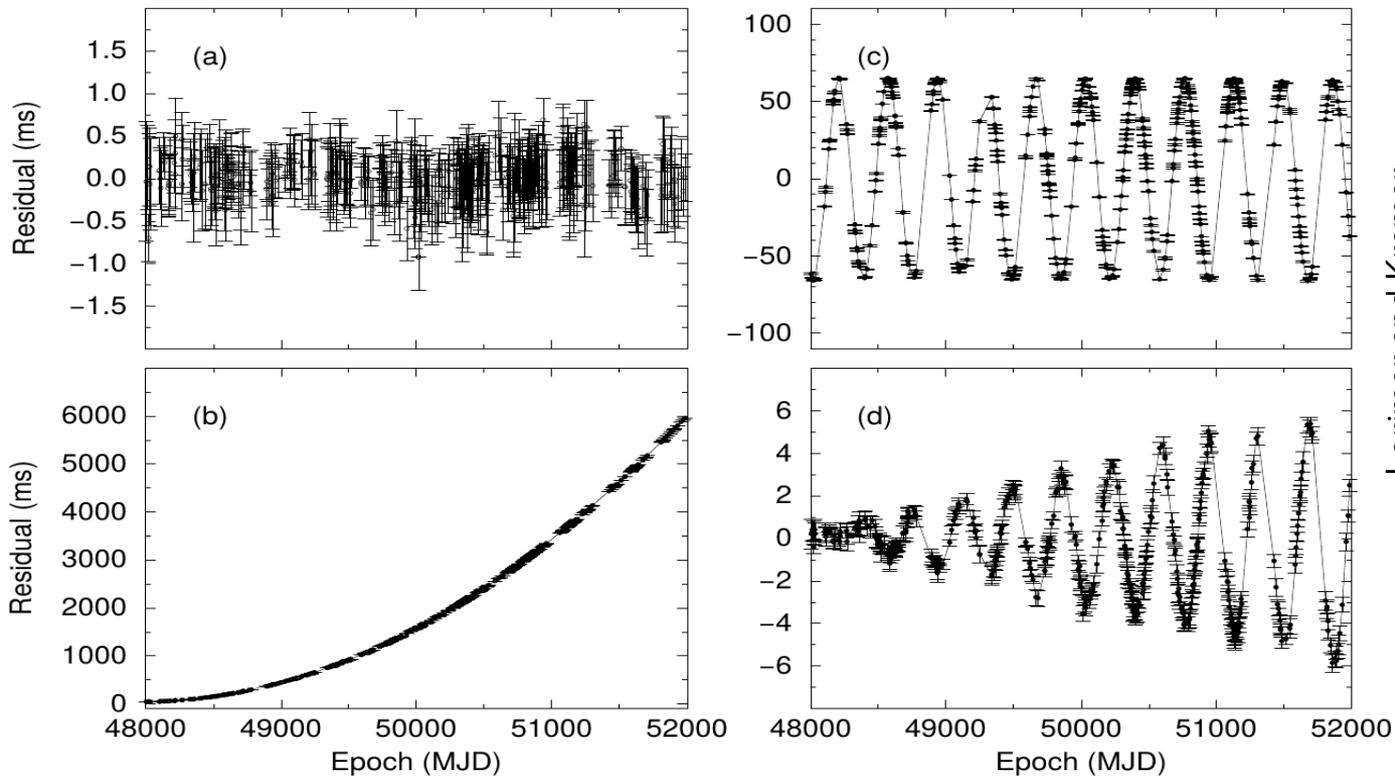
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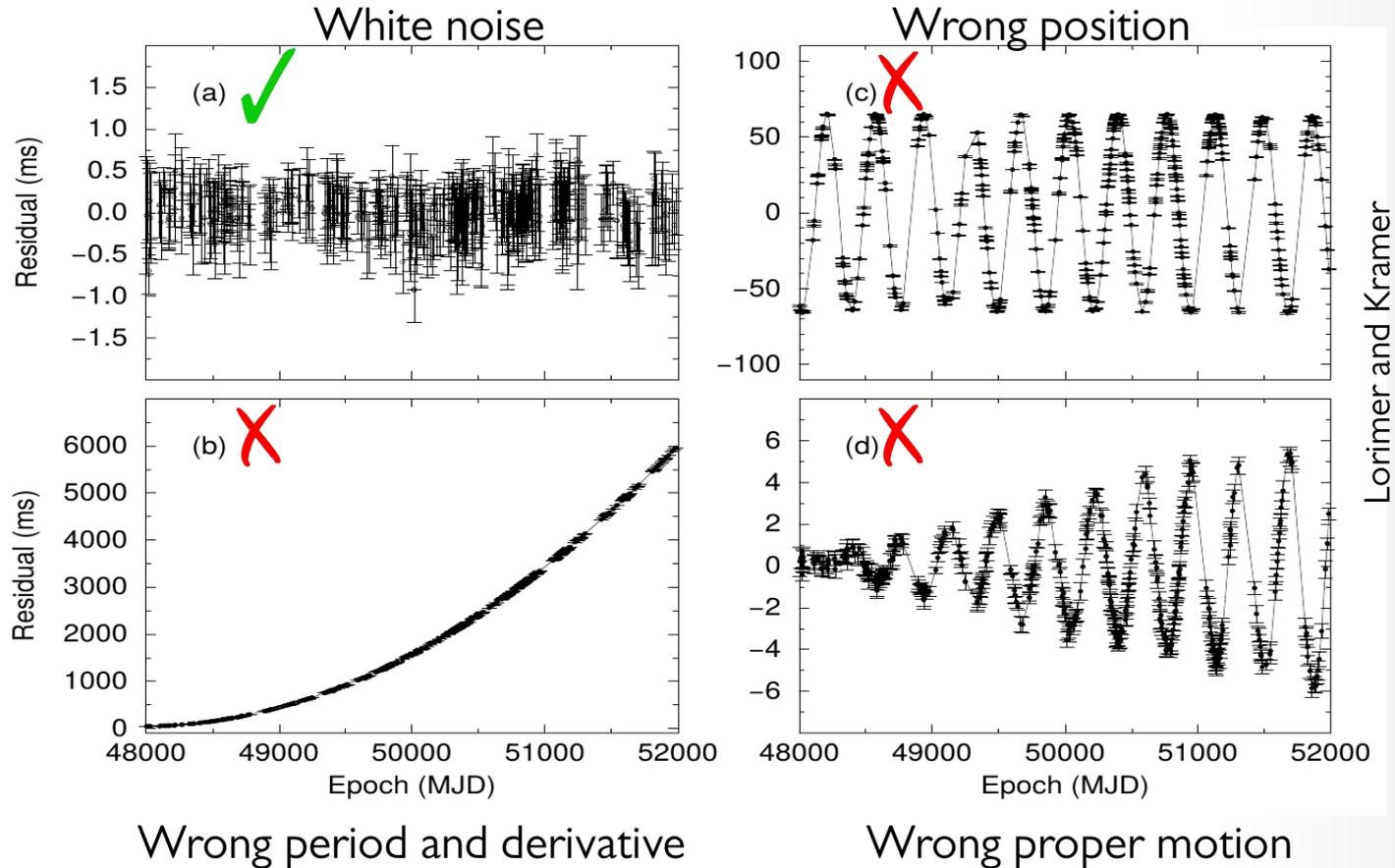
Residuals



Lorimer and Kramer

Pulsar Timing

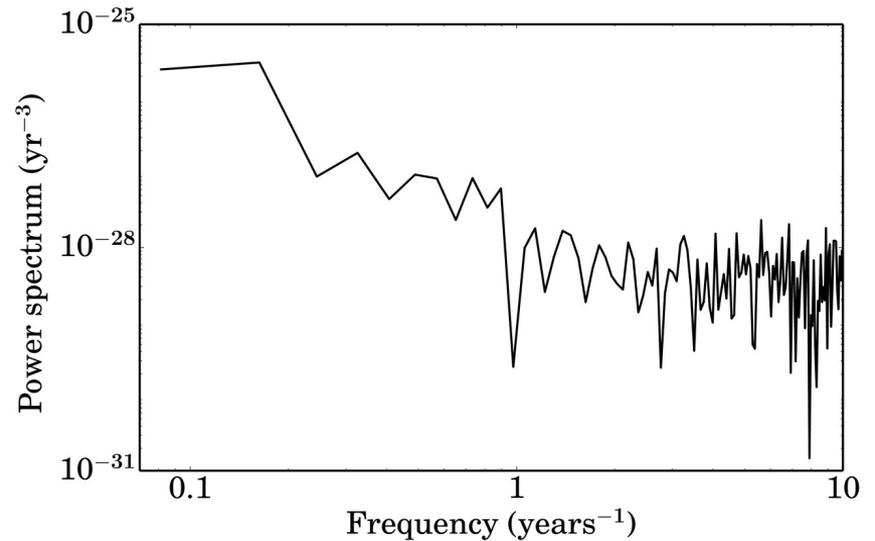
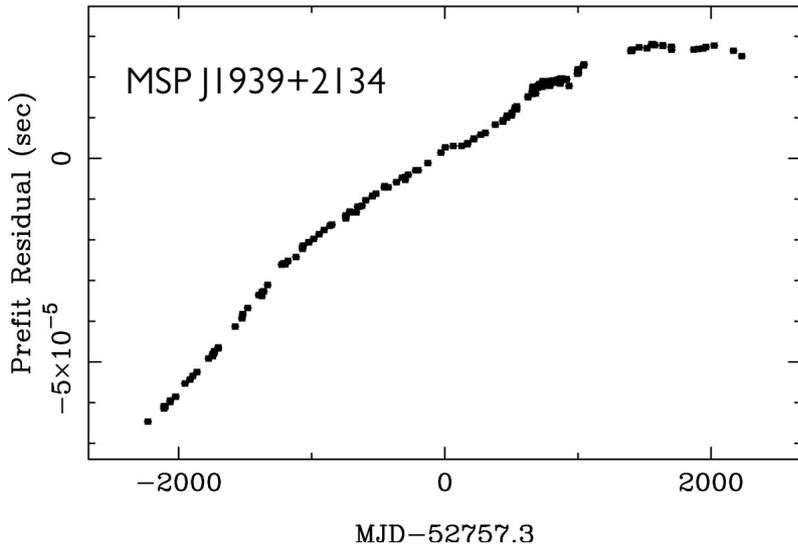
Residuals



Pulsar Timing

Red noise

Stochastic effects with long-term correlations in time cannot be modeled in a pulsars' ephemeris



Among their possible causes are ***gravitational waves at nHz frequencies***