The Low-Frequency Chords of Gravitational Waves: Insights from pulsar timing arrays

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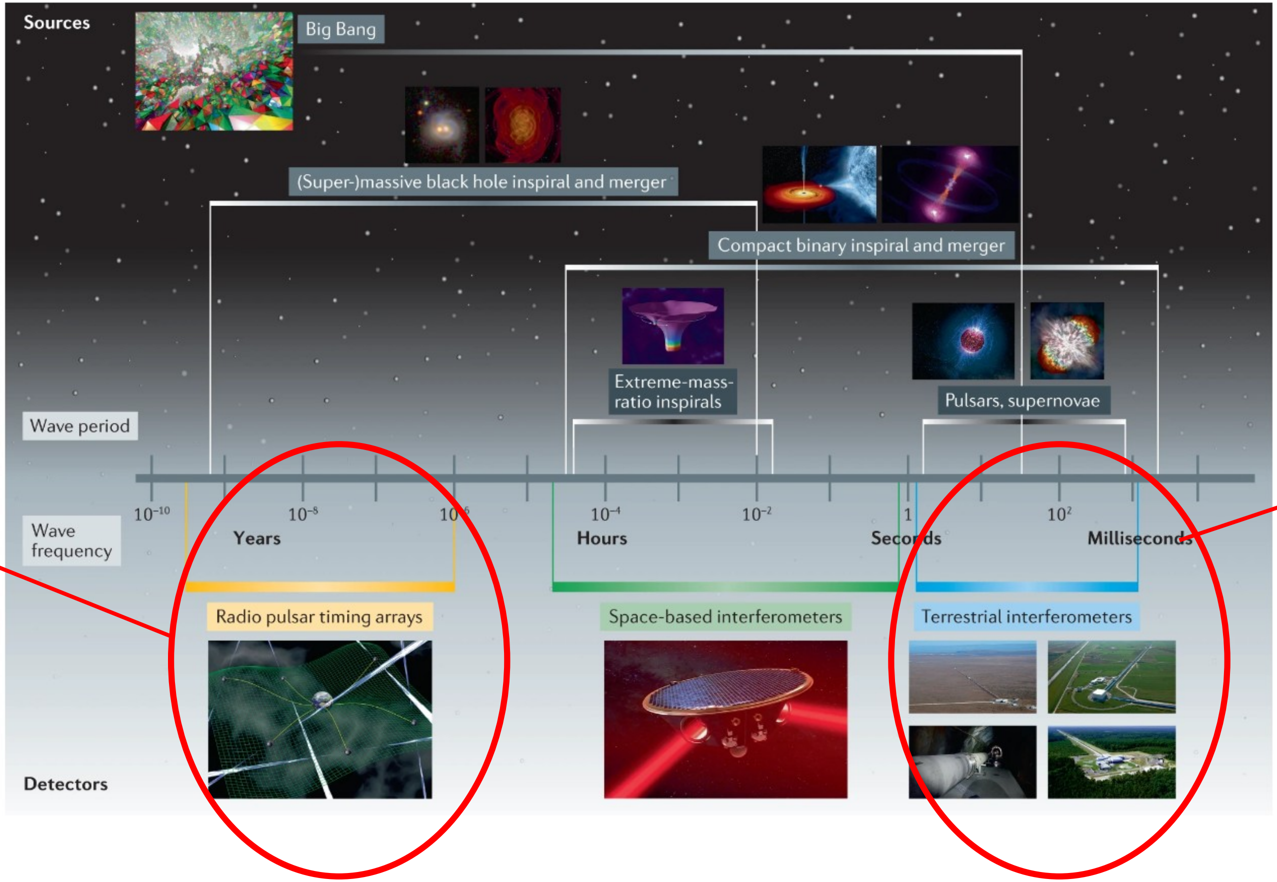
Introduction



Probing background

Probing single binary sources

Bailes, M., Berger, B.K., Brady, P.R. et al., Nat Rev Phys 3, 344–366 (2021)

What are we measuring?

Problem:*Timing a network of pulsars, resulting background amplitude?*

Looking for superposition of population of binaries

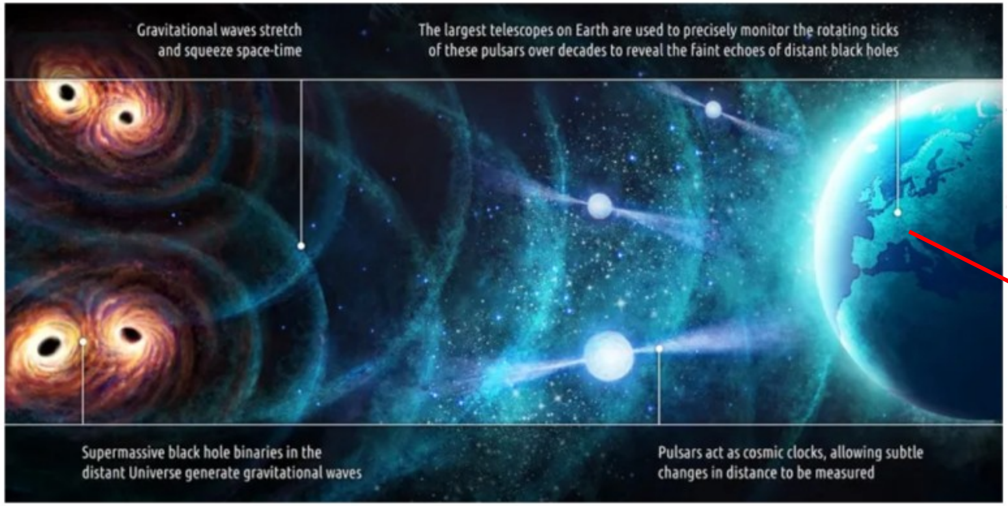
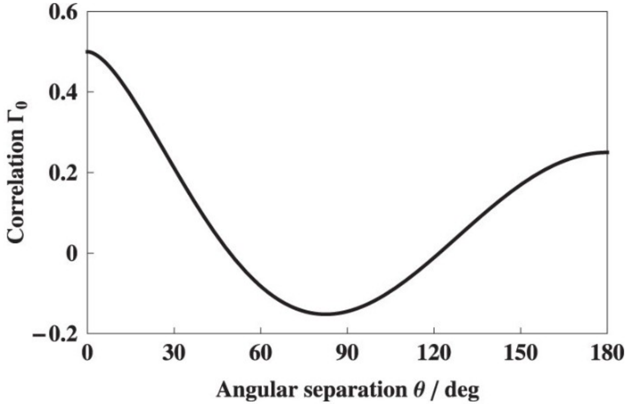


Figure: Daniele Futselaar, MPIfR



Hellings & Downs, 1983

Latest news...

The second data release from the European Pulsar Timing Array

Comparing Recent Pulsar Timing Array Results on the Nanohertz Stochastic Gravitational-wave Background

NANOGrav

NEWS & EVENTS

News

PUB: 28 JUN 2023

Scientists use Exotic Stars to Tune into Hum from Cosmic Symphony

NANOGrav's most recent dataset offers compelling evidence for gravitational waves with oscillations of years to decades. These waves are thought to arise from orbiting pairs of the most massive black holes throughout the Universe: billions of times more massive than the Sun, with sizes larger than the distance between the Earth and the Sun

Search for an Isotropic Gravitational-wave Background with the Parkes Pulsar Timing Array

The NANOGrav 15 yr Data Set

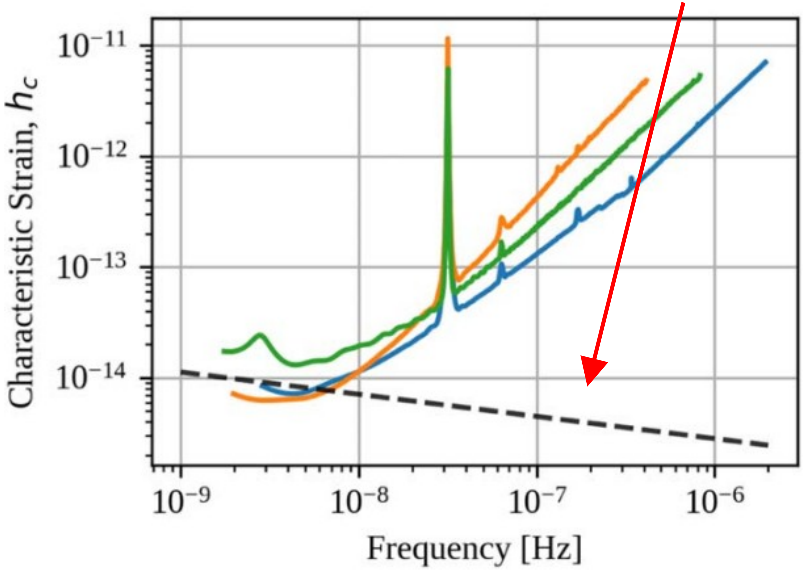
Signal model for background

Starting point:

$$h_c^2(f) = \int_0^\infty dz \int_0^\infty d\mathcal{M} \, \frac{d^3 N}{dz d\mathcal{M} d\ln f_r} \, h^2(f_r)$$

Resulting strain: smooth powerlaw:

$$h_c(f) = A_{\mathrm{GWB}} f^{\alpha}$$



$$\alpha = -2/3$$

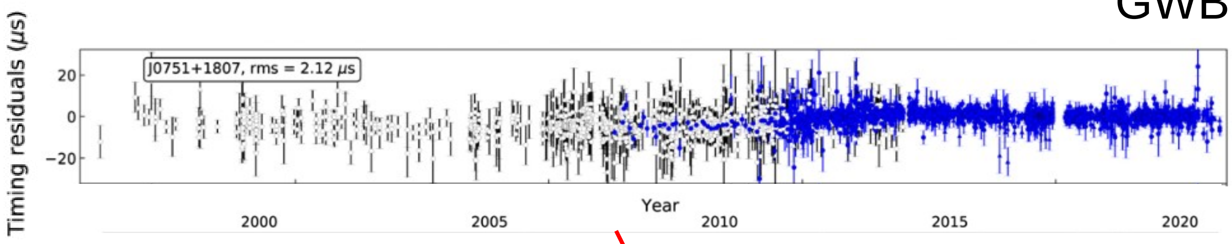
Ingredients needed:

- Population of massive black hole binaries
- Energy density as function of frequency

Agazie et al,, The Astrophysical Journal 966(1):105

Data and methodology

- *6 telescopes all over Europe*
- *25 millisecond pulsars*
- *Observation time ~ 25 years*
- *Parameters measured: GWB, but also pulsar-specific (red-noise) and telescope parameters (white-noise).*

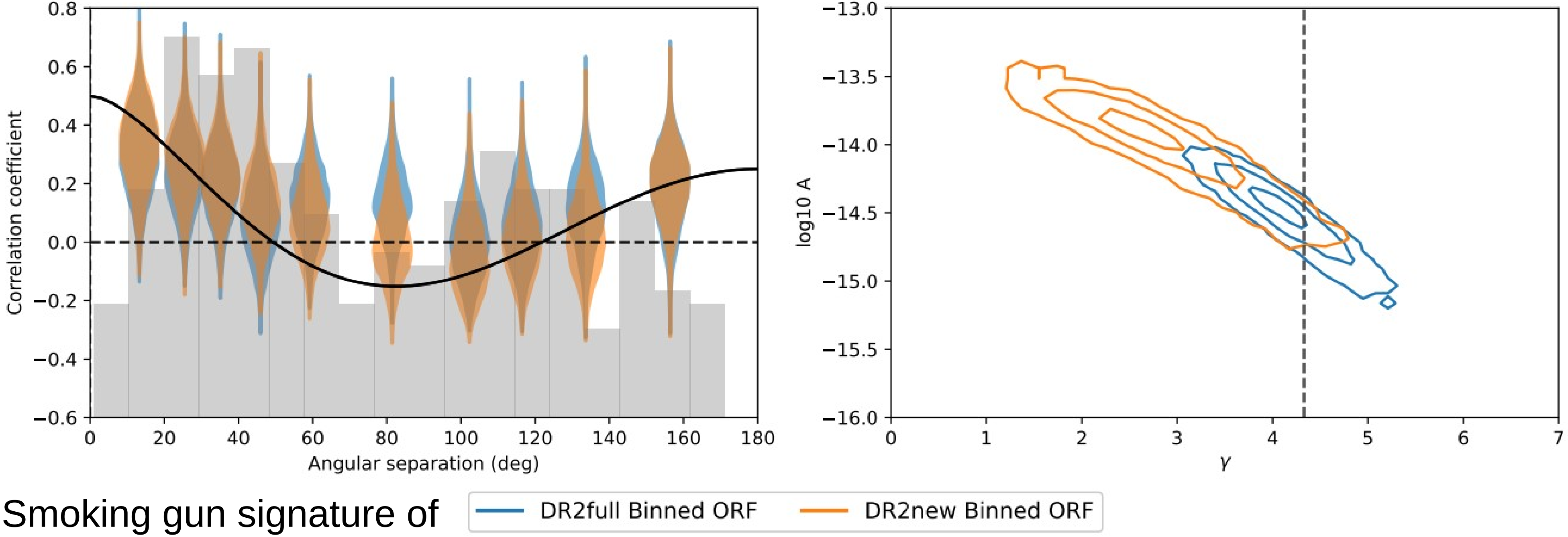


GWB amplitude   Pulsar residuals

$$p(\theta|d) = \frac{\mathcal{L}(d|\theta)\pi(\theta)}{\mathcal{Z}}$$

Residuals = Observed times of arrival – Expected times of arrival

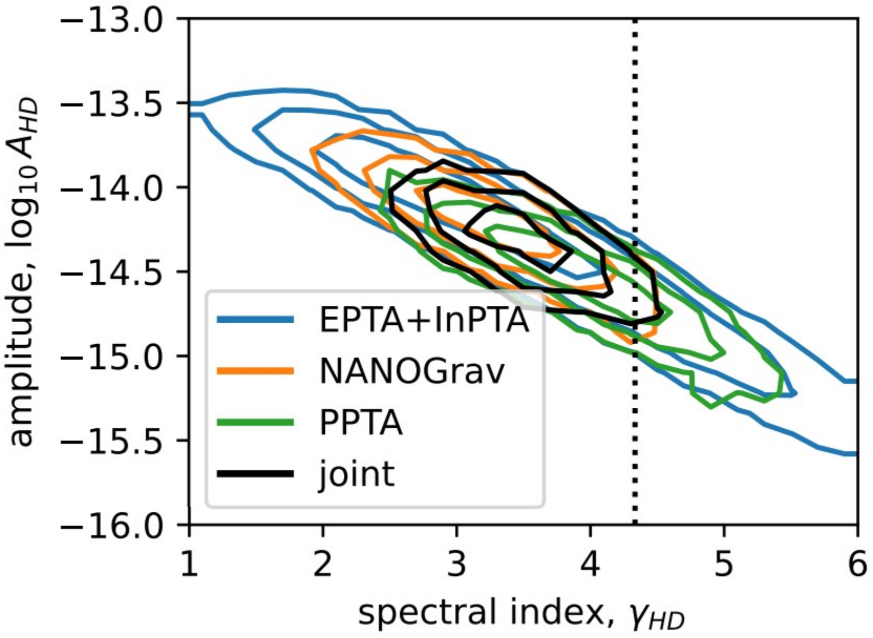
Latest EPTA results

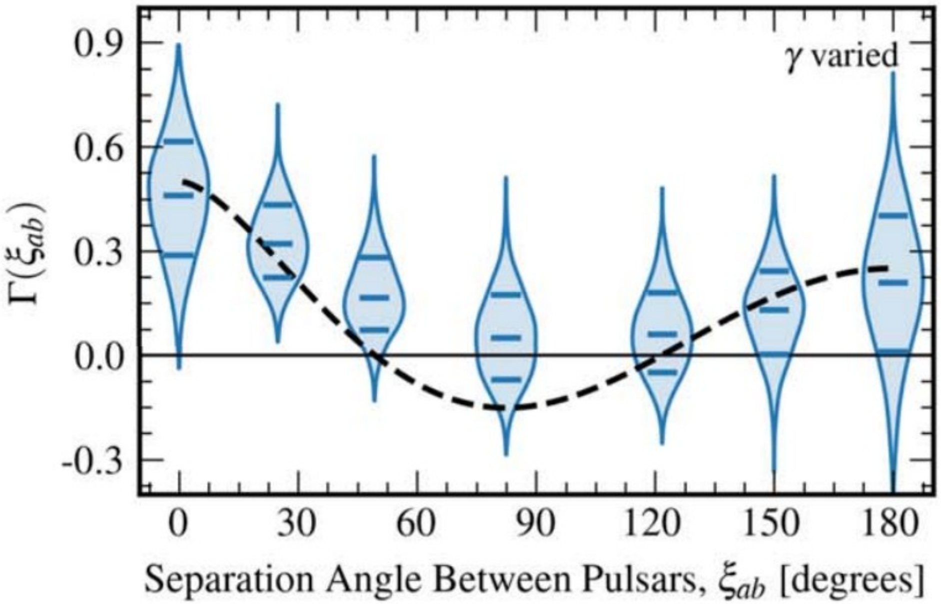


Smoking gun signature of gravitational wave origin

EPTA & InPTA, A&A 678, A50 (2023) https://doi.org/10.1051/0

Latest results: comparison across all PTAs





$$A_{\mathrm{GWB}} = 2.4^{+0.7}_{-0.6} \times 10^{-15}$$

$$\gamma_{\mathrm{HD}} = 3 - 2\alpha$$

Agazie et al,, The Astrophysical Journal 966(1):105

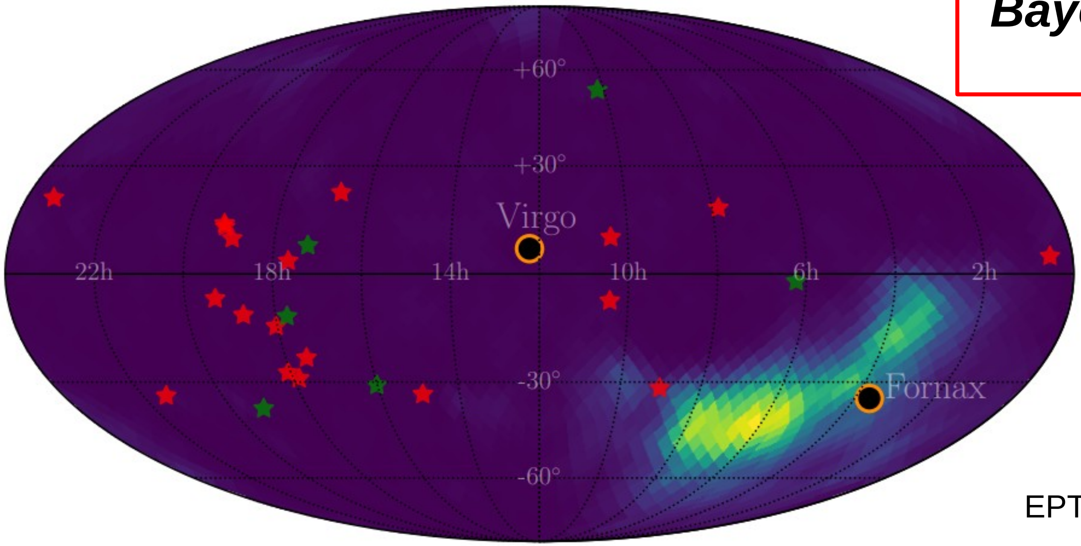
More results

- In addition, individual mergers were also searched for (*continuous waves*) …

$$h = 2\frac{\mathcal{M}^{5/3}}{d_L}(\pi f_{gw})^{2/3}$$

- GW frequency: 4-5 nHz.

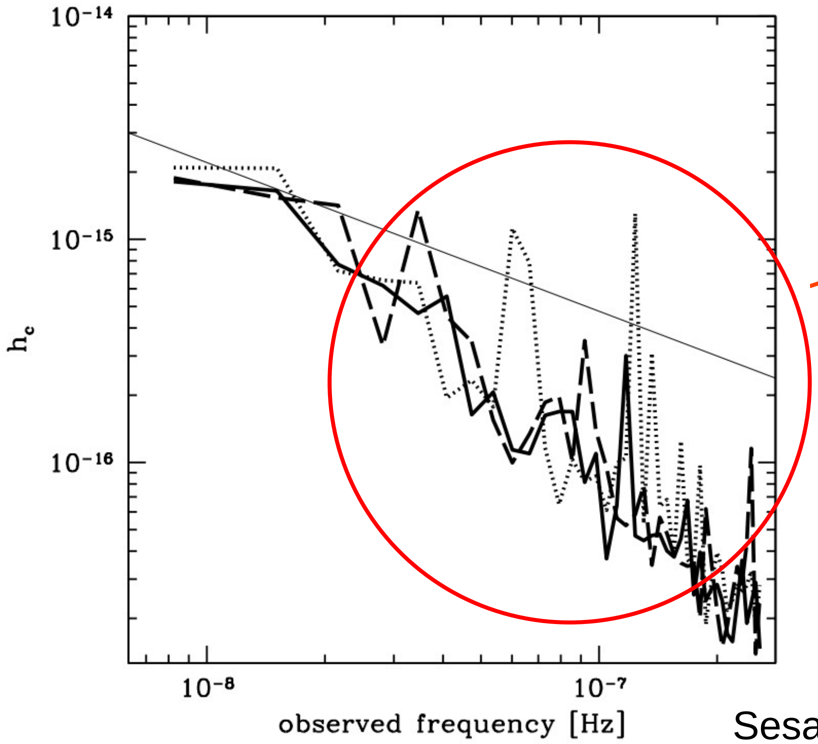
Bayes factor for CW ~ 0.7
Bayes factor for GWB ~ 60



EPTA & InPTA, A&A, 690, A118 (2024)

Signal model for background

- Numerically model the population using galaxy mass function
- Then add the strains instead of computing integral



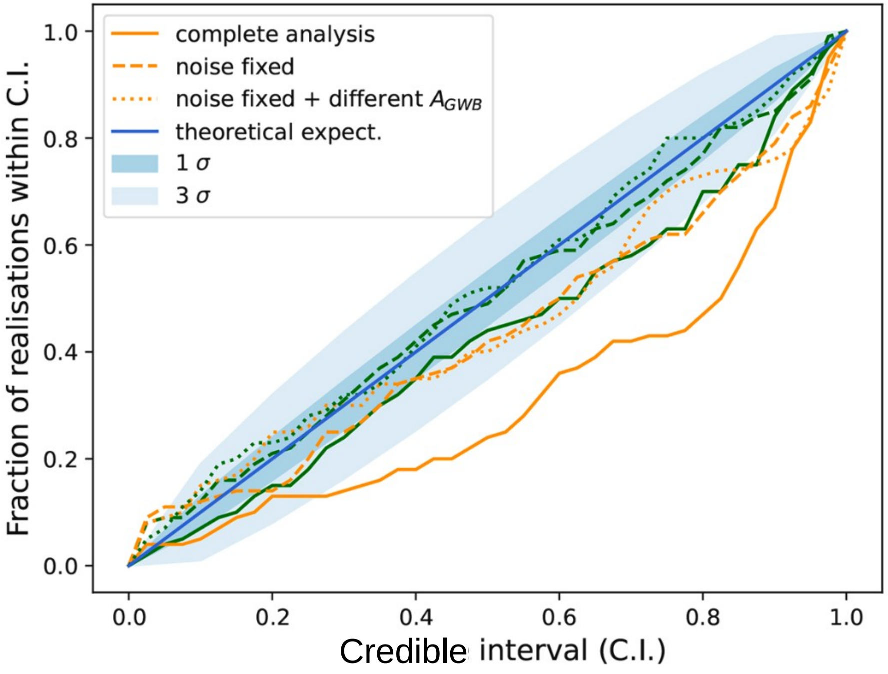
Not smooth function at high frequencies

Due to discrete nature of sources

Sesana, A., Vecchio, A., & Colacino, C. N. 2008, MNRAS, 390, 192

Model dependence on characterisation of background

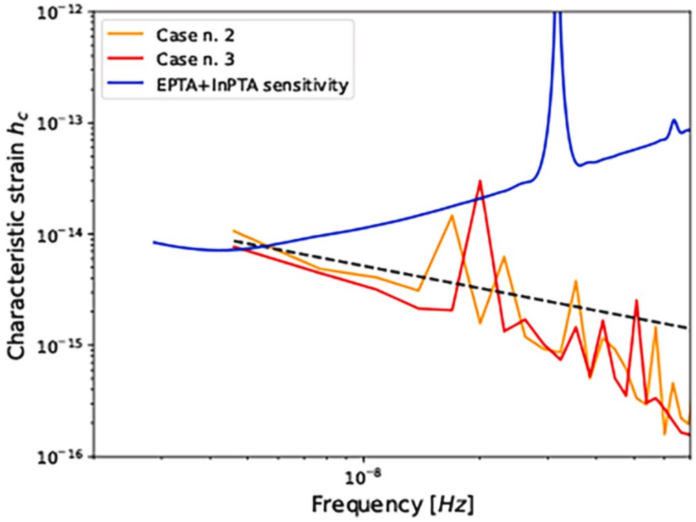
- Diagnostic plot: p-p
- Ideal case: diagonal line
- X% times simulated value is in X% credible region

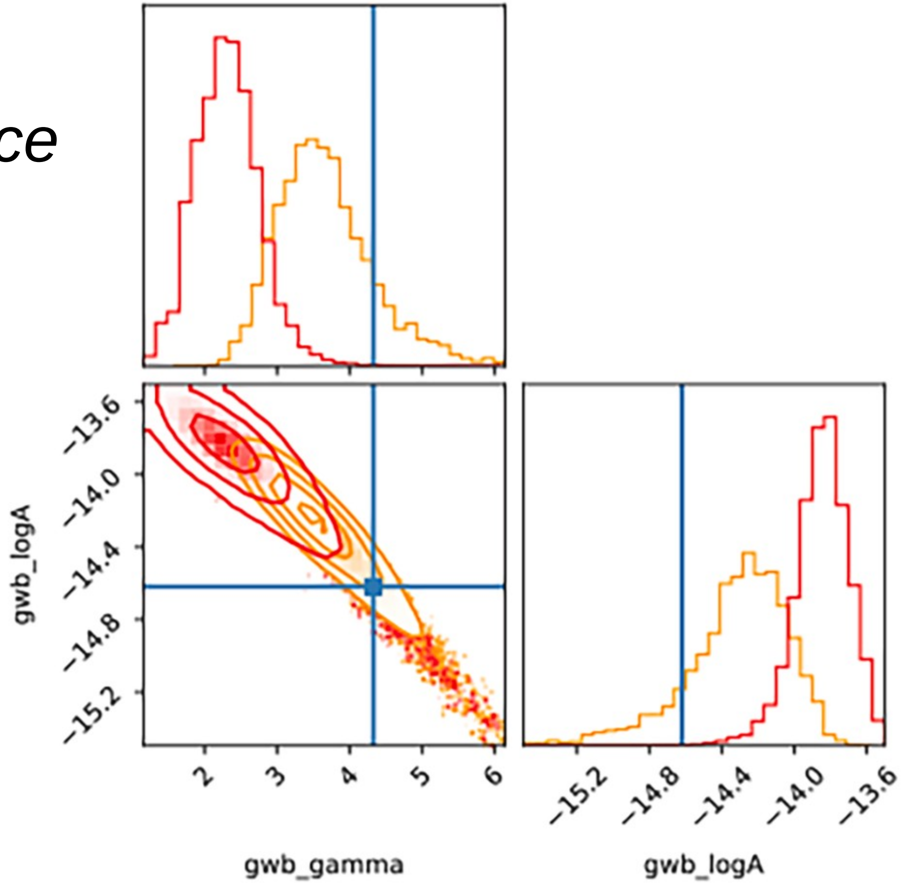


Astron.Astrophys. 683 (2024) A201, S. Valtolina, G. Shaifullah, **A. Samajdar**, A. Sesana

Model dependence on characterisation of background

- Importance of loud *single-source*





Astron.Astrophys. 683 (2024) A201, S. Valtolina, G. Shaifullah, **A. Samajdar**, A. Sesana

Summary

- Significant detection of GWB yet to come, but close.
- Low significance for single source for now.
- Synergy with LISA for some loud sources?