Search for Gravitational-Wave Background from Cosmic Strings with PPTA DR2

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Introduction

- A pulsar timing array (PTA) offers a unique opportunity of detecting very low frequency gravitaional waves (GWs) from nHz to μHz, by regularly monitoring the time of arrivals (ToAs) of radio pulses from an array of highly stable millisecond pulsars in the Milky Way.
- Cosmic strings are linear topological defects that can either form in the early Universe from symmetry-breaking phase transitions at high energies or be the fundamental strings of superstring theory (or one-dimensional D-branes) stretched out to astrophysical lengths.
- After their formation, the intersection between cosmic strings can lead to reconnections and form loops, which will then decay due to relativistic oscillation and emit gravitational waves.
- The gravitational-wave background (GWB) produced by cosmic strings could potentially detected by PTAs.

Dataset and Method

- The PPTA DR2 includes pulse ToAs from high-precision timing observations for 26 pulsars spanning about 15 years, with observations taken at a cadence of approximately three weeks.
- The timing residuals $\delta \mathbf{t}$ for each pulsar are decomposed into

$$\delta \mathbf{t} = M\boldsymbol{\epsilon} + \delta \mathbf{t}_{\mathrm{RN}} + \delta \mathbf{t}_{\mathrm{DET}} + \delta \mathbf{t}_{\mathrm{WN}} + \delta \mathbf{t}_{\mathrm{CP}}.$$

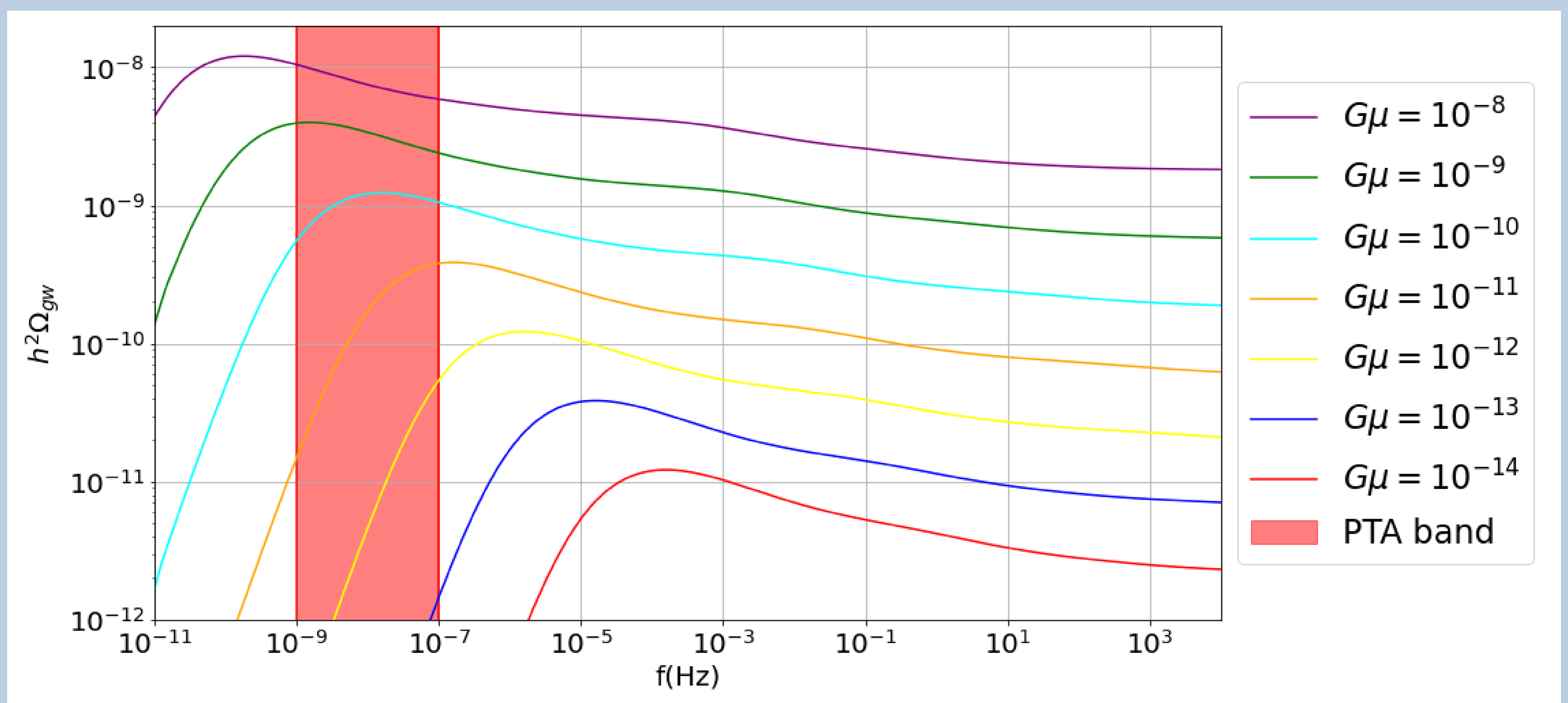
  - $M\boldsymbol{\epsilon}$ accounts for the inaccuracies in the subtraction of timing model.
  - $\delta \mathbf{t}_{\mathrm{RN}}$ is the contribution from red noise, including achromatic spin noise, frequency-dependent dispersion measure noise, frequency-dependent chromatic noise, achromatic band noise and system/group noise.
  - $\delta \mathbf{t}_{\mathrm{DET}}$ is deterministic noise, including chromatic exponential dips, extreme scattering events, and annual dispersion measure variations.
  - $\delta \mathbf{t}_{\mathrm{WN}}$ is white noise, including a scale parameter on the TOA uncertainties (EFAC), an added variance (EQUAD), and a per-epoch variance (ECORR) for each backend/receiver system.
  - $\delta \mathbf{t}_{\mathrm{CP}}$ is the contribution from the common-spectrum process (such as a GWB).

References

[1] Z. C. Chen, Y. M. Wu and Q. G. Huang, "Search for the Gravitational-Wave Background from Cosmic Strings with the Parkes Pulsar Timing Array Second Data Release," arXiv:2205.07194

[2] M. Kerr, D. J. Reardon, G. Hobbs, *et al.* "The Parkes Pulsar Timing Array project: second data release," Publ. Astron. Soc. Austral. **37**, e020 (2020)

GWB from Cosmic Strings



We describe the GWB energy spectrum of cosmic strings in terms of the dimensionless tension, $G\mu$, and the reconnection probability, p. Even though $p = 1$ for classical strings, it can be less than 1 in the string-theory-inspired models or pure Yang-Mills theory. The dimensionless GW energy density parameter per logarithm frequence as the fraction of the critical energy density is

$$\Omega_{\mathrm{gw}}(f) = \frac{8\pi G f}{3H_0^2 p}\rho_{\mathrm{gw}}(t_0, f), \quad (1)$$

where t_0 is cosmic time today, and ρ_{gw} is the GW energy density per unit frequency that can be computed by

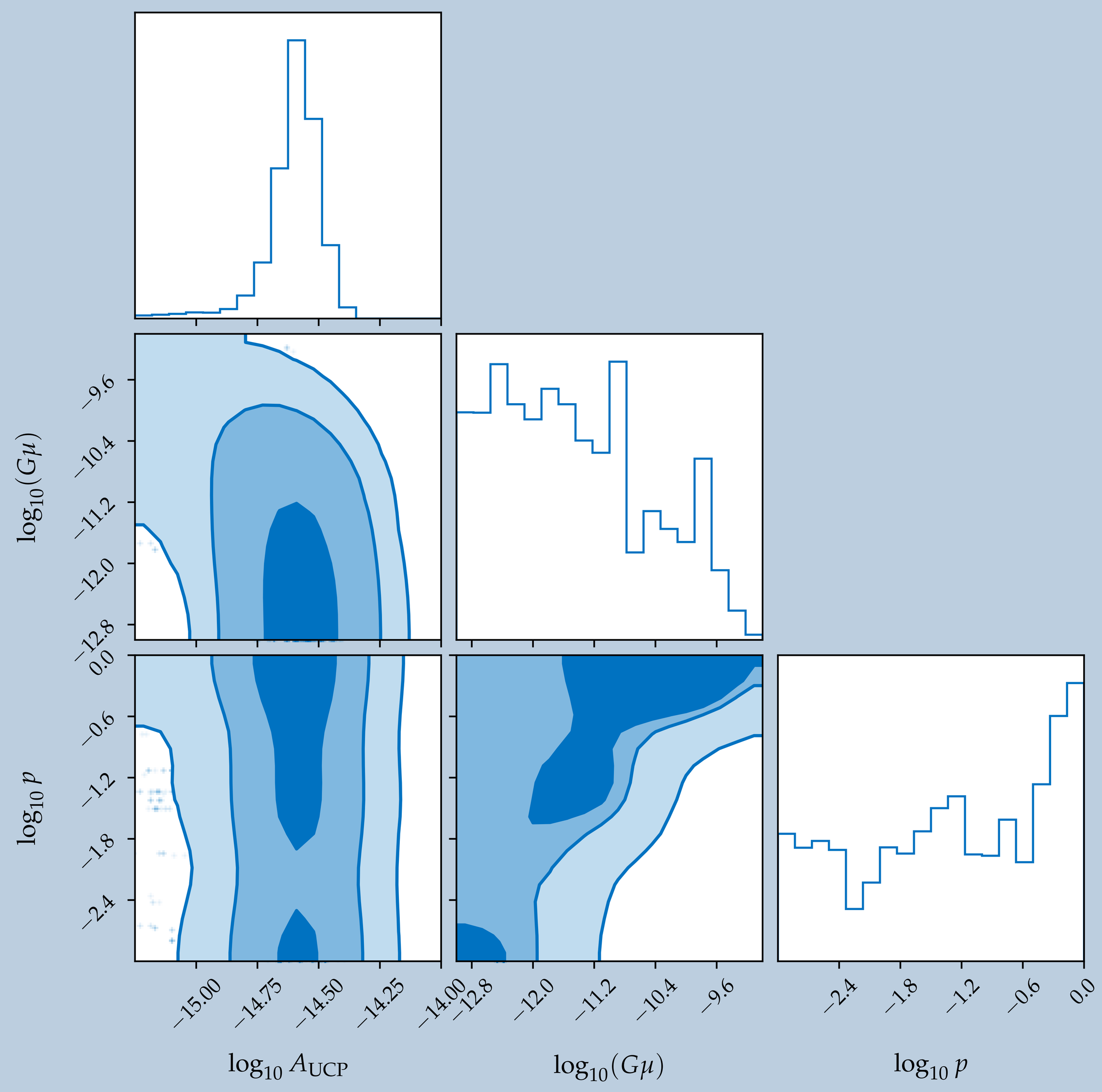
$$\rho_{\mathrm{gw}}(t, f) = G\mu^2 \sum_{n=1}^{\infty} C_n P_n, \quad (2)$$

with

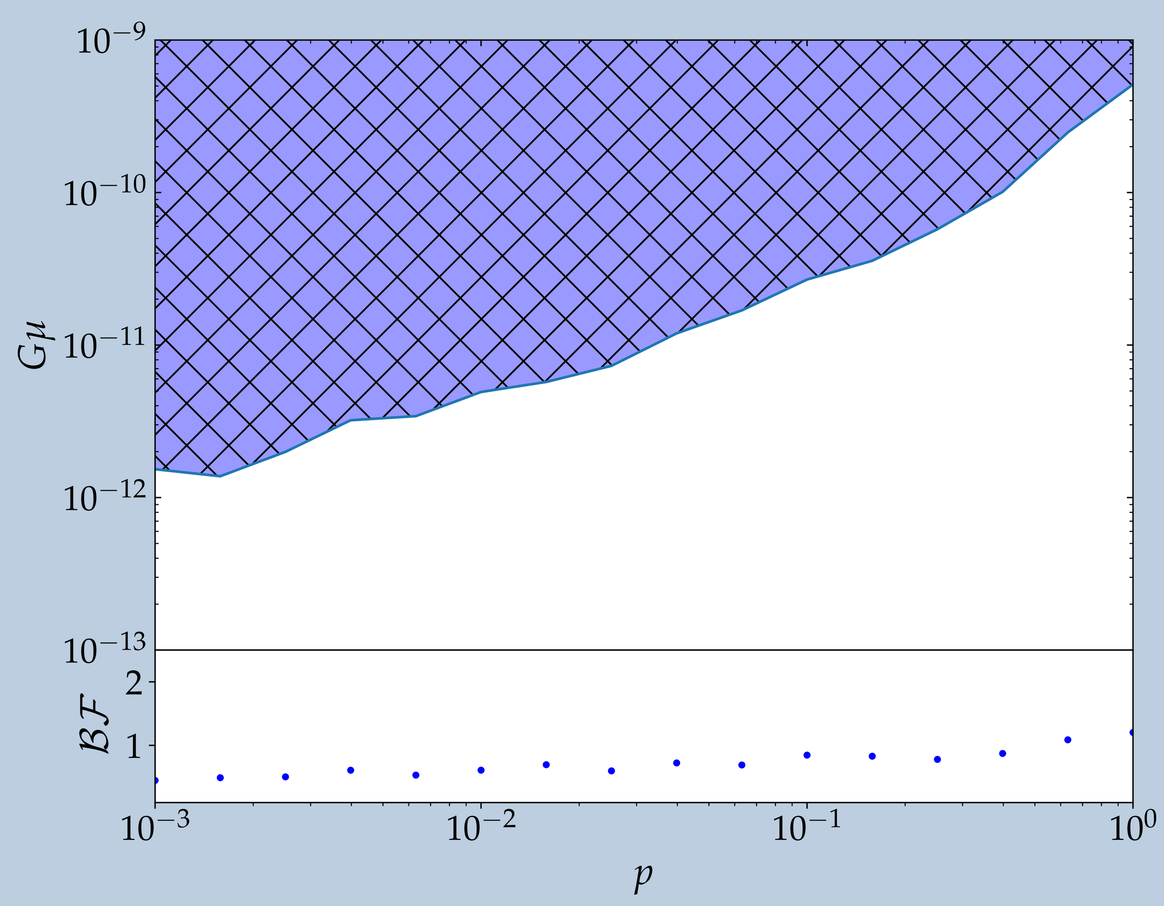
$$C_n(f) = \int_0^{t_0} \frac{dt}{(1+z)^5}\frac{2n}{f^2}\mathrm{n}(l, t). \quad (3)$$

Here, P_n is the radiation power spectrum of each loop, and $\mathrm{n}(l,t)$ is the density of loops per unit volume per unit range of loop length l existing at time t.

Results



- We first consider a model in which both the string tension $G\mu$ and the reconnection probability p are free parameters.
- The Bayes factor of the model including both the UCP and cosmic string signal versus the model including only the UCP is $\mathcal{BF}_{\mathrm{UCP}}^{\mathrm{UCP+CS}} = 0.591 \pm 0.008 < 3$, indicating no evidence for a GWB signal produced by the cosmic string in the PPTA DR2.



- We also consider models in which p is fixed while $G\mu$ is allowed to vary.
- For all of the values $p \in [10^{-3}, 1]$, we have $\mathcal{BF}_{\mathrm{UCP}}^{\mathrm{UCP+CS}} \lesssim 3$, confirming that there is no evidence for a GWB produced by cosmic strings in the PPTA DR2.
- We place 95% upper limit on cosmic string tension $G\mu$ as a function of p. For $p = 1$, the upper bound is $G\mu \lesssim 5.1 \times 10^{-10}$.