

Multi-Band Constraints on Cosmic Strings: Unifying Harmonic and Burst Spectra

Sunday, 25 October 2026 14:20 (20)

Cosmic-string loops generate a broadband gravitational-wave background (GWB) that is typically modeled via two distinct formalisms: a discrete harmonic expansion, commonly used in pulsar-timing-array (PTA) studies, and a continuous burst superposition, employed in ground-based GWB searches. In this work, we formally unify the two formalisms, showing that they provide discrete and continuous representations of the same underlying radiation process and converge on the scale-invariant spectrum plateau. On the rising low-frequency branch, where the first few harmonics dominate, the discrete nature becomes important, causing the two formalisms to diverge. Within this unified framework, the spectral calculation is more consistent across frequency bands, enabling multi-band inference. Leveraging this physical insight, we perform joint Bayesian inference across four representative loop-distribution models using the NANOGrav, EPTA, and LIGO–Virgo–KAGRA (LVK) datasets. By jointly sampling the string tension $G\mu$ alongside the average cusp and kink numbers $\{N_c, N_k\}$, the loop-radiation uncertainties are accounted for. We find that employing the harmonic expansion strengthens the LVK bounds by 21% – 31% for three of these models. Additionally, the stringent LVK bounds preclude three of these models from explaining the observed PTA common signal. For the sole surviving model, our multi-band analysis improves the inferred limit on $G\mu$.

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Session Classification : Gravitational Wave Physics (Room A)