

A Template-Based Search for Large-Scale-Structure–Correlated Anisotropy in the Nanohertz Gravitational-Wave Background Using the Public NANOGrav 15-Year Data Set

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Recent PTA analyses reporting evidence for a nanohertz common-spectrum process motivate targeted tests of whether any anisotropic component of the stochastic gravitational-wave background (SGWB) is correlated with the nearby large-scale structure (LSS), as anticipated for an astrophysical background dominated by supermassive black hole binaries. We present the first Bayesian PTA likelihood analysis that embeds an externally observed, full-sky galaxy-survey LSS template directly as an overlap-reduction-function (ORF) component. Using the 2MASS Photometric Redshift (2MPZ) galaxy catalog, we construct low-multipole LSS–correlated ORF templates in two redshift slices ($0 < z \leq 0.1$ and $0.1 < z \leq 0.2$) and model PTA cross-correlations as $\Gamma_{ab} = \Gamma_{ab}^{\text{HD}} + \sum_i \epsilon_i \Gamma_{ab}^{\text{LSS}(i)}$, where ϵ_i quantifies the amplitude of an SGWB component whose angular correlations project onto the fixed 2MPZ LSS templates. Applying this framework to the NANOGrav 15-year dataset, we find no evidence for an LSS-correlated component: the inferred ϵ_i values are consistent with zero in both single-bin and two-bin analyses (e.g., $\epsilon_1 = 0.20_{-1.66}^{+1.68}$ and $\epsilon_2 = -0.11_{-1.83}^{+2.04}$; 68% credible intervals), and Bayes factors favor the isotropic Hellings–Downs hypothesis ($\mathcal{B}_{\text{HD}+\text{LSS}_1, \text{HD}} = 0.40$, $\mathcal{B}_{\text{HD}+\text{LSS}_2, \text{HD}} = 0.43$, $\mathcal{B}_{\text{HD}+\text{LSS}_1+2, \text{HD}} = 0.11$). We therefore place upper limits on any 2MPZ-traced, LSS-correlated contribution to the SGWB at $z < 0.2$. More broadly, our framework provides a reproducible pathway for incorporating observed LSS information into PTA anisotropy searches and naturally motivates extensions to finer redshift tomography and next-generation PTA datasets.

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