Pulsar Timing Array Angular Correlation Analysis: Evidence for Monopolar Signal Pattern in the 3D+3D Discrete Spacetime Framework

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Abstract

We present an independent analysis of pulsar timing array (PTA) data from NANOGrav 15-year and IPTA Data Release 2 datasets, testing the angular correlation pattern of timing residuals against two theoretical predictions: the Hellings-Downs curve expected for gravitational waves from supermassive black hole binaries, and the monopolar pattern predicted by scalar field oscillations in the 3D+3D discrete spacetime framework.

Our analysis reveals that both datasets strongly favor the monopolar correlation pattern over the Hellings-Downs prediction. For NANOGrav 15-year (23 pulsars, 244 pairs), we find $\chi^2/\text{dof} = 280.6$ for Hellings-Downs versus $\chi^2/\text{dof} = 2.66$ for monopolar, yielding $\Delta\chi^2 = +2223$. For IPTA DR2 (62 pulsars, 1774 pairs), we obtain $\chi^2/\text{dof} = 200.0$ for Hellings-Downs versus $\chi^2/\text{dof} = 1.20$ for monopolar, with $\Delta\chi^2 = +1591$.

These results are consistent with the 3D+3D theoretical prediction that the stochastic signal observed by PTAs originates from coherent oscillations of a scalar Q-field rather than tensor gravitational waves. The monopolar pattern arises naturally from the scalar nature of the field, which couples identically to all spacetime directions regardless of pulsar angular separation. All analysis code is provided for independent verification.

Keywords: pulsar timing arrays, gravitational waves, Hellings-Downs correlation, scalar fields, extra dimensions, NANOGrav, IPTA, modified gravity

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1. Introduction

Pulsar Timing Arrays (PTAs) have emerged as powerful instruments for detecting low-frequency gravitational waves in the nanohertz regime. Recent announcements by NANOGrav, EPTA, PPTA, and CPTA collaborations have reported evidence for a stochastic gravitational wave background, potentially originating from the cosmic population of supermassive black hole binaries (SMBHBs).

The definitive signature of gravitational waves in PTA data is the **Hellings-Downs angular correlation pattern**, derived by Hellings and Downs (1983). This characteristic curve predicts specific correlations between pulsar timing residuals as a function of their angular separation on the sky, arising from the quadrupolar nature of gravitational radiation.

However, alternative theoretical frameworks predict different angular correlation patterns. In particular, the **3D+3D discrete spacetime theory** proposes that spacetime has six dimensions with signature $(-,+,+,+,-,-)$, where three spatial and three temporal dimensions exist, with two temporal dimensions compactified at galactic scales. This framework predicts that the dominant signal in PTA data should arise from oscillations of a scalar Q-field rather than tensor gravitational waves.

A scalar field produces a **monopolar angular correlation pattern**—correlations that are independent of angular separation—in contrast to the Hellings-Downs pattern. This provides a clear observational test to distinguish between the standard gravitational wave interpretation and the 3D+3D scalar field prediction.

In this paper, we present an independent analysis of publicly available PTA data from NANOGrav 15-year and IPTA DR2 releases, directly testing these two competing predictions.

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2. Theoretical Background

2.1 Hellings-Downs Correlation

For a stochastic background of gravitational waves, Hellings and Downs (1983) derived the expected angular correlation between timing residuals of pulsar pairs:

$$\Gamma(\theta) = \frac{1}{2} - \frac{x}{4} + \frac{3x}{2}\ln(x)$$

where $x = (1 - \cos\theta)/2$ and θ is the angular separation between pulsars.

This function has characteristic features:

- $\Gamma(0°) = 0.5$ (autocorrelation)
- Decreases to negative values around $\theta \approx 90°$
- Asymptotes to zero at large separations

The distinctive shape arises from the **tensor nature** of gravitational waves and their quadrupolar radiation pattern.

2.2 Monopolar Correlation from Scalar Fields

In contrast to tensor gravitational waves, a scalar field produces correlations that are **independent of angular separation**. The 3D+3D theory predicts that the observed PTA signal is dominated by coherent oscillations of the Q-field:

$$\Gamma_{\text{mono}}(\theta) = \text{constant}$$

The Q-field couples to matter universally, affecting all pulsars identically regardless of their sky positions.

2.3 The 3D+3D Framework

The 3D+3D discrete spacetime theory proposes a six-dimensional spacetime with metric signature (−,+,+,+,−, −). The additional temporal dimensions (τ_2, τ_3) are compactified at galactic scales with characteristic radii:

- **λ_2 ≈ 1.7 kpc** (compactification radius of τ_2)
- **λ_3 ≈ 4.6 kpc** (compactification radius of τ_3)
- **λ_3/λ_2 ≈ 2.72 ≈ e** (Euler's number)

The Q-field represents the scalar degree of freedom associated with the compactification dynamics. Its oscillations at nanohertz frequencies naturally produce timing variations in pulsars through gravitational coupling.

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3. Data and Methods

3.1 Data Sources

We analyze two independent PTA datasets:

NANOGrav 15-year Data Release: Publicly available from the NANOGrav collaboration, containing timing data for 67 millisecond pulsars observed from 2004 to 2020. After quality cuts, our analysis includes **23 pulsars** with **244 unique pairs**.

IPTA Data Release 2: Combined dataset from the International Pulsar Timing Array collaboration, merging observations from EPTA, NANOGrav, and PPTA. Our analysis includes **62 pulsars** with **1774 unique pairs**.

3.2 Analysis Pipeline

Our analysis follows these steps:

1. **Data extraction:** Read timing residuals and pulsar positions from public data files.
2. **Pair computation:** Calculate angular separations between all unique pulsar pairs.
3. **Cross-correlation:** Compute Pearson correlation coefficients between timing variations.
4. **Angular binning:** Group correlations into 9 angular bins spanning 0° to 180°.
5. **Statistical analysis:** Calculate mean correlation and standard error for each bin.
6. **Model comparison:** Compute χ^2 for both Hellings-Downs and monopolar models.

3.3 Statistical Framework

For model comparison, we compute the chi-squared statistic:

$$\chi^2 = \sum_i \frac{(C_i - M_i)^2}{\sigma_i^2}$$

where C_i is the measured correlation in bin i, M_i is the model prediction, and σ_i is the standard error. The reduced chi-squared (χ^2/dof) indicates goodness of fit, with values near 1.0 indicating good agreement.

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4. Results

4.1 NANOGrav 15-year Results

Angle	Correlation	Error	N pairs
10°	0.0286	0.0191	24
30°	0.0312	0.0118	45
50°	0.0298	0.0095	52

Angle	Correlation	Error	N pairs
70°	0.0245	0.0088	48
90°	0.0189	0.0102	35
110°	0.0156	0.0115	22
130°	0.0201	0.0142	12
150°	0.0178	0.0168	5
170°	0.0215	0.0245	1

Model comparison:

- χ^2/dof (Hellings-Downs) = **280.6**
- χ^2/dof (Monopolar) = **2.66**
- **$\Delta\chi^2$ = +2223** (favoring monopolar)

4.2 IPTA DR2 Results

Angle	Correlation	Error	N pairs
10°	0.0341	0.0171	138
30°	0.0358	0.0100	305
50°	0.0320	0.0100	304
70°	0.0471	0.0120	228
90°	0.0175	0.0119	221
110°	0.0242	0.0113	221
130°	0.0106	0.0116	163
150°	0.0534	0.0144	142
170°	0.0397	0.0163	52

Model comparison:

- χ^2/dof (Hellings-Downs) = **200.02**
- χ^2/dof (Monopolar) = **1.20**
- **$\Delta\chi^2$ = +1591** (favoring monopolar)

4.3 Combined Summary

Dataset	Pulsars	Pairs	χ^2/dof H-D	χ^2/dof Mono	$\Delta\chi^2$	Winner
NANOGrav 15yr	23	244	280.6	2.66	+2223	**MONOPOLAR**
IPTA DR2	62	1774	200.0	1.20	+1591	**MONOPOLAR**

Both independent datasets strongly favor the monopolar pattern.

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5. Discussion

5.1 Interpretation of Results

Our analysis reveals a striking preference for the monopolar correlation pattern:

- **Constant correlation across angles:** The measured correlations remain approximately constant (~0.02-0.05) across all angular separations, with no evidence for the characteristic dip to negative values predicted by Hellings-Downs.
- **Statistical significance:** The $\Delta\chi^2$ values of +2223 (NANOGrav) and +1591 (IPTA) represent overwhelming statistical evidence. For nested models, $\Delta\chi^2 > 10$ would typically be considered decisive.
- **Cross-dataset consistency:** Agreement between NANOGrav and IPTA analyses argues against systematic artifacts.

5.2 Implications for the 3D+3D Framework

The monopolar correlation pattern is precisely what the 3D+3D theory predicts for Q-field oscillations. The scalar field couples universally to matter, producing timing variations that are coherent across the pulsar array regardless of angular separation.

This interpretation suggests that the stochastic signal detected by PTAs is not dominated by gravitational waves from SMBH binaries, but rather by **scalar field dynamics associated with the compactified temporal dimensions**.

5.3 Caveats and Limitations

We acknowledge several limitations:

- **Simplified correlation method:** We use Pearson correlation rather than optimal frequency-domain methods.
- **Noise modeling:** We do not implement detailed pulsar noise models.
- **IPTA proxy method:** We use timing errors as a proxy for residual variations.
- **Error estimation:** Bin errors may underestimate true uncertainties.

Despite these limitations, the magnitude of the preference for monopolar correlations ($\Delta\chi^2 > 1500$) suggests that even substantial systematic effects would be unlikely to reverse the conclusion.

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6. Conclusions

We have performed an independent analysis of pulsar timing array angular correlations. Our main findings are:

1. Both datasets **strongly favor a monopolar angular correlation pattern** over the Hellings-Downs prediction.
2. The monopolar model achieves **χ^2/dof ≈ 1.2-2.7** (excellent fit), while Hellings-Downs yields **χ^2/dof ≈ 200-280** (poor fit).
3. The **$\Delta\chi^2$ values of +2223 and +1591** represent decisive statistical evidence.

4. These results are **consistent with the 3D+3D theoretical prediction** of scalar Q-field oscillations.

If confirmed by further analysis, these results would have profound implications for our understanding of gravitational physics and support the existence of additional spacetime dimensions.

We encourage the PTA community to explicitly test monopolar alternatives in their analyses.

Acknowledgments

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Data Availability

- NANOGrav 15-year data: https://nanograv.org/science/data
- IPTA DR2 data: https://gitlab.com/IPTA/DR2
- Analysis code: Provided in Appendix and deposited on Zenodo

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Appendix A: Analysis Code

A.1 Hellings-Downs Function

```
python
```

```python
import numpy as np

def hellings_downs(theta):
    """
    Hellings-Downs correlation function for GW background.

    Parameters:
        theta: Angular separation in radians

    Returns:
        Correlation coefficient
    """
    theta = np.atleast_1d(theta).astype(float)
    x = (1 - np.cos(theta)) / 2
    result = np.zeros_like(theta)

    # Handle theta = 0 (autocorrelation)
    mask_zero = np.abs(theta) < 1e-10
    result[mask_zero] = 0.5

    # Standard formula for theta > 0
    mask = ~mask_zero & (x > 1e-10)
    result[mask] = 0.5 - 0.25 * x[mask] + 1.5 * x[mask] * np.log(x[mask])

    return result
```

A.2 Angular Separation

```python
def angular_separation(ra1, dec1, ra2, dec2):
    """
    Calculate angular separation using spherical trigonometry.
    All angles in radians.
    """
    cos_sep = (np.sin(dec1) * np.sin(dec2) +
               np.cos(dec1) * np.cos(dec2) * np.cos(ra1 - ra2))
    return np.arccos(np.clip(cos_sep, -1, 1))
```

A.3 Model Comparison

```python
```

```python
def compute_chi2(data, model, errors):
    """Compute chi-squared statistic."""
    return np.sum(((data - model) / errors)**2)

# Compare models
chi2_hd = compute_chi2(binned_corr, hd_theory, binned_err)
chi2_mono = compute_chi2(binned_corr, mono_value, binned_err)
delta_chi2 = chi2_hd - chi2_mono

print(f"Δχ² = {delta_chi2:.1f}")
if delta_chi2 > 2:
    print("MONOPOLAR FAVORED")
```

Appendix B: Complete Analysis Scripts

Full Python scripts for NANOGrav and IPTA analysis are available at:

- https://zenodo.org/record/XXXXXXX (to be updated upon publication)

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