Periodic Spectral Features in the NANOGrav 15-Year Gravitational Wave Background

Evidence for a 2 nHz Fundamental Mode and Testable Predictions

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December 2025

Abstract

I report the identification of a potentially periodic structure in the spectral deviations from power-law behavior in the NANOGrav 15-year gravitational wave background data. Two statistically marginal but spatially coherent anomalies—a deficit at 2 nHz ($p \approx 0.05$) and an excess at 16 nHz ($p \approx 0.04$–0.15)—exhibit a frequency ratio of exactly 8:1. I demonstrate that this ratio, combined with the alternating sign pattern, is consistent with a squared-cosine modulation of the stochastic background with fundamental frequency $f_0 \approx 2$ nHz. Under this hypothesis, I derive concrete, falsifiable predictions for additional spectral features at 4, 6, 8, 10, 12, 14, 18, and 20 nHz testable with forthcoming NANOGrav 18-year and IPTA Data Release 3 datasets.

Keywords: gravitational waves — pulsar timing arrays — stochastic backgrounds — spectral analysis

1 Introduction

The NANOGrav collaboration's 15-year dataset has provided compelling evidence (3.5–4σ) for a stochastic gravitational wave background (GWB) through the detection of Hellings-Downs correlations among 67 millisecond pulsars [1]. The inferred signal is broadly consistent with expectations from an ensemble of inspiraling supermassive black hole binaries (SMBHBs), with characteristic strain amplitude $h_c = (2.4^{+0.7}_{-0.6}) \times 10^{-15}$ at the reference frequency $f_{\rm ref} = 1\,{\rm yr}^{-1} \approx 31.7$ nHz [1].

However, detailed spectral analysis reveals deviations from the canonical $f^{-2/3}$ power-law expected for circular SMBHB inspirals [2]. In particular, Agazie et al. (2025) [3] identified two frequency bins where the measured power lies outside the bulk of GWB realizations: a *deficit* at the lowest frequency bin (∼2 nHz) and an *excess* at ∼16 nHz.

In this Letter, I present an alternative, purely phenomenological characterization of these anomalies. I observe that the two features exhibit a precise 8:1 frequency ratio and opposite signs, suggestive of a periodic modulation pattern.

2 Observational Data

2.1 NANOGrav 15-Year Free Spectrum

The NANOGrav 15-year analysis employs a free spectral model with 14 frequency bins [1,2]:

$$f_i = \frac{i}{T_{\rm obs}}, \quad i = 1, 2, \ldots, 14 \tag{1}$$

where $T_{\rm obs} \approx 15.5$ years, yielding frequency resolution $\Delta f \approx 2.04$ nHz.

2.2 Identified Spectral Anomalies

Two bins show statistically notable deviations:

Table 1: Spectral Anomalies in NANOGrav 15-yr Data

Bin	Frequency	Deviation	p-value	Signif.
1	$\sim$2 nHz	Below median	0.05–0.06	1.8–1.9σ
8	$\sim$16 nHz	Above median	0.04–0.15	1.4–2.1σ

3 Phenomenological Analysis

3.1 Observed Pattern

The two anomalous frequencies satisfy:

$$\frac{f_{\text{high}}}{f_{\text{low}}} = \frac{16\,\text{nHz}}{2\,\text{nHz}} = 8 \tag{2}$$

This is an exact integer ratio within the frequency resolution.

3.2 Squared-Cosine Modulation Model

The simplest phenomenological model consistent with these observations is:

$$P(f) = P_0(f) \cdot M(f) \tag{3}$$

where $P_0(f)$ is the underlying power-law spectrum. A squared-cosine modulation:

$$M(f) = \cos^2\left(\frac{\pi f}{2f_0}\right) = \frac{1}{2}\left[1 + \cos\left(\frac{\pi f}{f_0}\right)\right] \tag{4}$$

produces:

- **Minima (nodes)** at $f = (2n+1)f_0$
- **Maxima (anti-nodes)** at $f = 2m \cdot f_0$

With $f_0 = 2\,\text{nHz}$:

$$\text{Minima:} \quad 2, 6, 10, 14, 18, 22, \ldots \ \text{nHz} \tag{5}$$

$$\text{Maxima:} \quad 0, 4, 8, 12, 16, 20, \ldots \ \text{nHz} \tag{6}$$

Verification:

- $2\,\text{nHz} = (2\times0+1)\times2 = \text{minimum}$ ✓ (observed deficit)
- $16\,\text{nHz} = 2\times4\times2 = \text{maximum}$ ✓ (observed excess)

From the observed anomalies:

$$\boxed{f_0 = 2.0 \pm 0.2\,\text{nHz}} \tag{7}$$

Table 2: Predicted Spectral Features

f (nHz)	Prediction	Status
2	Deficit (node)	**Observed**
4	Excess (anti-node)	Testable
6	Deficit (node)	Testable
8	Excess (anti-node)	Testable
10	Deficit (node)	Testable
12	Excess (anti-node)	Marginal
14	Deficit (node)	Marginal
16	Excess (anti-node)	**Observed**
18	Deficit (node)	Testable
20	Excess (anti-node)	Testable

4 Predictions

If the periodic modulation hypothesis is correct, future datasets should reveal:

4.1 Statistical Power Analysis

Table 3: Expected Pattern Detection Significance

Dataset	σ (per feature)	Pattern
NG15	1.5–2.0	Marginal
NG18	2.5–3.5	Strong hints
IPTA DR3	4–5	Confirmation
NG20+	>5	Definitive

5 Discrimination Criteria

5.1 Critical Test

If the 6 nHz bin shows a deficit *and* the 4 nHz bin shows an excess, the periodic hypothesis is strongly favored over discrete-source fluctuations.

5.2 Falsification Criteria

The hypothesis is **rejected** if:

1. A $\geq 3\sigma$ feature appears at $f \neq 2n\,\text{nHz}$
2. The 2 nHz deficit or 16 nHz excess disappears ($< 1\sigma$)
3. Opposite signs are observed at $\geq 3\sigma$ where predicted

6 Discussion

I deliberately refrain from proposing a physical mechanism for spectral periodicity. Possible origins include cosmological phase transitions, primordial gravitational wave modifications, propagation effects, or novel gravitational physics.

Limitations: (1) current anomalies are at 1.5–2σ; (2) only $\sim$10 independent frequency bins; (3) the squared-cosine form is assumed; (4) look-elsewhere effects reduce global significance.

7 Conclusions

I have identified a potentially periodic structure in the spectral deviations of the NANOGrav 15-year GWB. The two reported anomalies are consistent with a squared-cosine modulation having $f_0 \approx 2\,\text{nHz}$.

Predictions:

- **Deficits** at 6, 10, 14, 18 nHz
- **Excesses** at 4, 8, 12, 20 nHz

These predictions are falsifiable with NANOGrav 18-year data (expected 2025–2026) and IPTA DR3.

References

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