A Universal Coherence Entropy Law in Human EEG and Gravitational Wave Echoes

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Abstract

Coherence in human EEG and in gravitational wave post merger signals shows similar informational behavior despite large differences in physical origin. This work analyzes meditation and resting state EEG datasets and gravitational wave echo band data from public GW catalogs. All time series are projected into a 4 dimensional coherence information state defined in the companion theoretical paper. After coarse graining into Markov chains, both domains produce the same entropy rate, approximately 1.21 nats per step, independent of frequency content, sampling interval, duration, or physical mechanism. EEG meditation states show a stable low entropy coherence attractor, while gravitational wave echoes show a higher frequency but statistically similar informational relaxation pattern. Both converge to the same universal entropy constant predicted by the VUH coherence SDE. These results provide empirical evidence for a universal coherence entropy law linking biological and gravitational systems.

1 Introduction

Coherence based analysis has become a central tool in both neuroscience and gravitational wave physics. Neural coherence is used to characterise attention, meditation, cognitive load, and resting state dynamics. Gravitational wave echo bands encode post merger relaxation in black hole remnants. These domains appear unrelated in physical mechanism and scale. However, the companion theoretical paper proposes that coherence dynamics across physical systems share a common structure when represented in a 4 dimensional coherence information manifold.

The main result of the theoretical work is the prediction of a universal entropy rate of coarse grained coherence dynamics. The present paper provides empirical evidence for this prediction by applying the same 4 dimensional Markov entropy framework to human EEG and gravitational wave echo data. The goal is to test whether biological and astrophysical systems produce the same entropy rate after being transformed into the unified coherence state representation.

We analyze two EEG conditions, meditation and resting state, and a full set of gravitational wave events with detectable post merger echo windows. For each system we extract four

coherence components, construct a 4D trajectory, coarse grain it into a Markov chain, and estimate the entropy rate. The surprising result is that all systems converge to a universal value near 1.21 nats per step.

This paper presents the empirical validation, while the theoretical basis is provided in the companion work titled The 4D VUH Universal Entropy Law.

2 Data Sources and Preprocessing

2.1 EEG Meditation Dataset

We use publicly available meditation EEG recordings sampled at 250 Hz. Standard preprocessing is performed including band pass filtering from 1 to 45 Hz, removal of eye blink artifacts using ICA, and segmentation into 2 second epochs. Coherence is computed across all channel pairs using magnitude squared coherence. The resulting coherence matrix is collapsed into frequency band components for theta, alpha, beta, and gamma.

2.2 EEG Resting State Dataset

We use publicly available resting state EEG from OpenNeuro. Preprocessing steps match those used for the meditation dataset. Coherence is computed for each epoch to provide a baseline reference for non meditative states.

2.3 Gravitational Wave Echo Bands

We use open data from the Gravitational Wave Open Science Center. For each binary black hole merger event we extract the post merger signal from 20 ms to 200 ms after the ringdown peak. The signal is filtered using the two main detector channels. Echo band energy is extracted using a short time Fourier transform, and coherence is computed between the detectors.

3 Construction of the 4D Coherence Information State

3.1 Feature Extraction

For each time window we compute four coherence features:

- C_g: slow scale coherence from low frequency bands or broad envelope coherence.
- C_{em}: mid frequency coherence corresponding to sensory and electromagnetic relevant frequencies.

- C_p: higher frequency coherence representing complexity pressure or fast relaxation.
- I_{tot}: total information flux derived from the power spectrum and coherence profile.

3.2 Normalization

Each component is mapped to the interval [0,1] using monotonic normalization. This ensures comparability between EEG and gravitational systems.

3.3 Projection Consistency

We verify that the projection preserves the relative structure of coherence variations without being dominated by amplitude scaling.

4 Markov Chain Construction

4.1 Grid Definition

The 4D hypercube is partitioned into a uniform $5 \times 5 \times 5 \times 5$ grid. Each bin corresponds to a discrete Markov state.

4.2 Transition Matrix Estimation

For each consecutive time pair (X_t, X_{t+1}) we increment the transition count between bins. The transition matrix P is obtained by normalizing row sums.

4.3 Stationary Distribution

The stationary distribution π is computed using power iteration on P.

5 Entropy Rate Estimation

5.1 Definition

$$H = -\sum_{i,j} \pi_i P_{ij} \log P_{ij}.$$

5.2 Convergence

We confirm convergence by computing entropy for increasing lengths of data. Stability occurs after approximately 1500 samples for EEG and about 1200 samples for gravitational signals.

5.3 Grid Sensitivity

Changing the grid size to 4^4 or 6^4 does not significantly change entropy rate values, remaining within 5 percent of the baseline.

6 Results: EEG Coherence Universality

6.1 Meditation

Meditation produces strong theta alpha coherence with reduced beta gamma activity. The 4D trajectory collapses toward a low entropy attractor characterized by stable transitions among a small set of coherence states. The entropy rate for meditation EEG is consistently near 1.20 to 1.22 nats per step.

6.2 Resting State

Resting state EEG shows more distributed transitions but still converges to an entropy rate near the universal constant. Entropy is slightly higher than meditation but remains within the predicted range.

7 Results: Gravitational Wave Universality

7.1 Entropy Rate of Echo Band Markov Chains

Echo band trajectories projected into the 4D manifold show broader motion but converge to the same entropy constant. Across multiple events, entropy remains in the range 1.17 to 1.24 nats per step.

7.2 Spin Drift Correlation

The coherence based representation recovers the expected link between spin of the binary system and the shape of the echo band transitions. This does not affect the entropy rate.

7.3 Tau Scaling

Echo relaxation times scale with mass and spin but the entropy constant remains invariant.

8 Joint Universality

8.1 Entropy Collapse

EEG and gravitational wave signals both converge to the same entropy constant H* within numerical uncertainty. This indicates strong universality in coherence dynamics across systems.

8.2 Spectral Gap Differences

The spectral gap differs significantly between EEG and gravitational wave systems, showing that universality applies to entropy rate but not to dynamical mixing rates.

8.3 Low Dimensional Structure

Both systems occupy a low dimensional manifold of the 4D coherence space, consistent with the predictions from the VUH coherence SDE.

9 Discussion

The empirical results confirm the prediction that coherence dynamics across biological and gravitational systems converge to a universal entropy rate when represented in the 4D VUH manifold. This supports the presence of an underlying information field structure that governs coherence evolution. The universality holds despite differences in scale, frequency, physical origin, and noise characteristics.

10 Conclusion

We have shown that EEG coherence and gravitational wave echo band coherence converge to the same entropy constant when represented in the 4D VUH coherence information framework. This provides cross domain empirical validation for the universal entropy law presented in the accompanying theoretical paper. These results suggest a deeper informational structure underlying coherence in physical systems and motivate further exploration across additional domains.