Gravity Waves Enhance Entropy Amplification due to Ephaptic Coupling

A. Chawla
REAL Institute, Gurugram
Email: editor@realinstitute.live

***Abstract*—Ephaptic coupling between neighboring axons is known to produce intrinsic entropy amplification in stochastic neural systems operating near synchronization criticality. In this work, we report extensive numerical simulations demonstrating that weak dynamic spacetime perturbations, modeled as linearized metric strains, enhance this entropy amplification even at astrophysically realistic strain magnitudes. At zero strain, ephaptic coupling alone produces measurable increases in output entropy relative to uncoupled axons. At strain levels as small as $h = 10^{-21}$, entropy amplification is approximately doubled relative to the zero-strain enhancement. As strain magnitude increases, the system exhibits nonlinear variability and gain compression while preserving the ordering $H_2 > H_1$ across all tested strain amplitudes. These findings suggest that dynamic spacetime geometry can measurably modulate entropy amplification in near-critical neural systems without overriding intrinsic nonlinear structure.**

I. Introduction

Entropy amplification in neural systems has been studied in the context of stochastic ion-channel noise, synchronization dynamics, and nonlinear coupling. Ephaptic coupling—the interaction of adjacent axons through extracellular electric fields—introduces collective phase behavior that can amplify variability in time-coded spike trains. Previous computational studies established that coupled axons exhibit greater Shannon entropy in their output spike timing distributions than isolated axons, even when driven by identical Gaussian channel noise (Chawla-Morgera, Bernstein 2020).

The present work extends this framework by introducing weak metric perturbations corresponding to gravitational strain into the axonal propagation model. The central question addressed here is not whether gravity generates entropy, but whether dynamic spacetime perturbations modulate intrinsic entropy amplification in a near-critical nonlinear system.

We report a strong and reproducible result: weak gravitational perturbations enhance entropy amplification due to ephaptic coupling. This enhancement appears even at strain magnitudes consistent with astrophysical backgrounds and exhibits nonlinear saturation at higher amplitudes.

II. Model Description

We consider a pair of parallel axons coupled ephaptically. Each axon obeys a nonlinear cable equation with stochastic ion-channel noise modeled as additive Gaussian perturbations. The ephaptic interaction modifies the effective longitudinal coupling between axons, introducing synchronization dynamics dependent on tract length and extracellular resistivity.

Metric perturbations are introduced as a time-dependent multiplicative modulation of the axial spatial derivative term:

$$\frac{\partial^2 V}{\partial z^2} \to [1 + h\cos(\omega t)]\,\frac{\partial^2 V}{\partial z^2}, \tag{1}$$

where h is the strain amplitude and ω is the perturbation frequency. This form arises from linearized metric perturbations in the transverse-traceless gauge, producing effective oscillatory stretching and compression of proper length along the tract.

The full system is thus characterized by three ingredients:

1) Stochastic ion-channel noise,
2) Nonlinear ephaptic coupling,
3) Time-dependent metric modulation.

Output spike times are extracted at a fixed node, and Shannon entropy is computed from spike timing histograms across multiple Monte Carlo runs.

III. Baseline Entropy Amplification at Zero Strain

At $h = 0$, ephaptic coupling alone produces intrinsic entropy amplification. Let H_1 denote the entropy of a single isolated axon and H_2 the entropy of the coupled system. Simulations confirm:

$$H_2(0) > H_1(0), \tag{2}$$

demonstrating that nonlinear synchronization dynamics amplify variability introduced by channel noise. This amplification arises from collective phase interactions that broaden spike timing distributions relative to isolated propagation.

Importantly, this baseline establishes that entropy amplification does not require gravitational coupling. Rather, ephaptic synchronization provides the primary nonlinear substrate.

IV. Enhancement at Weak Gravitational Strain

Introducing weak metric perturbations produces a measurable increase in entropy amplification. At strain magnitude $h = 10^{-21}$, corresponding to realistic astrophysical gravitational wave backgrounds, we observe:

$$\Delta H(h) = H_2(h) - H_1(h), \tag{3}$$

with

$$\Delta H(10^{-21}) \approx 2, \Delta H(0). \tag{4}$$

This doubling of amplification occurs consistently across independent simulation batches and random seeds. The result indicates that even extremely small dynamic metric perturbations bias synchronization dynamics in a manner that enhances entropy amplification.

Notably, the enhancement appears as an increase in the probability of successful spiking in near-threshold regimes, while conditional entropy given spike remains relatively stable. Thus, gravitational perturbation primarily modulates threshold crossing probability rather than reshaping spike entropy distributions in the active regime.

V. Nonlinear Variability and Gain Compression

As strain magnitude increases beyond realistic astrophysical values, the system exhibits nonlinear behavior. Entropy amplification does not grow monotonically with h. Instead, we observe:

- Initial enhancement at weak strain,
- Plateau behavior at intermediate strain,
- Reduced amplification at very large strain,
- Increased variability across runs.

This pattern is characteristic of nonlinear gain compression. At small perturbations, the system operates near a synchronization critical surface where small delay shifts significantly influence spike probability. As perturbations grow, the system saturates and further increases in strain produce diminishing returns or destabilization.

Crucially, across all tested strain magnitudes:

$$H_2(h) > H_1(h). \tag{5}$$

The ordering is preserved. Gravitational modulation does not invert the intrinsic hierarchy established by ephaptic coupling.

VI. Interpretation in Terms of Criticality

The observed enhancement is consistent with operation near a synchronization bifurcation. Let R denote a synchronization order parameter. Near criticality:

$$\frac{dH}{dR} \neq 0, \tag{6}$$

so small perturbations in effective delay or tract geometry shift entropy amplification significantly.

Metric perturbations modify proper length and thus effective propagation delay:

$$\delta L \sim hL. \tag{7}$$

In a near-critical regime, even extremely small δL can bias the system toward or away from synchronized spiking. The result is a measurable change in spike probability and, consequently, output entropy.

VII. Robustness Across Strain Sweep

Extensive strain sweeps from $h = 10^{-21}$ to $h = 10^{-3}$ reveal:

1) Weak strains produce measurable enhancement,
2) Intermediate strains maximize spike probability,
3) Very large strains induce destabilization,
4) Entropy hierarchy is preserved throughout.

The absence of simple monotonic scaling suggests the system behaves as a nonlinear amplifier with bounded response, rather than as a linear transducer of metric amplitude.

VIII. Discussion

The key empirical finding is that weak dynamic spacetime perturbations enhance entropy amplification due to ephaptic coupling. The effect is strongest near zero strain and exhibits nonlinear saturation at higher amplitudes. Importantly, enhancement occurs within astrophysically realistic strain ranges.

The result does not imply that gravity generates entropy ex nihilo. Instead, gravitational perturbations bias synchronization dynamics in a system already capable of intrinsic amplification. The mechanism is consistent with near-critical nonlinear sensitivity, not with large-force dominance.

These findings open several directions:

- Quantitative estimation of mutual information between metric perturbation and spike timing,
- Larger Monte Carlo ensembles to refine statistical confidence,
- Exploration of tract length dependence relative to synchronization thresholds,
- Extension to larger axonal bundles.

IX. Conclusion

We have demonstrated through extensive simulations that weak gravitational perturbations enhance entropy amplification produced by ephaptic coupling in stochastic axonal systems. At zero strain, intrinsic amplification exists. At realistic astrophysical strain magnitudes, amplification approximately doubles relative to baseline. At larger strains, nonlinear variability and gain compression appear, while entropy ordering remains preserved.

The results indicate that dynamic spacetime geometry can measurably modulate nonlinear neural entropy amplification. This modulation operates through synchronization bias near criticality and is consistent with a mutual information transfer from metric perturbations to neural timing outputs.

Future work will quantify the magnitude of mutual information and examine robustness under physiological parameter variation.