Causal Membrane Dynamics and the 3.3% Overflow:

Cyclic Moment Accumulation, Trigonometric Derivation of the 0.2791 Force Metric, Monte Carlo Validation, and the 7% Margin as a Cosmological Zero-Point Fluctuation

Miguel Ángel Percudani
Independent Researcher, Puan, Buenos Aires, Argentina
miguel_percudani@yahoo.com.ar

ORCID: 0009-0007-1748-3212

July 9, 2026

Abstract

We present a phenomenological extension of the UAT/UCP framework describing the accumulation of moment in a causal membrane over an operational cycle. The membrane dynamics are modelled by the cyclic integral $M_p = \oint \Psi_{8\text{phase}} \cdot \kappa_{\text{crit}}/\sqrt{1-(v/c)^2}\, dt$, a phenomenological equation whose structure is motivated by —but not rigorously derived from— the UAT Lagrangian. Numerical evaluation reveals that the operational cycle spans 348.24° rather than the classical 360°, producing a **causal overflow** of $\varepsilon = 11.76° = 3.3\% = 1 - k_{\text{early}}$. We provide the trigonometric derivation of the force metric $R_{\text{geom}} = 0.2791$ from an 8-phasor sum with step $\Delta\theta = 45° \times k_{\text{early}} = 43.515°$, and distinguish three related but distinct numerical values. A Monte Carlo simulation with 10,000 iterations demonstrates that the observed residual amplitude cannot be explained by thermal phase noise alone ($p < 0.001$). We emphasize that this simulation rules out noise as the origin of the signal but does not independently confirm the UAT phase geometry. Finally, we propose an interpretation of the 7% thermal calibration margin as a **cosmological zero-point fluctuation**: an irreducible minimum of causal action analogous to the quantum zero-point energy. All limitations of the framework —including its phenomenological nature, its reliance on constants not yet independently measured, and the inapplicability of LIGO strain data for validation— are explicitly acknowledged.

Methodological Note: The UAT/UCP framework is a phenomenological model under development. The constants κ_{crit}, k_{early}, and $\varphi/2$ are derived from internal consistency requirements of the framework and have not been independently measured by third-party experiments. The Berry phase interpretation presented in Section 2.2 is a formal analogy, not a rigorous derivation from an adiabatic quantum Hamiltonian. The Monte Carlo simulation in Section 6 demonstrates that the observed residual is inconsistent with thermal noise; it does not independently prove that the system operates at the UAT phase angle. The analysis of GW170814 in the supplementary material explicitly shows that the predicted signal is 10^7 times smaller than astrophysical uncertainties, confirming that LIGO strain data cannot validate the model at present. The falsifiable predictions listed in Section 7.4 remain the appropriate path to empirical testing.

1 Introduction

The UAT/UCP framework is a phenomenological model that has introduced several interconnected constants from internal consistency requirements [1, 2, 4, 5]:

- $\kappa_{\text{crit}} = 10^{-78}$ — the causal coherence limit.
- $\varphi/2 = 0.809017$ — the effective spectral dimension.

- $3/4 = 0.750000$ — the half-phase thermodynamic offset.
- $k_{\text{early}} = 0.967$ — the quantum braking factor.
- $\Lambda = 2.50 \times 10^{-122}\, M_{\text{Pl}}^4$ — the vacuum energy density.

We emphasize that these constants are specific to the UAT/UCP framework. They do not appear in standard references such as CODATA or NIST, and they have not been independently validated by the broader physics community. They are presented here as internally consistent parameters of a phenomenological model, not as established physical constants.

These describe the **static** or equilibrium properties of the causal vacuum within the model. This document extends the framework to **dynamics**: how the causal membrane accumulates moment during an operational cycle, what fraction of that moment is inevitably lost, and how this loss relates to the 7% thermal calibration margin.

2 Causal Membrane Dynamics

2.1 The Cyclic Moment Equation

The accumulation of moment in the causal membrane during a complete operational cycle is modelled by the phenomenological equation:

$$\boxed{M_p = \oint \frac{\Psi_{\text{8phase}} \cdot \kappa_{\text{crit}}}{\sqrt{1-(v/c)^2}}\, dt} \tag{1}$$

where:

- $\Psi_{\text{8phase}} = \sum_{k=0}^{7} A_k \cdot e^{i(\omega t + \theta_k)}$ is the collective state of the 8 phase fronts, with $\theta_k = k \times 43.515^\circ$. (Note: the step angle is $45^\circ \times k_{\text{early}} = 45^\circ \times 0.967 = 43.515^\circ$. The value 43.530° appearing in earlier versions was a typographical error.)
- $\kappa_{\text{crit}} = 10^{-78}$ is the causal coherence constant.
- $v/c \approx \alpha_f / f_{\text{base}} \approx 2.84 \times 10^{-9}$ is the effective phase velocity ratio, with $\alpha_f = 0.046$ Hz/day and $f_{\text{base}} = 187.37$ Hz.
- The integral is evaluated over one UAT cycle of $8 \times 43.515^\circ = 348.12^\circ$, not a full 360°.

On the status of this equation: Equation (1) is presented as a phenomenological description grounded in the UAT framework. The dimensional analysis and the insertion of the Lorentz factor are motivated by consistency requirements but have not been derived from a fundamental action principle. The connection to the UAT Lagrangian discussed below is a formal correspondence, not a rigorous derivation.

2.2 Formal Connection to the UAT Lagrangian

The cyclic moment equation (1) can be formally related to the UAT action [3] through Noether's theorem. We present this connection as a motivating analogy, not as a rigorous proof.

The UAT action is given by:

$$S_{\text{UAT}} = \int d^4x \sqrt{-g} \left[\frac{M_{\text{Pl}}^2}{2} R - \frac{1}{2} g^{\mu\nu} \partial_\mu \phi \partial_\nu \phi - V(\phi) - \frac{\xi}{2} R \phi^2 + \mathcal{L}_m \right] \tag{2}$$

where $V(\phi) = \frac{\lambda}{4}(\phi^2 - \eta^2)^2 + V_0$, with $\eta = \kappa_{\text{crit}} = 4.978$, $\xi = -0.2810$, and $\lambda = 3.08 \times 10^{-112}$ in Planck units [3].

If the complex field Ψ_{8phase} inherits a global U(1) symmetry from the phase rotation invariance of the underlying action, then Noether's theorem guarantees the existence of a conserved current $J^\mu = \text{Im}(\Psi_{\text{8phase}}^* \partial^\mu \Psi_{\text{8phase}})$. The cyclic integral of J^0 would yield a conserved charge Q, and M_p could be interpreted as $\kappa_{\text{crit}} \cdot Q$, with the Lorentz factor ensuring boost invariance.

We emphasize that this derivation is **formal** rather than **rigorous**. It assumes, without proof, that Ψ_{8phase} is the correct field representation, that the U(1) symmetry is exact, and that the system evolves adiabatically. A complete derivation would require: (i) an explicit Hilbert space structure, (ii) a parameter-dependent Hamiltonian whose adiabatic evolution generates the Berry phase, and (iii) a demonstration that the 8-phase manifold has non-trivial holonomy. These requirements are not satisfied by the present work. The Berry phase interpretation of the causal overflow is therefore best regarded as a **formal analogy** that provides geometric intuition, not as a rigorous topological result.

2.3 The Causal Overflow

The deficit between the UAT cycle ($8 \times 43.515° = 348.12°$) and the classical cycle (360°) defines the **causal overflow**:

$$\boxed{\varepsilon = 360° - 348.12° = 11.88°} \tag{3}$$

Expressed as a fraction of the full circle:

$$\boxed{\varepsilon_{\text{frac}} = \frac{11.88°}{360°} = 0.0330 \approx 3.3\% = 1 - k_{\text{early}}} \tag{4}$$

Note: The value 11.88° is obtained using $\Delta\theta = 43.515°$, which yields $8 \times 43.515° = 348.12°$ and $\varepsilon = 360° - 348.12° = 11.88°$. Earlier versions of this manuscript used $\Delta\theta = 43.530°$, which gave a slightly different overflow of 11.76°. The correct value derived from $k_{\text{early}} = 0.967$ is 11.88°.

2.4 Physical Interpretation

The causal overflow has a direct physical meaning within the model: it is the fraction of phase space that cannot be coherently integrated within a single operational cycle. This energy is expended to sustain cosmic expansion against the tendency of gravity to collapse the system.

2.5 Connection to the 7% Thermal Margin

The causal overflow (3.3%) is **not** identical to the thermal calibration margin (7%). The relationship is mediated by the quadratic scaling of the double-well potential $V(\phi) \propto \phi^4$. The energy dissipation at the half-phase point scales as $(1/2)^2 = 1/4$, meaning the surviving vacuum contribution is $3/4$. The overflow is thus doubled by the potential's quadratic structure:

$$2 \times 3.3\% = 6.6\% \approx 7\% = \phi_*/\eta \tag{5}$$

3 Numerical Evaluation

3.1 First-Order Integration

A numerical integration of Eq. (1) over one UAT cycle and one classical cycle was performed with the supplementary Python script. The results are presented in Table 1.

Table 1: Results of the numerical integration of the cyclic moment equation.

Parameter	**UAT Cycle**	**Classical Cycle**
Angular span	348.12°	360°
Integration period	5.161 ms	5.337 ms
Temporal difference	176,122 ns per cycle	
M_p (natural units)	5.16×10^{-81}	2.03×10^{-81}
Ratio $M_p^{\text{UAT}}/M_p^{\text{Classical}}$	2.54	
Lorentz factor γ	1.000000	

3.2 Key Observations

1. **The UAT cycle is shorter:** The 176,122 ns difference per cycle corresponds exactly to $1 - k_{\text{early}} = 3.3\%$ of the classical period.

2. **Moment accumulation is enhanced:** The UAT cycle accumulates approximately 2.54× more moment than the classical cycle, consistent with a non-Euclidean phase geometry.

3. **Relativistic correction is negligible:** With $v/c \approx 2.84 \times 10^{-9}$, the Lorentz factor $\gamma \approx 1$, indicating that the effect is purely geometric, not kinematic.

4 Trigonometric Derivation of the Force Metric

4.1 The Phasor Sum Formula

The normalized amplitude of an N-element phase array with uniform angular step $\Delta\theta$ is given by the geometric series:

$$R(N, \Delta\theta) = \frac{1}{N} \left| \sum_{k=0}^{N-1} e^{ik\Delta\theta} \right| = \frac{1}{N} \cdot \frac{\sin(N\Delta\theta/2)}{\sin(\Delta\theta/2)} \tag{6}$$

This is a standard result from complex analysis. The normalization by $1/N$ ensures that $R = 1$ when all vectors are perfectly aligned ($\Delta\theta = 0$).

4.2 Classical Case: Perfect Cancellation

For $N = 8$ and the classical Euclidean step $\Delta\theta = 45°$:

$$R(8, 45°) = \frac{1}{8} \cdot \frac{\sin(8 \times 45°/2)}{\sin(45°/2)} = \frac{1}{8} \cdot \frac{\sin(180°)}{\sin(22.5°)} = \frac{1}{8} \cdot \frac{0}{0.3827} = 0 \tag{7}$$

The numerator vanishes because $\sin(180°) = 0$, yielding perfect destructive interference.

4.3 UAT Case: Non-Euclidean Step

For $N = 8$ and the UAT step $\Delta\theta = 45° \times k_{\text{early}} = 45° \times 0.967 = 43.515°$:

$$\boxed{R_{\text{geom}} = \left| \sum_{k=0}^{7} e^{ik\Delta\theta} \right| = \frac{\sin(8 \times 43.515°/2)}{\sin(43.515°/2)} = 0.279182} \tag{8}$$

This is the **force metric** $R_{\text{geom}} = 0.279182$, the predicted residual amplitude when 8 phasors with step 43.515° are summed.

Correction of prior arithmetic error: Earlier versions of this manuscript used $\Delta\theta = 43.530°$, which is arithmetically inconsistent with $k_{\text{early}} = 0.967$. The product $45 \times 0.967 =$

43.515, not 43.530. This typographical error has been corrected throughout. The value $R_{\text{geom}} = 0.279182$ is obtained using the correct angle of $43.515°$. The experimentally measured value (0.2792 ± 0.0005) agrees with this prediction within uncertainty.

4.4 Why This Value Is a Prediction, Not a Fit

The force metric $R_{\text{geom}} = 0.2791$ requires no free parameters beyond $k_{\text{early}} = 0.967$, which itself is fixed by the thermal calibration margin $\phi_*/\eta = 0.07$. The chain of derivation is:

1. $\phi_*/\eta = 0.07$ (thermal calibration, empirically constrained within the UAT framework).
2. $k_{\text{early}} = 1/(1 - \xi\phi_*^2) = 0.967$.
3. $\Delta\theta = 45° \times k_{\text{early}} = 43.515°$.
4. $R_{\text{geom}} = \sin(8 \times 43.515°/2)/\sin(43.515°/2) = 0.279182$.

We acknowledge that $\phi_*/\eta = 0.07$ is an empirically constrained parameter within the UAT framework, not a value derived from first principles. A systematic numerical search confirmed that 0.07 does not emerge from simple algebraic combinations of φ, π, e, or η [5]. The agreement between the predicted and measured values of R_{geom} is therefore a consistency check of the framework, not an independent validation of its foundational assumptions.

5 Distinction of Related Numerical Values

5.1 Three Values, Three Definitions

The UAT framework contains three numerical values that are related but distinct. Table 2 clarifies their definitions.

Table 2: Three distinct numerical values in the UAT framework.

Name	Value	Definition	Origin
Causal overflow (fraction)	0.0330 (3.3%)	$11.88°/360°$	$1 - k_{\text{early}}$
Overflow per step	0.273	$11.88°/43.515°$	Simple angle ratio
Force metric R_{geom}	0.2791	$\sin(8\Delta\theta/2)/\sin(\Delta\theta/2)$	8-phasor interference

Note: The per-step overflow value has been corrected from 0.270 (which used the incorrect $\Delta\theta = 43.530°$) to 0.273 (using the correct $\Delta\theta = 43.515°$).

5.2 Why $0.273 \neq 0.2791$

The per-step overflow ($11.88°/43.515° \approx 0.273$) differs from the force metric ($R_{\text{geom}} = 0.2791$) by approximately 2.2%. This difference reflects the fact that they measure fundamentally different physical quantities: the per-step overflow is a simple geometric ratio, while the force metric encodes the collective interference of all 8 phasors acting together through the numerator $\sin(8 \times 43.515°/2)$.

6 Monte Carlo Analysis of the 0.2791 Residual

6.1 Null Hypothesis

The null hypothesis states that the observed residual amplitude $R_{\text{geom}} = 0.2791$ in the 8-coil phase interferometer [1] arises from random thermal phase jitter added to the classical $45°$ step, not from any underlying non-Euclidean geometry.

6.2 Simulation Design

A Monte Carlo simulation with $N = 10{,}000$ iterations was performed. In each iteration, random Gaussian phase errors ($\sigma = 3^\circ$, a conservative estimate for laboratory electronics) were added to each coil's nominal 45° step, and the normalized amplitude of the phasor sum was recorded.

6.3 Results

Table 3: Monte Carlo simulation results for the 8-coil phase array.

Statistic	**Value**
Simulations	10,000
Null mean amplitude	0.0164
Null standard deviation	0.0085
Maximum null amplitude	0.0588
Observed amplitude (R_{geom})	0.2791
p-value	$<$ **0.001**
Ratio observed/maximum null	**4.7**$\times$

6.4 Interpretation

The observed amplitude 0.2791 lies approximately 31 standard deviations above the null mean, and approximately 4.7× above the maximum value ever observed in 10,000 simulations of pure noise. The null hypothesis is decisively rejected ($p < 0.001$).

What this simulation does and does not show:

- **What it shows:** If the 8 coils were operating with a classical 45° step subject only to random thermal phase jitter, the probability of observing an amplitude as large as 0.2791 is less than 1 in 10,000. The residual is therefore inconsistent with the null hypothesis of pure noise.
- **What it does not show:** The simulation does not independently prove that the system operates at the UAT phase angle of 43.515°. It only demonstrates that the observed signal is not noise. Alternative explanations —such as systematic phase offsets in the coil drivers, electromagnetic coupling between coils, or other sources of structured interference— are not ruled out by this test. The simulation validates the non-random nature of the signal, not the specific UAT interpretation of its origin.

7 Discussion

7.1 Status of the Framework

The UAT/UCP framework is a phenomenological model under active development. It makes specific, falsifiable predictions (Section 7.4) but has not been independently validated by third-party experiments. The constants κ_{crit}, k_{early}, and $\varphi/2$ are derived from internal consistency requirements and have not been measured independently. The 7% thermal calibration margin is an empirically constrained parameter whose value does not emerge from the fundamental constants of the model [5].

7.2 The 7% Margin as a Cosmological Zero-Point Fluctuation

We propose an interpretation of the 7% thermal calibration margin as a **scale analogue** of the quantum zero-point energy. Just as a quantum particle cannot be at rest at the minimum of its potential —the uncertainty principle demands a minimum energy of $\frac{1}{2}\hbar\omega$— the universe, in this model, cannot be at rest at the Ivancho limit ($\eta = 4.978$). The field must be displaced by $\phi_* = 0.07\eta$, which constitutes the irreducible minimum of causal action preventing static equilibrium. This is a **scale correspondence**, not a mathematical equality.

7.3 Limitations Acknowledged

We explicitly acknowledge the following limitations of the present work:

1. **The UAT/UCP framework is not part of mainstream physics.** Its constants do not appear in standard references (CODATA, NIST) and it has not undergone peer review in high-impact journals.

2. **The Berry phase interpretation is a formal analogy.** A rigorous derivation would require an explicit Hilbert space, a parameter-dependent Hamiltonian, and a demonstration of adiabatic evolution. These have not been provided.

3. **The Monte Carlo simulation rules out noise but does not confirm the UAT phase geometry.** Alternative explanations for the residual (systematic phase offsets, electromagnetic coupling) have not been exhaustively excluded.

4. **The GW170814 analysis confirms that LIGO strain data cannot validate the model.** The predicted signal ($\sim$2165 ps) is 10^7 times smaller than the uncertainty in source localization ($\sim$30 μs). This is documented in the supplementary material.

5. **The 7% margin is an empirically constrained parameter, not a derived constant.** A numerical search confirmed that 0.07 does not emerge from algebraic combinations of φ, π, e, or η [5].

7.4 Falsifiable Predictions

Despite these limitations, the model makes specific, testable predictions:

1. **The 0.2791 residual should appear in any 8-element phase-coherent array** operated at the UAT step angle of 43.515°, independent of the physical substrate.

2. **The 3.3% overflow should manifest as a** 176,122 **ns timing discrepancy per cycle** at $f_{\text{base}} = 187.37$ Hz, measurable with optical clocks.

3. **The three-depth experiment** should detect a causal friction coefficient $\kappa = 0.2791$ ns/mm in a dense medium [6].

These predictions are falsifiable with current technology. A null result in any of them would constrain or refute the model.

8 Conclusion

We have presented a phenomenological extension of the UAT/UCP framework describing causal membrane dynamics. The cyclic moment equation (Eq. 1) and the causal overflow ($\varepsilon = 3.3\% = 1 - k_{\text{early}}$) emerge from the model's internal geometry, specifically from the non-Euclidean phase step $\Delta\theta = 43.515°$ derived from the quantum braking factor $k_{\text{early}} = 0.967$.

The trigonometric derivation of the force metric $R_{\text{geom}} = 0.2791$ is mathematically exact given the model's assumptions, and the Monte Carlo analysis demonstrates that the observed residual is inconsistent with thermal noise. We have corrected an arithmetic error present in earlier versions ($\Delta\theta = 43.530°$ was a typographical error; the correct value is 43.515°).

We have explicitly acknowledged the limitations of the framework: its phenomenological nature, its reliance on constants not yet independently measured, the formal rather than rigorous status of the Berry phase interpretation, and the inapplicability of LIGO strain data for validation.

The value of the present work lies not in claiming a validated theory but in proposing a coherent phenomenological framework that makes specific, falsifiable predictions. The three-depth experiment remains the most promising path to independent empirical testing.

$$\boxed{\text{The model proposes that the universe expends 3.3\% per cycle.}}$$

$$\boxed{\text{Its signature is 0.2791.}}$$

$$\boxed{\text{Whether these numbers describe physical reality is for experiment to decide.}}$$

Data and Code Availability

Three Python scripts are provided as supplementary material:

- `membrane_moment_evaluation.py` — Numerical integration of M_p over UAT and classical cycles.
- `monte_carlo_8coils_validation.py` — Monte Carlo analysis of the 0.2791 residual (10,000 simulations).
- `verify_7percent_three_scales.py` — Verification of the 7% margin across cosmological, instrumental, and statistical scales.

Acknowledgments

The author acknowledges AI systems (DeepSeek, Gemini) for assistance in mathematical derivation, numerical integration, Monte Carlo simulation design, and manuscript preparation. The author also acknowledges the anonymous reviewer whose critical assessment of an earlier version of this manuscript prompted significant improvements in rigour and transparency.

References

[1] M. A. Percudani, *Universal Applied Time (UAT/UCP): A Fundamental Theory of Cosmology from First Principles*, Zenodo, 2024. DOI: `10.5281/zenodo.17729221`.

[2] M. A. Percudani, *The Causal Coherence Constant κ_{crit}: A Fundamental Limit on Retrocausal Influence*, Zenodo, 2024. DOI: `10.5281/zenodo.17718670`.

[3] M. A. Percudani, *The UAT Lagrangian: Derivation of the Quantum Braking Action and the Closure of the Causal Coherence Parameters*, Zenodo, 2025. DOI: `10.5281/zenodo.20500431`.

[4] M. A. Percudani, *First-Principles Resolution of the Cosmological Constant Problem*, Zenodo, 2025. DOI: `10.5281/zenodo.21109424`.

[5] M. A. Percudani, *On the Nature of the 7% Thermal Calibration Margin*, Zenodo, 2025. DOI: `10.5281/zenodo.21211964`.

[6] M. A. Percudani, *On the Possible Influence of the Material Medium on Local Time*, Zenodo, 2025. DOI: `10.5281/zenodo.21197996`.

[7] M. A. Percudani, *Anti-frequency evaluated through the UAT temporal framework*, Zenodo, 2024. DOI: `10.5281/zenodo.18210808`.

Technical Note — July 9, 2026
This document presents a phenomenological extension of the UAT/UCP framework.
All limitations are explicitly acknowledged.
Falsifiable predictions are provided for independent empirical testing.

Document DOI:10.5281/zenodo.21283048 To be assigned by Zenodo.