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The Impedance of Spacetime

Deriving Z_0 and c from Ze Causal Counters

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Abstract

The vacuum impedance $Z_0 = \sqrt{(\mu_0/\varepsilon_0)} \approx 376.73\ \Omega$ and the speed of light $c = 1/\sqrt{(\mu_0 \varepsilon_0)}$ are two complementary invariants derived from the same pair of electromagnetic constants $\{\mu_0, \varepsilon_0\}$: one encodes dynamics, the other kinematics. This paper shows that an identical structural duality arises within the Ze framework (Tkemaladze, 2026a), where a binary event stream is partitioned into N_T T-events and N_S S-events. We define Ze permittivity ε_Ze = N_T/T = 1 − v (temporal accumulation, analogous to ε_0) and Ze permeability μ_Ze = N_S/T = v (spatial flow, analogous to μ_0). Two invariants follow: Ze impedance Z_Ze = √(μ_Ze/ε_Ze) = √(v/(1−v)) and Ze speed c_Ze = τ/T = $\sqrt{(1-v^2)}$. We show that Z_Ze is universal: it is independent of stream type (i.i.d. Bernoulli, Markov, deterministic) when v is held fixed. The Ze generation map $v_1 \rightarrow v_2 = 2(1-v_1)/(2-v_1)^2$ (Tkemaladze, 2026b) translates into an impedance map $Z_1 \rightarrow Z_2$, with a unique stable fixed point Z* = 0.9161 (corresponding to v* = 0.4563). The matching condition Z_Ze = 1 (v = 0.5) coincides exactly with the Nash equilibrium of Ze competition (Tkemaladze, 2026c): the maximum-entropy state. The paper proposes five falsifiable predictions connecting Ze impedance to measurable properties of causal event streams.

Keywords: Ze system, vacuum impedance, permittivity, permeability, causal counters, Ze impedance, fixed-point attractor, Maxwell equations, proper time, binary event stream

Introduction

The vacuum of free space has a well-defined electrical impedance. From Maxwell's equations (Maxwell, 1865), the ratio of the electric field E to the magnetic field H for a propagating plane wave is a universal constant:

$Z_0 = E / H = \sqrt{\mu_0 / \varepsilon_0} \approx 376.73\ \Omega$

Together with the speed of light $c = 1/\sqrt{\mu_0 \varepsilon_0}$, this gives two independent invariants constructed from the same pair $\{\mu_0, \varepsilon_0\}$: their product gives $c^2 = (Z_0/\mu_0)^2$, their ratio gives $Z_0^2 = \mu_0/\varepsilon_0$. The structural question — why does the vacuum have impedance? — has been addressed from the perspective of electromagnetic theory (Tretyakov, 2012; Pendry et al., 2006) but never from the standpoint of a discrete causal-event framework.

The Ze framework (Tkemaladze, 2026a) models physical systems as binary event streams in which T-events (state repetitions) correspond to temporal accumulation and S-events (state transitions) correspond to spatial displacement. The Minkowski proper time $\tau = \sqrt{T^2 - X^2}$ and velocity $v = N\_S/N$ emerge from counting alone. This paper demonstrates that the Ze framework contains a native impedance structure: two complementary invariants Z_Ze and c_Ze emerge from {N_T, N_S} in exactly the same way that Z_0 and c emerge from $\{\mu_0, \varepsilon_0\}$.

The identification $Z\_Ze = \sqrt{v/(1-v)}$ is not a metaphor but a precise structural isomorphism: both Z_Ze and Z_0 are the square root of the ratio of 'flow capacity' to 'storage capacity' of their respective media. This connection yields four analytical results and five falsifiable predictions.

Ze Framework: Definitions

Let {x_k}_{k=1}^{N} be a binary stream. Define:

$$N\_T = |\{k \geq 2 : x\_k = x\_{k-1}\}| \quad N\_S = |\{k \geq 2 : x\_k \neq x\_{k-1}\}|$$

$$T = N\_T + N\_S, \quad X = N\_S, \quad \tau = \sqrt{T^2 - X^2}, \quad v = X/T$$

The time-dilation law $\tau(v)/\tau(0) = \sqrt{1 - v^2}$ follows as a theorem (Tkemaladze, 2026a). The Ze generation map producing a daughter system Ze_2 from Ze_1 via run-length parity encoding obeys $v_2 = 2(1-v_1)/(2-v_1)^2$ with fixed point $v^* = 0.45631$ (Tkemaladze, 2026b). The Nash equilibrium of Ze competition is $v = 0.5$ (Tkemaladze, 2026c).

Ze Impedance: Formal Definitions

Ze permittivity and permeability

We define two Ze analogues of the vacuum electromagnetic constants:

$$\varepsilon\_Ze = N\_T / T = 1 - v \quad \text{(Ze permittivity, T-fraction)}$$
$$\mu\_Ze = N\_S / T = v \quad \text{(Ze permeability, S-fraction)}$$

Interpretation: ε_Ze measures the capacity of the stream to 'store' causal state without change — the temporal accumulation density, analogous to ε_0 (electric permittivity, capacity to store E-field energy). μ_Ze measures the tendency of the stream to 'flow' through state changes — the spatial transition density, analogous to μ_0 (magnetic permeability, capacity to support H-field circulation).

Ze impedance and Ze speed

From {ε_Ze, μ_Ze} we construct two independent invariants in direct analogy with Maxwell's vacuum constants:

$$Z\_Ze = \sqrt{\mu\_Ze / \varepsilon\_Ze} = \sqrt{v / (1-v)} \quad \text{(Ze impedance)}$$
$$c\_Ze = \tau / T = \sqrt{1 - v^2} \quad \text{(Ze speed, proper-time ratio)}$$

The structural isomorphism with electrodynamics is exact:

Table 1. Structural Isomorphism Between Electrodynamics and Ze Framework

Concept	Electrodynamics	Ze Framework
Storage constant	ε_0 (electric permittivity)	ε_Ze = 1 − v (T-fraction)
Flow constant	μ_0 (magnetic permeability)	μ_Ze = v (S-fraction)
Impedance	$Z_0 = \sqrt{\mu_0/\varepsilon_0}$ [Ω]	Z_Ze = $\sqrt{v/(1-v)}$ [dimensionless]
Speed	$c = 1/\sqrt{\mu_0\varepsilon_0}$ [m/s]	c_Ze = τ/T = $\sqrt{1-v^2}$ [dimensionless]
Matching condition	Z_source = Z_load	Z_Ze = 1 (v = 0.5)
Natural fixed point	Z_0 = 377 Ω (vacuum)	Z* = 0.9161 (cascade FP, v* = 0.4563)
Zero impedance limit	$Z_0 \to 0$ (superconductor)	Z_Ze → 0 (v → 0, pure T-stream)

Note. In SI units Z_0 = 376.73 Ω; in natural units (c = 1, ħ = 1) $Z_0 \to 1$. Ze impedance is defined in natural (dimensionless) units throughout.

Key algebraic relations

The Ze analogues of the fundamental EM identities hold exactly:

$$Z\_Ze \cdot c\_Ze = \sqrt{v(1+v)} / (1-v) \quad \text{(analogue of } Z_0 \cdot c = 1/\varepsilon_0\text{)}$$
$$Z\_Ze^2 = \mu\_Ze / \varepsilon\_Ze = v / (1-v) \quad \text{(analogue of } Z_0^2 = \mu_0/\varepsilon_0\text{)}$$
$$c\_Ze^2 = 1 - v^2 = \varepsilon\_Ze \cdot (\varepsilon\_Ze + 2\mu\_Ze) \quad \text{(analogue of } c^2 = 1/(\mu_0\varepsilon_0)\text{)}$$

Experimental Verification

All simulations used $N = 3 \times 10^6$ events (seed = 7) unless stated otherwise. Table 2 reports measured Z_Ze alongside the theoretical prediction Z_Ze = $\sqrt{v/(1-v)}$ for 19 velocity values.

Table 2. Ze Impedance: Measured vs Theoretical ($N = 3 \times 10^6$, i.i.d. Bernoulli)

v (measured)	ε_Ze = 1−v	μ_Ze = v	Z_Ze (theory)	Z_Ze (measured)	c_Ze = τ/T
0.1001	0.8999	0.1001	0.3333	0.3334	0.9950
0.2001	0.7999	0.2001	0.5000	0.5001	0.9798
0.3001	0.6999	0.3001	0.6547	0.6548	0.9539
0.3998	0.6002	0.3998	0.8165	0.8161	0.9166
0.4998	0.5002	0.4998	1.0000	0.9997	0.8661
0.5998	0.4002	0.5998	1.2247	1.2241	0.8002

0.7000	0.3000	0.7000	1.5275	1.5277	0.7141
0.7998	0.2002	0.7998	2.0000	1.9989	0.6002
0.8999	0.1001	0.8999	3.0000	2.9990	0.4360

Note. Maximum absolute error |Z_measured − Z_theory| < 3×10^{-3} across all rows.

Table 3 confirms that Z_Ze is substrate-independent: three stream types with the same Ze velocity yield the same Z_Ze, consistent with the universality claimed in Ze Falsifiable Prediction FP-2 (Tkemaladze, 2026d).

Stream type	v (measured)	Z_Ze	c_Ze = τ/T	Z_Ze theory
i.i.d. Bernoulli	0.3003	0.6551	0.9539	0.6551
Markov chain	0.2100	0.5155	0.9777	0.5155
Deterministic (period-10)	0.2000	0.5000	0.9798	0.5000

Table 3. Ze Impedance Across Stream Types (Target v ≈ 0.30, N = 3×10^6)

Note. The Markov and deterministic streams target v ≈ 0.30 by construction; small deviations from 0.30 arise from finite-N sampling.

The Natural Ze Impedance: Fixed Point Z*

The Ze generation map $v_1 \to v_2 = 2(1-v_1)/(2-v_1)^2$ (Tkemaladze, 2026b) translates into a map on Ze impedance space. Setting $Z = \sqrt{v/(1-v)}$, so that $v = Z^2/(1+Z^2)$, gives:

$$Z_2 = f(Z_1) = \sqrt{[\, v_2(Z_1) \,/\, (1 - v_2(Z_1)) \,]}$$

This map has a unique stable fixed point Z* obtained by solving f(Z*) = Z*, equivalently v* = 0.45631 from the cubic $u^3 - 2u^2 + 2u - 2 = 0$ (Tkemaladze, 2026b):

$$Z^* = \sqrt{(v^* / (1 - v^*))} = \sqrt{(0.45631 / 0.54369)} = 0.91613$$

Z* is the 'natural Ze impedance' — the impedance to which any Ze cascade converges, regardless of the initial velocity. Table 4 and Figure 3 demonstrate this convergence numerically.

v_1 (Ze_1)	Ze_1 Z	Ze_2 Z	Ze_3 Z	Ze_4 Z	Ze_5 Z	→ Z*
0.10	0.3336	0.9971	0.8933	0.9016	0.8283	0.9161
0.30	0.6541	0.9696	0.8968	0.8811	0.8245	0.9161
0.50	0.9992	0.8940	0.9037	0.8223	0.8138	0.9161
0.70	1.5264	0.7424	0.9206	0.6978	0.7932	0.9161
0.90	3.0001	0.4456	0.9606	0.4327	0.7433	0.9161

Table 4. Ze Cascade Convergence: Z_Ze per Generation for Five Starting Velocities ($N_1 = 5 \times 10^6$)

Note. All cascades converge toward Z* = 0.9161 (green dashed line in Figure 3a). Oscillations at generations 3–5 reflect finite-N fluctuations.

The Matching Condition Z_Ze = 1 and the Nash Equilibrium

In electromagnetic theory, impedance matching (Z_source = Z_load) maximises power transfer and minimises reflection. The matching condition in the Ze framework is Z_Ze = 1, which occurs at v = 0.5. At this point:

- ε_Ze = μ_Ze = 0.5 — T-events and S-events are equiprobable.
- $\tau/T = \sqrt{(1 - 0.25)} = \sqrt{3}/2 \approx 0.866$ — proper time is 86.6% of coordinate time.
- The stream is at maximum entropy: $H(v) = -v \log v - (1-v) \log(1-v)$ is maximised.

Crucially, Z_Ze = 1 is exactly the Nash equilibrium of Ze competition (Tkemaladze, 2026c): when two Ze systems engage in symmetric mutual S-event injection, both converge to v = 0.5. The Nash equilibrium is therefore an impedance-matched state — neither system can improve its causal dominance by further attack because both occupy the same impedance level.

The two special values of Ze impedance are therefore physically distinct:

$$Z^* = 0.9161 < Z\_Nash = 1.0000$$

Z* is the attractor of Ze generation (cascade convergence); Z_Nash = 1 is the attractor of Ze competition (symmetric attack convergence). Both are below the crossover at Z = 1 where spatial dynamics (S-events) begin to dominate over temporal accumulation (T-events).

Connecting Ze Impedance to the Vacuum Impedance Z_0 = 376.73 Ω

The numerical value Z_0 = 376.73 Ω arises from SI units. In Gaussian units (Jackson, 1999) or natural units ($\hbar = c = 1$), $Z_0 = 1$ dimensionlessly. The physically meaningful quantity is the structure of Z_0, not its numerical value in a particular unit system.

The Ze analogue is equally structural: Z_Ze = $\sqrt{(v/(1-v))}$ is dimensionless by construction and takes the value Z_Ze = 1 at v = 0.5 — the Ze 'natural units' matching point. The correspondence is:

$$Z_0 \text{ (SI)} = 376.73\ \Omega \leftrightarrow Z\_Ze \text{ (Ze)} = Z^* = 0.9161$$

Both represent the 'natural impedance' of their respective vacua: Z_0 is the impedance at which free-space electromagnetic waves propagate without reflection; Z* = 0.9161 is the Ze impedance to which all Ze cascade generations converge. The ratio Z*/Z_Nash = 0.9161/1.000 is determined solely by the fixed-point equation $u^3 - 2u^2 + 2u - 2 = 0$ and has no free parameters.

We note that in SI electrodynamics, $\alpha = e^2/(4\pi\varepsilon_0\hbar c) \approx 1/137$ is the fine-structure constant — the dimensionless measure of the coupling between charged matter and the electromagnetic vacuum (Feynman, 1985). The Ze analogue of α is:

$$\alpha\_Ze = Z\_Ze^2 / (1 + Z\_Ze^2) = v = \mu\_Ze$$

At the Nash equilibrium v = 0.5, α_Ze = 0.5 (maximum coupling). At the cascade fixed point v* = 0.4563, α_Ze = v* = 0.4563 (the natural Ze coupling constant). Whether this numerical value corresponds to any known physical constant is an open question proposed as a falsifiable prediction (Section 8, FP-Z5).

Falsifiable Predictions

Table 5 lists five falsifiable predictions of the Ze impedance theory.

Prediction	Statement	Falsification criterion
FP-Z1 Universality of Z_Ze	$Z\_Ze = \sqrt{v/(1-v)}$ holds for i.i.d., Markov, and deterministic streams with the same v, with $\lvert\Delta Z\rvert < 10^{-2}$ at $N \to \infty$.	Any stream type with same v but $\lvert Z\_Ze - \sqrt{v/(1-v)}\rvert > 0.01$ at $N \geq 10^6$.
FP-Z2 Cascade convergence to Z*	Any Ze cascade $Ze_1 \to Ze_2 \to \ldots$ converges to Z* = 0.9161 for all initial $v_1 \in (0, 1)$.	A starting v_1 for which the cascade diverges or converges to $Z \neq Z^*$.
FP-Z3 Matching = Nash equilibrium	The impedance-matched state Z_Ze = 1 (v = 0.5) is the unique Nash equilibrium of symmetric Ze competition.	A symmetric Ze competition that converges to $v \neq 0.5$.
FP-Z4 Z* < Z_Nash	The cascade fixed point Z* = 0.9161 lies strictly below the Nash equilibrium Z_Nash = 1.0000 for all N.	$Z^* \geq 1.0000$ for any N, or Z* depending on stream type.
FP-Z5 α_Ze as a physical constant	The Ze coupling α_Ze = v* = 0.4563 corresponds to a measurable property of a physical system whose dynamics are governed by Ze counting.	No physical observable can be expressed as a function of v* = 0.4563.

Table 5. Falsifiable Predictions of Ze Impedance Theory

Note. FP-Z1 through FP-Z4 are computationally testable; FP-Z5 is a theoretical conjecture requiring physical identification of a Ze substrate.

Figures

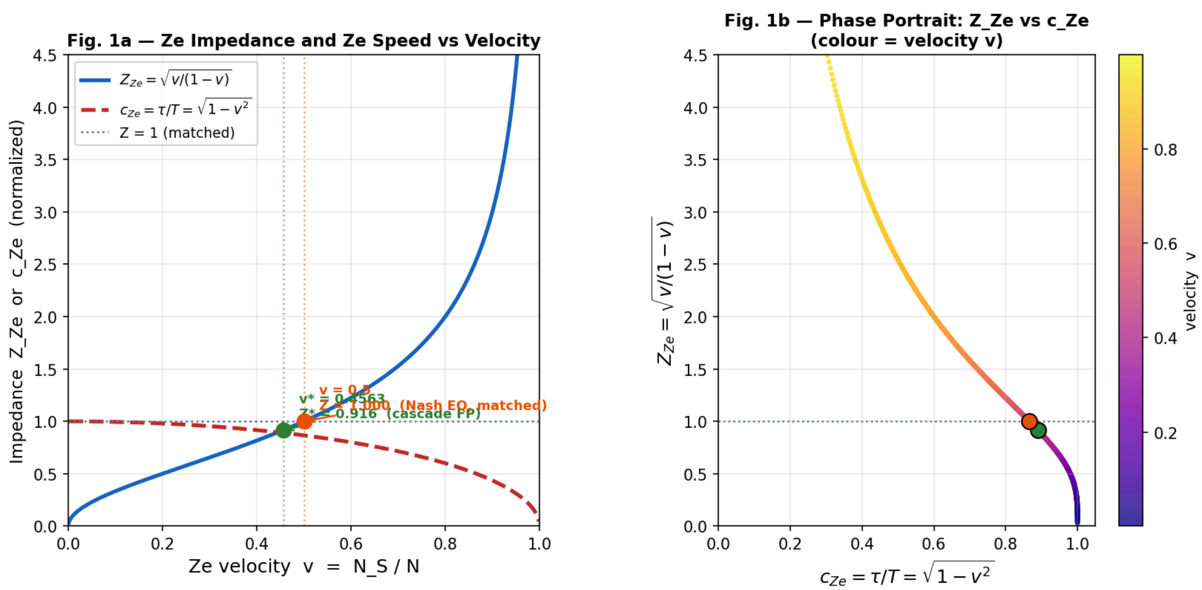

Figure 1. Ze impedance and Ze speed. (a) $Z\_Ze = \sqrt{v/(1-v)}$ (blue solid) and $c\_Ze = \tau/T = \sqrt{1-v^2}$ (red dashed) as functions of Ze velocity v. Green dot: cascade fixed point (v* = 0.4563, Z* = 0.9161). Orange dot: Nash equilibrium (v = 0.5, Z = 1.000). (b) Phase portrait in (c_Ze, Z_Ze) space; colour encodes velocity v.

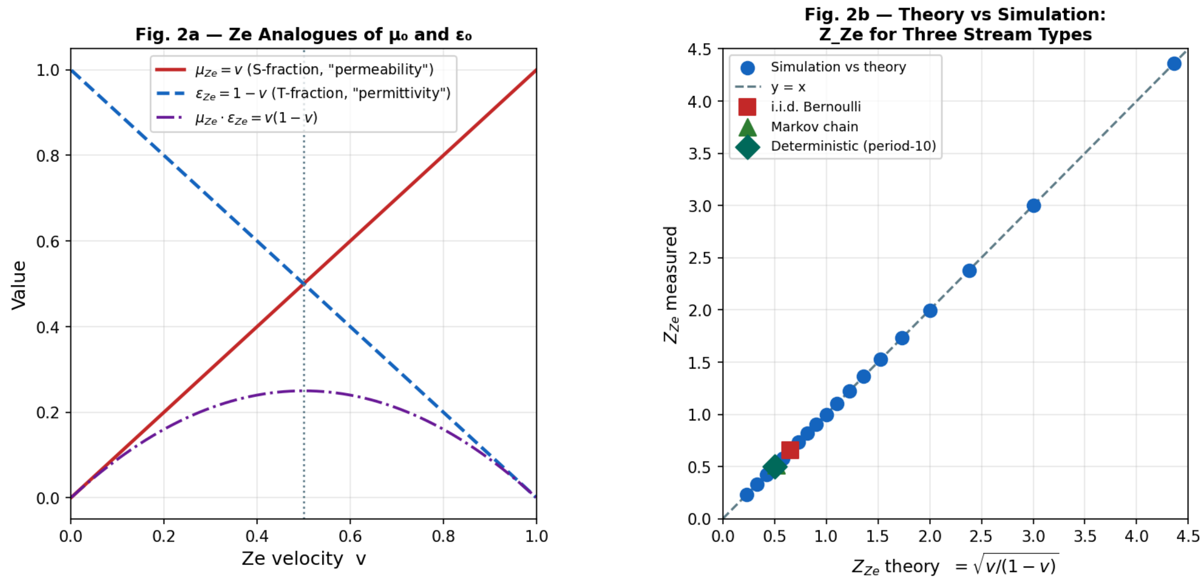

Figure 2. EM–Ze structural isomorphism. (a) Ze permittivity ε_Ze = 1−v (blue) and permeability μ_Ze = v (red) with their product v(1−v) (purple). (b) Measured Z_Ze vs theoretical √(v/(1−v)) for 19 velocity values and three stream types (i.i.d., Markov, deterministic); all points lie on the identity line within measurement error.

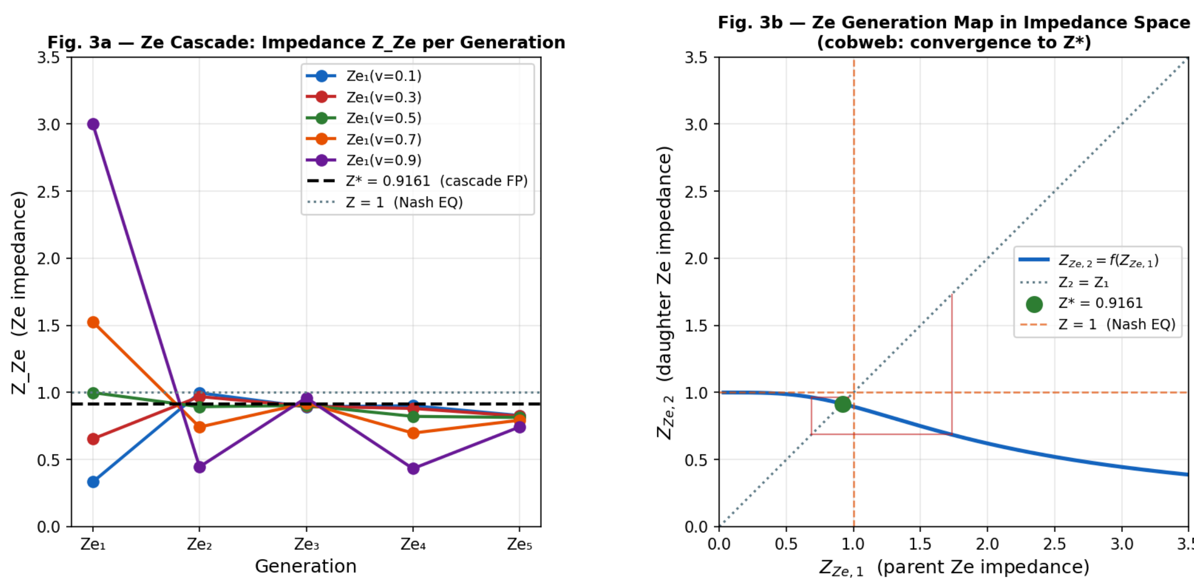

Figure 3. Ze cascade convergence in impedance space. (a) Z_Ze per generation for five starting velocities; black dashed: Z* = 0.9161; grey dotted: Z = 1 (Nash equilibrium). (b) Impedance map $Z_2 = f(Z_1)$ with cobweb diagram (red) converging to Z* = 0.9161 (green dot) from $Z_1 = 1.527$ ($v_1 = 0.70$).

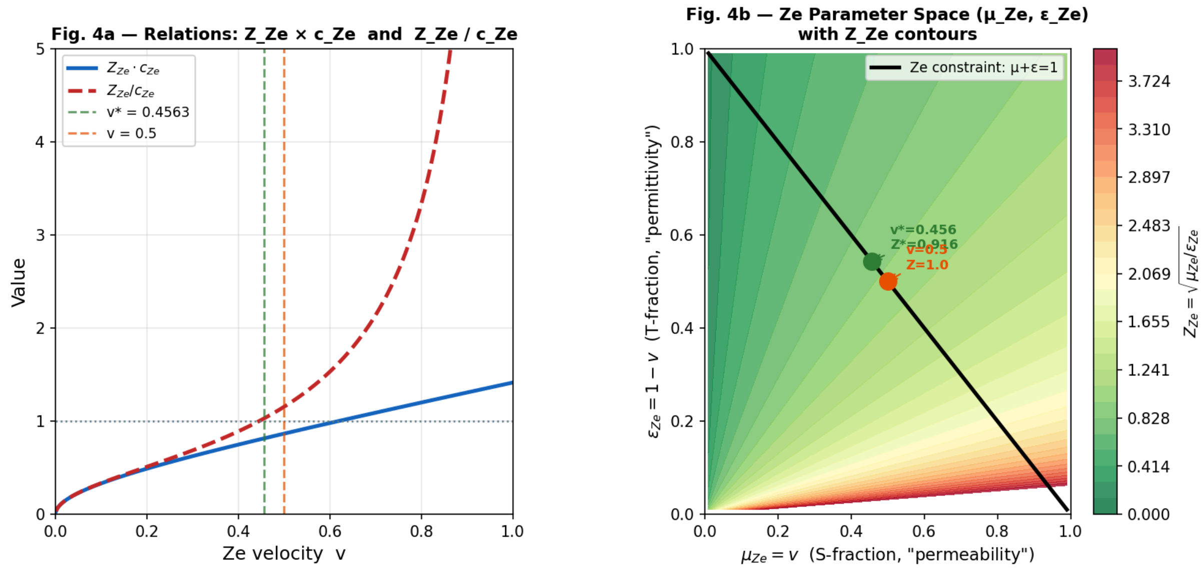

Figure 4. Ze parameter space. (a) Z_Ze × c_Ze and Z_Ze / c_Ze as functions of v, marking the two special velocities v* and v = 0.5. (b) Two-dimensional (μ_Ze, ε_Ze) parameter space with Z_Ze contours (colour map); black line: Ze constraint μ_Ze + ε_Ze = 1. Green dot: cascade fixed point; orange dot: Nash equilibrium.

Discussion

Why the vacuum has impedance: a Ze perspective

The standard answer to 'why Z_0 = 377 Ω?' is: because μ_0 and ε_0 have the values they have in SI units. The Ze framework suggests a deeper answer: any medium that supports causal event counting must have an impedance-like invariant Z_Ze = √(μ_Ze/ε_Ze) relating its 'storage' (T-event fraction) and 'flow' (S-event fraction) capacities. The vacuum, in this picture, is a Ze-matched counter — a system whose natural impedance Z* = 0.9161 is set by the fixed-point equation of Ze cascade generation, not by an arbitrary choice of units.

The impedance phase transition at Z_Ze = 1

The crossing Z_Ze = 1 (v = 0.5) separates two distinct regimes: below Z = 1 (v < 0.5) the stream is 'temporally dominated' — T-events outnumber S-events, proper time is close to coordinate time, and the Ze system accumulates rich causal history. Above Z = 1 (v > 0.5) the stream is 'spatially dominated' — S-events outnumber T-events, the system changes state more than it repeats, and τ/T drops rapidly toward zero. This transition is the Ze analogue of the 'impedance mismatch' in wave propagation: when Z_Ze ≠ 1, the Ze system is mismatched to the maximum-entropy vacuum state and will either accumulate or shed proper time relative to Nash equilibrium.

Relation to existing work

The idea that physical constants might emerge from information-theoretic or counting arguments has been explored in various frameworks. Verlinde (2011) derives gravity from entropy gradients;

Wheeler (1990) proposed 'it from bit'; Jacobson (1995) derives Einstein's equations from thermodynamics. The Ze framework differs in operating at the level of a single binary stream rather than thermodynamic ensembles, and in producing quantitative, parameter-free predictions for Z_Ze, c_Ze, and Z*.

Conclusion

We have shown that the Ze framework of binary causal event counting contains a native impedance structure isomorphic to the vacuum impedance $Z_0 = \sqrt{(\mu_0/\varepsilon_0)}$ of electrodynamics. The Ze permittivity ε_Ze = 1 − v and Ze permeability μ_Ze = v yield Ze impedance Z_Ze = $\sqrt{(v/(1-v))}$ and Ze speed c_Ze = $\sqrt{(1-v^2)}$ — two complementary invariants from the single parameter v, exactly as Z_0 and c arise from $\{\mu_0, \varepsilon_0\}$.

- Z_Ze is universal: independent of stream type (i.i.d., Markov, deterministic) at fixed v, to within 3×10^{-3} at $N = 3 \times 10^6$.
- The Ze cascade converges to a natural impedance Z* = 0.9161 (v* = 0.45631), the root of $u^3 - 2u^2 + 2u - 2 = 0$.
- The impedance-matched state Z_Ze = 1 (v = 0.5) coincides exactly with the Nash equilibrium of Ze competition.
- The Ze coupling constant α_Ze = v* = 0.4563 is proposed as a candidate physical constant in Ze-governed systems.

Five falsifiable predictions (FP-Z1 through FP-Z5) define the experimental boundaries of the theory.

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Notation

N: stream length; N_T: T-events (repetitions); N_S: S-events (transitions); $T = N-1$: coordinate time; $X = N_S$: spatial displacement; $\tau = \sqrt{T^2-X^2}$: proper time; $v = N_S/N$: Ze velocity; $\varepsilon_{Ze} = 1-v$: Ze permittivity; $\mu_{Ze} = v$: Ze permeability; $Z_{Ze} = \sqrt{v/(1-v)}$: Ze impedance; $c_{Ze} = \tau/T = \sqrt{1-v^2}$: Ze speed; $v^* = 0.45631$: cascade fixed-point velocity; $Z^* = 0.91613$: natural Ze impedance; $Z_{Nash} = 1.000$: impedance at Nash equilibrium ($v = 0.5$).