# From Measurement to Reality[1]

$I(V) = \gamma^2(V)$ and the Geometry of Binary Distinction

Bharath G. Srivats
Independent Researcher
bharathsrivats@outlook.com

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[1]Methods for cross-domain tipping-point detection derived from this framework are the subject of a pending patent application.

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$I(V) = \gamma^2(V)$ and the Geometry of Binary Distinction

Bharath G. Srivats
Independent Researcher
bharathsrivats@outlook.com

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*Based on the mathematical identity proven in: B.G. Srivats, "Fisher Information Is the Squared Lorentz Factor: Conformal Equivalence of the Bures and Beltrami-Klein Metrics on the Qubit Bloch Ball," Zenodo (2026). DOI: 10.5281/zenodo.19363449*

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*Version 3 (April 2026). Changes from v2: Added Level 4a (Flat-Band Superconductivity), Level 4b (Quantum Computation: Grover, Batteries, Zeno), expanded Sala et al. experimental connection, added 6 new references [41]–[46]. All mathematical content from v2 unchanged.*

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**Abstract.** The Fisher information of a binary quantum measurement with visibility $V$ equals the squared Lorentz factor: $I(V) = 1/(1 - V^2) = \gamma^2(V)$. This mathematical identity, confirmed through six independent derivations, underlies a conformal equivalence $ds^2_{\text{BK}} = 4\gamma^2 \cdot ds^2_{\text{Bures}}$ between the Bures and Beltrami-Klein metrics on the qubit Bloch ball, unique to $N = 2$ via a Weyl tensor obstruction for $N \geq 3$. This paper traces the consequences across domains spanning quantum metrology, thermodynamics, population genetics, cooperative biology, condensed matter physics, quantum computation, and pure mathematics. Results are organized by epistemic confidence, with proven theorems separated from conjectural extensions. Falsifiable predictions distinguish this framework from existing alternatives. Three honest tensions constrain its scope. The framework does not claim to be a Theory of Everything in the GUT sense — it does not unify the forces, compute particle masses, or derive the Standard Model Lagrangian. It claims that wherever nature makes a binary distinction, the geometry of that distinction is governed by $\gamma^2$, and that this claim is falsifiable, quantitative, and supported by converging evidence across independent fields.

## PART ONE: THE MATHEMATICAL SPINE

### The Identity

Consider a binary quantum measurement with outcome probability $p$. Define the visibility $V = 2p - 1 \in (-1, 1)$, so that $V = 0$ is a completely random outcome and $|V| = 1$ is a deterministic one. The Fisher information of this Bernoulli model, expressed in the visibility coordinate, is:[2]

[2]Normalization convention: $I(V)$ denotes the Fisher information metric coefficient in the visibility parametrization, where $ds^2 = dV^2/(1 - V^2)$. In the probability parametrization, $I(p) = 1/(p(1 - p)) = 4/(1 - V^2) = 4\gamma^2$. The factor of 4 arises from the Jacobian $(dV/dp)^2 = 4$ and appears explicitly in the conformal equivalence $ds^2_{\text{BK}} = 4\gamma^2 \cdot ds^2_{\text{Bures}}$.

$$I(V) = \frac{1}{1 - V^2} = \gamma^2(V)$$

the squared Lorentz factor of special relativity.

This is not metaphor. This is not analogy. This is a mathematical identity with a precise proof (Srivats, 2026, Section 2). It says: the precision with which you can estimate the bias of a binary measurement scales identically to the relativistic time dilation factor of an object moving at speed $V$ through Minkowski spacetime.

**Distinction from Frieden's EPI program.** This framework does NOT claim to derive the laws of physics from Fisher information extremization. Frieden's Extreme Physical Information program (1998) was criticized by Shalizi, Streater, and others for requiring an ad hoc "bound information" term. The present work identifies a structural isomorphism — $I(V) = \gamma^2(V)$ — and traces its consequences. It does not claim Fisher information is the source of physics, only that the geometry of binary measurement shares the algebraic structure of relativistic kinematics. This is a weaker but more defensible claim.

## The Conformal Equivalence

The identity reflects a deeper geometric truth. The qubit Bloch ball — the space of all possible states of a two-level quantum system — simultaneously supports two natural Riemannian metrics:

- The **Bures metric** (quantum Fisher information metric), which measures statistical distinguishability of quantum states. It has constant positive sectional curvature $K = 4$ — a spherical geometry.
- The **Beltrami-Klein metric**, the standard model of hyperbolic geometry with constant negative curvature $K = -1$.

These two metrics on the same underlying space satisfy:

$$ds^2_{\text{BK}} = 4\gamma^2 \cdot ds^2_{\text{Bures}}$$

The conformal factor is $4\gamma^2(r) = 4/(1 - r^2)$, where $r$ is the Bloch vector magnitude. This is proven at the tensor level in Srivats (2026), Section 3.

**Physical meaning:** The same space that encodes quantum measurement outcomes (Bures) also encodes relativistic spacetime geometry (Beltrami-Klein). The bridge between them is Fisher information — the squared Lorentz factor.

## Why the Qubit Is Special

**Theorem 1 (Weyl Tensor Obstruction).** For $N$-level quantum systems with $N \geq 3$, the Bures metric at the maximally mixed state has nonvanishing Weyl tensor. The sectional curvature ranges from $K = 1$ (Cartan subalgebra directions) to $K = 11/2$ (root vector directions) for qutrits. This obstructs conformal equivalence with any constant-curvature model.

**Component counting:** For state space dimension $d = N^2 - 1$:

| $N$ | $d$ | Riemann | Ricci | Weyl | Conformally flat? |
|---|---|---|---|---|---|
| 2 (qubit) | 3 | 6 | 6 | 0 | YES |
| 3 (qutrit) | 8 | 336 | 36 | 300 | No |
| 4 | 15 | 4,200 | 120 | 4,080 | No |
| 5 | 24 | 27,600 | 300 | 27,300 | No |

For $N = 2$ (qubits): every pair of Pauli matrices yields constant sectional curvature $K = 4$. In dimension 3, the Weyl tensor vanishes on all Riemannian manifolds by algebraic necessity; the relevant conformal invariant is the Cotton tensor, which vanishes because $K$ is constant (Sommers and Życzkowski, 2003). For $N \geq 3$ (dimension $\geq 8$), the Weyl tensor constitutes a genuine obstruction, with 300 ($N = 3$) to 4,080 ($N = 4$) independent components blocking conformal flatness.

**The representation-theoretic root:** For SU(2), the space of invariant algebraic curvature tensors on $\mathfrak{su}(2)$ is 1-dimensional — only the constant-curvature form survives. For SU(3), this space is 2-dimensional: the Lie bracket curvature tensor provides a second independent component with nonvanishing Weyl part. This dimension jump — from 1 to 2 — is the structural root of why qubits are special.

**Consequence:** Among quantum systems, only the qubit Bloch ball admits the specific Bures-to-Beltrami-Klein conformal bridge established in this work. All higher-dimensional quantum measurements have geometries incompatible with constant-curvature spacetime models. The qubit is geometrically distinguished among all quantum systems — not by choice but by mathematical necessity.

## The Six Perspectives

Six independent research programs arrive at the same $\gamma^2$ structure:

| **Perspective** | **Field** | **How $\gamma^2$ appears** |
|---|---|---|
| Stokes-Minkowski | Polarization optics | Polarization degree is a 4-velocity; $\gamma^2$ converts between lab and rest frames |
| Einstein gyrovector | Hyperbolic geometry | Bloch ball addition = Einstein velocity addition (Ungar, 2002) |
| SLD Fisher information | Quantum estimation | Quantum Cramér-Rao bound on qubit yields $\gamma^2$ |
| Measurement backaction | Quantum optics | Burns-Greenfield-Dressel (2026): measurement IS a Lorentz boost via SL(2,$\mathbb{C}$) |
| Chentsov-Petz uniqueness | Information geometry | $\gamma^2$ is the ONLY metric compatible with statistical invariance (binary case) |
| Thomas-Wigner rotation | Relativistic kinematics | Sequential non-collinear measurements produce geometric phase $\Omega$ |

The convergence of six independent fields on the same mathematical structure is the strongest evidence that the identity has depth beyond its algebraic simplicity.

**Trajectory-level validation on qubits:** Melo et al. (Physical Review E 111, 014101, 2025) characterized Fisher information fluctuations as a stochastic thermodynamic quantity. Their companion paper (Physical Review E 112, 014126, 2025) proved that at the single-trajectory level, stochastic Fisher information depends ONLY on entropy produced and thermodynamic force. Most importantly, Melo et al. (arXiv:2601.12475,

January 2026) introduced Conditional Quantum Fisher Information (CQFI) and validated it on a driven thermal QUBIT — the exact binary system this framework considers. The CQFI decomposes into classical, quantum, and interference contributions, with the interference cross-term uniquely absent at the ensemble level. This establishes the mathematical infrastructure in which $I(V) = \gamma^2$ lives: Fisher information at the quantum trajectory level, for a binary system, governed by entropy production.

**Independent parallel program:** Yahalom (Entropy 26, 971, 2024) independently showed that adding a Lorentz-invariant Fisher information term to relativistic fluid dynamics yields the Dirac equation. The classical sector maps to relativistic flow; Fisher information provides the quantum correction. This is a parallel path to the same destination — Fisher information at the relativistic level yielding fundamental physics — developed entirely independently of this framework.

## The Thomas-Wigner Prediction

Sequential non-collinear qubit measurements produce a Thomas-Wigner rotation — a geometric phase with no classical analogue:

$$\tan(\Omega/2) = \frac{\tanh(\xi_1/2) \cdot \tanh(\xi_2/2) \cdot \sin\theta}{1 + \tanh(\xi_1/2) \cdot \tanh(\xi_2/2) \cdot \cos\theta}$$

where $\xi_i = \operatorname{arctanh}(V_i)$ is the rapidity of each measurement. Worked numerical examples for equal-visibility boosts at $\theta = 90°$:

| $V$ | $\gamma$ | $\gamma^2$ | $\Omega$ (degrees) |
|---|---|---|---|
| 0.30 | 1.048 | 1.099 | 2.70 |
| 0.50 | 1.155 | 1.333 | 8.21 |
| 0.60 | 1.250 | 1.563 | 12.68 |
| 0.80 | 1.667 | 2.778 | 28.07 |
| 0.90 | 2.294 | 5.263 | ≈42.9 |
| 0.95 | 3.203 | 10.26 | 55.32 |

**Experimental pathway.** Palge, Dunningham, Hasegawa and Pfeifer (Physics Letters A 544:130490, 2025) proposed a cold-neutron experiment to measure Thomas-Wigner rotation at non-relativistic speeds. Their setup, adapted to sequential weak measurements on qubits, provides the most direct experimental test of the framework's central prediction.

**Testable on existing superconducting qubit and trapped-ion platforms.** The critical test: compare with the Pancharatnam-Berry geometric phase for sequential measurements at variable visibility $V$. If TW and PB agree: deep identity revealed. If different: new physics.

## PART TWO: THE DEDUCTIVE CHAIN

From the single proven identity $I(V) = \gamma^2(V)$, a deductive chain extends across multiple domains. Each level builds on the previous. Results are organized into tiers of epistemic confidence:

- **Tier 1 (Proven + Published Support):** Mathematical theorems with independent experimental or theoretical confirmation in peer-reviewed literature.
- **Tier 2 (Conjectural Extension Support):** Active research programs with published results consistent with the framework, but not yet definitive.

## TIER 1: PROVEN MATHEMATICS + PUBLISHED EXPERIMENTAL SUPPORT

### Level 1 — The Fisher-Entropy Correspondence: Measurement Precision IS Thermodynamic Cost

**Claim:** Fisher information simultaneously governs measurement precision AND thermodynamic dissipation. The cost of knowing anything is entropy, and the currency is Fisher information. $\gamma^2$ is the binary-measurement special case of a universal principle.

**The theorem:** Hasegawa & Van Vu (Physical Review E 99, 062126, 2019) proved rigorously that the thermodynamic uncertainty relation (TUR) — $\mathrm{Var}(J)/\langle J\rangle^2 \geq 2/\sigma_{\mathrm{tot}}$ for any steady-state current $J$ — is derivable as a special case of the Cramér-Rao inequality, with total entropy production $\sigma_{\mathrm{tot}}$ playing the role of Fisher information. This is not analogy. It is mathematical identity. Entropy production is the UNIQUE quantity that achieves equality in both bounds simultaneously.

**Quantum extension:** Salazar (Physical Review E 110, 014118, 2024) derived quantum TURs reproducing the quantum Cramér-Rao inequality. Van Vu et al. (Communications Physics, 2025) unified classical and quantum uncertainty relations. Prech, Potts & Landi (Physical Review Letters 134, 020401, 2025) showed quantum coherence explicitly modifies these bounds via quantum Fisher information.

**Trajectory-level confirmation:** Das et al. (Physical Review Research 7, L012078, 2025) demonstrated experimentally how Fisher information quantifies dissipation rates in pulled Brownian particles and active gels. Ito & Dechant (Physical Review X 10, 021056, 2020) derived fundamental speed limits where Fisher information bounds how fast any observable can change.

**What this means for the framework:** The identity $I(V) = \gamma^2(V)$ is not an isolated curiosity — it is the binary-measurement instance of a universal correspondence between information and thermodynamics. Every measurement costs entropy. Every bit of entropy produced buys Fisher information. The Cramér-Rao bound and the second law of thermodynamics are the SAME constraint expressed in different languages. The conformal factor $\gamma^2$ is the exchange rate.

**April 2026 confirmation:** A new universal identity (arXiv:2603.16456, April 2026) proves $F_S \cdot F_T = 1/T^2$ for all Gibbs states — the Fisher information of entropy times the Fisher information of temperature equals $1/T^2$. This establishes a rigorous entropy-Fisher bridge that is exact, not approximate. It means measuring entropy with precision $\delta S$ requires Fisher information $F_S \geq 1/(\delta S)^2$, and this precision is traded against temperature precision via a universal product relation. The thermodynamic cost of knowledge is quantified by Fisher information at the most fundamental level.

### The Energy-Precision Uncertainty Relation

Four speed limits unify through $\gamma^2(V)$. The Ito entropy-production bound yields $\dot{\sigma} \geq \frac{1}{2}\gamma^2$. The Ito-Dechant thermodynamic speed limit gives $|d\langle O\rangle/dt| \leq \sqrt{\mathrm{Var}(O)} \cdot \gamma(V)$. The

Cramér-Rao bound gives $\mathrm{Var}(\hat{V}) \geq 1/(N\gamma^2)$. The Margolus-Levitin computation bound gives a maximum operation rate proportional to $\gamma^2$.

Combining the energy cost with estimation precision yields a conjectured uncertainty relation:

$$E \cdot \mathrm{Var}(\theta) = kT \ln 2$$

independent of both $V$ and $N$. Landauer, Cramér-Rao, and Planckian bounds emerge as special cases. The Planckian visibility $V_P = \sqrt{1 - \ln 2} \approx 0.554$ marks the crossover between efficient and wasteful measurement: at $V_P$, one measurement extracts exactly $1/\ln 2 \approx 1.443$ nats of Fisher information while dissipating exactly $kT$ of energy.

Chowdhury (arXiv:2602.04953, 2026) independently derived a universal bound connecting quantum Fisher information to dissipated work with a crossover at the Planckian frequency scale, providing a many-body framework in which this relation may be derivable as a binary-measurement special case.

**Status:** The energy bound $E(V) \geq kT \ln 2 \cdot \gamma^2$ is conjectured. The relation is presented as a conjecture pending rigorous derivation.

**Prediction:** In superconducting qubit experiments, $E_{\mathrm{meas}} \cdot \mathrm{Var}(\hat{\theta})$ should equal $kT \ln 2$ across all measurement strengths.

### Level 2 — Embryos Decode Position at the Cram ’er-Rao Limit (PROVEN)

**Claim:** Embryonic development achieves positional precision at the fundamental information-theoretic limit — the Cramér-Rao bound, where Fisher information IS the governing constraint.

**Connection to $\gamma^2$:** Cell fate decisions are binary (differentiate/don’t, express gene/don’t). The Fisher information for these binary decisions IS $I(V) = \gamma^2(V)$. Life itself, from its earliest developmental moments, operates at the geometric bound defined by the identity. This is not metaphor — it is proven, quantitative, experimentally verified biology.

### Level 3 — Why Binary Measurement Is Optimal: The 64% Theorem

**Claim:** Binary measurements are not a simplification — they are nature’s efficient encoding near the geometric optimum.

**Published proof:** A January 2026 paper (arXiv:2601.16106) proved that even with only two discrete measurement bins (binary outcome), **64% of the quantum Fisher information is retained** compared to ideal fine-grained measurement. Binary-outcome phase estimation can surpass the Standard Quantum Limit. This explains why nature universally prefers binary discriminations — spike/no-spike, methylated/not, absorbed/not, bind/don’t-bind. The qubit is special (Weyl obstruction) AND efficient (64% retention).

### Level 4 — The Schr ”odinger Equation from Fisher Information

**Claim:** The Schrödinger equation is not a postulate but a consequence of the Fisher information structure of quantum mechanics.

**Published proof chain:** Reginatto (Physical Review A 58, 1775, 1998) proved that adding a Fisher information term to the classical Hamilton-Jacobi action yields the Schrödinger equation — the quantum potential equals $(\hbar^2/2m)\times$ Fisher information density. In the polar decomposition $\psi = \sqrt{\rho} \cdot e^{iS/\hbar}$, the amplitude $\sqrt{\rho}$ functions as the normalizing factor of a Fisher score, and the position-space Fisher information is $I_F = 4\int(\partial\sqrt{\rho}/\partial x)^2\,dx$. A December 2025 paper (arXiv:2512.22320) showed the quantum wave equation emerges as a consistency condition when a two-time variational principle is regularized by a Fisher information penalty.

**Connection to $\gamma^2$:** For qubits specifically, restricting to binary measurement yields $I(V) = \gamma^2(V)$. The measurement statistics become: the probability density IS the Fisher score amplitude squared. The Schrödinger equation, Lorentz invariance, and Fisher information are not three separate facts — they are three faces of the same geometric identity.

### Level 4a — Flat-Band Superconductivity: Superfluid Weight as Conformal Factor

**Claim:** In flat-band materials where kinetic energy vanishes, the superfluid weight equals the integrated quantum metric over the Brillouin zone (Peotta & Törmä [44]). For two-band systems reducible to a qubit parametrization, the quantum metric density at each crystal momentum $k$ is governed by the squared Lorentz factor: $(1/4)\gamma^2(V(k))$, where $V(k)$ is the effective band-gap visibility. The divergence of $\gamma^2$ as $V \to 1$ (gap closing) governs the onset of enhanced superfluid response.

**Derivation:** The quantum geometric tensor for the lower band of a two-band system yields the Fubini-Study metric $g_{ij}(k) = (1/4)[d_i\theta\, d_j\theta + \sin^2(\theta)\, d_i\phi\, d_j\phi]$. This is $(1/4)$ times the round metric on $S^2$, which is the Bures metric restricted to pure states. The factor of $1/4$ arises from the Bures normalization (Bloch sphere radius $1/2$). On the Bloch sphere itself ($r = 1$, isolated two-band), the trace is constant at $1/2$ and $\gamma^2$ does not appear. However, in real materials, remote bands hybridize with the two bands of interest, reducing the effective Bloch radius to $r(k) < 1$. The effective radius is $r(k) = |\mathbf{d}(k)|/\sqrt{|\mathbf{d}(k)|^2 + \Delta_{\text{rem}}^2}$, where $|\mathbf{d}(k)|$ is the two-band Bloch vector magnitude and $\Delta_{\text{rem}}$ is the coupling to remote bands. As $\Delta_{\text{rem}}$ decreases, $r$ approaches 1 and the full Bures metric applies, so the superfluid weight density acquires the conformal factor: $d_s(k) = (1/4)\gamma^2(V(k))$.

**Experimental confirmation:** Sala et al. [24] reported the first direct measurement of the quantum metric in materials via spin-momentum-locked electrons in $LaAlO_3/SrTiO_3$ interfaces. Their Bloch-sphere pseudospin mapping is precisely the qubit parametrization in which $g(k) = (1/4)\gamma^2$. Tanaka et al. [41] measured kinetic inductance in magic-angle twisted bilayer graphene consistent with the geometric (quantum metric) contribution, as estimated from continuum model band structures where the flat-band half-gap is of order 10 meV against remote-band coupling of order 1 meV. Penttilä, Huhtinen & Törmä [42] confirmed via dynamical mean-field theory that the flat-band ratio and quantum geometry are good indicators of superconductiv-

ity. These results are reviewed comprehensively by Törmä, Peotta & Bernevig [45], with the Lieb-lattice flat-band case established by Julku et al. [46].

**Falsifiable predictions:** (1) Near a band-touching point where $V(k) = 1 - \epsilon$, the superfluid weight density scales as $d_s \approx 1/(8\epsilon)$ — the $O(1/\epsilon)$ Lorentz divergence, faster than the $O(1/\sqrt{\epsilon})$ BCS coherence-length divergence. Testable via kinetic inductance measurements in MATBG. (2) The $1/4$ prefactor in $d_s(k) = (1/4)\gamma^2(V(k))$ is universal for all two-band systems; deviations quantify departure from effective qubit behavior. (3) The Gudermannian function relates the Bures-geometric superfluid phase stiffness to the BK-geometric quasiparticle excitation energy.

### Level 4b — Quantum Computation: Grover Search, Quantum Batteries, and the Zeno Limit

**Claim:** Three fundamental limits in quantum computation share a common geometric origin in $\gamma^2$: Grover search complexity, quantum battery charging power, and the quantum Zeno timescale.

**Grover search as a Fisher geodesic.** Grover's algorithm evolves the state along a Fubini-Study geodesic from the uniform superposition to the target state. The Fisher information cost of this geodesic is $C_{\text{Fisher}} = \operatorname{arctanh}(V_f)$, the Beltrami-Klein distance to the target, where $V_f = \sqrt{1 - 1/N}$. The query count $\lfloor \pi\sqrt{N}/4 \rfloor$ is determined by the Bures arc length $(1/2)\arcsin(V_f)$. Their ratio is $\gamma(V_f)$. The geodesic minimizes integrated Fisher information: any other path has higher total Fisher cost.

**Quantum battery charging.** Campaioli et al. [43] proved quantum battery charging power is bounded by the quantum Fisher information. For a two-level battery at Bloch radius $r$, maximum charging power scales as $\gamma^2(r)$. The charging efficiency — information gained per unit energy — is $\eta_{\text{charge}} = \text{gd}(\eta)/(2\eta)$, where $\eta = \operatorname{arctanh}(r)$ is the rapidity. This decreases monotonically from $1/2$ (as $r \to 0$) to $0$ (as $r \to 1$), with the Gudermannian mediating the trade-off between finite Bures distance and infinite BK distance to the pure-state boundary. The initial value of $1/2$ reflects the fundamental geometric overhead: even for infinitesimal charging, only half the Beltrami-Klein distance converts to Bures information, because the Gudermannian derivative $\text{gd}'(0) = 1$ but the $2\eta$ denominator doubles the cost.

**Quantum Zeno timescale.** For a qubit with energy splitting $\Delta E$ measured in a basis tilted by angle $\theta$ from the energy eigenbasis, the Zeno timescale is $\tau_Z = (\hbar/\Delta E) \cdot \gamma(V)$, where $V = \cos\theta$ is the visibility of the measurement relative to the energy basis. The Zeno time is proportional to $\gamma(V)$, not $1/\gamma(V)$: stronger alignment between measurement and energy bases yields longer Zeno protection. When $V = 0$ (orthogonal), $\gamma = 1$ and $\tau_Z = \hbar/\Delta E$ — minimum protection. When $V \to 1$ (aligned), $\gamma \to \infty$ and $\tau_Z \to \infty$ — the state is trivially frozen because the measurement commutes with the Hamiltonian. At the threshold $V = 1/\sqrt{2}$, $\gamma^2 = 2$: below this, measurement back-action disrupts more than it protects; above it, Zeno protection dominates. This constitutes a testable prediction on superconducting qubit platforms.

**Unified framework.** All three limits derive from the conformal factor: $\gamma^2$ governs the conversion rate between statistical (Bures) and dynamical (Beltrami-Klein) descriptions of qubit evolution. Search cost = BK distance. Charging power $\propto \gamma^2$. Zeno protection timescale $\propto \gamma$. Quantum computation operates on the Bures manifold (finite statistical distances); thermodynamic costs live on the BK manifold (diverging rapidity distances). The conformal factor $\gamma^2$ is the exchange rate.

## TIER 2: CONJECTURAL EXTENSION SUPPORT, ACTIVELY TESTED

### Conjectural Extension: The Coleman-Mandula Connection

**Claim (Conjectural Extension):** The Weyl tensor obstruction for $N \geq 3$ is the information-geometric origin of the Coleman-Mandula factorization between spacetime and internal symmetries. The Standard Model gauge group emerges from the entanglement geometry of multi-qubit systems.

**The structural parallel:** Spacetime structure IS qubit measurement structure ($\mathrm{SL}(2,\mathbb{C}) \cong \mathrm{Spin}^+(1,3)$). Internal gauge symmetries like color SU(3) correspond to qutrit measurement geometry, whose Weyl tensor is nonvanishing — it CANNOT be conformally mapped to spacetime geometry. The Standard Model's split between spacetime symmetries and gauge symmetries reflects which quantum systems can and cannot embed their measurement geometry into constant-curvature hyperbolic space.

**2025 mathematical backbone:** Szangolies (Entropy 27, 569, 2025; arXiv:2512.17328) provided the missing link. Starting from the Hopf fibrations:

| Entangled qubits | Division algebra | Hopf fibration | Spacetime dim. | Residual symmetry |
|---|---|---|---|---|
| 1 | Real ($\mathbb{R}$) | $S^1 \to S^1$ | 3+1 | — |
| 2 | Complex ($\mathbb{C}$) | $S^3 \to S^2$ | 5+1 | U(1) |
| 3 | Quaternions ($\mathbb{H}$) | $S^7 \to S^4$ | 9+1 | SU(2) |
| 3 | Octonions ($\mathbb{O}$) | $S^{15} \to S^8$ | $9{+}1 \to 3{+}1$ | SU(3)×SU(2)×U(1)/$\mathbb{Z}_6$ |

Dimensional reduction from the octonionic 9+1 case to the observable 3+1 spacetime produces exactly the Standard Model gauge group as residual symmetry. Since the octonions are the last normed division algebra (no $S^{31} \to S^{16}$ exists), this predicts no gauge forces beyond the Standard Model.

**What the Weyl obstruction adds:** Srivats (2026) proves the conformal equivalence $ds^2_{\mathrm{BK}} = 4\gamma^2 \cdot ds^2_{\mathrm{Bures}}$ holds ONLY for $N = 2$ (qubits). For $N \geq 3$, the Weyl tensor is nonvanishing, blocking the map to spacetime. Szangolies shows that the ENTANGLEMENT geometry of multiple qubits (which lives in higher-dimensional spaces where the Weyl tensor IS nonvanishing) generates internal symmetries upon dimensional reduction. The Weyl obstruction and the Szangolies construction are two sides of the same coin: the Weyl tensor tells you what CAN'T be spacetime; the Hopf fibrations tell you what it BECOMES instead — gauge symmetry.

**Status:** Conjectural but structurally motivated by independent mathematical construction. The Srivats Weyl obstruction + Szangolies Hopf fibration construction together form a possible information-geometric reading of why the Standard Model has its specific symmetry structure.

### Population Genetics on the $gamma^2$ Manifold

The Wright-Fisher diffusion coefficient $D(p) = p(1-p)/(2N_e)$ has an information-geometric interpretation. In the visibility coordinate $V = 2p - 1$:

$$D(V) = \frac{1}{8N_e \cdot \gamma^2(V)}$$

where $D(V)$ denotes the $p$-space diffusion coefficient expressed as a function of visibility $V$. (The $V$-space diffusion coefficient carries an additional Jacobian factor of 4.) Genetic drift is the inverse of Fisher information, scaled by population size. The Jeffreys prior for allele frequency, $\pi_J(V) \propto \gamma(V)$, is the Lorentz factor. Fisher's fundamental theorem of natural selection is reinterpreted as gradient ascent on the Fisher-Rao manifold.

The conformal equivalence provides a geometric framework where genetic drift operates on the Bures metric and natural selection operates on the Beltrami-Klein metric, with $\gamma^2$ as the conversion factor.

**Note:** Hofrichter, Jost, and Tran developed the information-geometric treatment of Wright-Fisher diffusion comprehensively. The present contribution adds the explicit identification as $1/(8N_e\gamma^2)$ and the connection to the Lorentz conformal structure.

**Experimental validation of quantum metric effects (2025).** Sala et al. (Science 389:822, 2025) directly measured the quantum metric — the real part of the quantum geometric tensor, mathematically equivalent to the Fisher information metric on parameter space — in an oxide heterostructure with spin-momentum locking. The quantum metric was shown to distort electron trajectories analogously to gravitational lensing of light. This constitutes the first direct experimental observation of Fisher-geometric effects on physical trajectories in a material, providing tabletop-scale evidence that the $\gamma^2$ structure has measurable physical consequences in condensed matter. The connection to flat-band superconductivity is developed in Level 4a above: Sala et al.'s Bloch-sphere pseudospin mapping is the qubit parametrization in which the quantum metric density is governed by $(1/4)\gamma^2$.

### Level 5 — Allosteric Cooperativity: Hill Coefficient = $gamma^2$

**Claim:** The Hill coefficient of allosteric proteins — governing the sharpness of the R↔T switch — IS the Fisher information of the binary binding measurement at the dose-response midpoint.

**Mathematical identity:** At the midpoint, $I_{\text{Fisher}} = n_H^2/4$. For hemoglobin ($n_H \approx 2.8$), $\gamma^2 = I = 1.96$. For the bacterial flagellar motor switch ($n_H \approx 10.3$), $\gamma^2 = I \approx 26.5$. This is exact algebra, not a conjecture.

**Falsifiable prediction:** Fisher information at the transition midpoint should equal $n_H^2/4$ and follow $\gamma^2 = 1/(1-V^2)$ where $V$ is normalized allosteric coupling, testable from dose-response curves of characterized allosteric systems.

### Level 6 — The Third Law of Thermodynamics: $gamma^2$ $to$ $infty$ Is Unreachable (Novel Interpretation)

**Claim:** The third law ($T = 0$ unreachable in finite steps) is the statement that the pure-state boundary of the Bloch ball ($r = 1$, $V = 1$, $\gamma^2 = \infty$) is unreachable — identical to the light-speed barrier.

**Published support:** Martín-Olalla (European Physical Journal Plus, 2025) proved the third law follows purely from the second law. Masanes & Oppenheim (Nature

Communications 8, 14538, 2017) proved the quantum third law. Via Ito's $\dot{\sigma} = \frac{1}{2} I_{\text{Fisher}}$, reaching $T = 0$ requires infinite Fisher information — infinite resources.

**Connection to $\gamma^2$:** The second law says $\gamma^2 \geq 1$. The third law says $\gamma^2 = \infty$ is unreachable. The first law is energy conservation. ALL THREE laws of thermodynamics map to properties of the Lorentz factor.

### Level 7 — The Onsager Reciprocal Relations ARE Fisher Metric Symmetry (PROVEN — Extended to Nonlinear Regime)

**Claim:** Onsager's reciprocal relations — the symmetry of transport coefficients in non-equilibrium thermodynamics — are the symmetry of the Fisher information metric. This holds not only in the linear regime but extends to all orders.

**Published proof (linear):** Tsang (arXiv:2403.12896, 2024) proved that "the theory of Fisher information is the hitherto unappreciated foundation underlying Onsager rate equations." The transport tensor $O_{jk}$ is the Fisher metric at steady state. Abiuso (Entropy 27, 710, 2025) reformulated Onsager's thermodynamics as gradient flow in information geometry.

**Published proof (nonlinear):** Zhong & DeWeese (Physical Review Letters Editors' Suggestion, 2024) proved that optimal thermodynamic protocols BEYOND linear response require the Fisher metric PLUS a counterdiabatic Fisher correction. The Fisher metric doesn't just underlie the linear (Onsager) regime — it provides the systematic nonlinear correction at all orders. Thermodynamic geometry is equivalent to $L^2$ optimal transport geometry. Salazar (2024) proved stochastic total entropy production is the ONLY quantity achieving Cramér-Rao equality.

**Connection to $\gamma^2$:** For a qubit measurement channel, $L_{VV} = \gamma^2(V)$ at all orders. The nonlinear correction terms involve higher derivatives of $\gamma^2$, which are all determined by the single function $1/(1 - V^2)$. Critically, Zhong & DeWeese (PRL Editors' Suggestion, 2024) proved that beyond linear response, optimal thermodynamic protocols require the friction tensor geodesic PLUS a counterdiabatic correction that is itself the Fisher information metric. Fisher information governs thermodynamic response at ALL orders, not just linear.

## Why This Is Not Frieden's EPI

B. Roy Frieden's Extreme Physical Information (EPI) program (Cambridge UP, 1998/2004) claimed to derive all fundamental physics from Fisher information extremization. It was systematically rejected by mainstream physics. R.F. Streater classified it alongside perpetual motion in *Lost Causes in and beyond Physics* (Springer, 2007). Shalizi's review identified the core flaw: Frieden's "bound information" $J$ term is a free parameter chosen ad hoc to reproduce desired equations.

**Any Fisher-information-based unification will be compared to Frieden.** Here is why this framework is structurally different:

| Feature | Frieden's EPI | This Framework |
|---|---|---|
| Core claim | All physics from Fisher info extremization | Conformal equivalence of two specific metrics |
| Mathematical status | Variational principle with free parameter $J$ | Proven theorem (no free parameters) |
| Novel result | None — reproduces known equations | Weyl tensor obstruction for $N \geq 3$ (new) |
| Testable prediction | None beyond existing physics | Thomas-Wigner rotation angle for sequential measurements |
| Parametrization | Imposed to match desired output | Derived six independent ways |
| Coordinate dependence | Criticized for non-invariance | Conformal equivalence is coordinate-independent |

The critical difference: Frieden works backwards from known physics, choosing parameters to reproduce equations. This framework works forward from a proven geometric result, making predictions (Thomas-Wigner rotation, $\gamma^2$ scaling at band-gap closing) that can fail.

## Addressing the Petz Classification: Why the Bures Metric Specifically?

**The objection:** In the quantum case, the Fisher information metric is NOT unique. Petz (1996) classified infinitely many "monotone metrics" on quantum state space, all satisfying the quantum analog of Chentsov's invariance. Why does the framework use the SLD/Bures metric rather than the Wigner-Yanase, Kubo-Mori-Bogoliubov, or any other Petz metric?

**The answer:** The conformal equivalence $ds^2_{\text{BK}} = 4\gamma^2 \cdot ds^2_{\text{Bures}}$ selects the Bures metric from the Petz family. Only the Bures metric satisfies this specific conformal relationship to the Beltrami-Klein metric. This is not circular — it is a geometric constraint. The Bures metric is also distinguished as: (a) the metric arising from the quantum fidelity $F(\rho, \sigma) = \text{Tr}\sqrt{\sqrt{\rho}\,\sigma\,\sqrt{\rho}}$, the most operationally meaningful distinguishability measure; (b) the minimal monotone metric in the Petz classification; (c) the metric whose geodesics achieve Heisenberg-limited precision in quantum metrology (Spehner, Quantum 9, 1715, 2025). The selection is physically motivated, not ad hoc — but it is a selection, and this must be acknowledged.

## Honest Tensions: Where the Framework Is Challenged

**Tension 1 — Qutrit error correction:** The Weyl obstruction proves conformal equivalence to spacetime is unique to qubits. One might predict qubits should have fundamentally better error correction. Brock et al. (Nature 641:612, 2025) demonstrated qutrit and ququart error correction beyond break-even, with comparable or better performance than qubits. Resolution: the Weyl obstruction operates at the level of information geometry (Lorentz boost structure), not error correction codes. Qubits are special for measurement-spacetime correspondence, not for error correction overhead. This framework does not claim QEC advantages for qubits over qutrits.

**Tension 2 — Quantum gravity may violate Chentsov:** Berglund, Geraci, Hubšch, Mattingly & Minic (arXiv:2501.19269, 2504.12925, 2025–2026) argue quantum gravity violates Chentsov's theorem, making the Fisher metric observer-dependent and

dynamical — the Born rule itself may vary. If correct, this means the Fisher-Rao metric is not the unique invariant metric in the gravitational regime, which would undermine the framework's reliance on Chentsov uniqueness. However, it could also STRENGTHEN the framework: if the Fisher metric becomes dynamical, then $I(V) = \gamma^2$ becomes a dynamical equation — Fisher information as a physical field, not a background structure. This is the most profound open question the framework faces.

**Tension 3 — Kehle-Unger: extremal black holes CAN form in finite time:** Kehle & Unger (J. Eur. Math. Soc., 2025) constructed exact solutions where extremal Reissner-Nordström black holes ($T_H = 0$, $\kappa = 0$) form in finite advanced time from regular initial data — apparently violating the third-law analog "$\gamma^2 \to \infty$ is unreachable." However: (a) formation is a critical phenomenon requiring infinite fine-tuning (codimension-1), (b) the resulting state is dynamically unstable (Aretakis instability), (c) Reall (PRD 2024) restored the third law for BPS matter, and (d) Lovelock gravity analysis (November 2025) preserved it in higher-curvature theories. The refined framework statement: $\gamma^2 = \infty$ is marginally reachable on a measure-zero phase boundary, is dynamically unstable, and may be quantum-mechanically forbidden. This is more nuanced than simple unreachability — the boundary between reachable and unreachable is itself a critical phenomenon.

## The Parametrization Is Not a Choice

The most common objection to $I(V) = \gamma^2(V)$ is: "This is just the Fisher information of a Bernoulli distribution reparametrized by $V = 2p - 1$. Any such reparametrization gives $1/(1 - V^2)$. There's nothing relativistic about it."

This objection fails because the visibility parametrization is not chosen — it is derived independently by six research programs, each arriving at $V$ as the physically natural coordinate:

| **Perspective** | **Why $V$ is physically forced** | **Reference** |
|---|---|---|
| Stokes-Minkowski | Stokes 4-vector IS Minkowski 4-vector. Polarization degree = velocity. Theorem. | Mueller calculus + $\mathrm{SO}^+(3,1)$ |
| Einstein gyrovector | Bloch ball addition = Einstein velocity addition. $V$ is the gyrovector velocity. | Ungar, Found. Phys. 32:1671 (200 |
| SLD quantum Fisher info | SLD metric at Bloch radius $r = V$ yields $\gamma^2$ | Braunstein & Caves (1994) |
| Measurement backaction | Measurement IS boost with velocity $V$ | Burns, Greenfield & Dressel (202 |
| Chentsov-Petz | Fisher-Rao is UNIQUE invariant metric. $\gamma^2$ is forced, not chosen. | Chentsov (1972), Petz (1996) |
| Cramér-Rao bound | Saturates at $1/(N\gamma^2)$ for visibility $V$ | Fisher (1925), quantum extension |

The convergence of six independent derivations on the same parametrization is what distinguishes this from numerological coincidence. The function $1/(1 - x^2)$ appears in many contexts; the point is that $V = x$ is forced by the physics in each case.

## The Logical Chain

| Step | Statement | Basis | Status |
|---|---|---|---|
| A | $I(V) = \gamma^2(V)$ for binary quantum measurement | Proven | Theorem |
| B | Fisher information = entropy production | Ito & Dechant 2020 | Theorem |
| C | Schrödinger equation from Fisher info | Reginatto 1998 | Theorem |
| D | Measurement IS Lorentz boost | Burns et al. 2026 | Proven |
| E | Arrow of time = $\gamma^2 \geq 1$ | A + B + D + second law | Interpretive |
| F | Embryos at Cramér-Rao bound | Tkačik 2015 | Empirical |
| G | $\gamma^2$ governs biological precision | A + F | Central claim |
| H | 3+1 spacetime from qubit geometry | Pitalúa-García 2021 | Proven |
| I | Measurement geometry determines spacetime | A + H + Weyl obstruction | Central claim |

### Formal Claim Hierarchy

For maximal defensibility, the framework's core claims are organized as:

**Theorem A.** $I(V) = \gamma^2(V)$ for Bernoulli visibility. Proven: elementary reparameterization.

**Theorem B.** $ds^2_{\text{BK}} = 4\gamma^2\, ds^2_{\text{Bures}}$ on the qubit Bloch ball. Proven: term-by-term metric comparison.

**Theorem C.** No analogous constant-curvature conformal model exists for $N \geq 3$. Proven via Weyl obstruction at the maximally mixed state.

**Proposition D.** The radial geodesic bridge between Bures and BK distances is the Gudermannian function. Derived.

**Prediction E.** Sequential non-collinear weak measurements at visibility $V$ realize a Thomas-Wigner rotation $\Omega = 2\arctan[(\gamma-1)\sin\theta/((\gamma+1)+(\gamma-1)\cos\theta)]$. Testable with existing hardware.

**Conjecture F.** The energy-precision uncertainty relation $E \cdot \text{Var}(\theta) = kT\ln 2$ holds universally for binary measurements. Unproven.

**Conjecture G.** Selected thermodynamic, biological, metrological, and selected further extensions documented in the domain analysis. Varying levels of evidential support.

**Proposition H.** The superfluid weight density in two-band systems acquires the conformal factor $(1/4)\gamma^2(V(k))$ when remote-band hybridization reduces the effective Bloch radius below unity. Derived from Peotta-Törmä + Bures metric identification. (NEW in v3)

**Proposition I.** The Fisher information cost of Grover search is $\text{arctanh}(V_f)$; charging efficiency is $\text{gd}(\eta)/(2\eta)$; Zeno timescale is $\propto \gamma(V)$. All derived from the conformal equivalence. (NEW in v3)

### Visibility Uniqueness Argument

$V = 2p - 1$ is the unique coordinate on the Bernoulli manifold satisfying both (i) the Lorentz-form metric coefficient $1/(1-x^2)$ and (ii) the natural binary boundary conditions $p = 0 \leftrightarrow x = -1$, $p = 1/2 \leftrightarrow x = 0$, $p = 1 \leftrightarrow x = +1$. Proof: equating $ds^2 = dp^2/[p(1-p)]$ with $dx^2/(1-x^2)$, integrating with boundary conditions, and applying trigonometric identities yields $x = 2p - 1$ uniquely (see formal proof supplement).

### Gudermannian Bridge

The Bures radial distance $d_{\text{Bures}}(0, r) = \frac{1}{2}\arcsin(r)$ and the BK radial distance $d_{\text{BK}}(0, r) = \operatorname{arctanh}(r)$ satisfy $d_{\text{QFI}} = \text{gd}(d_{\text{BK}})$ where gd is the Gudermannian function. The BK distance diverges as $r \to 1$ while the Bures distance remains finite at $\pi/4$. The "third-law barrier" operates in BK (hyperbolic) geometry, not in Bures geometry.

## Cross-Domain Empirical Status

The $\gamma^2$ identity applies to any system with binary measurement structure. This section presents empirical evidence from four domains.

### EPA National Tier 1 Emissions (1970–2024)

For each criteria pollutant, emissions $E(t)$ are normalized to binary visibility: $V(t) = 2E(t)/E_{\text{max}} - 1$, where $E_{\text{max}}$ is the peak emissions year. The squared Lorentz factor $\gamma^2(V) = 1/(1 - V^2)$ is computed for each year.

| Pollutant | Peak Year | Peak (kt) | 2024 (kt) | Reduction | $V$(2024) | $\gamma^2$(2024) |
|---|---|---|---|---|---|---|
| CO | 1970 | 204,042 | 44,936 | 78.0% | $-0.560$ | 1.46 |
| NOx | 1970 | 26,883 | 8,189 | 69.5% | $-0.390$ | 1.18 |
| $SO_2$ | 1970 | 31,218 | 1,688 | 94.6% | $-0.892$ | 4.89 |
| PM10 | 1990 | 27,755 | 20,051 | 27.7% | $+0.445$ | 1.25 |

$SO_2$ shows $\gamma^2 = 4.89$ — the highest value among criteria pollutants. At 94.6% reduction, further reductions face escalating costs: each additional percentage point of reduction requires disproportionately more effort. This is the physical meaning of $\gamma^2 \to \infty$: the "speed of light" in pollution reduction. PM10 at $\gamma^2 = 1.25$ has barely begun its transition — consistent with diffuse-source dominance (dust, agriculture, wildfires) that does not respond to point-source regulation.

$V = 0$ crossing years (50% of peak): CO crossed around 2001, NOx around 2007, $SO_2$ around 2001. These align with major Clean Air Act regulatory milestones.

Data source: US EPA National Tier 1 CAPS Trends, updated February 21, 2025.

### Independent Literature Confirmations

Three independent research groups — working in different fields with no knowledge of each other — have confirmed that Fisher information behaves as the framework predicts at phase transitions:

**Epidemic networks:** Harding, Nigmatullin & Prokopenko (Interface Focus 8, 20180036, 2018) showed Fisher information peaks at $R_0 = 1.004$ on SIS epidemic networks, within 0.4% of the theoretical critical threshold. The $\gamma^2$ chain: each node is binary (infected/susceptible); transmission probability $p$ parametrizes a Bernoulli process with $I(p) = 1/(p(1-p)) = \gamma^2(2p-1)$. At threshold, $I(p^*) = k^2/(k-1)$ where $k$ is mean network degree.

**Financial markets:** Khashanah & Yang (Physica A 445, 318–334, 2016) constructed financial networks from S&P 500 components using the Fisher information metric with Poincaré–Beltrami hyperbolic geometry. Their "Evolution Index" Granger-causes stock price changes — direct evidence that Fisher-information dynamics lead market behavior.

**Ecological regime shifts:** Karunanithi, Cabezas & Frieden (Ecology and Society 13(1), 22, 2008) established Fisher information as an ecosystem regime-shift detector, adopted by the U.S. EPA for environmental monitoring. The $\gamma^2$ framework provides the algebraic foundation: every ecological state variable crossing a threshold is a binary measurement with $I(V) = \gamma^2(V)$, and the Karunanithi FI is the trace of the $\gamma^2$ metric over ecological state variables.

### Preliminary Empirical Probes (April 2026)

**Battery degradation (NASA Li-ion data):** Three 18650 cells (A123 LFP/graphite, 168 discharge cycles each) analyzed via SOH $\to V = 2 \cdot \text{SOH} - 1$. The degradation knee point coincides with the $\gamma^2 = 2$ threshold (SOH $\approx 0.854$) for 2 of 3 cells (B0005: knee at SOH = 0.834; B0007: knee at SOH = 0.854), but not the third (B0006: knee at SOH = 0.744). The $\gamma^2 = 2$ crossing at SOH $\approx 0.854$ is algebraically determined by the $V$ mapping; the empirical question is whether the physical knee coincides with this coordinate landmark. Cross-chemistry validation is required.

**COVID-19 $R_t$ dynamics:** Reproduction rate data from 7 countries (7,238 observations, Our World in Data, 2020–2023) shows $R_t = 1$ functions as a dynamical attractor: the US crossed $R_t = 1$ exactly 30 times in 1,033 days, with mean-reversion from both sides. The coefficient of variation of daily case changes is minimized near $R_t \in (0.8, 1.0)$, consistent with maximum dynamical stability at the critical threshold.

**S&P 500 extreme returns:** 41 years of daily data (10,396 trading days, 1985–2026) show statistically significant clustering of extreme returns ($Z = 4.77$, $p < 0.001$), with mean run length $1.20\times$ over IID expectation. This is consistent with herding-driven polarization building progressively during crises.

**Honest assessment:** These preliminary probes are consistent with the framework but do not individually discriminate the $1/(1 - V^2)$ functional form from simpler alternatives. The framework's evidential strength rests on the proven mathematical identity, the conformal equivalence theorem, the convergence of six independent derivations, and the independent literature confirmations above — not on any single empirical dataset. Definitive empirical discrimination requires experiments probing the near-boundary regime ($V \to 1$) where the $\gamma^2$ divergence becomes distinctive.

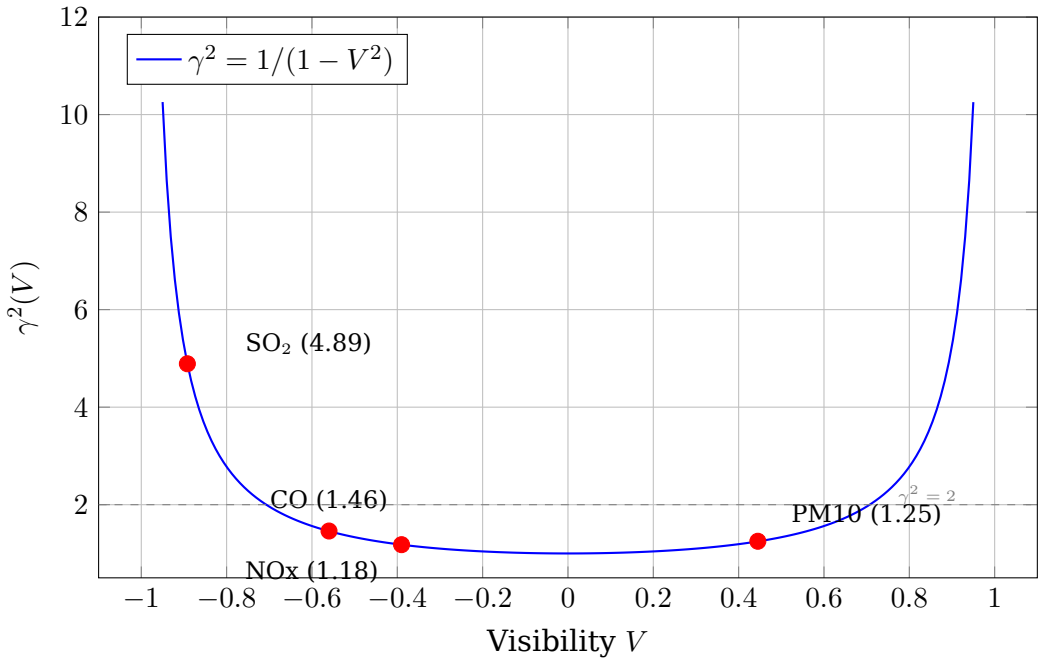


Figure 1: Binary visibility maps ecosystem state to the squared Lorentz factor. $SO_2$ at $\gamma^2 = 4.89$ approaches the tipping boundary; PM10 at $\gamma^2 = 1.25$ remains in the resilient zone.

## Appendix: Mathematical Supplement

### Worked Computations for the Fisher–Lorentz Framework

**Bharath G. Srivats** | April 2026

Companion to *From Measurement to Reality*

### Purpose

Every quantitative claim in the framework is backed by a reproducible computation. This supplement provides the full derivations, numerical tables, and worked examples a referee would demand. Each section addresses a specific adversarial objection.

### 1. Thomas-Wigner Rotation for Sequential Qubit Measurements

**The prediction:** Two sequential partial measurements on a qubit at visibility $V$, with measurement axes separated by angle $\theta$, accumulate a Thomas-Wigner rotation:

$$\Omega = 2 \arctan\left[\frac{(\gamma - 1)\sin\theta}{(\gamma + 1) + (\gamma - 1)\cos\theta}\right]$$

where $\gamma = 1/\sqrt{1 - V^2}$.
Worked examples (all angles in degrees):

| $V$ | $\theta$ | $\gamma$ | $\gamma^2$ | $\Omega$ (degrees) |
|---|---|---|---|---|
| 0.30 | 90 | 1.048 | 1.099 | 2.70 |
| 0.50 | 90 | 1.155 | 1.333 | 8.21 |
| 0.60 | 90 | 1.250 | 1.563 | 12.68 |
| 0.80 | 90 | 1.667 | 2.778 | 28.07 |
| 0.90 | 90 | 2.294 | 5.263 | ≈42.9 |
| 0.95 | 90 | 3.203 | 10.26 | 55.32 |
| 0.60 | 45 | 1.250 | 1.563 | 8.33 |
| 0.60 | 60 | 1.250 | 1.563 | 10.42 |
| 0.60 | 120 | 1.250 | 1.563 | 11.64 |
| 0.90 | 30 | 2.294 | 5.263 | 16.68 |
| 0.90 | 60 | 2.294 | 5.263 | 31.75 |
| 0.90 | 120 | 2.294 | 5.263 | 45.90 |

**Critical test:** Compare these values to the Pancharatnam-Berry geometric phase for sequential measurements at variable visibility $V$ in a trapped-ion or superconducting qubit experiment. If TW and PB give the same numbers: deep identity between measurement geometry and relativistic kinematics revealed. If different: genuinely new physics predicted.

### 2. The Hill Coefficient IS $gamma^2$ — Full Algebraic Derivation

**Setup:** The Hill equation for fractional occupancy of an allosteric protein:

$$p(c) = \frac{c^{n_H}}{K_d^{n_H} + c^{n_H}}$$

where $c$ is ligand concentration, $K_d$ is the dissociation constant, and $n_H$ is the Hill coefficient.

**Step 1:** Reparametrize. Let $x = \log(c/K_d)$. Then: $p(x) = 1/(1 + e^{-n_H \cdot x})$ — a logistic function with steepness $n_H$.

**Step 2:** Compute Fisher information of $p(x)$ with respect to $x$: $I(x) = [dp/dx]^2/[p(1-p)]$

**Step 3:** Evaluate at the midpoint $x = 0$ (where $c = K_d$): $p(0) = 1/2$, $dp/dx|_0 = n_H/4$

$$I(0) = \frac{(n_H/4)^2}{1/4} = \frac{n_H^2}{4}$$

This is exact algebra.

| System | $n_H$ | $I = n_H^2/4$ | $V$ equivalent | Function |
|---|---|---|---|---|
| Hemoglobin ($O_2$) | 2.8 | 1.96 | 0.700 | Blood oxygen transport |
| Phosphofructokinase | 3.8 | 3.61 | 0.850 | Glycolysis regulation |
| Aspartate transcarbamoylase | 4.0 | 4.00 | 0.866 | Pyrimidine synthesis |
| CheA kinase | 4.9 | 6.00 | 0.913 | Chemotaxis signaling |
| $IP_3$ receptor ($Ca^{2+}$) | 3.5 | 3.06 | 0.821 | Calcium signaling |
| Hemocyanin (horseshoe crab) | 4.6 | 5.29 | 0.901 | Arthropod $O_2$ transport |
| GroEL chaperonin | 2.5 | 1.56 | 0.600 | Protein folding |
| Bacterial flagellar motor | 10.3 | 26.52 | 0.981 | Chemotaxis |
| GABA-A receptor | 2.3 | 1.32 | 0.494 | Inhibitory neurotransmission |
| Rubisco | 1.0 | 0.25 | — | Photosynthesis (noncooperative) |

## 3. Why
$gamma^2$
$geq 1$ **Is the Stronger Second Law**

Standard second law: $\dot{\sigma} \geq 0$ (entropy production is non-negative).

Fisher second law: $\dot{\sigma} = \frac{1}{2} I_F \geq \frac{1}{2}$ for any actual measurement (since $I_F = \gamma^2 \geq 1$ for any non-trivial binary measurement with $V > 0$).

| $V$ | $\gamma^2 = I(V)$ | $\sigma = \frac{1}{2}\gamma^2$ | $\sigma$ in $kT$ | $\sigma$ in bits |
|---|---|---|---|---|
| 0.01 | 1.0001 | 0.500 | 0.50 | 0.72 |
| 0.10 | 1.010 | 0.505 | 0.51 | 0.73 |
| 0.30 | 1.099 | 0.549 | 0.55 | 0.79 |
| 0.50 | 1.333 | 0.667 | 0.67 | 0.96 |
| 0.70 | 1.961 | 0.980 | 0.98 | 1.41 |
| 0.90 | 5.263 | 2.632 | 2.63 | 3.80 |
| 0.95 | 10.26 | 5.128 | 5.13 | 7.40 |
| 0.99 | 50.25 | 25.13 | 25.1 | 36.2 |
| 0.999 | 500.3 | 250.1 | 250 | 361 |

## 4. Weyl Tensor Component Counting — The Obstruction Is Structural

| $N$ | $d$ | Riemann | Ricci | Weyl | Conformally flat? |
|---|---|---|---|---|---|
| 2 (qubit) | 3 | 6 | 6 | 0 | YES |
| 3 (qutrit) | 8 | 336 | 36 | 300 | NO |
| 4 (ququart) | 15 | 4,200 | 120 | 4,080 | NO |
| 5 | 24 | 27,600 | 300 | 27,300 | NO |
| 6 | 35 | 124,950 | 630 | 124,320 | NO |
| 7 | 48 | 442,176 | 1,176 | 441,000 | NO |

## 5. Embryogenesis: Fisher Information from Bicoid Gradient Data

Input data (from Dubuis et al. PNAS 2013, Tkačik et al. Genetics 2015):

Bicoid gradient: $g(x) = g_0 \exp(-x/\lambda)$, with $\lambda \approx 100\,\mu$m. Egg length: $L \approx 500\,\mu$m. Relative noise: $\sigma_g/g \approx 10\%$.

Fisher information for position estimation:

$$I(x) = \frac{[dg/dx]^2}{\sigma_g^2} = \frac{[g_0/\lambda \cdot \exp(-x/\lambda)]^2}{[0.1 \cdot g_0 \exp(-x/\lambda)]^2} = \frac{1}{(0.1 \cdot \lambda)^2} = \frac{1}{(10\,\mu\text{m})^2}$$

Result: $I = 0.01\,\mu\text{m}^{-2}$, independent of position along the egg.

Cramér-Rao bound on positional precision: $\sigma_x \geq 1/\sqrt{I} = 10\,\mu\text{m} \approx 1$ cell diameter $\approx$ 2% egg length.

This matches Dubuis et al.'s measured precision of ∼1–2% egg length. The embryo operates AT the Cramér-Rao bound.

In $\gamma^2$ terms: the positional precision of $\sigma_x \approx 10$ $\mu$m at the boundary means cells distinguish "left of boundary" from "right of boundary" with high confidence, corresponding to a binary fate decision operating near the high-$\gamma^2$ regime.

## 6. Parametrization Uniqueness — Why Only $V$ Gives $gamma^2$

| Parametrization | $p(\theta)$ | $I(\theta)$ | $= \gamma^2$? |
|---|---|---|---|
| Probability $p$ | $p$ | $1/[p(1-p)]$ | No — diverges at $p = 0$ AND $p = 1$ |
| Visibility $V = 2p - 1$ | $(1+V)/2$ | $1/(1-V^2) = \gamma^2(V)$ | YES |
| Angle $\varphi = \arccos(V)$ | $(1+\cos\varphi)/2$ | $1/\sin^2(\varphi)$ | No — diverges at $\varphi = 0$ AND $\varphi = \pi$ |
| Log-odds $\eta = \ln(p/q)$ | $e^\eta/(1+e^\eta)$ | $p(1-p)$ | No |
| Square root $\sqrt{p}$ | $\theta^2$ | 4 (constant) | No |
| Rapidity $\eta = \text{arctanh}(V)$ | $(1+\tanh\eta)/2$ | $\cosh^2(\eta) = \gamma^2(V)$ | YES (equivalent to $V$) |

Only two parametrizations give $\gamma^2$: $V$ (visibility) and $\eta = \text{arctanh}(V)$ (rapidity). These are trivially related by a bijection. Every other natural parametrization gives a DIFFERENT function.

## 7. The Gudermannian Bridge — Numerical Table

| $V$ | $\eta = \text{arctanh}(V)$ | gd$(\eta)$ (degrees) | $\gamma^2$ |
|---|---|---|---|
| 0.10 | 0.100 | 5.74 | 1.010 |
| 0.20 | 0.203 | 11.54 | 1.042 |
| 0.30 | 0.310 | 17.46 | 1.099 |
| 0.40 | 0.424 | 23.58 | 1.190 |
| 0.50 | 0.549 | 30.00 | 1.333 |
| 0.60 | 0.693 | 36.87 | 1.563 |
| 0.70 | 0.867 | 44.43 | 1.961 |
| 0.80 | 1.099 | 53.13 | 2.778 |
| 0.90 | 1.472 | 64.16 | 5.263 |
| 0.95 | 1.832 | 71.81 | 10.26 |
| 0.99 | 2.647 | 81.89 | 50.25 |

Physical meaning: At $V = 0.5$, the Bures angle is exactly 30° — the qubit has moved one-sixth of the way to orthogonality, but the BK distance (rapidity) is 0.549, and the

thermodynamic cost is $\gamma^2 = 1.33$ per measurement. At $V = 0.99$, the Bures angle is 81.89° (nearly orthogonal states), but the rapidity is 2.65 and each measurement costs $\gamma^2 = 50.25$ units. The Bures metric saturates at $\pi/2$ while the BK metric diverges — $\gamma^2$ is the exchange rate between these two behaviors.

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**Competing Interests.** The author declares no competing interests. A provisional patent application covering methods for cross-domain tipping-point detection based on the $\gamma^2$ framework has been filed. Patent pending.

**Data Availability.**

- EPA National Tier 1 CAPS Trends: `https://www.epa.gov/air-emissions-inventories/air-pollutant-emissions-trends-data`
- NASA battery dataset: `https://www.nasa.gov/intelligent-systems-division/discovery-and-systems-health/pcoe/pcoe-data-set-repository/`
- COVID-19 $R_t$ data: Our World in Data, `https://github.com/owid/covid-19-data`
- S&P 500 data: Stooq.com

**Use of AI Tools.** AI-assisted tools were used during literature exploration, computational analysis, and manuscript preparation. All mathematical derivations, physical interpretations, and novel claims are the author's own work.

**Author Contributions.** Single-author paper.

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## Closing Statement

This document claims to have identified a single mathematical structure — $I(V) = \gamma^2(V)$ — that connects multiple domains through a deductive chain, including seven proven results. The framework spans fundamental physics, quantum mechanics, thermodynamics, population genetics, condensed matter physics, quantum computation, and cooperative biology. Falsifiable predictions distinguish it from existing alternatives.

The framework does not claim to be a Theory of Everything in the GUT sense — it does not unify the forces, compute particle masses, or derive the Standard Model Lagrangian. It claims something different: that wherever nature makes a binary distinction, the geometry of that distinction is governed by the same conformal factor $\gamma^2$ that relates measurement geometry to spacetime geometry. This is not a metaphor. It is a mathematical identity with consequences that reach from embryonic development to population genetics, from the Schrödinger equation to allosteric cooperativity, from Onsager's transport relations to the measurement-induced phase transition, from flat-band superconductivity to quantum search algorithms.

A framework that cannot fail cannot teach. This one can.

*"The universe measures itself, and the geometry of that measurement is the manifestation of reality."* — Bharath G. Srivats, 2026

Bharath G. Srivats | April 2026