Emergent Gravity from a Two-Postulate Phenomenological Model of Galactic Dynamics

Joshua Whitmer

Independent Researcher

June 2026

Abstract

We present a proof-of-concept phenomenological model mapping information geometry to galactic dynamics, intended to motivate a future covariant theory. Two postulates are introduced from which galactic rotation curves, the baryonic Tully-Fisher relation, halo radii, and velocity dispersion enhancements all follow without free parameters. P1 establishes a universal acceleration scale $a_0 \approx 1.2\times10^{-10}$ m/s² from the thermodynamic condition T_Unruh = T_Hubble, yielding $a_0 = c\cdot H_0/(2\pi)$ within 15% of the observed value from established physics alone. P2 gives the modified dynamical law $a\_eff = a\_N + \sqrt{a_0\cdot a\_N}\cdot f(\tau)$, where $f(\tau) = 1/(1+\tau^2)$ is motivated by the Fisher Information geometry of the thermal states defined by P1 — not chosen empirically. The specific exponent $\gamma = 2$ is a phenomenological ansatz consistent with quantum Chernoff bound arguments but not yet uniquely derived from a covariant action. MOND's deep-field limit is a special case of P2. The transition function ensures that emergent corrections vanish to 5×10^{-27} m/s² at Earth's surface, consistent with all precision tests of Newtonian gravity without fine-tuning or screening mechanisms. A proposed extension P3 addresses pressure-supported systems where P2 does not apply, reducing velocity dispersion discrepancies from 42% to 14% in NGC 185. Consistency checks focus on the isolated void dwarf KK246 — the only confirmed galaxy in the Tully Void — where the framework gives a flat rotation velocity of 43.7 km/s against an observed value of ~42 km/s (+4.0%, within baryonic mass uncertainties) with zero free parameters and zero external field contamination. The framework is checked across eleven orders of magnitude in acceleration from the strong-field regime near Sgr A* to the deep emergent regime of the Tully Void. This is a phenomenological framework, not a complete theory of gravity: no Lagrangian formulation exists, and all theoretical gaps are stated explicitly in Section 8. A companion paper develops the primary observational prediction: if a_0 evolves with H(z), the BTFR normalization evolves as $v\_TF(z)/v\_TF(0) = (H(z)/H_0)^{1/4}$, testable with JWST kinematic surveys.

1. Introduction

The flat rotation curves of spiral galaxies remain one of the most persistent anomalies in modern astrophysics. Standard Newtonian gravity predicts $v \propto r^{-1/2}$ beyond the visible mass distribution, inconsistent with observations showing $v \approx$ constant to large radii. Dark matter and MOND (Milgrom 1983) both address this phenomenology but face significant theoretical challenges. Dark matter has not been directly detected despite decades of searches. MOND succeeds observationally but provides no physical derivation of its acceleration scale $a_0 \approx 1.2\times10^{-10}$ m/s², which is inserted as a fitted constant.

The numerical coincidence $a_0 \sim c\cdot H_0$ has been noted since Milgrom (1983) and reviewed by Famaey & McGaugh (2012). Emergent gravity approaches (Verlinde 2011, 2016) offer a third path, deriving gravitational behavior from thermodynamic and information-theoretic principles. The present framework develops this approach into a minimal two-postulate theory with three advances over prior work: a proposed physical derivation of a_0 from horizon thermodynamics; a transition function $f(\tau)$ motivated by information geometry rather than chosen empirically; and an explicit extension P3 to pressure-supported systems.

All quantitative claims are numerically verified and all open questions are explicitly stated. This framework is presented as a proof-of-concept phenomenological model mapping information geometry to galactic dynamics, intended to motivate a future covariant theory. It is not a complete theory of gravity in the sense that general relativity or TeVeS is complete. It makes no claims to that status. What it provides is a parameter-free mapping from the thermodynamic structure of the cosmological horizon to the observed acceleration-scale phenomenology of galactic rotation curves, with all theoretical gaps stated explicitly in Section 8.

2. Framework Overview

The complete framework rests on two postulates and one proposed extension:

	Postulate	Status	Produces
P1	$a_0 \sim 1.2\times10^{-10}$ m/s²	Empirical input. Proposed thermodynamic origin: $a_0 = c\cdot H_0/(2\pi)$.	The transition scale. All results scale with this.
P2	a_eff = a_N + √(a_0·a_N)·f(τ)	Phenomenologically motivated dynamical law. f(τ) = 1/(1+τ²) from information geometry; γ = 2 is a motivated ansatz.	Flat curves, BTFR, halo radii, transition radius.
P3	Coherence threshold at g_eff = a_0	Proposed extension. Speculative, not fully derived.	Pressure-supported systems, ellipticals, dwarf spheroidals.

MOND's deep-field limit is a special case of P2. P3 is explicitly disconnected from P1+P2 pending derivation of the coupling function F(N_crit/N).

3. Postulate 1: Thermodynamic Origin of the Acceleration Scale

3.1 The Unruh-Hubble Connection

The most pressing question for any MOND-like framework is the physical origin of the acceleration scale a_0. Three approaches were investigated: variational principles, entropy gradient arguments, and horizon thermodynamics. The horizon thermodynamics approach gives the most physically motivated result.

The Unruh effect states that an observer accelerating at rate a perceives a thermal bath at temperature:

T_Unruh = ħ·a / (2π·k_B·c)

The cosmological horizon has an associated Hawking temperature:

T_Hubble = ħ·H_0 / (2π·k_B)

Setting T_Unruh = T_Hubble and solving for the acceleration:

$a_0 = c\cdot H_0/(2\pi) = 1.098\times10^{-10}$ m/s²

Formula	Value	Match to observed a_0
Observed (empirical)	1.200×10^{-10} m/s²	Reference
$c\cdot H_0$	6.900×10^{-10} m/s²	Factor 5.75 off

$c \cdot H_0/(2\pi)$	1.098×10^{-10} m/s²	15% off ✓

The formula $a_0 \sim c \cdot H_0/(2\pi)$ matches the observed value to within 15% from a purely theoretical argument involving no free parameters and no galactic observations.

3.2 Physical Interpretation

The Unruh-Hubble connection provides a physical picture for P1: a_0 is the acceleration at which the local Unruh temperature equals the Hawking temperature of the cosmological horizon. When a particle's local gravitational acceleration drops below a_0, it can no longer be thermodynamically distinguished from the quantum vacuum fluctuations of the cosmic horizon. At this point gravity transitions from classical to emergent behavior, producing the residual term $\sqrt{(a_0 \cdot a\_N)}$ in P2.

3.3 Honest Assessment

This is a motivated physical picture, not a full derivation. Three things remain unresolved:

- The 2π factor emerges from the Unruh temperature formula but is observed rather than derived as uniquely necessary from a deeper principle.
- The connection between T_Unruh = T_Hubble and the specific form of P2 is established through information geometry but not yet derived from a covariant action.
- The relationship $a_0 \sim c \cdot H_0/(2\pi)$ implies a time-varying a_0 as the universe expands, which has significant observational implications developed in the companion paper (Whitmer 2026b).

Despite these limitations, $a_0 \sim c \cdot H_0/(2\pi)$ within 15% from established thermodynamics is significantly stronger than a purely dimensional argument. It provides a physical mechanism, not just a number.

3.4 Derivation of the Transition Function from Information Geometry

3.4.1 The Statistical Manifold

The local gravitational environment is modeled as a thermal state parameterized by temperature T. Two physically distinct states are defined on the manifold: the local Unruh state at $T\_local = \hbar a\_N/(2\pi \cdot k\_B \cdot c)$, and the cosmic horizon state at $T\_horizon = \hbar H_0/(2\pi \cdot k\_B)$. These states represent distinct points on a one-dimensional statistical manifold — the space of thermal probability distributions parameterized by temperature. The natural metric on this manifold is the Fisher Information metric:

$$g(T) = F(T) = C/T^2$$

where C is a constant scaling factor dictated by the field's underlying degrees of freedom. This metric encodes the statistical distinguishability between adjacent thermal states and is standard in information geometry.

3.4.2 Fisher Information Weights (Phenomenological Ansatz)

The Fisher Information metric evaluated at each state yields metric components proportional to $1/T^2$. We assign statistical weights to each dynamical regime proportional to the Fisher Information weight at the corresponding thermal state: $Z \propto g(T)$. This is the central modeling assumption of the information-geometric construction. It reflects the physical principle that states with higher Fisher Information are more statistically distinguishable from neighboring states and therefore carry greater classical dynamical weight. We note that moving from Fisher-information weights to physical dynamical probabilities is a modeling postulate rather than a theorem of information geometry — it is physically motivated by the connection between statistical distinguishability and gravitational regime, but is not automatically derived from the metric structure alone. The Fisher-information weights at our two states are:

- Cosmic horizon baseline: $g(T\_horizon) \propto 1/T^2\_horizon$
- Local accelerated state: $g(T\_local) \propto 1/T^2\_local = 1/(\tau^2 T^2\_horizon)$

where $\tau \equiv T\_local/T\_horizon = a\_N/a_0$ is the dimensionless scaling parameter from P1. The relative Fisher-information weight between the baseline horizon state and the local state is:

$$g(T\_horizon)/g(T\_local) = T^2\_local/T^2\_horizon = \tau^2$$

3.4.3 Projective Probability on the Manifold

We partition the system into two mutually exclusive dynamical regimes: Classical gravity — dominant when the local accelerated state is statistically distinguishable from the cosmic horizon baseline (statistical weight Z_classical); and Emergent gravity — dominant when the local accelerated state becomes statistically indistinguishable from the background cosmic horizon vacuum (statistical weight Z_emergent). The relative weight of the classical regime grows against the emergent baseline in proportion to the ratio of their Fisher-information weights:

$$Z\_classical/Z\_emergent = g(T\_horizon)/g(T\_local) = \tau^2$$

This formalizes the physical principle that the relative weight of classical versus emergent behavior is a direct function of state distinguishability. When $\tau \gg 1$ the local state is highly distinct from the cosmic horizon — classical gravity dominates. When $\tau \ll 1$ the local state becomes thermodynamically indistinguishable from the vacuum background — collective emergent behavior governs the dynamics.

3.4.4 The Transition Function

The projective probability that the system exhibits emergent holographic behavior is defined by the relative statistical weight of the emergent regime within the two-state partition:

$$f(\tau) = Z\_emergent/(Z\_classical + Z\_emergent) = 1/(1 + \tau^2)$$

Within this information-geometric framework, the transition function follows from the normalized statistical weights of the two thermal sectors given the ansatz of Section 3.4.2. The scaling variable τ is established strictly by the fundamental temperature ratio from P1. No free parameters are introduced.

3.4.5 Verification of Limiting Behavior

- Deep classical regime ($\tau \gg 1$, $a\_N \gg a_0$): $f(\tau) \to \tau^{-2} \to 0$. The anomalous emergent term is heavily suppressed, recovering standard classical gravity. ✓
- Deep emergent regime ($\tau \ll 1$, $a\_N \ll a_0$): $f(\tau) \to 1$. The emergent correction becomes fully active, recovering the deep MOND-like asymptotic scaling. ✓
- Transition point ($\tau = 1$, $a\_N = a_0$): $f(\tau) = 1/2$. Equal weight. Transition occurs exactly at $a\_N = a_0$, defining $r_0 = \sqrt{GM/a_0}$. ✓

3.4.6 Earth Surface Verification

At Earth's surface where $a\_N \approx 9.81$ m/s²:

$$\tau = 9.81 / 1.2\times10^{-10} = 8.175\times10^{10}$$

$$f(\tau) = 1/(1 + (8.175\times10^{10})^2) \approx 1.496\times10^{-22}$$

$$\Delta a = \sqrt{(a_0 \cdot a\_N)} \cdot f(\tau) = (3.43\times10^{-5}\ m/s^2) \times (1.496\times10^{-22}) \approx 5.13\times10^{-27}\ m/s^2$$

This correction is approximately 18 orders of magnitude below current laboratory instrument detection thresholds. The information-geometric framework naturally satisfies all local precision tests of Newtonian gravity without requiring fine-tuned screening mechanisms or hand-selected interpolation formulas.

3.4.7 On the Derivability of $f(\tau)$ from First Principles

We document three derivation paths explored in developing the transition function, and their honest limitations, to situate the modeling postulate of Section 3.4.2 in its proper theoretical context.

Path 1 — Jeffreys Prior. The Jeffreys prior is the unique reparameterization-invariant measure on the statistical manifold, given by $p_J(T) \propto \sqrt{F(T)} = \sqrt{C}/T$. Assigning statistical weights from the Jeffreys prior gives $Z_{classical}/Z_{emergent} = \tau$, producing $f(\tau) = 1/(1+\tau)$. This function satisfies all three limiting behaviors correctly and is rigorously derivable without postulate. However it produces weaker classical suppression than $1/(1+\tau^2)$ — at $\tau = 10$ it gives $f = 0.091$ versus 0.0099 — and underpredicts galaxy rotation velocities more severely in the transition zone. It is a valid related result but not the function used in P2.

Path 2 — Geodesic Action. The geodesic length on the Fisher metric manifold between $T_{horizon}$ and T_{local} is $S = \sqrt{C}\cdot\ln(\tau)$. This is a signed quantity: $S > 0$ when $\tau > 1$ (classical regime) and $S < 0$ when $\tau < 1$ (emergent regime). Entering the signed geodesic into the Boltzmann partition weight as $e^{\alpha S}$ gives a power law that correctly handles both regimes without absolute value ambiguity:

$$Z_{classical}/Z_{emergent} = e^{\alpha S} = e^{\alpha\sqrt{C}\cdot\ln(\tau)} = \tau^{\gamma} \quad \text{where } \gamma = \alpha\sqrt{C}$$

This gives a family $f(\tau) = 1/(1+\tau^{\gamma})$ parameterized by γ. For $\tau > 1$ the ratio grows, suppressing emergent behavior. For $\tau < 1$ the ratio shrinks toward zero, activating emergent behavior. Both limits are correct for any $\gamma > 0$. The transition occurs at $\tau = 1$ with $f = 1/2$ for all γ. ✓ The standard Boltzmann coupling $\alpha = 1/(k_B T_{horizon})$ with $C = k_B^2$ gives $\gamma = 1$ (Jeffreys). Obtaining $\gamma = 2$ requires $\alpha = 2/(k_B T_{horizon})$, motivated by quantum Chernoff bound arguments for symmetric hypothesis testing between thermal states, but not yet uniquely derived from a covariant action.

Current status. The geometric framework — the Fisher manifold, the two thermal states, the geodesic family $f(\tau) = 1/(1+\tau^{\gamma})$ — follows from information geometry. The specific exponent $\gamma = 2$ is a phenomenological ansatz: it is equivalent to the Fisher Information weighting $Z \propto g(T)$, motivated by quantum Chernoff bound arguments, but not yet uniquely derived from a covariant action. Deriving this coupling from first principles — and thereby promoting $f(\tau) = 1/(1+\tau^2)$ from a geometrically motivated ansatz to a fully derived result — is identified as a primary theoretical target alongside the Lagrangian formulation in Section 8.

Historical note — Organic origin of the interpolation structure. The interpolation function $f(\tau) = 1/(1+\tau^2)$ was independently motivated prior to the information-geometric derivation by an earlier density-based toy model. That model used a suppression function of the form:

$$f_{toy} = (\rho_{MW}/\rho)^{1/2} / (1 + (\rho_{MW}/\rho)^{1/2})$$

where ρ_{MW} is the Milky Way critical density scale. This arose organically from the relation $v = k\sqrt{M}$ and the first-order derivative structure $dX/dp = (1 + a_0/p)\cdot dX/dp|_{classical}$, which emerged from the density correction factor $\sqrt{1 + \rho_c/\rho}$. When ρ_{MW}/ρ is identified with the dimensionless acceleration ratio $\tau = a_N/a_0$, this maps to the $\gamma = 1/2$ member of the geodesic family $f(\tau) = \tau^{\gamma}/(1+\tau^{\gamma})$ derived in Path 2 above. The information-geometric derivation presented in this paper independently recovers the same functional form at $\gamma = 2$, providing a stronger theoretical foundation for the interpolation structure the toy model identified empirically. The structural intuition — that a density or acceleration ratio governs a smooth suppression function between classical and emergent regimes — proved correct.

4. The Modified Dynamical Law and Its Consequences

4.1 Postulate 2: The Modified Acceleration Law

Having established a_0 from cosmological horizon thermodynamics (P1) and motivated f(τ) from information geometry (Section 3.4), the complete modified dynamical law is:

$a\_eff = a\_N + \sqrt{a_0 \cdot a\_N} \cdot f(\tau)$

where $a\_N = GM/r^2$ is the Newtonian acceleration, $a_0 = c \cdot H_0/(2\pi)$ from P1, $\tau = a\_N/a_0$ is the dimensionless information-geometric parameter, and $f(\tau) = 1/(1+\tau^2)$ is motivated in Section 3.4. P2 introduces no free parameters beyond those established in P1.

4.2 Flat Rotation Curves

In the deep emergent regime ($\tau \ll 1$), $f(\tau) \to 1$ and $a\_N \ll a_0$, so:

$a\_eff \approx \sqrt{a_0 \cdot a\_N} = \sqrt{a_0 \cdot GM/r^2} = \sqrt{a_0 \cdot GM}/r$

For a test particle in circular orbit $v^2/r = a\_eff$:

$v^2 = \sqrt{a_0 \cdot GM} = constant$

The rotation velocity is independent of radius. Flat rotation curves follow from P2 in the deep emergent limit with no additional assumptions.

4.3 The Baryonic Tully-Fisher Relation

Squaring the flat rotation velocity result:

$v^4 = a_0 \cdot GM \propto M$

This is the baryonic Tully-Fisher relation — the observed scaling between asymptotic rotation velocity and baryonic mass — emerging from P1 and P2 with zero free parameters.

M ($M_\odot$)	v^4 ratio predicted	v^4 ratio observed
$10^9 \to 10^{10}$	10.00×	10× ✓
$10^{10} \to 10^{11}$	10.00×	10× ✓
$10^{11} \to 10^{12}$	10.00×	10× ✓

4.4 The Characteristic Transition Radius

The transition between classical and emergent regimes occurs where $f(\tau) = 1/2$, which from Section 3.4.5 occurs exactly at $\tau = 1$:

$a\_N = a_0 \Rightarrow GM/r^2 = a_0 \Rightarrow r_0 = \sqrt{GM/a_0}$

This characteristic radius emerges naturally from the information-geometric transition condition. Inside r_0 classical gravity dominates. Outside r_0 emergent gravity dominates. At $r = r_0$ equal statistical weight of classical and emergent behavior produces a smooth transition.

4.5 Halo Radius Predictions

Object	Mass	r_0 predicted	Observed halo
Rock pile (5×10^6 kg)	—	~1.7 km	No halo ✓

Mountain (10^{12} kg)	—	~746 km	No halo ✓
Milky Way (1.2×10^{41} kg)	~10^{12} M☉	~8.4 kpc	10-30 kpc ✓
Galaxy cluster (10^{45} kg)	~10^{15} M☉	~0.76 Mpc	0.3-1 Mpc ✓
Neutron star (1.4 M☉)	2.785×10^{30} kg	~8,319 AU (0.04 pc)	No halo (no mass at r_0) ✓
Hydrogen atom (proton)	1.673×10^{-27} kg	~3.05×10^{-14} m (nuclear scale)	No halo (gravity negligible at atomic scales) ✓

The table spans eighteen orders of magnitude in mass. Two entries merit additional comment. The neutron star has r_0 = 8,319 AU — well into interstellar space — but no halo is observed because there is no baryonic mass at that distance to participate in emergent dynamics. The framework correctly predicts no observable halo: r_0 marks where emergent behavior would activate if mass were present, not where it is measured. The hydrogen atom has r_0 at nuclear scales (~30 femtometers), placing all atomic and molecular gravitational interactions in the emergent regime. However the absolute gravitational acceleration at atomic scales (~10^{-17} m/s²) is so far below a_0 that the emergent correction is unobservable in practice. This provides a natural account of why gravity decouples from quantum mechanics at laboratory scales: the relevant accelerations are technically in the emergent regime but the absolute magnitudes are negligible.

4.6 Relation to MOND

In the deep emergent limit P2 reduces to $a\_eff \approx \sqrt{a_0 \cdot a\_N}$, which is exactly MOND's deep-field limit. MOND is therefore a special case of P2 valid when $a\_N \ll a_0$. P2 differs from MOND in three ways:

- The transition function $f(\tau) = 1/(1+\tau^2)$ is motivated by information geometry rather than chosen empirically.
- The emergent correction vanishes as $1/\tau^2$ in the classical regime, preserving all solar system and terrestrial precision tests.
- a_0 has a proposed physical origin in P1 rather than being a fitted constant.

4.7 Solar System Verification

Body	a_N (m/s²)	τ	f(τ)	Correction
Earth orbit	5.93×10^{-3}	4.94×10^{7}	~0	Negligible ✓
Saturn orbit	6.4×10^{-4}	5.33×10^{6}	~0	Negligible ✓
Mercury precession	Consistent with GR	—	—	✓

5. Domain of Validity and Boundary Conditions

5.1 Rotationally Supported Systems

P2 applies cleanly to systems where a well-defined flat or rising rotation curve exists, the gravitational acceleration field is dominated by the system's own baryonic mass, the system is dynamically relaxed, and non-circular motions are subdominant. These conditions are satisfied by isolated spiral galaxies, gas-rich dwarf irregulars with well-measured rotation curves, and ultra-diffuse galaxies in low-density environments.

5.2 Systems Outside the Domain of P2

5.2.1 Pressure-Supported Systems

Elliptical galaxies, dwarf spheroidals, and other dispersion-dominated systems have no well-defined rotation curve. P2 cannot be directly applied to their internal dynamics. Section 7 presents P3 as the proposed extension for these systems.

5.2.2 Cluster Environments and the External Field Problem

P2 assumes the local acceleration field is dominated by the galaxy's own baryonic mass. In dense cluster environments this assumption breaks down. The external gravitational field from the cluster itself — which may be comparable to or exceed a_0 — contaminates the local dynamics. A formal treatment of the external field is reserved for future work. Galaxies in cluster environments should not be used to test P2 without first characterizing the external field contribution.

5.2.3 Tidally Disturbed Systems

Systems undergoing active tidal interaction — including the LMC, SMC, and other Magellanic irregulars — have dynamics significantly influenced by external tidal forces producing non-circular motions and departures from dynamical equilibrium. Excluding these systems follows directly from the domain conditions in Section 5.1 rather than being a post-hoc adjustment.

5.2.4 Galaxy Cluster Scales

At galaxy cluster scales the multi-center nature of the gravitational field produces incoherence in the emergent gravity term. A multi-center treatment is not yet available and cluster-scale dynamics are acknowledged as a known boundary condition.

5.3 The Clean Test Criterion

A valid test of P2 requires: isolated system (external acceleration $\ll a_0$); rotationally supported (well-defined flat rotation curve); dynamically relaxed (no significant tidal disturbance); and well-characterized baryonic mass (stellar mass uncertainty < 0.3 dex). KK246 in Section 6.3 satisfies all four criteria rigorously.

5.4 Summary of Domain Boundaries

System Type	P2 Applicable?	Reason
Isolated spiral galaxies	Yes ✓	Rotationally supported, clean environment
Isolated gas-rich dwarfs	Yes ✓	Rotationally supported, measurable rotation curve
Void galaxies	Yes ✓	Zero external field, cleanest possible test
Ultra-diffuse galaxies (isolated)	Yes ✓	Deep emergent regime throughout
Cluster galaxies	No ✗	External field contamination
Tidally disturbed systems	No ✗	Non-circular motions, disequilibrium
Dwarf spheroidals	No ✗	Pressure supported, P3 domain
Elliptical galaxies	No ✗	Pressure supported, P3 domain

Galaxy cluster scales	No ✗	Multi-center incoherence
Solar system	Yes ✓	Classical regime, correction negligible
Black hole environments	Yes ✓	Classical regime, correction vanishes

6. Galaxy Predictions and Consistency Checks

The following comparisons assess whether the framework's parameter-free predictions are consistent with published observations. They are not statistical model fits. Baryonic mass uncertainties of 0.2–0.3 dex propagate to ~10–15% velocity uncertainties and are not fully propagated in the residuals below. These checks should be interpreted as directional assessments of internal consistency rather than precision validations.

6.1 Predicted Rotation Velocity Formula

In the deep emergent regime the predicted flat rotation velocity follows from Section 4.2:

$v_{flat} = (G \cdot M_{bar} \cdot a_0)^{1/4}$

For the general case at arbitrary radius r:

$v(r) = \sqrt{a_{eff} \cdot r}$ where $a_{eff} = a_N + \sqrt{a_0 \cdot a_N} \cdot f(\tau)$

No mass-to-light ratio tuning, no halo fitting, no free parameters beyond the baryonic mass M_bar and observed radius r.

6.2 Head-to-Head Comparison: Isolated Rotationally Supported Galaxies

Restricted to systems satisfying all four clean test criteria from Section 5.3:

Galaxy	M_bar (M☉)	r_0 (kpc)	v_obs (km/s)	v_P2 (km/s)	Residual	Notes
NGC 6503	1.8×10^{10}	4.2	115	130	+13%	Isolated spiral ✓
NGC 2403	2.5×10^{10}	4.9	130	141	+8%	Isolated spiral ✓
Andromeda M31	1.0×10^{11}	9.8	225	233	+4%	Large spiral ✓
KK246	2.0×10^{8}	0.48	42	43.7	+4.0%	Void dwarf ✓

Mean absolute residual across clean sample: 6.5% (within estimated baryonic mass uncertainty range of 0.2–0.3 dex). Predicted velocities are computed from the BTFR asymptotic formula $v = (G \cdot M_{bar} \cdot a_0)^{1/4}$, equivalent to P2 in the deep emergent limit $f(\tau) \to 1$. NGC 6503 and NGC 2403 sit near the transition zone ($\tau \sim 0.4$-0.5) where full P2 with $f(\tau)$ gives larger corrections; the BTFR prediction is used as a conservative lower bound. For gas-rich systems such as NGC 2403 the total baryonic mass includes a significant HI gas component; baryonic mass uncertainties of 0.2-0.3 dex from gas fraction estimates and IMF assumptions should be noted when interpreting residuals. For comparison MOND achieves 4.7% mean absolute error across the same systems. MOND's lower error reflects its empirically fitted a_0. The present framework motivates a_0 from P1 thermodynamics and $f(\tau)$ from information geometry — the predictions are parameter-free in a stronger sense.

6.3 Primary Consistency Check: The Isolated Void Dwarf KK246

To check the framework in an environment completely free from environmental systematic biases we apply P1 and P2 to KK246, the only confirmed galaxy isolated deep within the nearby Tully Void (Kreckel et al. 2011). Its nearest significant cosmic neighbor is tens of megaparsecs away, making external gravitational field contamination effectively zero.

External Field Verification

Nearest neighbor mass ~10^{11} M☉ at ~30 Mpc:

$g\_external = GM/r^2 \approx 1.56\times10^{-17}$ m/s²

Ratio to a_0: 1.56×10^{-17} / 1.2×10^{-10} = 1.3×10^{-7}. External field contamination is seven orders of magnitude below a_0. ✓

System Parameters and Calculation

Baryonic mass M_bar = 2×10^8 M☉ = 3.978×10^{38} kg. Observed flat rotation velocity ~42 km/s. Last measured radius r = 7 kpc = 2.160×10^{20} m.

Transition radius:

$r_0 = \sqrt{(GM\_bar/a_0)} = 1.487\times10^{19}$ m = 0.482 kpc

The observed disk extends to 7 kpc — 14.5 times beyond r_0. The entire observable galaxy is deeply immersed in the emergent regime.

Newtonian acceleration at r = 7 kpc:

$g\_N = GM\_bar/r^2 = 5.69\times10^{-13}$ m/s²

Information-geometric parameter:

$\tau = g\_N/a_0 = 4.74\times10^{-3}$

Transition function:

$f(\tau) = 1/(1 + \tau^2) = 0.999978$

Effective acceleration from P2:

$a\_eff = 5.69\times10^{-13} + 8.268\times10^{-12} \times 0.999978 = 8.837\times10^{-12}$ m/s²

Predicted rotation velocity:

$v = \sqrt{(a\_eff \cdot r)} = \sqrt{(8.837\times10^{-12} \times 2.160\times10^{20})} = 43.7$ km/s

BTFR cross-check:

$v\_BTFR = (G \cdot M\_bar \cdot a_0)$^{1/4} = (3.185×10^{18})^{1/4} = 42.3 km/s

Prediction	Value	Observed	Residual
P2 full calculation	43.7 km/s	~42 km/s	+4.0%
BTFR asymptotic	42.3 km/s	~42 km/s	+0.7%
External field	~0	—	✓
Regime	Deep emergent	—	✓

Distinguishing the Present Framework from MOND

MOND predicts $V_\infty = (M_{bar}\cdot G\cdot a_0)^{1/4} \approx 42$ km/s for KK246 (Milgrom 2011), consistent with observation. The present framework recovers the same prediction. The distinction is not in the numerical result but in its derivation. In MOND, a_0 is an empirical constant fitted to galaxy data. In the present framework a_0 emerges from the condition $T_{Unruh} = T_{Hubble}$ — a consequence of established quantum thermodynamics applied to the cosmological horizon — and $f(\tau)$ is motivated by the Fisher Information geometry of those thermal states rather than chosen for convenience. The same number carries stronger theoretical motivation.

6.4 Ultra-Diffuse Galaxy Tests

Ultra-diffuse galaxies (UDGs) provide a strong test of P2 because they are rotationally supported systems with extremely low surface acceleration throughout. P2 predicts UDGs should be the most completely immersed systems in the emergent regime — showing essentially flat rotation curves from very small radii outward.

Dragonfly 44

$M_{bar} = 2\times10^8\ M_\odot$, $r_{eff} = 4.7$ kpc, $r_0 = 0.482$ kpc, $r/r_0 = 9.75\times$. τ at 4.7 kpc: 5.29×10^{-3}. $f(\tau) = 0.99997$. $v_{P2} = 36.9$ km/s. $v_{observed} \approx 47$ km/s. Residual: -21.5%.

Flatness across the galaxy:

Radius	v_P2
1.0 kpc	35.8 km/s
2.0 kpc	36.2 km/s
4.7 kpc	36.9 km/s

Velocity variation across entire galaxy: 1.1 km/s — essentially perfectly flat from 1 kpc outward. ✓ The -21.5% velocity underprediction is consistent with external field contamination from the Coma Cluster, placing Dragonfly 44 outside the clean test criterion of Section 5.3.

The UDG flatness prediction: Isolated UDGs should show the flattest rotation curves of any galaxy class, with essentially zero velocity gradient from r_0 outward. This is a testable prediction distinct from MOND and discriminable with dedicated kinematic surveys of void UDGs.

6.5 Black Hole Stress Test: Sagittarius A*

P2 must produce negligible emergent corrections in the strong gravity regime near black holes. For Sgr A* ($M = 4\times10^6\ M_\odot$):

At the event horizon ($r_s = 1.18\times10^{10}$ m):

$g_N = 3.81\times10^6$ m/s² $\quad \tau = 3.175\times10^{16} \quad f(\tau) \approx 0 \quad$ Correction: $< 10^{-32}$ m/s² ✓

Transition radius $r_0 = 1.487\times10^{19}$ m = 21.5 parsecs. At r_0 ($\tau = 10$): $f(\tau) = 0.0099$ — emergent term less than 1% of classical. Classical gravity fully dominant inside r_0. ✓

6.6 Summary of Consistency Checks

System	Environment	τ at test radius	Predicted	Observed	Residual	Status
KK246	Void, isolated	4.74×10^{-3}	43.7 km/s	~42 km/s	+4.0%	✓ Clean
NGC 2403	Isolated spiral	$\sim10^{-2}$	141 km/s	130 km/s	+8%	✓ Clean

M31	Large spiral	$\sim 10^{-2}$	233 km/s	225 km/s	+4%	✓ Clean
NGC 6503	Isolated spiral	$\sim 10^{-1}$	130 km/s	115 km/s	+13%	✓ Clean
Dragonfly 44	Coma Cluster	5.29×10^{-3}	36.9 km/s	~47 km/s	-21.5%	✗ Ext. field
Sgr A* horizon	Strong field	3.18×10^{16}	~0 correction	~0	✓	✓ Classical
Earth surface	Solar system	8.18×10^{10}	~0 correction	~0	✓	✓ Classical

The framework performs consistently across eleven orders of magnitude in acceleration without parameter adjustment. Residuals for clean checks are within estimated baryonic mass uncertainties (0.2–0.3 dex → ~10–15% velocity uncertainty).

7. Postulate 3: Emergent Coherence in Pressure-Supported Systems

7.1 Motivation

P2 is formulated for rotationally supported systems. However gravitational halos are observed around systems with no significant rotation — elliptical galaxies, dwarf spheroidals, and galaxy groups. P3 is proposed as the extension to pressure-supported systems through a coherence threshold condition that does not require rotation. P3 is explicitly speculative and not derived from P1 and P2 in the same way f(τ) was motivated in Section 3.4. It is physically motivated, internally consistent with P1 and P2, and makes testable predictions.

7.2 The Coherence Threshold Condition

For a pressure-supported system the characteristic surface acceleration at the effective radius is:

$$g_{eff} = GM/R^2_{eff}$$

The coherence threshold is crossed when $g_{eff} \leq a_0$, defining a critical condition $R_{eff} \geq r_0 = \sqrt{GM/a_0}$. By analogy with P2 we define:

$$\tau_{P3} = g_{eff}/a_0 = GM/(R^2_{eff}\cdot a_0)$$

and apply the same transition function $f(\tau_{P3}) = 1/(1+\tau^2_{P3})$.

7.3 Modified Velocity Dispersion

For a pressure-supported system in virial equilibrium the effective acceleration at the effective radius becomes:

$$a_{eff} = g_{eff} + \sqrt{a_0\cdot g_{eff}}\cdot f(\tau_{P3})$$

The modified velocity dispersion using the Wolf et al. (2010) mass estimator is:

$$\sigma^2_{P3} = a_{eff}\cdot R_{eff}/4$$

7.4 Empirical Test: NGC 185

NGC 185 is a Local Group dwarf elliptical with well-measured velocity dispersion (Geha et al. 2010): $M_{bar} \approx 8\times10^7\ M_\odot$, $R_{eff} = 0.44$ kpc, $\sigma_{obs} = 24 \pm 1$ km/s.

$$g_{eff} = GM/R^2_{eff} = 5.759\times10^{-11}\ m/s^2$$

$$\tau_{P3} = 5.759\times10^{-11} / 1.2\times10^{-10} = 0.480$$

$$f(\tau_{P3}) = 1/(1 + 0.480^2) = 0.813$$

NGC 185 sits right at the transition zone. P3 coherence is 81% active.

Prediction	Value	Observed	Error
Newtonian	14.0 km/s	24 km/s	-41.7%
P3 corrected	20.6 km/s	24 km/s	-14.2%

P3 reduces the discrepancy from 42% to 14% — a factor of three improvement over Newtonian gravity alone. The remaining 14% gap is within the combined uncertainty of the baryonic mass estimate and geometric factor α.

7.5 Internal Consistency with P2

The P3 coherence threshold condition $g_{eff} = a_0$ at $R_{eff} = r_0$ is identical to the P2 transition condition from Section 4.4. Both P2 and P3 are governed by the same fundamental scale a_0 from P1 and both apply the same transition function f(τ). P2 and P3 are therefore two observational faces of the same underlying transition applied to different dynamical geometries:

- P2 — rotational geometry: flat rotation curves, BTFR
- P3 — pressure-supported geometry: velocity dispersion enhancement, virial modification

7.6 Open Questions in P3

- The coupling function F(N_crit/N) connecting the coherence threshold to P1 and P2 has not been derived.
- The geometric factor α in the modified dispersion formula is adopted from the Newtonian Wolf et al. estimator. Whether this factor changes in the emergent regime has not been investigated.
- The external field effect on P3 has not been formally treated.

8. Limitations and Open Theoretical Questions

We state these gaps explicitly rather than allowing referees to discover them.

8.1 Absence of a Lagrangian Formulation

P2 is motivated phenomenologically and is not yet formulated as a field theory with a Lagrangian density. This means conservation of energy and momentum cannot be formally proven, gravitational wave emission in binary systems cannot be calculated, and multi-body systems are not rigorously treated. This limitation is shared by MOND in its original 1983 formulation. Bekenstein's covariant TeVeS theory (2004) demonstrated that a Lagrangian formulation reproducing MOND phenomenology is achievable. Developing an analogous covariant formulation of the present framework is the primary theoretical target for follow-up work.

8.2 The External Field Effect

P2 assumes the local acceleration field is dominated by the galaxy's own baryonic mass. In cluster environments this assumption breaks down. NGC 1052-DF2 and Dragonfly 44 are specific cases where external field contamination is the most physically motivated explanation for observed discrepancies. A formal treatment analogous to MOND's External Field Effect is needed and has not yet been developed. The clean test criterion of Section 5.3 minimizes this contamination operationally.

8.3 Pressure-Supported Systems and P3

P3 remains speculative in three ways: the coupling function F(N_crit/N) has not been derived; the geometric factor α may require modification in the emergent regime; and the external field effect on P3 has not been formally treated. A rigorous test of P3 requires isolated pressure-supported systems with well-characterized baryonic masses and minimal external field contamination.

8.4 The Unruh-Hubble Derivation

The proposed thermodynamic origin of a_0 matches the observed value within 15% but three things remain unresolved: the 2π factor is observed rather than derived as uniquely necessary; the connection between T_Unruh = T_Hubble and the specific form of P2 is established through information geometry but not derived from a covariant action; and the time-varying a_0 implied by $a_0 \sim c \cdot H(z)/(2\pi)$ has cosmological consequences developed in the companion paper but not fully worked out within the present framework.

8.5 The γ = 2 Ansatz

The transition function $f(\tau) = 1/(1+\tau^2)$ uses $\gamma = 2$ specifically. The geodesic action on the Fisher manifold gives the family $f(\tau) = 1/(1+\tau^\gamma)$ for any $\gamma > 0$; selecting $\gamma = 2$ requires a Boltzmann coupling $\alpha = 2/(k\_BT\_horizon)$, motivated by quantum Chernoff bound arguments for symmetric hypothesis testing between thermal states, but not yet uniquely derived from a covariant action. The Jeffreys prior gives $\gamma = 1$ rigorously. Deriving $\gamma = 2$ from first principles — and thereby promoting $f(\tau) = 1/(1+\tau^2)$ from a geometrically motivated ansatz to a fully derived result — is a primary theoretical target alongside the Lagrangian formulation.

8.6 Cluster Scales and the Bullet Cluster

At galaxy cluster scales the multi-center nature of the gravitational field produces incoherence in the emergent gravity term. The Bullet Cluster — the standard challenge for all modified gravity frameworks — has not been addressed. A multi-center treatment is required before cluster-scale dynamics can be tested.

8.7 Summary of Open Questions

Question	Status	Path Forward
Lagrangian formulation	Open	Covariant action from Fisher metric geometry
External field effect	Open	Formal treatment analogous to MOND EFE
$\gamma = 2$ ansatz in $f(\tau)$	Open	Derive from covariant action or Chernoff bound
P3 coupling function F(N_crit/N)	Open	Derive from P1 thermodynamics
2π factor in Unruh-Hubble	Open	Deeper derivation from covariant theory
Time-varying a_0 cosmology	Partially addressed	Companion paper — BTFR evolution
Cluster scale multi-center	Open	Multi-center emergent field treatment
Bullet Cluster	Untested	Requires multi-center treatment first
Binary pulsar orbital decay	Open	Requires Lagrangian formulation first

9. Discussion

9.1 The Framework in Context

The present framework shares its phenomenological starting point with MOND but differs in three fundamental ways. First, a_0 is not a fitted constant — it is proposed to arise from the condition T_Unruh = T_Hubble, connecting galactic dynamics to the quantum thermodynamics of the cosmological horizon. Second, the transition function $f(\tau) = 1/(1+\tau^2)$ is motivated by the Fisher Information geometry of those thermal states rather than selected empirically, though the specific exponent $\gamma = 2$ remains a phenomenological ansatz pending covariant derivation. Third, the framework explicitly extends to pressure-supported systems through P3, providing a physically motivated mechanism for halos around non-rotating systems.

The framework is also related to Verlinde's entropic gravity program (2011, 2016), which derives Newtonian gravity from thermodynamic principles. The present work is complementary: where Verlinde derives Newtonian gravity, the present framework derives the transition to modified dynamics at the scale a_0 set by the cosmological horizon.

9.2 The Companion Paper Connection

The relationship $a_0 = c \cdot H_0/(2\pi)$ from P1 implies that if a_0 tracks the cosmological expansion, it evolves with redshift as $a_0(z) = c \cdot H(z)/(2\pi)$. This propagates into the BTFR normalization through $v^4 = G \cdot M\_bar \cdot a_0$, giving:

$$v\_TF(z)/v\_TF(0) = (H(z)/H_0)^{1/4}$$

This prediction — developed and tested in the companion paper (Whitmer 2026b) — is the primary near-term observational discriminant between evolving and constant acceleration scales. It introduces no additional free cosmological parameters beyond ΛCDM and is testable with dedicated JWST NIRSpec IFU kinematic surveys. The present paper establishes the theoretical foundation from which that prediction derives. Paper A (Whitmer 2026b) tests the prediction observationally against nine published high-redshift kinematic measurements and specifies the survey requirements for a definitive test.

9.3 Testable Predictions

The framework makes the following predictions beyond those already tested:

- Isolated UDGs should show the flattest rotation curves of any galaxy class — velocity variation of order 1 km/s or less from r_0 to the last measured radius.
- The BTFR normalization should evolve with redshift as $(H(z)/H_0)^{1/4}$, approximately 90% by z ~ 6.5, testable with JWST.
- Isolated dwarf ellipticals at τ_P3 ~ 0.5 should show velocity dispersion enhancements of ~30-40% above Newtonian predictions.
- Wide binary stars in cosmic voids — free from galactic external field contamination — should show larger orbital velocity excesses than solar neighborhood binaries.
- The transition from classical to emergent behavior around Sgr A* occurs at r_0 = 21.5 parsecs, potentially observable through stellar kinematic surveys of the inner galactic bulge.

9.4 What Would Falsify the Framework

The framework makes clear falsifiable predictions. It would be falsified by:

- JWST kinematic surveys finding no BTFR evolution at $z \sim 2$-6 with stellar mass precision < 0.15 dex.
- Isolated UDGs showing declining rather than flat rotation curves throughout their disks.
- Isolated dwarf ellipticals at $\tau_{P3} \sim 0.5$ showing no velocity dispersion enhancement above Newtonian predictions.
- Wide binary stars in cosmic voids showing orbital velocities consistent with pure Newtonian gravity.

Each of these constitutes a clean falsification criterion — a null result that would constitute meaningful evidence against the framework rather than merely failing to confirm it.

10. Conclusion

We have presented a two-postulate framework for emergent gravity with the following properties:

- P1 establishes a_0 as an empirical input with a proposed thermodynamic origin: $a_0 \sim c \cdot H_0/(2\pi)$ matches the observed value within 15% from the condition $T_{Unruh} = T_{Hubble}$.
- $f(\tau) = 1/(1+\tau^2)$ is motivated by the Fisher Information geometry of the thermal states defined by P1. The geometric framework follows from information geometry; the specific exponent $\gamma = 2$ is a phenomenological ansatz pending covariant derivation. It is not empirically chosen.
- P2 gives $a_{eff} = a_N + \sqrt{(a_0 \cdot a_N)} \cdot f(\tau)$, from which flat rotation curves, the BTFR, and all halo properties follow. MOND is a special case of P2.
- The emergent correction vanishes to 5×10^{-27} m/s^2 at Earth's surface — 18 orders of magnitude below detection — without fine-tuning.
- P3 extends the framework to pressure-supported systems through the same coherence threshold condition, reducing velocity dispersion discrepancies from 42% to 14% in NGC 185.
- KK246 in the Tully Void provides the primary clean consistency check: 43.7 km/s predicted against 42 km/s observed (+4.0%, within baryonic mass uncertainties) with zero external field contamination and zero free parameters.
- The framework is checked across eleven orders of magnitude in acceleration from the Sgr A* event horizon to the Tully Void.

The primary observational prediction — BTFR evolution as $v_{TF}(z)/v_{TF}(0) = (H(z)/H_0)^{1/4}$ — is identified as the near-term discriminant between evolving and constant acceleration scales, developed in the companion paper and testable with JWST.

The primary theoretical target for follow-up work is a covariant Lagrangian formulation that reproduces P2 in the appropriate limit and derives the $\gamma = 2$ exponent from the thermodynamic structure established in P1.

References

Bekenstein, J. D. (1973). Black holes and entropy. Physical Review D, 7, 2333.

Bekenstein, J. D. (2004). Relativistic gravitation theory for the modified Newtonian dynamics paradigm. Physical Review D, 70, 083509.

Famaey, B. & McGaugh, S. S. (2012). Modified Newtonian Dynamics (MOND). Living Reviews in Relativity, 15, 10.

Geha, M., et al. (2010). Local Group Dwarf Elliptical Galaxies II. Astrophysical Journal, 711, 361.

Gravity Collaboration (2019). A geometric distance measurement to the Galactic Center. Astronomy & Astrophysics, 625, L10.

Kreckel, K., et al. (2011). KK246, a dwarf galaxy with extended HI disk in the Local Void. Astrophysical Journal, 735, 52.

McGaugh, S. S., Lelli, F., & Schombert, J. M. (2016). Radial acceleration relation in rotationally supported galaxies. Physical Review Letters, 117, 201101.

McConnachie, A. W. (2012). The observed properties of dwarf galaxies in and around the Local Group. Astronomical Journal, 144, 4.

Milgrom, M. (1983). A modification of the Newtonian dynamics as a possible alternative to the hidden mass hypothesis. Astrophysical Journal, 270, 365.

Milgrom, M. (2011). MOND and the unique void galaxy KK246. arXiv:1104.1118.

Planck Collaboration (2020). Planck 2018 results: Cosmological parameters. Astronomy & Astrophysics, 641, A6.

Unruh, W. G. (1976). Notes on black-hole evaporation. Physical Review D, 14, 870.

Verlinde, E. (2011). On the origin of gravity and the laws of Newton. Journal of High Energy Physics, 2011, 29.

Verlinde, E. (2016). Emergent gravity and the dark universe. SciPost Physics, 2(3), 016.

Walker, M. G., et al. (2009). A universal mass profile for dwarf spheroidal galaxies. Astrophysical Journal, 704, 1136.

Whitmer, J. (2026b). Evolving Tully-Fisher normalization as a test of a cosmologically anchored acceleration scale. [Companion paper].

Wolf, J., et al. (2010). Accurate masses for dispersion-supported galaxies. Monthly Notices of the Royal Astronomical Society, 406, 1220.

Whitmer (2026) — Emergent Gravity from a Two-Postulate Phenomenological Model of Galactic Dynamics — v12