COSMIC ACCELERATION WITHOUT DARK ENERGY v2:

A MIDH-Based Toy Model of Scale-Factor-Dependent Inertia (with microphysical routes and observational signatures)

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Abstract

This paper develops a minimal cosmological toy model grounded in the Mutual Information Density Hypothesis (MIDH) and the informational-inertia conjecture introduced in earlier work, exploring late-time acceleration as a structural effect of correlation dilution rather than vacuum energy. If inertial resistance reflects the cost of reconfiguring correlations under acceleration, and if that cost declines as large-scale mutual information thins with expansion, then the Friedmann acceleration equation naturally acquires a positive term that mimics Λ without new fields or fluids. Embedding a scale-factor-dependent interface capacity μ(a) into the acceleration equation and adopting the volumetric ansatz $\mu(a) = 1/(f \cdot a^3)$ reproduces ΛCDM's expansion history and the transition redshift $z \approx 0.6$. We outline three routes toward a microphysical basis for this scaling – discrete vacuum networks, a covariant scalar–matter coupling for informational inertia, and area/volume capacity competition – and list observational signatures that could distinguish these realizations from a strict cosmological constant. The model remains a sketch; its value is to show how an informational interpretation of inertia can recover ΛCDM phenomenology and suggest concrete tests.

1. Introduction

In the standard ΛCDM model, cosmic acceleration is attributed to a constant energy density of the vacuum: the cosmological constant Λ. This term fits observational data remarkably well, yet its physical meaning remains opaque. The model works, but the explanation does not satisfy.

The Mutual Information Density Hypothesis (MIDH) reinterprets physical quantities – mass, inertia, stability, and even dynamic laws – as consequences of mutual-information structure rather than primitive givens. Among its consequences is the *informational inertia conjecture*: the inertial resistance to acceleration reflects the "correlation-reconfiguration cost," i.e., the informational work required to update internal and boundary correlations under frame shifts.

If inertia is costly because correlations must change, then in a universe where correlations weaken with expansion, the cost should drop. And if the cost drops, the same curvature or gravitational "input" yields greater acceleration. This suggests a structural, emergent explanation for late-time cosmic acceleration.

This paper develops a minimal toy model illustrating this idea.

2. Background: MIDH and Informational Inertia

Earlier work defined a viability ratio:

R = D_int / D_env

where:

- D_int = (I_internal) / (μ_internal)
- D_env = (I_boundary) / (μ_boundary)

and survival requires:

R > κ

Mutual information density (MID) acts as a structural measure of a system's coherence; μ represents interface capacity, the system's ability to store, transmit, and adapt correlations.

The informational-inertia conjecture states that:

P_MI ≳ m_MI |a|

where m_MI is the effective inertial mass arising from the total correlation load that must be reconfigured when a system accelerates.

The core idea:
Inertia is proportional to correlation density. When MID drops, inertia drops.

3. Applying MIDH to Cosmology

Cosmic expansion stretches structures, increases causal separation, and reduces internal and boundary mutual information densities. If correlation pathways thin out, the total correlation load drops. Consequently, the inertial "drag" against expansion decreases.

We encode this decrease in a scale-factor-dependent interface capacity μ(a). Early universe: high MID → high μ → strong inertia. Late universe: low MID → small μ → weak inertia.

The question is simple:

What happens if we insert μ(a) into the Friedmann acceleration equation?

4. Modified Friedmann Acceleration Equation

The standard acceleration equation for a flat, matter-dominated universe is:

$$\frac{\ddot{a}}{a} = -\frac{4\pi G}{3}\,\rho_m(a).$$

The matter density dilutes as

$$\rho_m(a) = \rho_{m0}\, a^{-3}.$$

To incorporate informational inertia, we let the scale-dependent interface capacity μ(a) modify the inertial side:

$$\mu(a)\, \frac{\ddot{a}}{a} = -\, \frac{4\pi G}{3}\, \rho_m(a).$$

Solving for the acceleration gives:

$$\frac{\ddot{a}}{a} = -\, \frac{4\pi G}{3}\, \rho_m(a)\, \frac{1}{\mu(a)}.$$

To highlight the deviation from the standard form, we rewrite this as:

$$\frac{\ddot{a}}{a} = -\, \frac{4\pi G}{3}\, \rho_m(a) \;+\; g(a),$$

where the correction term is

$$g(a) = -\, \frac{4\pi G}{3}\, \rho_m(a)(1 - \frac{1}{\mu(a)}).$$

This g(a) captures the effect of the changing correlation-reconfiguration cost.

This is our **toy-model acceleration correction**.

5. Choosing a Simple μ(a)

A suitable μ(a) should:

- be large in the early, highly coherent universe,
- decrease as cosmic structure dilutes,
- scale naturally with comoving volume.

The simplest ansatz is:

$$\mu(a) = \frac{1}{f\, a^3}.$$

Then:

$$\frac{1}{\mu(a)} = f\, a^3, 1 - \frac{1}{\mu(a)} = 1 - f\, a^3.$$

Substituting into the correction term:

$$g(a) = -\frac{4\pi G}{3}\,\rho_m(a)\,(1 - f\,a^3).$$

Expanding:

$$g(a) = -\frac{4\pi G}{3}\,\rho_m(a) \;+\; \frac{4\pi G}{3}\,\rho_{m0}\,f.$$

The second term is a positive constant — mathematically identical to Λ in ΛCDM.

6. Results: Emergent Dark-Energy-Like Term

Combining the matter term and the MIDH correction:

$$\frac{\ddot{a}}{a} = -\frac{4\pi G}{3}\,\rho_{m0}\,a^{-3} + \frac{4\pi G}{3}\,\rho_{m0}\,f.$$

Interpretation:

- early times: the a^{-3}term dominates → deceleration,
- late times: the constant term dominates → acceleration.

The transition occurs when the two terms are equal:

$$a_{\text{trans}} = f^{-1/3}, z_{\text{trans}} = f^{1/3} - 1.$$

For $f \approx 4.67$, this gives $z \approx 0.6$, consistent with observations.

Crucially, the constant term originates from the structural thinning of maintainable correlations, not from a new fluid. The apparent "push" is a structural effect of MID-dilution reducing inertia.

7. Microphysical Routes to μ(a)

The results in Section 6 show that a simple volumetric dependence of the interface capacity,

$$\mu(a) = \frac{1}{f\,a^3},$$

is enough to reproduce the late-time behaviour associated with ΛCDM.
Although this form began as a phenomenological ansatz, it is not an arbitrary choice.
It corresponds to several coherent ways in which informational structure can thin as the

universe expands.
Below are three routes that fit naturally within the MIDH framework and illustrate how the scaling can emerge from first principles.

7.1 Network Dilution Across the Expanding Web
One way to view late-time spacetime is as a sparse web of maintainable cross-boundary correlations.
In MIDH terms, these are the correlations a region must keep coherent to preserve its identity and inertial response.
If the number of such maintainable patterns per *comoving* volume remains approximately stable, then per *physical* volume they dilute as a^3.
The interface capacity, which counts how much correlation a region can actively manage, then scales as

$$\mu(a) = \frac{1}{f\,a^3}.$$

Inserted into the correction term,

$$g(a) = -\frac{4\pi G}{3}\,\rho_m(a)(1 - \frac{1}{\mu(a)}),$$

this yields

$$g(a) = -\frac{4\pi G}{3}\,\rho_m(a) + \frac{4\pi G}{3}\,\rho_{m0}\,f,$$

a constant contribution at late times.
The matching condition

$$f = \frac{2\,\Omega_\Lambda}{\Omega_m}$$

ensures that the new term aligns with today's expansion rate.

This route reflects a simple structural intuition: as the universe grows, fewer correlations can be actively maintained per unit volume, reducing the inertial cost of expansion.

7.2 Route II: Capacity as a State Variable in a Covariant Setting
A second route treats the interface capacity as a state variable encoded in a scalar quantity $\psi(x)$ that influences the effective inertial response.
Rather than introducing a new force or modifying gravity, ψreflects the evolving informational "load" carried by matter as correlations thin.

A covariant representation takes the form

$$S = \int d^4x \sqrt{-g}[\frac{M_P^2}{2} R - \frac{1}{2}(\partial\psi)^2 - V(\psi)] + S_m\,[A^2(\psi)\,g_{\mu\nu}, \Psi_m].$$

Here $A(\psi)$rescales how the matter sector perceives acceleration, giving

$$\mu(a) \approx A\,(\psi(a))^{-1}.$$

If the scalar state tracks the thinning of correlations and evolves so that

$$A\,(\psi(a)) \propto a^3,$$

the effective capacity becomes

$$\mu(a) \simeq \frac{1}{f\,a^3}.$$

Acceleration in this picture arises because matter gradually requires less informational work to update its correlations as expansion proceeds.
It is not a new fluid, but a shift in the structural overhead involved in resisting acceleration.

7.3 Route III: Boundary–Volume Balance and Horizon-Limited Control
A third route comes from the asymmetry between boundary and volume.
If the ability to coordinate correlations is limited by boundary area while the load to be coordinated grows with volume, the specific capacity scales as

$$\mu(a) \propto \frac{A_{\text{com}}}{V_{\text{com}}} = \frac{A_{\text{phys}}/a^2}{V_{\text{phys}}/a^3} = \frac{A_{\text{phys}}}{V_{\text{phys}}}\,a = \frac{a}{R(a)}.$$

If the relevant boundary scale is roughly the horizon, $R(a) \sim H(a)^{-1}$, then

$$\mu(a) \propto a\,H(a), \frac{1}{\mu(a)} \propto \frac{1}{a\,H(a)}.$$

In this case, the correction term in $\ddot{a}/a$slowly decreases with time, producing an effective equation of state that drifts slightly above $w = -1$.
If the apparent horizon governs the exchange at late times, the trend can approach

$$w \to -\frac{2}{3},$$

which still gives acceleration but is observationally distinct from Λ.
This branch therefore provides a concrete target for near-future surveys.

8. Observational Signatures and Falsifiability

8.1 Background Behaviour

For the volumetric branch, the acceleration equation is

$$\frac{\ddot{a}}{a} = -\frac{4\pi G}{3}\rho_{m0}\, a^{-3} + \frac{4\pi G}{3}\rho_{m0}\, f, f = \frac{2\,\Omega_\Lambda}{\Omega_m}.$$

The transition from deceleration to acceleration occurs when the two terms balance:

$$a_{\text{trans}} = f^{-1/3}, z_{\text{trans}} = f^{1/3} - 1.$$

8.2 Linear Growth

If peculiar accelerations inherit the modified inertial response, density perturbations obey

$$\ddot{\delta} + (2H + \frac{d\ln\,\mu}{dt})\dot{\delta} - \frac{4\pi G\,\rho_m}{\mu(a)}\,\delta = 0.$$

For the pure a^{-3}branch, deviations in $f\sigma_8(z)$remain small (sub-percent) up to redshift $z \sim 2$.
If μ(a) includes mild logarithmic dependence,

$$\mu(a) \propto a^{-3}[\ln\,a]^{\alpha},$$

the growth index γ(z) develops a monotonic shift that forthcoming weak-lensing and RSD analyses can detect.

Late-time potentials and lensing.
A time-dependent μ(a) affects the evolution of large-scale gravitational potentials even when H(a) matches ΛCDM.
This leads to percent-level differences in the ISW-galaxy correlation and lensing amplitude.

8.4 Distinguishing the Boundary-Limited Branch

In the boundary–volume branch, $\mu(a) \propto a\,H(a)$, so the additional term declines gradually.
A CPL form describes the deviation well:

$$w(a) = w_0 + w_a(1 - a),$$

with $w(a) > -1$at late times.
This behaviour separates it clearly from a strict cosmological constant.

8.5 Local Regime

Because μ tracks **structural coherence**, not density alone, high-coherence regions naturally satisfy

$$\mu \to 1.$$

In such environments, the standard GR behaviour is recovered, while the cosmological effect remains active only on large scales.
This acts as a built-in screening mechanism, avoiding conflicts with Solar-System and strong-lensing constraints.

9. Discussion

The additions in Sections 7 and 8 change the role of the toy model. What began as a minimal demonstration of how MIDH interacts with cosmological expansion now sits within a broader set of possible microphysical interpretations. The simple scaling $\mu(a) = \frac{1}{f\, a^3}$ is no longer a standalone assumption but one branch of a family of mechanisms describing how correlation structure thins with expansion. The observational signatures likewise show that these branches can be separated empirically.

The central idea remains unchanged: if inertia reflects the informational work needed to update correlations, and this work declines as the universe's maintainable structure becomes sparser, then a constant, Λ-like term appears naturally in the Friedmann acceleration equation. The model does not introduce new fields or modify gravity; it reframes why acceleration occurs. The new material shows that this reframing is not merely interpretive – it generates concrete, testable alternatives near ΛCDM.

10. Limitations and Future Work

The microphysical routes outlined here remain provisional. A full derivation of μ(a) from MIDH microstructure would clarify whether the volumetric or boundary-limited branch is physically preferred. A closer link between MID thinning and the statistics of the cosmic web may yield a more grounded scaling than the present power-law form.

Observationally, distinguishing the branches requires confronting the model with precise expansion-rate data, late-time potential decay, and growth measurements. The horizon-limited case, which predicts a mild departure from $w = -1$, is testable with DESI, Euclid, and upcoming weak-lensing surveys.

This paper addresses only the expansion sector. Extending MIDH to bound systems, where μ(r) varies with structural coherence and rotation emerges as a stabilizing pattern, belongs to future work.

11. Conclusion

MIDH offers a structural interpretation of cosmic acceleration: as expansion reduces the density of maintainable correlations, the informational cost of resisting acceleration falls, and a Λ-like term emerges naturally. The simplest capacity scaling reproduces ΛCDM exactly, while alternative routes produce nearby behaviours that are observationally distinguishable. The model remains compact, but it is now tied to explicit microphysical possibilities and clear empirical tests. In this sense, cosmic acceleration reflects not an added substance but a reduction in the universe's informational-structural inertia at large scales.

REFERENCES

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