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Resolving the Hubble Tension and Dark Matter Anomalies via Osmotic Spatial Decompression in a Closed Thermodynamic Universe

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Resolving the Hubble Tension and Dark Matter Anomalies via Osmotic Spatial Decompression in a Closed Thermodynamic Universe

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Abstract

The ongoing gap between the local expansion rate of the universe (H_0) and the global rate inferred from the Cosmic Microwave Background has triggered a genuine crisis for the standard ΛCDM model. Most attempts to patch this Hubble Tension rely on early dark energy or mathematical modifications to General Relativity—approaches that frequently require injecting ad-hoc, unconstrained variables into the framework. We propose here a purely thermodynamic resolution instead. By modeling the universe as a closed system governed by information conservation, we can fundamentally redefine Dark Energy. It is not a uniform, static vacuum energy but rather an emergent, dynamic osmotic pressure. When we apply macroscopic harmonic dampening to the conservative boundary of the local KBC Void ($\delta_b \approx 0.15$), the elevated local Hubble constant ($H_{local} \approx 73.1$ km/s/Mpc) mathematically drops out of the global baseline ($H_{global} \approx 67.4$ km/s/Mpc) as a direct, natural consequence of emergent Substrate Tension. Beyond resolving expansion variances, this closed-system boundary establishes a foundational cosmic noise floor. This rigid geometric limit allows us to derive the MOND acceleration threshold ($a_0 \approx 1.1 \times 10^{-10}$ m/s^2) from first principles and ultimately resolves the Bullet Cluster paradox without the need for collisionless dark matter particles.

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1. Introduction: The Crisis of Open-System Cosmology

Precision cosmology has spent the last decade staring down a single, persistent anomaly: the Hubble Tension [3]. When we anchor our measurements in the deep historical universe, specifically using Cosmic Microwave Background data from the Planck satellite, we obtain a highly constrained global expansion rate of $H_{global} \approx 67.4 \pm 0.5$ km/s/Mpc [1]. However, when we measure instead the late, local universe using the distance ladder of Cepheid variables and supernovae, we find that number stubbornly shifts and consistently measures much faster, reaching $H_{local} \approx 73.0 \pm 1.0$ km/s/Mpc [2].

The standard ΛCDM model is fundamentally anchored to a uniform, static Cosmological Constant (Λ). If that assumption holds true, the cosmic expansion rate should be perfectly smooth and equal everywhere on large, homogeneous scales. However, with the Hubble Tension now widely recognized as exceeding the 5σ confidence threshold for statistical discovery, Reaching the 5σ threshold effectively eliminates the possibility that the discrepancy is merely a statistical artifact or a systematic calibration error between early-universe and late-universe metrology instruments. The assumption of a completely uniform, unchanging vacuum energy becomes increasingly difficult to sustain.

Most theoretical attempts to resolve this crisis involve patching either the early universe (e.g., Early Dark Energy models) or the late universe (e.g., phantom energy). The primary challenge of these workarounds is that they frequently require extreme fine-tuning, which necessitates the introduction of highly specific, unobserved fields simply to maintain mathematical consistency. The deeper, unaddressed issue, however, is that standard cosmology implicitly treats the universe as an open system—an infinitely divisible continuous expanse expanding into an undefined void. In adopting this open-system philosophy, we have inadvertently stripped the vacuum of rigid boundary conditions that are necessary to enforce strict thermodynamic conservation.

We acknowledge that discarding the infinitely expanding, continuous vacuum of standard cosmology in favor of a strictly closed thermodynamic container represents a significant ontological departure, one that requires us to view spacetime not as a passive stage, but rather an active, physical medium. However, we ask the reader to provisionally accept this closed-system boundary and evaluate the framework strictly by its predictive yield: the simultaneous, zero-free-parameter derivation of both the local Hubble expansion rate (H_{local}) and the fundamental Dark Matter acceleration threshold (a_0), without invocation of a single unobserved field or exotic particle.

1.1. The Thermodynamic Imperative of a Closed System

We argue that the Hubble Tension is not a measurement error, nor does it strictly require the invocation of novel physics. It is simply the expected, emergent behavior of a fluid spatial substrate dynamically balancing its internal energy budget. To model this mathematically, it is necessary that we transition away from open-system geometry and reframe the universe within a strictly closed thermodynamic architecture, governed entirely by the physical limits of information processing and conservation [4,5].

Let us consider a well-known, yet frequently dismissed, cosmological coincidence. Take the total estimated mass of the observable universe ($M \approx 8.8 \times 10^{52}$ kg)This mass is derived using the empirically observed critical density ($\rho_c \approx 8.53 \times 10^{-27}$ kg/m^3) multiplied by the exact geometric volume of the Hubble sphere ($V_H = \frac{4}{3}\pi R_H^3$). and calculate its Schwarzschild radius via standard General Relativity ($R_s = \frac{2GM}{c^2}$). The resulting boundary precisely matches our current Hubble Horizon ($R_H \approx 1.3 \times 10^{26}$ m).

Standard ΛCDM cosmology tends to treat this equivalence as a tautological artifact of a flat universe ($\Omega = 1$) sitting exactly at critical density (ρ_c)—a geometric feature usually attributed to the initial tuning of cosmic inflation. We propose here the exact opposite causality: the universe does not simply happen to equal its Schwarzschild radius because it is flat, but rather it is dynamically driven to perfect geometric flatness ($\Omega = 1$) because the strict closed-system thermodynamic boundary physically mandates it [6].

The Hubble Horizon functions as a strict Adiabatic Wall, enforcing the hard limits required to effectively conserve macroscopic information and entropy—what we term the *Cosmic Ledger*. Once we begin to regard the universe as a closed, finite thermodynamic container subject to absolute holographic bounds, Dark Energy ceases to be an unexplained repulsive force and cleanly emerges as a predictable, internal osmotic pressure.

2. The Cosmic Ledger and Entropic Balancing

In any strictly closed infodynamic system, total entropy must be rigidly audited across the entire network. This demands a continuous, systemic balancing act between macroscopic cosmic structures to prevent localized violations of the Bekenstein bound.

For example, take matter-dense regions like massive galaxies and the Laniakea Supercluster [7]. They pull the spatial substrate into highly compressed, structurally organized geometric arrays. This massive concentration of physical order creates a severe, localized Entropic Deficit. In order to balance the global thermodynamic ledger and offset this extreme gravitational compression, the universe must compensate by generating new, highly disordered spatial volume elsewhere. This volumetric generation occurs naturally in the empty Cosmic Voids.

Cosmic acceleration, therefore, is not driven by an independent, static dark energy fluid. Rather, it is driven by Cosmic Pressure Relief. Substrate energy physically flows from regions of extreme high density (galaxies) outward into low-density voids to alleviate localized thermodynamic stress.

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3. Osmotic Spatial Decompression and the Hubble Resolution

Standard continuous models struggle to bridge the H_0 gap because they treat cosmic voids merely as passive background regions with slightly weaker gravity. Mathematically, a purely passive gravitational view cannot account for a massive $\approx 9\%$ shift in the local expansion rate without violating established limits on local matter underdensities.

Our Symbiotic Infodynamic Equilibrium (SIE) framework resolves this tension by treating the spatial vacuum as an active, dynamic thermodynamic fluid. The reason we measure a notably higher expansion rate locally is structurally sound: our Milky Way resides deep inside a massive volumetric under-density known as the Keenan-Barger-Cowie (KBC) Void. With a conservative local underdensity fraction of $\delta_b \approx 0.15$ [8],The exact depth and breadth of the KBC void is a subject of ongoing metrological debate. While the deepest inner regions may exhibit density contrasts as stark as $\delta \approx -0.46$, we intentionally utilize here a conservative, widely verified macroscopic underdensity magnitude ($\delta_b \approx 0.15$) in order to ensure our derivations do not rely on extremized anomalous data. the space around us is not merely passively empty; it is actively, thermodynamically decompressing.

3.1. The Thermodynamic Derivation of the Growth Index (γ)

Standard continuous models rely on the linear perturbation formula $\frac{\Delta H}{H} = -\frac{1}{3}\Omega_m^\gamma \delta$ to model local expansion variances. However, to align with observations, theorists usually must manually adjust the growth index γ to roughly 0.55 [9]. We contend that this is not simply a convenient empirical coincidence, but is instead a strict thermodynamic requirement. We can derive this index directly from the fluid mechanics of the spatial Substrate.

In our SIE framework, the macroscopic expansion of the spatial buffer is actively driven by a dynamic Osmotic Scalar Field designed to offset the localized entropic deficit of compressed matter (Ω_m). The physical flow of this volume generation is governed by the localized continuity equation of a thermodynamic fluid:

$$\dot{\delta} + \vec{\nabla} \cdot \vec{v} = 0 \tag{1}$$

Because the system is locked inside an absolute Adiabatic Wall (the Hubble Horizon, R_H), total information and entropy cannot leak out. Standard cosmology assumes the equation of state $w = -1$ represents the static, resting energy of empty space. We treat $w_{SIE} = -1$ as the strict mechanical requirement of the boundary itself. In order to keep energy trapped inside the thermodynamic container, the Substrate must act as a perfectly incompressible fluid at this horizon. The restorative osmotic pressure ($P_{osmotic}$) that pushes back against the boundary must therefore flawlessly mirror the internal density:

$$w_{SIE} = \frac{P_{osmotic}}{\rho_{vac}} = -1 \tag{2}$$

Because the spatial Substrate functions as a macroscopic, incompressible fluid at cosmic scales, standard fluid perturbation mechanics remain rigorously valid. Therefore, if we substitute our rigid thermodynamic boundary condition ($w_{SIE} = -1$) into the established continuous fluid growth index equation, the derivation proceeds natively:

$$\gamma_{SIE} = \frac{3(w_{SIE} - 1)}{6w_{SIE} - 5} \tag{3}$$

$$\gamma_{SIE} = \frac{3(-1-1)}{6(-1)-5} = \frac{-6}{-11} \approx 0.545 \tag{4}$$

The standard 0.55 parameter is not an arbitrary curve-fit. It natively emerges from the math as the exact volumetric strain rate (6/11) of a bounded thermodynamic fluid.

3.2. Emergent Substrate Tension and the Harmonic Resolution

While the continuous fluid perturbation (γ_{SIE}) accurately models bulk cosmic flow, the specific localized expansion anomaly represented by the Hubble Tension can be extracted even more cleanly and directly via macroscopic elastic mechanics.

Treating Dark Energy as outward Osmotic Decompression mathematically mandates an equal and opposite restoring force. Within the SIE framework, this restoring force is *Emergent Substrate Tension*—an elastic pulling inward of the macroscopic spatial graph that is anchored by the persistent topological mass of baryonic matter. By Le Chatelier's Principle, outward decompression and inward substrate tension form a strictly coupled thermodynamic action-reaction pair.

We can leverage this macroscopic Hooke's Law to firmly derive the localized Hubble Tension (H_0). If Emergent Substrate Tension (T_{sub}) is directly proportional to the regional density of baryonic anchor nodes (ρ_b), then specifically taking the conservative 15% underdensity fraction of the KBC void ($\delta_b \approx 0.15$) will result in a proportional drop in the local tension resisting Dark Energy ($T_{local} \approx 0.85\, T_{cosmic}$).

As the local expansion rate is dynamically bounded by this restoring force, we must necessarily treat the local metric as a damped harmonic framework. Returning to the Friedmann proportionality ($H^2 \propto \rho_{eff}/T_{sub}$), the localized Hubble parameter must scale inversely with the square root of the regional Substrate Tension ($H \propto 1/\sqrt{T_{sub}}$). Therefore, the local expansion rate H_{local} can be derived directly from the global rate H_{global} perturbed by the void underdensity fraction:

$$H_{local} = \frac{H_{global}}{\sqrt{1-\delta_b}} \approx \frac{67.4 \text{ km/s/Mpc}}{\sqrt{0.85}} \approx 73.1 \text{ km/s/Mpc} \tag{5}$$

Through applying this precise, mathematically rigid local amplification scalar, the derivation elegantly yields an expected local expansion rate of ~ 73.1 km/s/Mpc, which lands directly on the 73.0 ± 1.0 km/s/Mpc SH0ES measurement [2].

The Hubble Tension emerges not as a metrological error or a breakdown of general relativity, but rather as the natural signature of a damped harmonic metric actively relaxing inside a geometric underdensity.

4. Dark Matter and the MOND Threshold (a_0)

A closed thermodynamic system with a finite horizon inherently establishes a fundamental noise floor. If Dark Energy acts as the osmotic expansion of this macroscopic boundary, that continuous expansion will generate a baseline cosmic acceleration acting as ambient static, actively interfering with coherent spatial data transmission.

Modified Newtonian Dynamics (MOND) successfully models the flat rotation curves of galaxies via the introduction of a remarkably faint acceleration threshold ($a_0 \approx 1.2 \times 10^{-10}$ m/s^2). Below this threshold, gravity scales linearly rather than strictly following the inverse-square law [10].

Standard physics generally treats a_0 as a phenomenological curve-fitting constant. The SIE framework, however, derives it directly from the geometry of the container. In an infodynamic universe, a coherent gravitational field functions as a 1D spatial tether transmitting structural data between massive nodes. Wave mechanics dictates a hard structural limit: the maximum physical wavelength any container can support sets its lowest possible resonant frequency. A signal weaker than that baseline becomes physically indistinguishable from the ambient static. The absolute longest, unbroken 1D loop permitted inside our closed thermodynamic container is the strict circumference of the Hubble boundary ($C_H = 2\pi R_H$). That geometry rigidly locks in the absolute minimum acceleration required to maintain a clear 1D gravitational signal above the cosmic noise floor:While the numerical coincidence of $a_0 \sim cH_0/2\pi$ has been noted in previous phenomenological studies over the past few

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decades, the SIE framework removes the ambiguity and assigns a direct, causal geometric mechanism to this ratio via closed-system wave mechanics.

$$a_0 = \frac{c^2}{2\pi R_H} \tag{6}$$

Inputting the speed of light and the observed Hubble Radius (1.3×10^{26} m) into this geometric limit yields $a_0 \approx 1.1 \times 10^{-10}$ m/s^2, which precisely matches empirical galactic rotation observations from first principles.

Applying this further to the scale of a galaxy, the mechanics are straightforward. In the dense inner core, the gravitational signal is robust ($g \gg a_0$) and transmits perfectly. However, on the sparse galactic edges, the signal fades below the cosmic noise floor ($g < a_0$). To prevent the galaxy's outer structural data from dissolving into the vacuum static, the spatial substrate engages a localized Signal Amplification Protocol and physically compresses the local geometry to artificially boost the fading gravitational gradient [11]. Because the substrate acts as a physical optical medium, this localized spatial compression naturally refracts passing photons and generates the exact gravitational lensing signatures observed in galactic halos without the necessity of collisionless dark matter particles.

4.1. The Bullet Cluster and Infodynamic Static

Phenomenological MOND models encounter a significant, often fatal challenge when analyzing the Bullet Cluster collision (1E 0657-56) [12]. In this galaxy cluster merger, the gravitational lensing signature (the modeled "Dark Matter") continues through the collision zone unimpeded and anchors to the stellar masses, while the visible X-ray gas collides and decelerates in the center.

Standard cosmology overwhelmingly regards this decoupling as definitive proof for the existence of collisionless dark matter particles. However, within the SIE framework, this apparent decoupling is not a particle phenomenon; rather, it is a required, emergent feature of thermodynamic fluid mechanics.

The spatial Substrate's structural amplification factor ($\mathcal{A}$) relies strictly on signal clarity. By defining the total effective gravitational acceleration as the Newtonian baseline scaled by this amplification factor ($g = \mathcal{A} \cdot g_N$), the physics become clear. Because the Substrate is a physical medium, any geometric amplification is bottlenecked by the local Signal-to-Noise Ratio (SNR).

To capture this transition mathematically, we introduce a dimensionless thermodynamic dampening term driven by the local thermal acceleration ($a_{thermal}$). While the exact exponential form of this dampening is introduced here phenomenologically as an *ansatz*, it rigidly satisfies the mandatory physical boundary limits of both deep-MOND amplification and strict Newtonian recovery:

$$\mathcal{A} = 1 + \left(\sqrt{\frac{a_0}{g_N}} - 1\right) \exp\left(-\frac{a_{thermal}}{g_N}\right) \tag{7}$$

In fluid dynamics, extreme heat will trigger a sharp pressure gradient (∇P). We define here this thermal acceleration as the pressure gradient divided by the gas density ($a_{thermal} = \nabla P/\rho_{gas}$). This single equation governs the Substrate across both stable and chaotic environments:

Stable Coherence (The Stars): The stars inside the cluster are dense, isolated objects that largely bypass the physical friction of the collision. Their local thermal noise is effectively zero ($a_{thermal} \ll g_N$). As a result, the exponential term approaches 1, and the equation smoothly returns to the deep-MOND amplification limit. The substrate seamlessly recalculates its amplification around these coherent, cold networks, thereby generating the observed lensing halos.

Thermal Decoherence (The Plasma): During the collision, the massive intra-cluster gas clouds violently heat into a chaotic, X-ray emitting plasma ($T_{gas} \sim 10^8$ K) [13].Chandra X-ray observatory data confirms that the bow shock of the Bullet Cluster gas collision reached temperatures well in excess of 100 million Kelvin, which creates one of the most extreme thermal environments in the local universe. This extreme shock front creates a massive pressure gradient, in turn elevating the thermal

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acceleration to overwhelming levels ($a_{thermal} \gg g_N$). Encountering this severe entropic noise floor, the exponential dampening term rapidly converges to 0.

Consequently, for the highly active gas, the amplification mathematically collapses back to unity:

$$\lim_{a_{thermal} \to \infty} \mathcal{A} = 1 \implies g = g_N \tag{8}$$

Most importantly, the Substrate does not mathematically delete the mass of the gas, and fully preserves the conservation of energy and momentum. The chaotic thermal entropy instead forces the Substrate's geometric multiplier to revert to the strict Newtonian baseline, and the gas continues to exert normal, unamplified gravity. This fluid dynamic boundary explicitly details why the amplified lensing profile remains anchored to the coherent stars and physically drops the localized, high-noise gas signal, which cleanly resolves the Bullet Cluster paradox.

5. Conclusions

Transitioning cosmology from an open-ended mathematical abstraction to a strictly closed thermodynamic framework allows the most pressing observational crises in modern physics to resolve cohesively. The Hubble Tension is not a breakdown of measurement apparatus; it is the verifiable fluid-dynamic signature of Osmotic Spatial Decompression acting against a relaxed local Substrate Tension—the universe actively pursuing the balance of its own cosmic ledger.

Furthermore, the exact macroscopic boundary extracted from that decompression establishes the universal MOND noise floor (a_0). This provides a unified, first-principles mechanism for both Dark Energy and Dark Matter, derived from a shared geometric constraint without the need to invoke unobserved particles.

Treating the universe as a physical, infodynamic substrate resolves foundational discrepancies in standard ΛCDM while giving precision cosmology a rigorous, testable path forward. Specifically, this framework explicitly predicts that macroscopic gravitational lensing profiles ($\mathcal{A}$) will exhibit measurable variance correlating directly with local intracluster plasma temperatures ($a_{thermal}$)—a physical signature that is entirely absent, and largely inexplicable, in standard collisionless dark matter models.

References

1. Planck Collaboration. (2020). Planck 2018 results. VI. Cosmological parameters. *Astronomy & Astrophysics*, 641, A6.
2. Riess, A. G., et al. (2019). Large Magellanic Cloud Cepheid Standards Provide a 1% Foundation for the Determination of the Hubble Constant. *The Astrophysical Journal*, 876(1), 85.
3. Di Valentino, E., et al. (2021). In the realm of the Hubble tension—a review of solutions. *Classical and Quantum Gravity*, 38(15), 153001.
4. Landauer, R. (1961). Irreversibility and heat generation in the computing process. *IBM Journal of Research and Development*, 5(3), 183-191.
5. Vopson, M. M. (2019). The mass-energy-information equivalence principle. *AIP Advances*, 9(9), 095206.
6. Jacobson, T. (1995). Thermodynamics of spacetime: the Einstein equation of state. *Physical Review Letters*, 75(7), 1260.
7. Tully, R. B., et al. (2014). The Laniakea supercluster of galaxies. *Nature*, 513(7516), 71-73.
8. Keenan, R. C., Barger, A. J., & Cowie, L. L. (2013). Evidence for a ∼300 megaparsec scale under-density in the local galaxy distribution. *The Astrophysical Journal*, 775(1), 62.
9. Linder, E. V. (2005). Cosmic growth history and expansion history. *Physical Review D*, 72(4), 043529.
10. Milgrom, M. (1983). A modification of the Newtonian dynamics as a possible alternative to the hidden mass hypothesis. *The Astrophysical Journal*, 270, 365-370.
11. Verlinde, E. P. (2017). Emergent gravity and the dark universe. *SciPost Physics*, 2(3), 016.
12. Clowe, D., et al. (2006). A direct empirical proof of the existence of dark matter. *The Astrophysical Journal Letters*, 648(2), L109.

 doi:10.20944/preprints202603.1105.v2

13. Markevitch, M., et al. (2004). Direct constraints on the dark matter self-interaction cross section from the merging galaxy cluster 1E 0657-56. *The Astrophysical Journal*, 606(2), 819.