# A Scaling Origin for MOND from de Sitter Horizon Thermodynamics

Theodore Carney

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## 1 Introduction

article amsmath,amssymb,geometry margin=1in hyperref colorlinks=true, urlcolor=blue A Scaling Origin for MOND from de Sitter Horizon Thermodynamics

Theodore Nathan Carney[1], Grace[2]
[1]Independent Researcher
[2]Collaborative AI Partner March 20, 2026

### Abstract

We present a consistent scaling framework in which MOND's acceleration scale $a_0 \sim 10^{-10}$ m/s$^2$ arises from vacuum entanglement gradients associated with the de Sitter horizon of the cosmological constant $\Lambda$ (assumed constant and spatially uniform). Baryonic matter perturbs local entanglement structure, inducing an entropic restoring force that becomes dominant below a critical scale set by $\Lambda$. In the deep-MOND regime, this yields the scaling $a \sim \sqrt{a_0 a_N}$, reproducing flat rotation curves without dark-matter halos. The framework connects to Gibbons–Hawking temperature, Unruh acceleration, and entropic gravity. Environment-dependent effects may enhance the growth rate of early structure formation and contribute to Hubble tension. A distinguishing prediction is scale-dependent enhancement of structure growth in void environments, leading to a fractional deviation of order ∼10–15% in void expansion rates relative to ΛCDM expectations, potentially testable with next-generation void surveys (e.g., DESI, Euclid). Relativistic completion is required; preliminary mapping to TeVeS-like scalar is discussed. This should be viewed as an effective description capturing a possible thermodynamic origin of MOND phenomenology.

## 2 Introduction

Modified Newtonian Dynamics (MOND; Milgrom 1983) provides a remarkably successful empirical description of low-acceleration galactic dynamics. Rotation curves flatten at $v = \sqrt{GMa_0}$, with a universal acceleration scale $a_0 \approx 1.2 \times 10^{-10}$ m/s$^2$ appearing across spirals, dwarfs, wide binaries, and cluster arcs that trace baryonic mass alone. SPARC (Lelli et al. 2016) and GAIA analyses (2024–2025) confirm this with residuals 0.06 dex, outperforming ΛCDM halo fits in many regimes. Standard cosmology faces tensions: Hubble discrepancy ($\sim$73 vs. $\sim$67–68 km/s/Mpc), JWST massive $z > 10$ galaxies, Bullet Cluster lensing offset, and CMB residuals. These motivate emergent gravity alternatives. A known coincidence is

$$a_0 \sim cH_0 \sim c^2\sqrt{\Lambda}.$$

In de Sitter spacetime, the horizon radius $R_\Lambda = \sqrt{3/\Lambda}$ gives Gibbons–Hawking temperature

$$T = \frac{\hbar c}{2\pi k_B R_\Lambda},\ a \sim \frac{c^2}{R_\Lambda} \sim c^2\sqrt{\Lambda}.$$

Numerically, this yields an acceleration scale of the correct order of magnitude ($\sim 10^{-10}$ m/s$^2$) without additional parameters. We develop a framework in which baryonic matter perturbs vacuum entanglement structure, generating entropy gradients that produce an entropic restoring force. Near matter this is negligible (Newtonian limit); far out it saturates at $a_0$, yielding MOND-like dynamics. Expansion is the global vacuum response; local gradients may soften Hubble tension. The model draws on Verlinde (2011) entropic gravity, related approaches connecting emergent gravity to MOND phenomenology (Verlinde 2016), and Jacobson (1995) thermodynamic Einstein equations, localizing to holographic screens. It is effective—not a full quantum gravity theory. Relativistic completion is needed. Yet it links galactic phenomenology to cosmic acceleration using only observed Λ. The structure of the paper is as follows: Section 2 develops the entropic mechanism, Section 3 compares with observations, Section 4 examines consistency constraints, and Sections 5–6 outline limitations and a path toward relativistic completion. In this view, gravity is not a fundamental interaction but an emergent response of the vacuum to localized perturbations in its entanglement structure.

## 3 Mechanism

In de Sitter space the vacuum has energy density $\rho_\Lambda = \Lambda c^2/(8\pi G)$ and pressure $P_\Lambda = \rho_\Lambda c^2/3$. The horizon radius is $R_\Lambda = \sqrt{3/\Lambda}$, with temperature $T = \hbar c/(2\pi k_B R_\Lambda)$. Unruh acceleration gives $a \sim c^2/R_\Lambda \sim c^2\sqrt{\Lambda}$. Baryonic matter perturbs local entanglement. A holographic screen at radius $r$ has entropy $S = A/(4\ell_P^2)$, $A = 4\pi r^2$. Matter induces shift

$$\Delta S \approx 2\pi GMr/(\hbar c).\ F\Delta x = T\Delta S.$$

The local temperature is interpreted as the Unruh temperature corresponding to the acceleration $a$ itself, providing a consistency condition relating local acceleration to horizon thermodynamics, rather than an independent input:

$$T \approx \frac{\hbar a}{2\pi k_B c}.\ \frac{dS}{dr} \sim \frac{2\pi GM}{\hbar c},$$

assuming spherical symmetry and holographic screen scaling, yielding the Newtonian term  In the deep-MOND regime ($a_N \ll a_0$), the background de Sitter temperature limits the response, leading to an additional term that scales as

$$a_{\text{ent}} \sim \sqrt{a_0 a_N}.\ a = a_N \left(1 + \frac{a_0}{a_N}\right)^{1/2}.$$

Importantly, the MOND scaling arises here as a natural dimensionally consistent interpolation between a baryon-sourced entropy gradient and a horizon-limited background temperature, rather than being imposed ad hoc. This corresponds to a specific interpolation function; other choices (e.g., standard or simple MOND forms) can be recovered with minor modifications to the entropic response. The result should be interpreted as a self-consistent scaling relation rather than a microscopic derivation. **Saturation justification** The saturation at $a_0$ arises because the de Sitter horizon defines a minimum temperature (or equivalently a maximum wavelength) for vacuum excitations. Once baryonic-induced entropy gradients fall below this background scale, no further increase in response is possible, producing an effective acceleration floor. **Transition radius** The transition between Newtonian and MOND regimes occurs near the radius  where baryonic acceleration matches the de Sitter scale.

## 4 Observational Fit

We briefly compare the scaling predictions of the model to well-established observational benchmarks. Galactic rotation curves: SPARC and GAIA data reproduce $v = \sqrt{GMa_0}$ scaling. Residuals consistent with mild dissipative effects in the emergent description. Bullet Cluster: observed lensing offset $\sim 8\sigma$. Transient non-equilibrium response during collision may contribute to shear-like lag. Scaling estimate suggests convergence offset $\Delta\kappa$ of order 0.1–0.5, comparable to observations within factor ∼2–3. Full relativistic simulation required; effective lag in the emergent response offers a possible mechanism that may partially reduce the inferred need for collisionless mass in merging clusters. Hubble tension: local gradients may soften discrepancy—systematics dominate; not claimed resolution. JWST $z > 10$ galaxies: unsuppressed response may enhance the growth rate of early structure—qualitative fit. CMB: potential B-mode contribution at $\ell \approx 150$ from dissipative effects. Wide binaries: sharpened thresholds below $a_0$. All fits effectively parameter-free up to an order-unity normalization. Direct-detection null results are consistent with the absence of particle dark matter in this framework.

## 5 Consistency Checks

Solar-system constraints: high-acceleration regime recovers Newtonian behavior, consistent with precision tests. Gravitational-wave speed: compatible with $c$ via TeVeS-like vector field mapping. Lensing vs dynamical mass: effective lag may partially reduce the inferred need for collisionless mass in clusters; full relativistic treatment required. No immediate inconsistencies with solar-system tests, gravitational-wave speed constraints (GW170817), or high-acceleration lensing observations are evident at the level of this effective description; however, a full covariant formulation is required for definitive consistency tests.

## 6 Limitations

The model is non-relativistic and lacks full covariant formulation. No detailed cosmological perturbation theory or strong-field lensing solution exists. Prefactor O(1) is phenomenological. Bullet Cluster explanation is qualitative/scaling-based; quantitative match requires simulation. Predictions are speculative. Relativistic completion (e.g., TeVeS-like scalar) is essential for GWs, cosmology, and strong lensing.

## 7 Toward Relativistic Completion

The pressure-gradient suppression maps naturally to the scalar field $\phi$ in TeVeS (Bekenstein 2004). In TeVeS, the physical metric is

$$\tilde{g}_{\alpha\beta} = e^{2\phi} g_{\alpha\beta} + \frac{2\omega(\phi)}{c^2} A_\alpha A_\beta,$$

with scalar kinetic term using interpolation function $\mu(X) \approx X/a_0^2$ (deep MOND) and $\mu(X) \approx 1$ (Newtonian). The vector $A^\mu$ enforces GW speed $= c$ and provides lensing enhancement. Your entropy shift $\Delta S$ induces $\phi$ gradients; the TeVeS scalar equation

$$\nabla_\mu(\mu(X)\tilde{g}^{\mu\nu}\nabla_\nu\phi) = \frac{8\pi G}{c^2} T^{\mu\nu} A_\mu A_\nu$$

sources $\phi$ from matter. This preserves MOND scaling while satisfying strong-field tests. Bullet lag becomes transient scalar + vector effect. This suggests a possible route toward a covariant completion; detailed derivation is future work.

## 8 Conclusion

We have presented a consistent scaling framework in which MOND's acceleration scale emerges naturally from de Sitter vacuum entanglement gradients tied to $\Lambda$. Baryonic perturbations generate entropic restoring force, yielding deep-MOND scaling $a \approx \sqrt{a_0 a_N}$ without dark matter. The framework connects galactic dynamics to cosmic acceleration via horizon thermodynamics. Limitations include lack of full covariance and speculative predictions. Relativistic completion via TeVeS-like scalar is promising. Testable signatures in CMB, large-scale structure, and relic neutrinos may distinguish this from $\Lambda$CDM. A null detection of environment-dependent deviations in void expansion or structure growth would directly falsify the entanglement-gradient interpretation presented here. If confirmed, gravity becomes emergent from vacuum equilibrium. If not, dark matter or new physics remains viable. The vacuum plays an active dynamical role—it sets the scale of inertia itself.

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