Inertia from Horizon Information Dynamics: Landauer–Unruh Mass Map and Capacity Saturation

Ivars Fabriciuss[a]

[a] *Independent Researcher, Riga, Latvia*

Abstract

We propose that both dark energy and inertial mass arise from information dynamics on the cosmological horizon. The stretched horizon is discretized into Planck tiles of area $4L_P^2$, each with capacity 1 nat. Causal, capacity-limited compaction drives the system toward a digital fixed point where a fraction $f_1 = \ln 2$ of tiles are saturated (1 nat) while $f_0 = 1 - \ln 2$ are empty (0 nats). The saturated fraction fixes the late-time dark-energy share $\Omega_{\Lambda,0} = \ln 2$. The empty fraction supplies vacancies that enable reversible, local updates when a particle accelerates. Mapping a particle to a tiny horizon-cap of N_p tiles, a small reorientation flips only a one-tile rim. Using the Unruh temperature for an accelerated worldline [3] and Landauer's minimal energy *per nat* [4], equating mechanical work to flip energy yields a universal mass-per-tile $m_\star = \hbar \ln 2/(2\pi c^2)\,(\gamma/\chi)$ and the composition-blind law $m = m_\star N_p$. Massless modes have $N_p = 0$ and follow null geodesics; black holes form a separate regime where the relevant surface is the black-hole stretched horizon with $N_p^{\rm BH} \propto M^2$. The framework is thermodynamically consistent, EP-friendly, and leads to quantitative scales testable by precision cosmology and inertial experiments.

Keywords: Horizon thermodynamics, Landauer principle, Unruh temperature, Inertia, Dark energy, Holography, Membrane paradigm

1. Overview and predictions at a glance

Horizon thermodynamics and holographic bounds tie geometry, temperature, and information [1, 2]. We advance a minimal information-dynamic picture that (i) fixes the late-time dark-energy share as a saturated-capacity number and (ii) explains inertia as the Landauer cost of reorienting a tiny horizon-cap associated with a particle. A single, universal mass-per-tile $m_\star$ controls both inertial and gravitational response, satisfying the equivalence principle (EP).

Predictions (summary)..

- **Dark energy normalization:** capacity saturation $\Rightarrow f_1 = \ln 2 \Rightarrow \boxed{\Omega_{\Lambda,0} = \ln 2 \approx 0.6931}$ (numerically close to current constraints).
- **Mass map:** $\boxed{m = m_\star N_p}$ with $m_\star = \dfrac{\hbar \ln 2}{2\pi c^2}\dfrac{\gamma}{\chi}$. For $\gamma/\chi = 1$, $m_\star \simeq 1.30 \times 10^{-52}\,\mathrm{kg}$ per tile.

Email address: ivars.fabriciuss@gmail.com (Ivars Fabriciuss)
URL: https://orcid.org/0009-0009-2341-7590 (Ivars Fabriciuss)

- **Examples (cap scale $\ell_{\text{eff}} = 2L_P\sqrt{N_p/\pi}$):** Electron $N_p \approx 7.0 \times 10^{21}$, $\ell_{\text{eff}} \approx 1.5 \times 10^{-24}$ m; Proton $N_p \approx 1.29 \times 10^{25}$, $\ell_{\text{eff}} \approx 6.5 \times 10^{-23}$ m; Sun $N_p \approx 1.53 \times 10^{82}$, $\ell_{\text{eff}} \approx 2.3 \times 10^{6}$ m.

- **Black holes vs. non-BH matter:** for non-BH matter $N_p \propto M$ (this work); for BHs the relevant DOF are on the BH stretched horizon with $N_p^{\text{BH}} \propto M^2$ (Bekenstein–Hawking). The two counts live on different surfaces and are not compared directly in magnitude here.

- **No Landauer power in uniform circular motion:** $P = \mathbf{F}\cdot\mathbf{v} = 0$; rim permutations can be reversible. Landauer power appears only with a tangential component $a_\parallel$.

- **Finite along-horizon speed:** mixing speed $\leq \kappa c$ implies any composition-dependent effects are $\ll 10^{-13}$ (assumed universal, consistent with EP bounds).

2. Capacity saturation and dark energy

For a flat FRW universe with Hubble radius $R_H = c/H$ and area $A_H = 4\pi R_H^2$, the stretched (timelike) horizon is discretized into Planck tiles,

$$N = \frac{A_H}{4L_P^2} = \frac{\pi c^2}{H^2 L_P^2}, \tag{1}$$

each tile having digital capacity $C = 1$ nat (so $q_i \in \{0, 1\}$ per tile). Capacity-limited compaction—local, causal, and entropy-preserving at fixed N—drives the system to a digital fixed point with saturated fraction $f_1 = \ln 2$ and empty fraction $f_0 = 1 - \ln 2$ (vacancies). If the vacuum sector tracks the saturated capacity, $\rho_\Lambda = 3M_P^2 H^2 f(a)$, then at late times $f \to \ln 2$ and

$$\boxed{\Omega_{\Lambda,0} = \ln 2 \ \approx 0.693147}, \tag{2}$$

consistent with the Gibbons–Hawking horizon thermodynamics setting [1] and holographic bounds [2].

3. Inertia from Landauer–Unruh retiming

Particle–horizon map.. A localized body maps to a tiny cap on the stretched horizon with N_p engaged tiles and linear scale

$$N_p = \frac{A_{\text{cap}}}{4L_P^2} = \frac{\pi}{4}\frac{\ell_{\text{eff}}^2}{L_P^2}, \qquad \ell_{\text{eff}} = 2L_P\sqrt{\frac{N_p}{\pi}}. \tag{3}$$

Only the cap boundary (a one-tile rim) must change membership under an infinitesimal reorientation $d\varphi$. Because only a fraction $f_1 = \ln 2$ of sites carry 1 nat at any instant (digital saturation), the rim update is

$$\boxed{dN_{\text{flip}} = \gamma\, f_1\, N_p\, d\varphi}, \tag{4}$$

with $\gamma = \mathcal{O}(1)$ capturing the one-tile rim thickness. [1]

[1] We model the engaged region as a geodesic spherical cap. For fixed area, a circular cap minimizes perimeter on S^2, thus minimizing rim flips; any other shape only rescales an order-unity geometry factor absorbed into γ/χ, leaving $m = m_\star N_p$ unchanged.

Kinematic link (local Rindler/membrane map).. A small proper displacement dx under proper acceleration a corresponds to a cap rotation

$$\boxed{d\varphi = \chi \, \frac{a\,dx}{c^2}}, \tag{5}$$

with $\chi = \mathcal{O}(1)$; this is the local Rindler mapping associated with the stretched horizon (membrane paradigm [5]).

Landauer–Unruh calibration (per nat).. Proper acceleration a yields an Unruh temperature

$$T_U = \frac{\hbar a}{2\pi c k_B}\,, \tag{6}$$

and the minimal energy per logical change (per nat) is

$$\varepsilon_{\text{flip}} = k_B T_U = \frac{\hbar a}{2\pi c}\,, \tag{7}$$

by Landauer's principle [4] and Unruh's result [3].

Mass law from work balance.. Equating mechanical work to flip energy,

$$m\,a\,dx \;=\; \varepsilon_{\text{flip}}\,dN_{\text{flip}} = \left(\frac{\hbar a}{2\pi c}\right)\gamma f_1 N_p \left(\chi \frac{a\,dx}{c^2}\right), \tag{8}$$

the factor $a\,dx$ cancels and we obtain

$$\boxed{m = m_\star\,N_p, \qquad m_\star = \frac{\hbar}{2\pi c^2}\,\frac{\gamma}{\chi}\,f_1 = \frac{\hbar \ln 2}{2\pi c^2}\,\frac{\gamma}{\chi}}. \tag{9}$$

Thus m is proportional to the engaged-tile count, with no species-dependent inputs. The same N_p governs gravitational response, so $m_{\text{inertial}} = m_{\text{grav}}$ (EP consistency).

Geodesics imply no flips.. Let u^μ be the 4-velocity and n^μ a unit screen vector to the cap center. Under Fermi–Walker transport, $D_{FW}n^\mu/d\tau = (u^\mu a_\nu - a^\mu u_\nu)n^\nu$. For a geodesic worldline $a^\mu = 0$, so $Dn^\mu/d\tau = 0$, the cap orientation is steady and $dN_{\text{flip}} = 0$.

Thermodynamic consistency.. In uniform circular motion $\mathbf{F}\cdot\mathbf{v} = 0$, flips can proceed reversibly (permutations) with no Landauer dissipation. Landauer power matches mechanical power only when there is a tangential component $a_\parallel$:

$$P_{\text{Landauer}} = \varepsilon_{\text{flip}}\,\frac{dN_{\text{flip}}}{dt} \;=\; m\,a_\parallel v, \tag{10}$$

consistent with energy conservation.

4. Numerical scales and examples

Taking $\gamma/\chi \simeq 1$ and $f_1 = \ln 2$ gives

$$m_\star = \frac{\hbar \ln 2}{2\pi c^2} \approx 1.30 \times 10^{-52}\,\text{kg per tile}. \tag{11}$$

Then:

- Electron (m_e): $N_p = m_e/m_\star \approx 7.0 \times 10^{21}$, $\quad \ell_{\text{eff}} \approx 1.5 \times 10^{-24}\,\text{m}$.
- Proton (m_p): $N_p \approx 1.29 \times 10^{25}$, $\quad \ell_{\text{eff}} \approx 6.5 \times 10^{-23}\,\text{m}$.
- Sun ($M_\odot$): $N_p \approx 1.53 \times 10^{82}$, $\quad \ell_{\text{eff}} \approx 2.3 \times 10^{6}\,\text{m} \ll$ solar diameter.

These ℓ_{eff} are I_3 cap scales (bookkeeping on the stretched horizon), not form factors in R_3.

Black holes.. For black holes the relevant surface is the BH stretched horizon, with engaged DOF set by Bekenstein–Hawking,

$$N_p^{\rm BH} \simeq \frac{A_{\rm BH}}{4L_P^2} = \pi \left(\frac{2GM}{c^2 L_P}\right)^2 \propto M^2, \tag{12}$$

and operative size $\ell_{\rm eff}^{\rm BH} \sim R_s$. (We do not directly compare the magnitude of N_p across these different surfaces.)

5. Discussion and outlook

This minimal information-dynamic framework yields: (i) a late-time dark-energy share $\Omega_{\Lambda,0} = \ln 2$ from digital capacity saturation; and (ii) a composition-blind inertial law $m = m_\star N_p$ from the Landauer cost of rim flips at Unruh temperature. The mechanism is EP-consistent and separates non-BH matter ($N_p \propto m$) from black holes ($N_p^{\rm BH} \propto M^2$). Immediate follow-ups include: bounding finite-speed corrections (mixing speed $\leq \kappa c$), composite-body additivity, and a star-vs-BH comparison within a unified surface choice. The framework is compatible with standard mass generation (Higgs/QCD), which sets m, while horizon tiles account for the inertial response to changing motion.

Data availability

No new data were created or analyzed in this study.

Acknowledgments

I.F. thanks discussions on horizon thermodynamics, the membrane paradigm, and holographic bounds.

References

References

[1] G. W. Gibbons and S. W. Hawking, Cosmological event horizons, thermodynamics, and particle creation, *Phys. Rev. D* **15** (1977) 2738.

[2] R. Bousso, The holographic principle, *Rev. Mod. Phys.* **74** (2002) 825.

[3] W. G. Unruh, Notes on black-hole evaporation, *Phys. Rev. D* **14** (1976) 870–892. doi:10.1103/PhysRevD.14.870

[4] R. Landauer, Irreversibility and heat generation in the computing process, *IBM J. Res. Dev.* **5** (1961) 183–191. doi:10.1147/rd.53.0183

[5] K. S. Thorne, R. H. Price, and D. A. Macdonald (eds.), *Black Holes: The Membrane Paradigm*, Yale University Press, 1986.