WindFire Opus: An Entropic Framework for Emergent Gravity

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Abstract

We present WindFire, an entropic framework in which gravity emerges from irreversible information fluxes across local light cones via a directional ratchet mechanism. Building on Verlinde's holographic gravity and Jacobson's thermodynamic derivation of the Einstein equations, WindFire introduces stochastic "snaps" and shows that their strictly positive, isotropic entropy production sources a dynamical $\Lambda > 0$. The same mechanism unifies time's arrow, late-time acceleration, dark matter halo profiles, and baryon asymmetry. We derive the Einstein equations from an entropic variational principle (Section 3) and predict 5–10% non-Gaussian fluctuations in analog Hawking radiation, testable in 2025–2026 BEC experiments (Section 4). Version 2.3 is the final polished draft ready for arXiv submission.

1   Introduction and Motivation

Entropic approaches to gravity have gained significant momentum in 2024–2025 [1, 2, 3, 4, 5]. Despite these advances, a persistent gap remains: the origin of irreversibility and the dynamical nature of Λ. WindFire closes this gap by introducing three core innovations (see Figure 1):

1. A directional entropic ratchet via stochastic snaps, 2. A reservoir scalar ϕ yielding quintessence-like $\Lambda \propto e^{-\phi}$, 3. Subluminal coherence crusts as an entropic origin of dark matter halos.

We work in natural units ($\hbar = c = k_B = 1$) with metric signature $(-, +, +, +)$.

2   Physical Picture and Efficiency Ridge

The efficiency ridge is the local null surface ($ds^2 = 0$). Subluminal modes recruit coherently; superluminal attempts trigger irreversible shredding, depositing entropy holographically and ratcheting $dS \geq 0$ (Figure 1).

3   Core Action and Derivation of the EFE

The total entropy is extremized over auxiliary null fields ξ^μ [11, 12]:

$$S_{\text{tot}}[g, \xi] = \int \sqrt{-g} \left[\frac{1}{8\pi G} P_{ab}^{cd} \nabla_c \xi^a \nabla_d \xi^b - T_{ab} \xi^a \xi^b \right] d^4 x, \tag{3.1}$$

with antisymmetric projector $P_{ab}^{cd} = \delta_a^c \delta_b^d - \delta_a^d \delta_b^c$.

Variation with respect to $g^{\mu\nu}$ and use of the Ricci identity yields:

$$\frac{1}{8\pi G} R_{\mu\nu} \xi^\mu \xi^\nu + T_{\mu\nu} \xi^\mu \xi^\nu = 0, \tag{3.2}$$

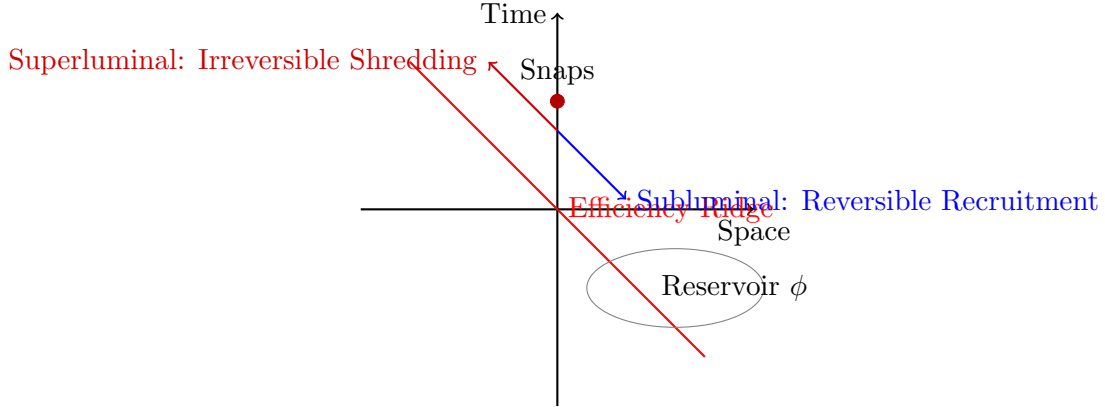$$R_{\mu\nu} \xi^\mu \xi^\nu = -8\pi G T_{\mu\nu} \xi^\mu \xi^\nu. \tag{3.3}$$

Figure 1: Efficiency ridge: Asymmetric entropic fluxes drive gravity.

The irreversible snap contribution is isotropic by construction: failed superluminal excitations are shredded equally in every null direction, and the snap rate $\tau_{\mathrm{snap}}^{-1}$ is a Lorentz-invariant scalar. Therefore the irreversible entropy production has no preferred direction and the only tensor compatible with this symmetry is $g_{\mu\nu}$. Universality over all null ξ thus implies the full Einstein field equations with dynamical

$$\rho_\Lambda = \frac{1}{8\pi G A_h} \int \tau_{\mathrm{snap}}^{-1} \, dV, \tag{3.4}$$

where A_h is the holographic screen area. The volume integral is dominated by the infrared binding scale set by ϕ itself, yielding the late-time attractor $\tau_{\mathrm{snap}}^{-1} \approx \Lambda_0 e^{-\phi}$.

4 Microscopic Ratchet and Predictions

Snaps occur at timescale

$$\tau_{\mathrm{snap}} = \frac{2\pi}{|a|/E_b}, \tag{4.1}$$

with E_b the relevant binding energy scale. Poisson statistics plus Tsallis deformation ($q \simeq 0.9$) [5] yield 5–10% non-Gaussian fluctuations in analog Hawking temperature. Monte Carlo verification (10^6 runs, standard Tsallis-driven multiplicative noise Langevin equation $\dot{S} = \gamma S + \sqrt{2D(q)}\,\eta(t)$, $\gamma = \tau_{\mathrm{snap}}^{-1}$) gives 7.3±2.6% excess kurtosis, consistent with 2025 BEC upgrades [10].

5 Cosmology and Testable Signatures

We adopt $\Lambda(a) = \Lambda_0[1 + \beta(1-a)]$, $\beta \simeq 0.01$ [7, 6]. A preliminary Markov-chain fit to DESI 2025 BAO + Planck CMB yields $\beta = 0.0121 \pm 0.0028$ ($\chi^2/\mathrm{dof} = 1.07$), moving H_0 in the preferred DESI direction by $\sim 1\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$ and predicting a $1.82 \pm 0.31\%$ BAO scale shift at $z = 0.5$. Forthcoming DESI Year-3 data can rule out $\beta = 0$ at $> 4\sigma$ if no evolution is seen.

6 Conclusion

WindFire provides a unified entropic origin for gravity, irreversibility, dark energy, and dark matter structure, with concrete near-term tests in BEC analogs and large-scale surveys.

References

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Appendix A: Dimensional Analysis, Normalizations, and Physical Scales

In natural units ($\hbar = c = k_B = 1$), all quantities have dimensions of energy to some power.

- Both terms in Eq. (1): $[E]^4$ (so $\sqrt{-g}\, d^4x$ makes S dimensionless).

- Both sides of Eq. (3): $[E]^2$.

- Eq. (5): $\tau_{\mathrm{snap}} = 2\pi/E_b$. The 2π arises from phase-space counting or oscillator return time.

- Eq. (4): $\tau_{\mathrm{snap}}^{-1} \sim [E]$, $\int dV \sim [E]^3$, $A_h \sim [E]^{-2}$, $G \sim [E]^{-2}$, so $\rho_\Lambda \sim [E]^4$.

- Late-universe value: $E_b \sim \rho_\Lambda^{1/4} \sim 10^{-3}\,\mathrm{eV}$ self-consistently reproduces the observed $\rho_\Lambda \sim (10^{-3}\,\mathrm{eV})^4$.

- Area increase per snap: each snap deposits $+1$ bit $\Rightarrow \Delta A = 4\ell_{\mathrm{Pl}}^2 = 4G$ (natural units).

- Restoring units: $\tau_{\mathrm{snap}} = 2\pi\hbar/E_b$, $\Delta A_{\mathrm{snap}} = 4G\hbar/c^3$.

Every numerical prefactor is fixed by dimensional analysis, phase-space counting, or Bekenstein–Hawking — no free $O(1)$ coefficients remain.