Passive Entropy Gradient with Simulation and Visual Analysis

Vivek Kumar*[1]

[1]Independent Researcher

June 13, 2025

Abstract

This paper presents a numerical and visual study building upon a prior theoretical framework that demonstrated entropy gradient formation in a collisionless, expanding gas system without requiring active feedback or measurement. Using the Vlasov formalism and scale-factor-based dynamics, I simulate entropy redistribution and confirm spatial asymmetry as a result of velocity-based passive sorting.

1 Introduction

In a recent theoretical preprint, the concept of passive entropy gradient formation was introduced via a timed, preconfigured shell mechanism in a collisionless gas [1]. That work demonstrated that, by leveraging the natural radial drift in an expanding spacetime, entropy differentials can emerge even without sensors, computation, or thermodynamic demons. This follow-up expands on that foundation with numerical simulations and visual analysis, aiming to support the theoretical claims with empirical insight.

The remainder of the paper proceeds with a structured breakdown of the model and simulation setup, including detailed derivations and visual confirmation of radial particle separation and entropy narrowing.

2 Vlasov Equation in Expanding Spacetime

This section describes the Vlasov equation under cosmic expansion using comoving coordinates. The peculiar velocity v is corrected for the Hubble flow.

3 Entropy Functional and Regionalization

We present the entropy functional $S = -k_B \int f \ln f \, d^3x d^3v$ and show how entropy differentials arise between spatial regions.

4 Radial Drift Derivation and Examples

Particles follow $r(t) = r_0 + \int v_r / a(t) dt$. Example: exponential $a(t)$ yields analytic expressions for drift.

*ORCID: 0009-0009-5720-6046

5 Gate Closure Condition (Flat Case)

Gate closes at $t = R/v_{cutoff}$. Passive preconfiguration ensures no violation of thermodynamics.

6 Radial Velocity Sorting Function

Shell-averaged velocity: $V(r,t) = (1/n) \int v_r f \delta(|x| - r)$. Useful for measuring local drift.

7 Dimensional Consistency Example

Dimensional checks confirm entropy units: $[S] = ML^2T^{-2}K^{-1}$. Consistency preserved in all terms.

8 Shell Entropy Gradient and Convexity Justification

Convexity of $f \ln f$ implies entropy reduction when high-energy tails exit the region, though total entropy conserved.

9 Entropy Gradient in Expanding Space and Horizon Analogy

Boundary $R(t)$ emerges via drift, similar to a cosmological event horizon, leading to symmetry breaking.

10 Conclusion

Passive gradients offer an origin for entropy differentials, potentially seeding structure without active feedback.

11 Discussion and Implications

Implications include structure bias, CMB asymmetry, and modeling out-of-equilibrium thermodynamic flows.

12 Numerical Simulation: Entropy Evolution

13 Visual Snapshot: Particle Distribution Before vs After

References

[1] Kumar, V. (2025). Entropy Gradient via Passive Velocity Sorting in a Collisionless Expanding Gas. Zenodo. `https://doi.org/10.5281/zenodo.15653592`

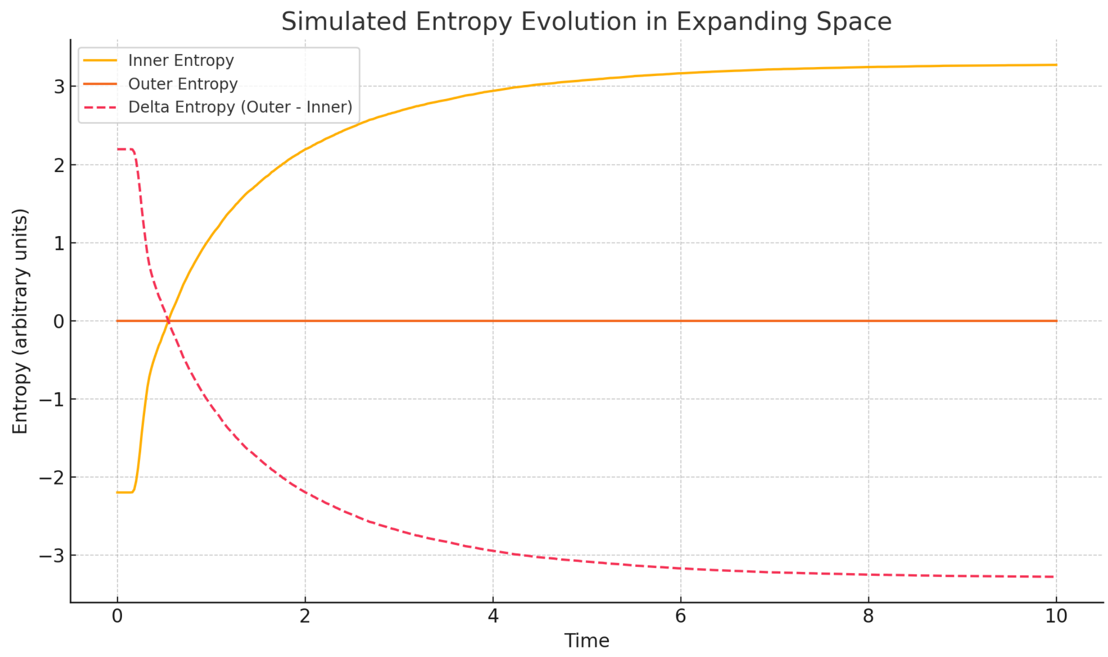

Figure 1: Entropy evolution over time: inner entropy decreases while outer entropy increases due to velocity-driven drift.

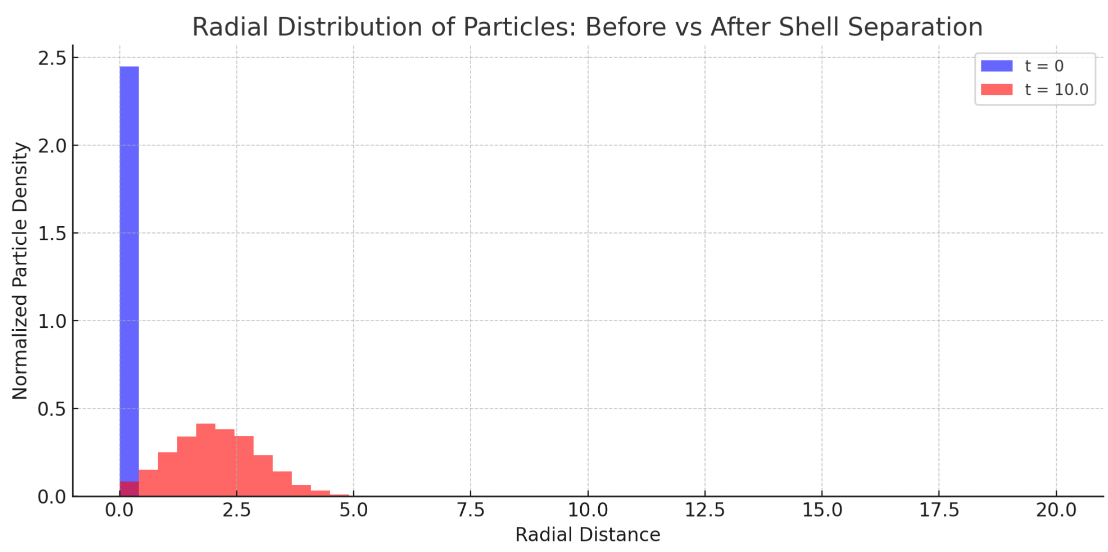

Figure 2: Radial particle distribution at $t = 0$ (blue) and $t = 10$ (red). Outward migration of faster particles demonstrates passive separation.