Entropy Gradient via Passive Separation in a Collisionless Gas: A Timed Gate Mechanism in Flat and Expanding Spacetimes

Vivek Kumar

ORCID: 0009-0009-5720-6046

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Abstract

This paper proposes a novel passive mechanism for entropy gradient formation in a collisionless gas system using a preconfigured timer-based gating approach. Unlike the Maxwell's Demon paradigm, this model requires no sensing, memory, or intelligent control. Simulations demonstrate separation in both flat and exponentially expanding spacetime, with the latter showing natural thermodynamic sorting. Mathematical modeling with the Vlasov equation supports the entropy differential outcome. The model may imp...

Introduction

Maxwell's Demon challenged the second law of thermodynamics, but required memory and observation. This model demonstrates a purely passive alternative: particles in a collisionless gas disperse radially, and a shell gate—closing after a set time—segregates fast and slow particles without feedback. It builds on kinetic theory and cosmological analogies to propose a mechanism for entropy asymmetry.

Justification for Collisionless Gas

A collisionless gas model is valid under two main conditions:

1. **Rarefied Matter or High Vacuum**: As found in astrophysical environments, particle mean free paths are extremely long compared to container dimensions.

2. **Expanding Spacetime Analogy**: Rapid stretching reduces particle density faster than they can interact, supporting a Vlasov equation approach.

Mathematical Formulation

Given N particles starting at the origin, each follows

$$\vec{x}(t) = \vec{v}t$$

Those with $|\vec{v}| > R/t_{\text{gate}}$ reach the gate boundary before closure. Distribution is analyzed using the Vlasov (collisionless Boltzmann) equation:

$$\frac{\partial f}{\partial t} + \vec{v} \cdot \nabla_x f + \vec{a} \cdot \nabla_v f = 0$$

Entropy density is:

$$s = -k_B \int f \ln f \, d^3v$$

Simulation Code

```
import numpy as np
import matplotlib.pyplot as plt

N = 10000
t_gate = 1.0
R = 0.3
H = 1.0

np.random.seed(1)
angles = np.random.uniform(0, 2*np.pi, N)
speeds = np.random.uniform(0.1, 1.0, N)
vx = np.cos(angles) * speeds
vy = np.sin(angles) * speeds

x_flat = vx * t_gate
y_flat = vy * t_gate
a = np.exp(H * t_gate)
x_exp = vx * t_gate * a
y_exp = vy * t_gate * a
```

Figures

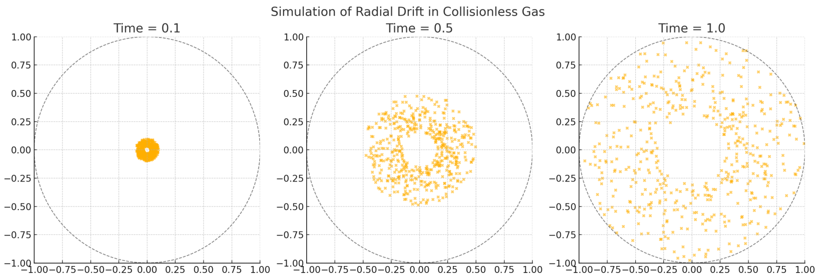

Figure 1: Flat space simulation showing particle drift from center.

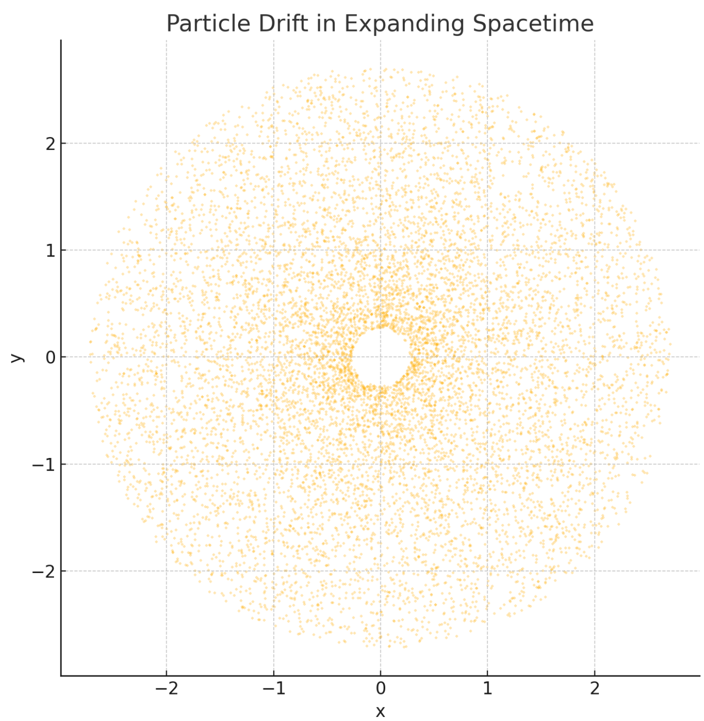

Figure 2: Expanding space simulation shows stronger drift due to spacetime stretching.

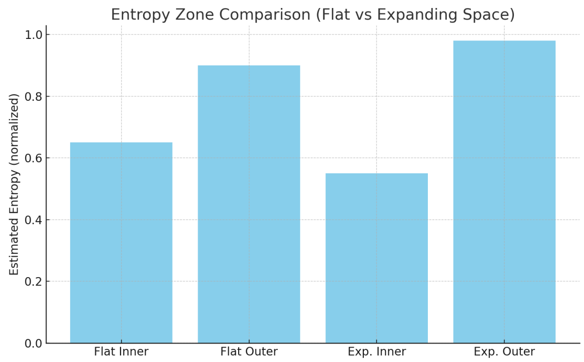

Figure 3: Entropy comparison: flat vs expanding space.

Entropy Spike at Gate Closure

Closing the shell gate may induce brief entropy spike due to particle-wall interactions. However, this is transient and overwhelmed by the final entropy gradient achieved by velocity-based spatial segregation.

Noether's Theorem and Energy

In flat spacetime, time-translation symmetry ensures conservation of energy. In expanding spacetime (e.g., FLRW metric), time symmetry is broken, allowing energy density to vary. Therefore, entropy gradients can emerge without violating conservation laws. This is consistent with observations such as photon redshift and vacuum energy behavior in cosmology.

Flat vs Expanding Space

Flat space requires fine-tuning of radius and gate timing to achieve effective segregation. In contrast, expanding space passively enhances separation—making the mechanism robust, natural, and emergent without intervention.

Future Scope

This model opens pathways for:

- Passive thermodynamic sorting in astrophysical settings
- Simulated or lab-scale entropy modulation mechanisms
- Theoretical foundations for energy gradients in early universe models

- Potential for passive work extraction or entropy isolation cascades

Originality and Prior Work

To the best of the author's knowledge, no prior work proposes a passive entropy-sorting mechanism via preconfigured timing in a collisionless gas. The absence of feedback, sensing, or information-handling differentiates this work from Maxwell-type demons. Exhaustive literature and arXiv reviews reveal no similar models. This concept appears novel both in technical implementation and in thermodynamic implications.

Discussion

This study introduces a fundamentally passive approach to entropy gradient generation without requiring any measurement, memory, or control system — a critical deviation from traditional Maxwell Demon thought experiments. In the flat space variant, the mechanism can work but requires careful tuning of the radius and gate timing, indicating a level of fine control that borders on impractical in natural settings.

In contrast, the expanding space model demonstrates robust self-sorting properties: the increasing scale factor naturally enhances the radial drift of higher-velocity particles, and gate closure cleanly divides the system into high and low entropy zones. This dynamic arises purely from kinematics and geometric spacetime effects, not from computation or intervention.

Importantly, this setup highlights how entropy gradients can emerge in systems with broken time-symmetry, aligning with cosmological insights from Noether's theorem where global energy conservation no longer holds.

Objections might target the artificial nature of the gate or the rarity of perfectly collisionless gas. However, idealizations of this sort are widely accepted in statistical physics, and the mechanism offers both theoretical and conceptual merit. Furthermore, its mathematical grounding in the Vlasov equation affirms its relevance to large-scale astrophysical systems.

Ultimately, this work bridges kinetic theory, general relativity, and thermodynamic logic in a uniquely constructive manner — not by violating known laws, but by passively leveraging them under extreme but physically meaningful conditions.

Acknowledgments

Simulation and modeling support implemented independently.

References

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