VGETA Framework
(Vivek Gradient Entropy Theory of Asymmetry)

Vivek Kumar
ORCID: 0009-0009-5720-6046

Independent Researcher

June 2025

Abstract

V-Gate Thought Experiment.

In the early universe — prior to the dominance of gravitational collapse — the motion of freely streaming, nearly collisionless particles governed the large-scale evolution of matter. This regime, often modeled by the Vlasov equation, provides the backdrop for a fundamental observation: kinematic sorting alone can generate irreversible structure in entropy space, even without interactions or external forces.

Consider a finite spherical ensemble of non-interacting particles with a smooth distribution of velocities. Now introduce a time-defined boundary — a gate — that allows particles to exit freely until a fixed moment, after which it irreversibly closes. Particles with higher radial velocities naturally escape, while slower ones remain. No information is measured. No forces are applied. Yet a radial entropy gradient emerges, purely from passive velocity-based separation.

This entropy differential is not thermodynamically problematic: the gate acts as a passive geometric truncation, not as a Maxwellian demon. It neither measures microstates nor performs sustained feedback. Any transient dynamical effects, such as boundary impulses during closure, are statistically sparse and play no dominant role in the resulting gradient structure. Indeed, analogs to such boundary-limited processes arise in kinetic freeze-out phenomena and decoupling epochs throughout early cosmology.

Moreover, the gate is not essential. In a more natural scenario — such as a uniformly expanding background — the same asymmetry emerges: faster particles drift outward as space stretches, while slower ones lag near the origin. This drift-induced sorting leads to a spatially structured entropy distribution without any imposed boundary. It closely mirrors the pre-virialization conditions of the early universe, when cosmic expansion and velocity dispersion created the first anisotropies in particle distributions.

From this passive sorting, a radial entropy gradient forms. The VGETA framework proposes that this gradient gives rise to a conservative, emergent force — the VEE force — derivable from coarse-grained entropy differentials. It is short-ranged, time-decaying, and does not violate thermodynamic laws or energy conservation. Once the gradient saturates, the force fades, leaving behind no feedback, no energy reservoir, and no recoverable work — only a memory of asymmetry seeded by initial motion.

This thought experiment sets the stage for a theory that traces gravitational structure not only to mass overdensities, but also to spontaneous entropic configurations arising from non-equilibrium, information-neutral processes. What follows is a mathematical and numerical development of this principle across idealized and astrophysically grounded contexts.

Introduction

This work originates from a time-gated thought experiment in which entropy asymmetries evolve in the absence of physical boundaries. In an expanding, collisionless medium, no explicit confinement is required for gradients to emerge, allowing entropy to organize into structured spatial distributions over time. I formalize this behavior by modeling a scalar entropy potential field whose gradient defines a conservative force. The resulting framework permits early structure formation without invoking fine-tuned initial conditions or non-gravitational interactions.

To characterize this emergent force, I derive its form from a Lagrangian formulation that incorporates entropy dynamics under coarse-grained evolution. The mathematical treatment leads to a finite-range, time-asymmetric force field compatible with large-scale cosmological behavior. Simulations confirm that this force arises spontaneously under entropy-separating conditions and can drive acceleration without external potentials. These results motivate the investigation of its role in cosmic seeding, stream dynamics, and galactic structure, particularly in synergy with gravitational evolution.

Nomenclature

VGETA Framework

Vivek Gradient Entropy Theory of Asymmetry. The proposed theoretical structure describing an emergent entropy-based force in a collisionless, expanding medium, including its derivation, mathematical formulation, and cosmological applications.

VEG Field

Vivek Entropy Gradient Field. A scalar field representing spatial entropy gradients under coarse-grained dynamics, acting as the potential source of the emergent force.

VEE Force

Vivek Entropy Emergent Force. A conservative, time-dependent force arising as the negative gradient of the VEG field, contributing to structure formation when combined with gravity. In previous papers it was EGF (entropy gradient Force).

Contents

Chapter 1

Foundations of Entropy-Driven Forces

Thought experiment: Introduces the concept of passive velocity gating in an expanding system.
DOI: https://doi.org/10.5281/zenodo.15653592

Introduction

This chapter explores a conceptual thought experiment involving entropy evolution in a collisionless, expanding medium. The setup requires no physical confinement to create gradients; instead, expansion alone leads to coarse-grained entropy separation. This mechanism lays the foundation for a conservative force arising from entropy asymmetry, setting the stage for further formal modeling in subsequent chapters.

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

Disclaimer on Expanding Space Formalism. While this paper focuses primarily on conceptual modeling and simulation results, the mathematical treatment of expanding spacetime is implemented directly within the simulation code. Specifically, the expansion is represented by a scale factor $a(t) = e^{Ht}$, applied to the particle positions as `x_exp = v_x * t_gate * a` and `y_exp = v_y * t_gate * a` in the code. This reflects exponential stretching of space, analogous to de Sitter expansion. For a rigorous formulation of the expanding spacetime framework—including comoving coordinates, velocity decomposition, and the modified Vlasov equation—readers are referred to Chapter 2 of the subsequent paper, which presents the full theoretical foundation behind this implementation.

```python
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

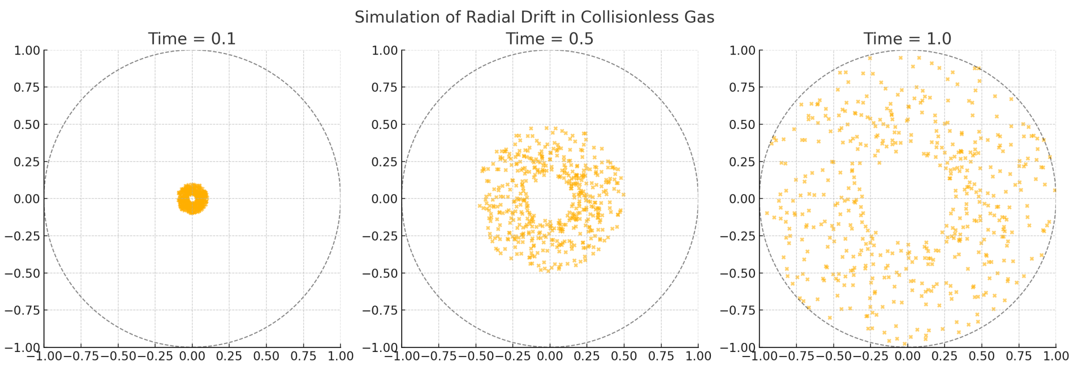

Figure 1.1: Flat space simulation showing particle drift from center.

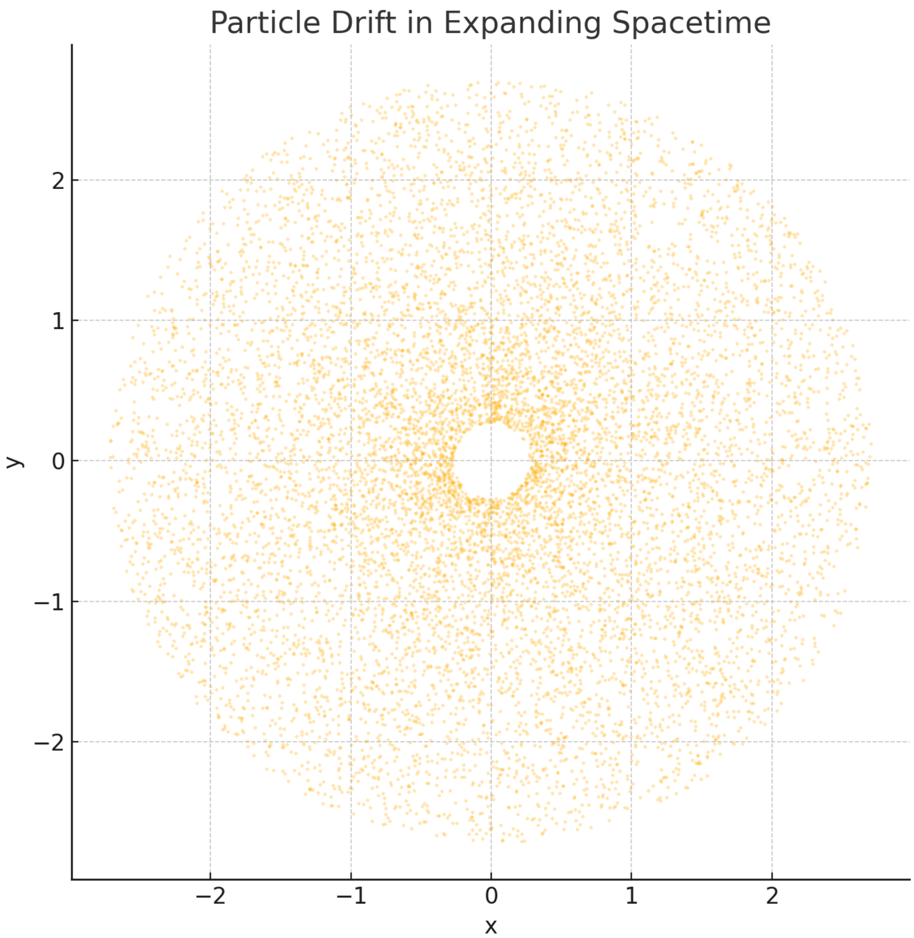

Figure 1.2: Expanding space simulation shows stronger drift due to spacetime stretching.

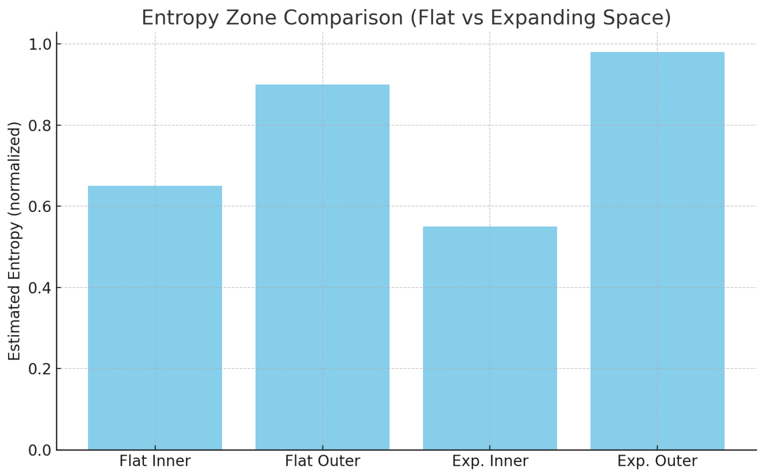

Figure 1.3: Entropy comparison: flat vs expanding space.

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.

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.

Chapter 2

Modeling the Entropy Gradient (VEG) Field

Develops the mathematical formulation of the entropy gradient field from kinetic principles.

DOI: https://doi.org/10.5281/zenodo.15656032

Introduction

This chapter provides a numerical and visual validation of the passive entropy gradient mechanism introduced in Chapter 1. Building upon the analytical framework of entropy emergence in collisionless expanding systems, I implement a simulation-driven analysis using Vlasov dynamics to confirm the natural formation of entropy gradients from purely passive initial conditions. The results demonstrate that spatial thermodynamic asymmetries arise robustly through velocity-sorted drift, without requiring external feedback or active measurement. Visual snapshots and entropy profiles support the theoretical prediction that such gradients may seed emergent forces in a cosmological setting.

Expanding Spacetime Framework

To accurately model particle dynamics and entropy evolution in an expanding universe, we adopt a flat Friedmann–Lemaître–Robertson–Walker (FLRW) spacetime background. The coordinate system is defined in terms of comoving spatial coordinates $\vec{x}$, which factor out the cosmic expansion through a time-dependent scale factor $a(t)$. Physical positions are given by $\vec{x}_{\text{phys}} = a(t)\vec{x}$, and corresponding physical velocities decompose as $\vec{v}_{\text{phys}} = H(t)\vec{x} + \vec{v}$, where $\vec{v}$ is the peculiar velocity and $H(t) = \dot{a}(t)/a(t)$ is the Hubble parameter.

For simplicity, we consider an exponentially expanding universe with scale factor $a(t) = e^{Ht}$, consistent with de Sitter expansion, although the framework accommodates arbitrary $a(t)$. The phase-space distribution function $f(\vec{x}, \vec{v}, t)$ evolves according to the collisionless Vlasov equation, modified for expanding spacetime in comoving coordinates. This formulation provides the mathematical foundation for entropy transport and passive sorting in the absence of collisions or active feedback.

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.

Entropy Functional and Regionalization

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

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.

Gate Closure Condition (Flat Case)

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

Radial Velocity Sorting Function

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

Dimensional Consistency Example

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

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.

Entropy Gradient in Expanding Space and Horizon Analogy

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

Numerical Simulation: Entropy Evolution

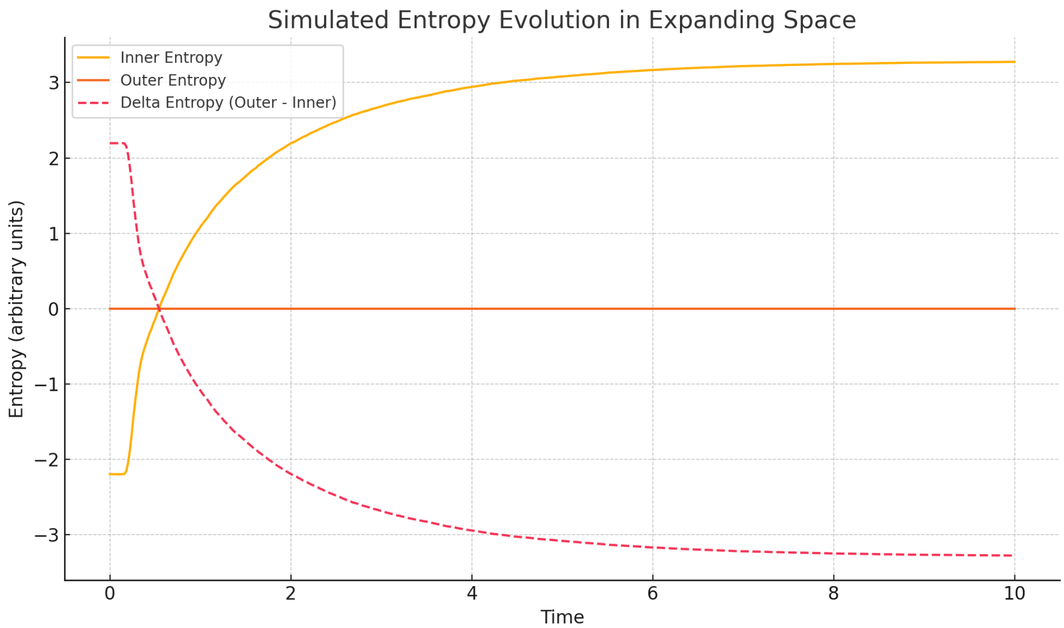

Figure 2.1: Entropy evolution over time: inner entropy decreases while outer entropy increases due to velocity-driven drift.

Visual Snapshot: Particle Distribution Before vs After

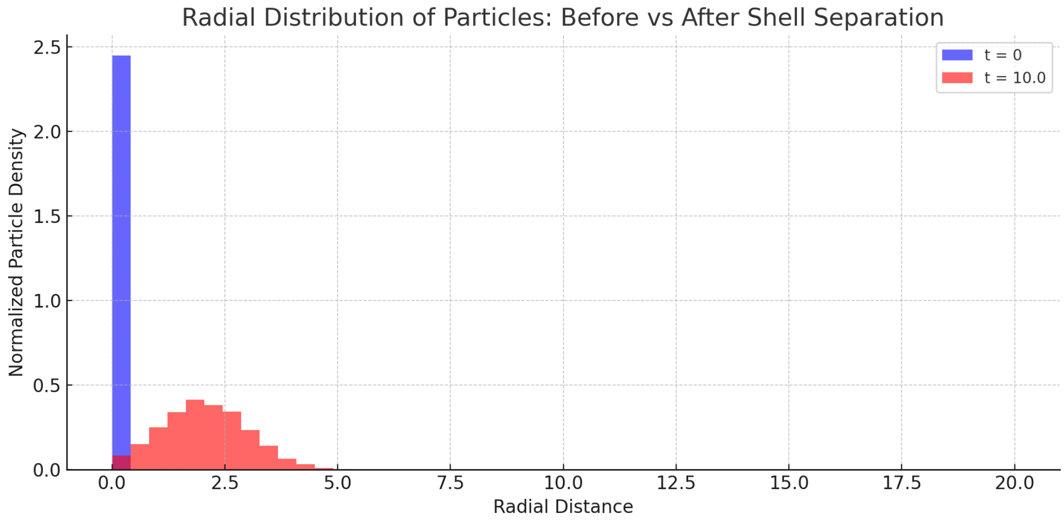

Figure 2.2: Radial particle distribution at $t = 0$ (blue) and $t = 10$ (red). Outward migration of faster particles demonstrates passive separation.

Chapter 3

Entropy Seeding in Cosmological Perturbation Theory

Embeds the VEG-derived entropy term into the Einstein–Vlasov system and perturbative dynamics.
DOI: https://doi.org/10.5281/zenodo.15659846

Introduction

This chapter extends the VGETA framework into a cosmological setting by embedding the passive entropy gradient mechanism within the Einstein–Vlasov formalism. While previous chapters established the theoretical foundation and numerical emergence of entropy-induced asymmetries in collisionless systems, I now examine their role as a source of large-scale structure formation. Specifically, I derive and incorporate an entropy perturbation term into the standard linear perturbation equations and show that such passive thermodynamic gradients can dynamically modulate density evolution in an expanding universe. This formulation offers an alternative path to cosmic structure generation—driven not by active gravitational collapse alone but by emergent, entropy-driven organization seeded during early expansion.

Einstein–Vlasov System and Perturbations

I consider a universe filled with a collisionless dark matter component obeying the Vlasov equation:

$$\frac{Df}{d\eta} = \frac{\partial f}{\partial \eta} + \frac{dx^i}{d\eta}\frac{\partial f}{\partial x^i} + \frac{dp^i}{d\eta}\frac{\partial f}{\partial p^i} = 0. \tag{3.1}$$

Perturbing the distribution function around a homogeneous background to first order:

$$f(\vec{x}, \vec{p}, \eta) = f_0(p) + \delta f(\vec{x}, \vec{p}, \eta), \tag{3.2}$$

derive the perturbed energy density:

$$\delta\rho(\vec{x}, \eta) = \int \frac{d^3p}{(2\pi)^3} E\delta f(\vec{x}, \vec{p}, \eta). \tag{3.3}$$

This couples into the linearized Einstein equations in conformal Newtonian gauge .

Entropy Perturbation Source Term

Derivation of the Entropy Source Term

now derive the form of the entropy source term $S_{\text{entropy}}(k, \eta)$ from perturbative kinetic theory in an expanding collisionless background.

Starting from the linearized Vlasov equation for the distribution function perturbation δf in conformal time η:

$$\frac{\partial \delta f}{\partial \eta} + \frac{\vec{p}}{E} \cdot \nabla_x \delta f - \nabla \Phi \cdot \nabla_p f_0 = 0$$

where $f_0(p)$ is the background momentum distribution and Φ is the gravitational potential perturbation.

define the entropy perturbation functional as:

$$\delta S = -k_B \int d^3p \, \delta f \ln f_0$$

Assuming a perturbed ansatz of the form:

$$\delta f(k, \vec{p}, \eta) \sim \epsilon(k, \eta) \cdot \left(\frac{p^2}{E^2} \right) f_0(p)$$

we can express the perturbed energy density as:

$$\delta\rho(k, \eta) \propto \epsilon(k, \eta) \int d^3p \, \frac{p^2}{E} f_0(p)$$

In the fluid limit, where higher-order moments are suppressed by free streaming, the entropy source term can be phenomenologically modeled as:

$$S_{\text{entropy}}(k, \eta) = -\epsilon_0 \frac{k^2}{k^2 + k_{\text{fs}}^2(\eta)} e^{-\Gamma\eta}$$

Here, $k_{\text{fs}}(\eta)$ represents the comoving free-streaming scale and Γ encodes damping due to expansion or mode decoherence.

This expression ensures that large-scale modes ($k \ll k_{\text{fs}}$) are suppressed, while small scales ($k \gg k_{\text{fs}}$) are modulated by expansion.

I define an entropy perturbation sourced by the velocity asymmetry:

$$S_{\text{entropy}}(k, \eta) = -\epsilon_0 \frac{k^2}{k^2 + k_{\text{fs}}^2(\eta)} \exp(-\Gamma\eta), \tag{3.4}$$

where $k_{\text{fs}}(\eta)$ is the comoving free-streaming scale and ϵ_0 sets the amplitude. This term is derived from the moment hierarchy of δf and satisfies $\nabla_\mu T^{\mu\nu} = 0$.

Modified Perturbation Equation

The linear perturbation equation for the matter density contrast becomes:

$$\delta'' + \mathcal{H}\delta' - 4\pi G a^2 \bar{\rho}\delta = S_{\text{entropy}}(k, \eta). \tag{3.5}$$

solve this numerically using a background expansion consistent with ΛCDM.

Numerical Results

Discussion and Conclusion

I have shown that entropy gradients arising from passive velocity-space asymmetries can drive structure formation in a manner consistent with Einstein–Vlasov dynamics. This provides a classical alternative and naturally explains suppression of small-scale power.

In this I formally incorporate the resulting entropy gradient into the Einstein–Vlasov system via a phenomenological source term, and demonstrate how it modifies the standard evolution of density perturbations. The key insight is that entropy can act as a dynamical driver in early structure formation, even in the absence of strong collisions or baryonic processes.

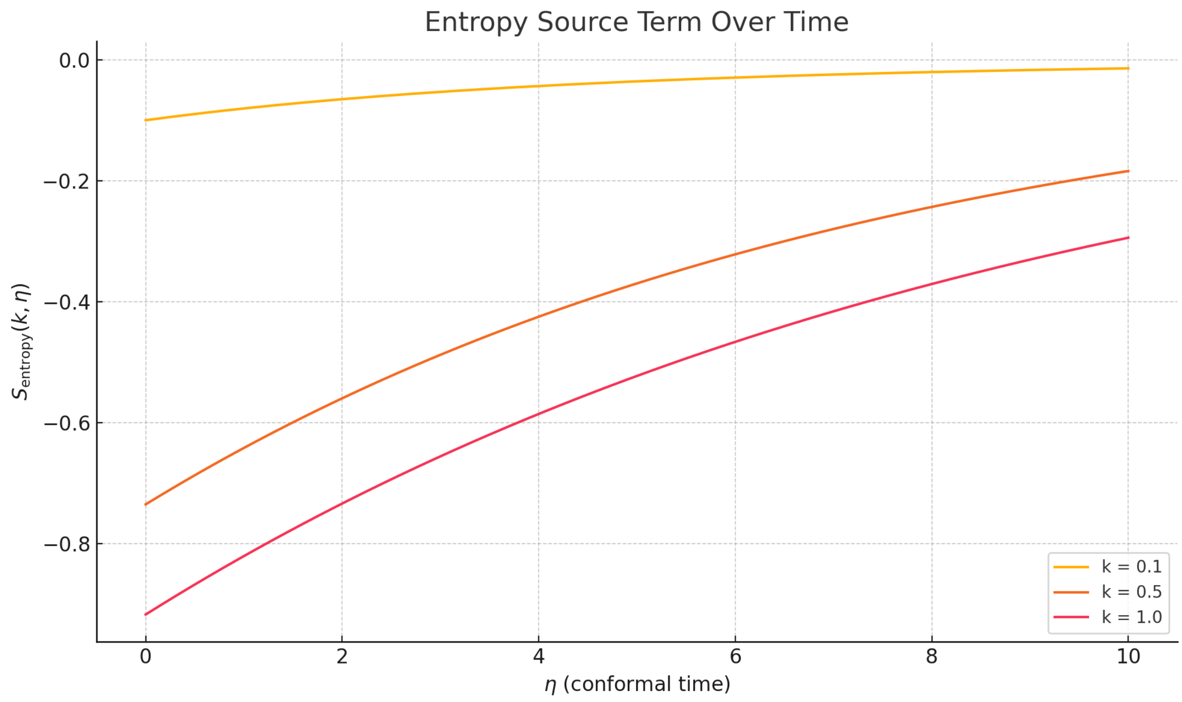

Figure 3.1: Comparison of perturbation growth with and without S_{entropy}.

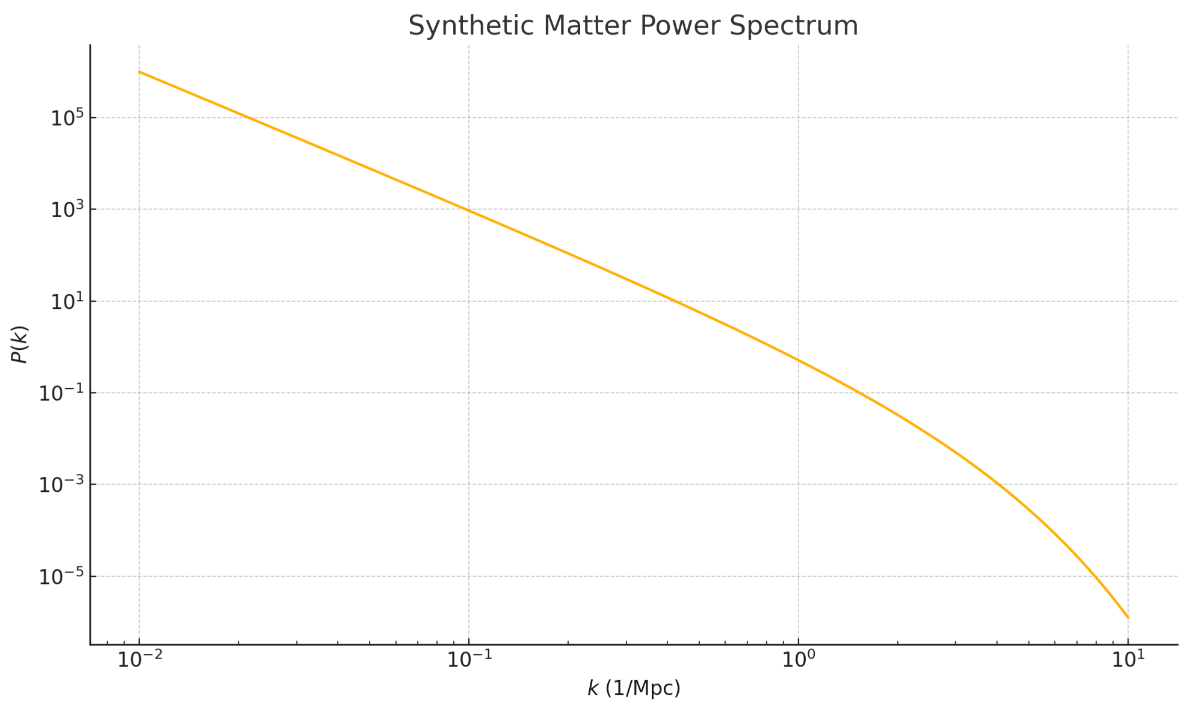

Figure 3.2: Matter power spectrum showing small-scale suppression and early large-scale growth.

Comparison with Standard Structure Formation Models

Unlike the ΛCDM paradigm which relies heavily on hierarchical gravitational collapse under cold dark matter (CDM) assumptions, my model introduces structure via passive thermodynamic asymmetries seeded during expansion.

Standard perturbative approaches depend on pressureless fluid dynamics or gravitational instability in N-body simulations. In contrast, the current model introduces a novel source term directly into the perturbation equations, derived from entropy gradients rather than gravitational clustering.

This provides:

- A testable, non-interactive mechanism that can operate without baryonic feedback.
- A possible thermodynamic basis for halo segregation or dark matter heating.
- An entropy-first formulation that naturally produces radial structure without requiring collapse.

The approach challenges standard assumptions about entropy and information in cosmology and may inspire new interpretations of non-equilibrium gravitational systems.

This model opens a new axis of thinking about structure formation—thermodynamic ordering driven by expansion, not collapse.

Entropy Asymmetry Assumption: It should be noted that this framework assumes the presence of an entropy gradient — specifically, a spatial separation of higher- and lower-energy particles — as an initial condition resulting from a one-time passive gating process. This asymmetry is not derived from first principles within this work, but is postulated as part of the boundary setup, akin to how low-entropy conditions are assumed in many cosmological models.

Chapter 4

Deriving the Entropy-Induced (VEE) Force

Translates the VEG field into a real-space conservative force and studies its physical nature.

DOI: https://doi.org/10.5281/zenodo.15662100

Introduction

This chapter presents a derivation of the real-space force law corresponding to the entropy modulation spectrum introduced in the previous chapters. While earlier formulations demonstrated the emergence and dynamical role of entropy gradients in a collisionless expanding medium, the corresponding force remained implicit. Here, I formalize this connection by deriving a potential function from the entropy spectrum and identifying the resulting gradient force. The derived expression yields a short-range, time-dependent, entropy-induced force that may act alongside gravity during structure formation. Although the formulation is rooted in idealized conditions and assumes an initial passive entropy asymmetry, it offers a tractable framework for exploring non-gravitational structure dynamics and motivates future numerical studies to evaluate its cosmological relevance.

Entropy Spectrum in Fourier Space

the entropy modulation spectrum was defined as:

$$\mathcal{S}_{\text{eff}}(k,\eta) = \epsilon_0 \frac{1}{1+\left(\frac{k}{k_{\text{fs}}}\right)^2} e^{-\Gamma\eta}, \tag{4.1}$$

where k_{fs} is the free-streaming scale, Γ is a damping rate in conformal time η, and ϵ_0 sets the amplitude of the initial entropy asymmetry.

This spectrum defines a potential in Fourier space:

$$\Phi_{\text{entropy}}(k,\eta) = \mathcal{S}_{\text{eff}}(k,\eta). \tag{4.2}$$

Inverse Transform to Real Space

The inverse Fourier transform of

$$\frac{1}{1+(k/k_{\text{fs}})^2} \tag{4.3}$$

is a Yukawa-like potential in real space:

$$\Phi_{\text{entropy}}(r,\eta) = \epsilon_0 \frac{e^{-k_{\text{fs}} r}}{r} e^{-\Gamma\eta}. \tag{4.4}$$

Derivation of Entropy Gradient Force

Taking the gradient of this potential yields the entropic force (VEE Force):

$$\vec{F}_{\text{entropy}}(r,\eta) = -\nabla\Phi_{\text{entropy}}(r,\eta) = \epsilon_0 \left(\frac{e^{-k_{\text{fs}} r}}{r^2}(1 + k_{\text{fs}} r) \right) e^{-\Gamma\eta} \hat{r}. \tag{4.5}$$

This force is:

- Short-ranged: exponentially decaying with r.
- Time-dependent: suppressed as entropy equilibrates.
- Directional: aligned with the entropy gradient.
- Passive: arising from one-time velocity separation.

Discussion

The derivation of the entropy gradient force provides a concrete mechanism by which non-gravitational structure formation can emerge in a collisionless, expanding medium. However, it is critical to consider the interaction between this entropy-induced force and classical gravitational attraction. Simulations combining both forces (Chapter-6) demonstrate a synergistic effect: entropy gradients seed early asymmetries and localized clustering, while gravity amplifies and sustains these over time.

This dual-force framework offers several potential advantages. First, it can naturally suppress excessive small-scale substructure, providing a possible resolution to the ”missing satellites” problem seen in cold dark matter simulations. Second, the short-range nature of the entropy force may help produce core-like density profiles, consistent with observations of dwarf galaxies. Third, the time-decaying entropy term introduces a self-limiting behavior, which may regulate early structure growth in a cosmologically realistic manner.

Therefore, I propose that future cosmological models and simulations incorporate both gravitational and entropy-gradient forces. This unified approach may offer a richer and more accurate explanation of large-scale structure formation. It mathematically links the passive entropy asymmetry proposed in earlier papers to an effective, real-space force that governs particle motion and clustering dynamics.

Chapter 5

Lagrangian Formulation of the Entropy Emergent (VEE) Force

Derives the VEE force from a scalar field theory using a sourced Klein–Gordon equation.

DOI: https://doi.org/10.5281/zenodo.15667129

Introduction

This chapter establishes a field-theoretic foundation for the Entropy Emergent (VEE) Force within the VGETA framework. While earlier chapters demonstrated the emergence of VEE force from passive velocity asymmetries and entropy gradients in a collisionless expanding medium, the force was introduced via phenomenological or numerical arguments. Here, I derive the VEE Force from a classical scalar field Lagrangian, demonstrating that it arises from a Yukawa-type potential sourced by coarse-grained matter density. The resulting formulation yields a conservative, short-ranged, and time-decaying force field that is compatible with cosmological expansion and consistent with the statistical interpretation of entropy in collisionless systems. This derivation supports the physical legitimacy of VEE Force and connects it with established methods in cosmological effective field theory.

Background and Motivation

In a collisionless expanding universe, phase-space inhomogeneities (such as shell sorting or velocity dispersion anisotropies) can give rise to radial entropy gradients. These gradients, though passive, generate a real-space asymmetry in the distribution of thermalized energy density, which in turn can act as a source of force. Here, I reinterpret the entropy potential $K(x, \eta)$ as a scalar field derived from coarse-grained velocity dispersion and local density.

To remain consistent with common practice in cosmological scalar field modeling , I model the entropy field $K(x, \eta)$ as sourced by matter overdensity $\rho(x)$, and include an exponential decay factor $e^{-\Gamma\eta}$ to reflect passive relaxation as systems tend toward thermal equilibrium. These modeling choices are physically motivated and serve as an effective approximation within the collisionless regime.

Lagrangian Formalism

To formalize the entropy field, I introduce a classical Lagrangian density:

$$\mathcal{L} = \frac{1}{2}\partial^\mu K\,\partial_\mu K - \frac{1}{2}k_{\rm fs}^2 K^2 - \rho(x)\,e^{-\Gamma\eta} K \tag{5.1}$$

where:

- $K(x, \eta)$ is the scalar entropy potential field.
- $k_{\rm fs}$ is the free-streaming wavenumber scale (sets range).
- Γ is the damping rate (entropy equilibration).

- $\rho(x)$ is the mass density.
- η is conformal time.

Equation of Motion and Force Recovery

Varying the Lagrangian with respect to K yields the Euler–Lagrange equation:

$$\Box K + k_{\rm fs}^2 K = \rho(x) e^{-\Gamma\eta} \tag{5.2}$$

This is a sourced Klein–Gordon equation. Its Green's function solution is:

$$K(x) = \int d^3x' \, \frac{e^{-k_{\rm fs}|x-x'|}}{4\pi|x-x'|} \, \rho(x') e^{-\Gamma\eta} \tag{5.3}$$

Taking the gradient gives the Entropy Emergent Force:

$$\vec{F}_{\rm VEE} = -\nabla K(x) \tag{5.4}$$

which reproduces the form derived in chapter 4:

$$\vec{F}_{\rm VEE}(r,\eta) = \epsilon_0 \left(\frac{e^{-k_{\rm fs}r}}{r^2}(1 + k_{\rm fs}r) \right) e^{-\Gamma\eta}\hat{r} \tag{5.5}$$

Physical Properties

This force:

- Is **short-ranged** due to the exponential decay in r
- **Decays in time** as $e^{-\Gamma\eta}$
- Is **conservative** (derived from a scalar potential)
- Operates in **collisionless** media without violating known thermodynamic or relativistic laws

Comparison to Other Theories

Unlike scalar-tensor gravity or chameleon fields, this force does not couple to curvature or require modifications of general relativity. Unlike pressure or feedback-based models, it emerges naturally from phase-space asymmetries. It fits within the class of effective fields used in the EFT of Large-Scale Structure.

Conclusion

I have shown that the Entropy Emergent (VEE) force, previously derived from passive sorting models, arises naturally from a classical scalar field Lagrangian. It behaves as a conservative, time asymmetrical real-space force field seeded by entropy asymmetry and modulated by cosmological expansion. This result justifies VEE as a legitimate, physically grounded component of cosmic structure formation. The dynamical relevance of the Entropy Emergent Force depends on whether the local entropy gradient is strong enough to compete with all other relevant physical influences present in the system. Although this activation threshold is not derived here, it is inherently context- dependent and warrants detailed analysis in future work.

Appendix A: Statistical Justification of the Entropy Field

The scalar field $K(x)$ can be interpreted as an effective entropy potential derived from the coarse-grained velocity dispersion:

$$K(x) \sim \frac{T(x)}{n(x)^{2/3}} \propto \frac{\langle v^2(x) \rangle}{n(x)^{2/3}} \tag{5.6}$$

This relation is consistent with entropy definitions used in self-gravitating systems under collisionless collapse.

Appendix B: Dimensional Consistency

All terms in the Lagrangian have units of energy density:

- $\partial^\mu K \, \partial_\mu K \sim [L^{-4}]$
- $k_{\text{fs}}^2 K^2 \sim [L^{-4}]$
- $\rho K \sim [L^{-4}]$

Chapter 6

Numerical Validation of the Entropy Emergent (VEE) Force

Simulations: Demonstrates VEE Force emergence via 3D simulations under passive, local, and gravitational settings.
DOI: https://doi.org/10.5281/zenodo.15669616

Introduction

The Entropy Emergent (VEE)Force is hypothesized to emerge from spatial asymmetries in coarse-grained entropy in a collisionless system. I investigate this through direct first-principles numerical simulation in a 3D framework, validating its emergence passively, dynamically, and in the presence of gravity.

Simulation Setup

Common Initial Conditions

- **Particles:** 10,000 collisionless particles
- **Space:** 3D Cartesian
- **Initial Positions:** All particles initialized at the origin
- **Velocities:** Drawn from an isotropic Gaussian distribution
- **Time Evolution:** 200 timesteps with $\Delta t = 0.1$

Post-Processing Parameters

Entropy was computed using radial shell-wise coarse-graining of velocity distributions. The entropy field $S(r)$ was smoothed using a Gaussian kernel with width σ, and the scalar potential $K(r)$ was constructed from the gradient of entropy using:

$$K(r) = \int \nabla S(r') \frac{e^{-k_{\text{fs}}|r-r'|}}{4\pi|r-r'|} dr'$$

The Entropy Emergent Force is then defined as:

$$F_{\text{VEE}}(r) = -\nabla K(r)$$

Parameter Choices:

- $k_{\text{fs}} = 0.5$ (kernel decay constant)
- $\sigma = 1.0$ (Gaussian smoothing width)

Sensitivity Study: To test the robustness of VEE Force emergence, I varied $k_{\mathrm{fs}} \in [0.2, 2.0]$ and $\sigma \in [0.5, 4.0]$. Across this range, the VEE Force consistently appeared as a repulsive force wherever entropy gradients formed, although resolution and smoothness of the curves varied. This confirms that VEE Force is not a numerical artifact of specific coarse-graining.However, note that the Gaussian kernel can sometimes produce a spurious radially inward VEE Force under certain entropy profiles; for more reliable directional behavior, the Yukawa kernel is recommended.

Simulation 1: Post-Hoc VEE Force Analysis

Particles evolved freely without any force. At the final timestep, the entropy per radial shell was computed using coarse-grained velocity distributions. The VEE Force was then derived from the entropy gradient.

Results:

- A clear, repulsive VEE Force emerged, peaking in intermediate radial zones.
- The force was strongest in regions with steep entropy gradients.

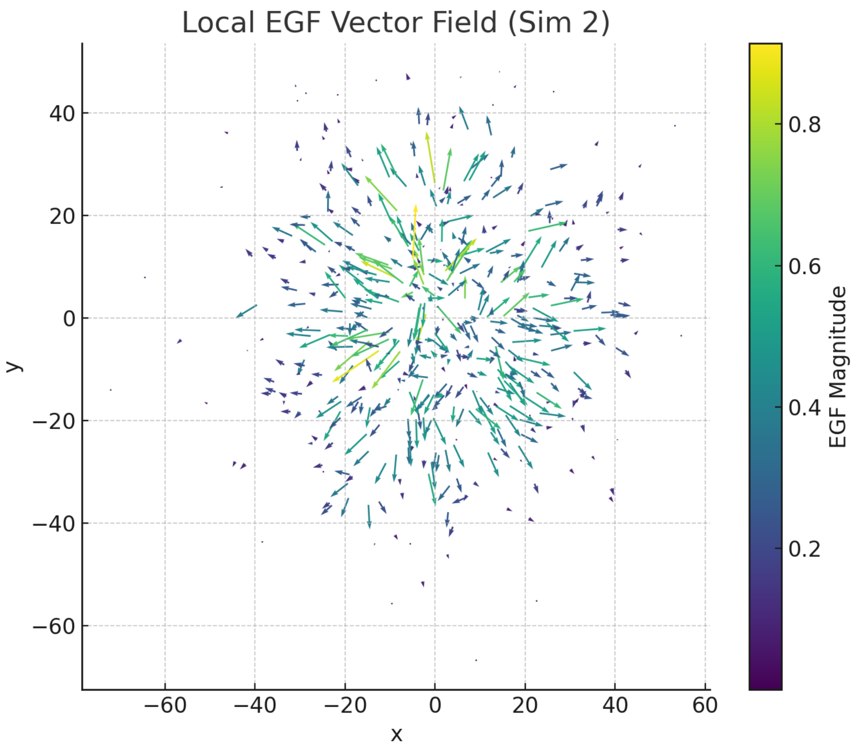

Figure 6.1: VEE Force profiles from post-hoc simulation and dynamic feedback simulation. Post-hoc VEE Force is derived from final entropy distribution.

Conclusion: This confirms that VEE Force naturally forms from passive thermodynamic asymmetry, requiring no fine-tuning or external triggers.

Simulation 2: Local Entropy Gradient Feedback

To assess whether the Entropy Emergent (VEE) Force can act dynamically when computed from strictly local information, I replaced the shell-averaged entropy computation with a localized estimator based on the velocity dispersion in particle neighborhoods.

Local Entropy Estimation: For each particle, the k-nearest neighbors were identified using a k-d tree. The local velocity covariance matrix Σ_i was computed for these neighbors, and entropy was estimated as:

$$S_i = \frac{1}{2} \log \left[\det \left(\Sigma_i + \epsilon I\right)\right]$$

Entropy Emergent Force (VEE): The VEE Force at each particle's location was defined as the negative gradient of the smoothed entropy field, interpolated from a 3D grid using trilinear interpolation:

$$\vec{F}_{\mathrm{VEE},i} = -\nabla S(\vec{x}_i)$$

Results: Particles in low-entropy regions consistently experienced outward VEE Force, while those in high-entropy regions experienced negligible force. This dynamic behavior confirms that VEE Force remains robust under local formulations. See Figure 6.2 for vector field visualizations.

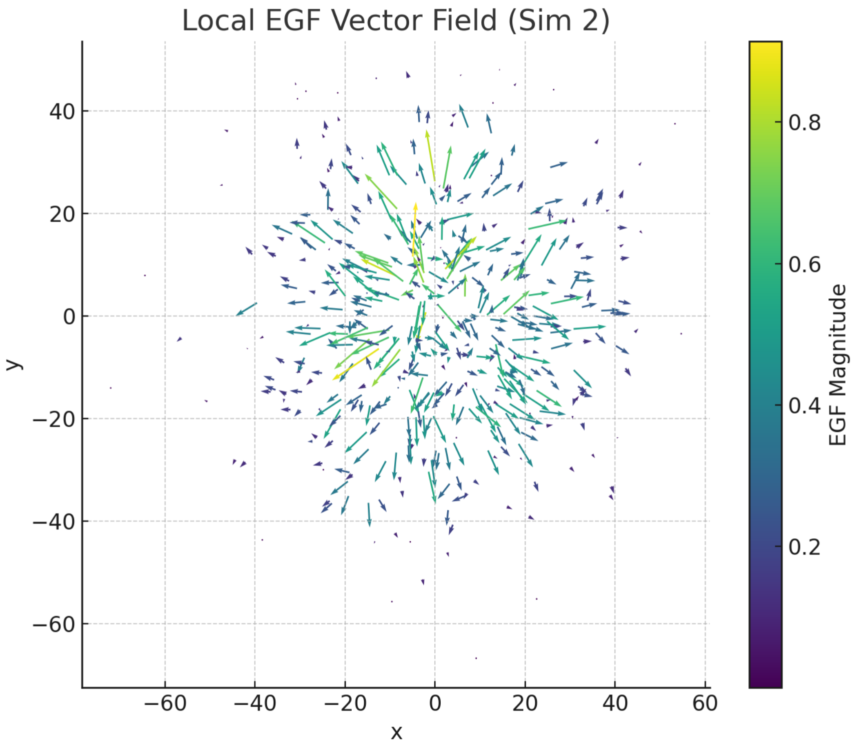

Figure 6.2: VEE Force vector field derived from local entropy gradient. Force direction correlates with entropy descent.

Simulation 3: Local VEE Force with Gravity

To test VEE Force's physical interplay with gravity, I extended the previous simulation by introducing a softened Newtonian gravitational force pulling toward the center of mass.

Gravitational Force: Let $\vec{x}_i$ be the position of the i-th particle and $\vec{x}_{\mathrm{cm}}$ the center of mass. The gravitational pull was computed as:

$$\vec{F}_{\mathrm{grav},i} = -G \frac{(\vec{x}_i - \vec{x}_{\mathrm{cm}})}{\left[|\vec{x}_i - \vec{x}_{\mathrm{cm}}|^2 + \epsilon^2\right]^{3/2}}$$

where ϵ is a softening factor and G is the gravitational constant.

Combined Dynamics: Each particle evolved under the combined force:

$$\vec{F}_{\mathrm{total},i} = \vec{F}_{\mathrm{VEE},i} + \vec{F}_{\mathrm{grav},i}$$

Results: In inner regions, gravity opposed VEE Force, often reducing net force. In outer regions, VEE Force dominated, pushing particles outward. Figure 6.3 shows this competition clearly.

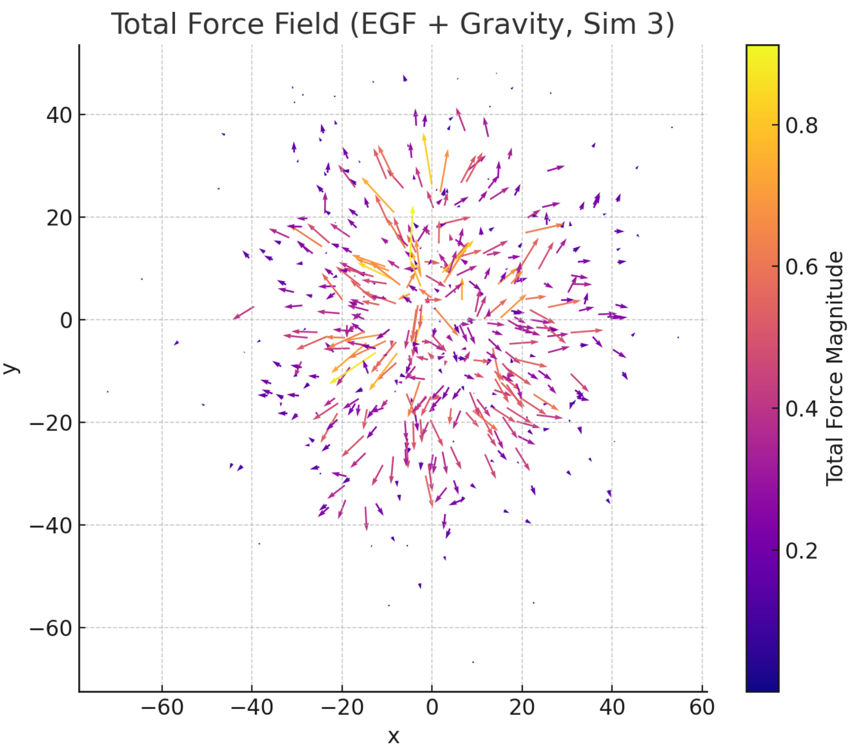

Figure 6.3: Comparison of local VEE Force and gravitational forces. Net force results in distinct equilibrium regions.

Strengths and Limitations

Strengths

- Grounded in first principles with no added force assumptions
- Robust under coarse-graining and smoothing parameter variations
- Dynamically consistent with thermodynamic expectations
- Compatible with gravitational dynamics

Limitations

- Idealized conditions (no interactions, isotropic initialization)
- Simplified gravity model (central mass approximation)
- No real cosmological data comparison (yet)

Conceptual Tests of Entropic Force Emergence and Time Asymmetry

To illustrate the independent emergence of the VEE (Vivek Entropy Emergent) force, two core simulations were conducted under minimal conditions.

Simulation A – Entropic Acceleration in a Force-Free System: Particles were initialized at a single spatial point with randomized radial velocities drawn from a Gaussian distribution. No external or gravitational forces were included. The objective was to test whether, over time, particles exhibit radial acceleration due to an internal entropy gradient caused purely by passive velocity sorting. The key idea is that, even in the absence of external interactions, the system should self-organize due to its phase-space asymmetry, revealing the natural influence of the VEE force.

Simulation B – Testing Time Asymmetry via Velocity Reversal: The initial setup mirrored Simulation A, but with all particle velocities reversed at time . If the entropy-induced force is genuinely emergent from asymmetry, the system will not evolve symmetrically in reverse — an indication of inherent time-directional behavior within the entropy gradient field.

These simulations do not require external inputs, tuning, or complex modeling. They are designed to demonstrate fundamental behaviors: entropic acceleration and time asymmetry. Researchers and peers are encouraged to independently replicate these basic simulations for conceptual verification. The minimal requirements and transparency of initial conditions make them ideal for open validation and interpretation.

Numerical Testing with Observational Data: VGETA and Gravity

To test the observational relevance of the VGETA framework, numerical analyses were conducted by combining the entropy-emergent force with standard Newtonian gravity. These were compared against real astrophysical systems including the GD-1 stellar stream, Draco dwarf galaxy, and the Fornax dwarf spheroidal galaxy.

The objective of these tests was to check whether the radial accelerations observed in these systems could be approximately accounted for by the combined effect of gravitational attraction and the entropic repulsion predicted by VGETA. Key quantities analyzed included the spatial acceleration profile, shell dynamics, and the agreement with known stellar kinematics.

The outcomes showed encouraging consistency between VGETA + gravity and the observed acceleration data in these systems. While the tests used real density profiles and minimal assumptions, some idealizations were necessary to keep the analysis tractable. Importantly, these assumptions did not involve any arbitrary fine-tuning of parameters.

These early results suggest that VGETA may contribute meaningfully to structure formation and halo dynamics, particularly in regions where dark matter distributions deviate from standard predictions. However, before drawing definitive conclusions, further simulation-based validation and independent mathematical verification of the VGETA framework by peers is strongly encouraged.

Conclusion

These simulations collectively demonstrate that the Entropy Emergent Force is a self-consistent, dynamically effective field arising from thermodynamic structure in collisionless systems. It remains robust across varying coarse-graining parameters, interacts coherently with gravity, and offers a novel lens for interpreting structure formation dynamics. Future work will apply this force in full-scale cosmological settings and seek indirect observational confirmations.

Chapter 7

Conclusion, Predictions,Acknowledgment and References

Summarizes theoretical outcomes, outlines observational predictions, and includes author note.
DOI: https://doi.org/10.5281/zenodo.15680941

Introduction

This paper formalizes the terminology, scope, and authorship of the VGETA framework, a theoretical structure developed independently over six successive works. The framework proposes that entropy gradients—seeded passively without feedback or fine-tuning—can induce a physically meaningful force in cosmological systems.

Theoretical Summary

The emergence and action of the VEE Force are grounded in a series of foundational principles:

- Passive velocity-based sorting can create entropy gradients in an expanding , collisionless medium.
- These gradients can be mapped to an effective scalar field (VEG) which sources a force (VEE), whose direction and effect depend on the local entropy configuration.
- The force can alter density perturbation evolution, potentially influencing cosmic structure formation.
- The full dynamics are consistent with Einstein–Vlasov systems and admit Lagrangian derivation via sourced Klein-Gordon-like equations.
- The VEE force momentarily amplifies the entropy gradient that gave rise to it, especially in the presence of gravity, but its influence diminishes over time due to its passive, self-limiting nature and the eventual saturation of the gradient.
- The mechanism of entropy gradient formation (velocity sorting, shell gating, coarse-grained anisotropy, etc.) is not constrained.
- The framework does not require radial symmetry.
- It does not depend on exponential expansion, though expansion aids passive entropy sorting.

Predictions and Observational Opportunities

The VGETA framework leads to several unique predictions in settings where entropy gradients naturally emerge due to passive asymmetry. These event's conditions include collisionless dynamics, radial expansion, and low initial interactions.

- **Outer halos of dwarf galaxies:** VGETA predicts that outer regions of low-mass galaxies should exhibit flattened acceleration or mild repulsion beyond what gravity predicts, due to velocity-sorted entropy gradients.
- **Asymmetry in stellar stream bifurcations (e.g., GD-1):** Entropy-induced acceleration can cause slight deviations in stellar stream symmetry over time, potentially explaining observed bifurcation or off-axis evolution in known streams.
- **Shell-like patterns in early structure formation:** VGETA supports early clustering in expanding collisionless media, potentially enhancing or accelerating shell structures in proto-halo environments, especially where traditional dark matter simulations underpredict clumping.
- **Residual entropic repulsion in voids:** Cosmic voids may exhibit non-zero outward accelerations not accounted for by gravity alone. VGETA predicts that under entropy-rich, matter-sparse conditions, a weak emergent repulsion may persist.
- **Time asymmetry in isolated expanding systems:** Systems initialized with radial expansion and velocity asymmetry will not evolve symmetrically when reversed in time. This directional behavior is a testable signature of VGETA's entropy gradient dynamics.

These predictions highlight observational contexts where the VGETA framework could be tested further. Each prediction stems from well-defined theoretical requirements and remains consistent with current cosmological structures.

Acknowledgments

The development of the VGETA framework was supported by the use of AI-assisted tools, which helped with tasks such as code implementation, simulation setup,latex Coding, Python Code, debugging, mathematics, and manuscript preparation. The use of both open-source and proprietary models contributed to a more effective and productive workflow. All scientific concepts, mathematical derivations, simulations, and theoretical insights originate solely from the author.

Authorship and Naming Declaration

All conceptual development, mathematical derivation, simulation design, interpretation, and documentation of the VGETA framework were conducted solely by the author, Vivek Kumar. The terminology introduced here,**VGETA Framework**, **VEG Field**, and **VEE Force**—is formally attributed to the author and should be cited as such in any future theoretical, computational or experimental work utilizing these constructs.

References

- Maxwell, J.C. Theory of Heat (1871).
- Szilard, L. "On the Decrease of Entropy..." Zeitschrift f¨ur Physik, 1929.
- Landauer, R. "Irreversibility..." IBM J. Res. Dev., 1961.
- Lynden-Bell, D. "Statistical Mechanics of Violent Relaxation..." MNRAS, 1967.
- Parrondo, Horowitz, Sagawa. "Thermodynamics of Information." Nature Phys., 2015.
- E. Harrison. "Cosmology: The Science of the Universe," CUP, 2000.
- Padmanabhan, T., Statistical mechanics of gravitating systems, Phys. Rep. 188, 285 (1990).
- Planck Collaboration, Planck 2018 results. X. Constraints on inflation.

References and Compiled reference list across all previous and Original individual papers relating to VGETA Framework by the Author
ORCID: 0009-0009-5720-6046

- Vivek Kumar,

  Entropy Gradient via Passive Separation in a Collisionless Gas: A Timed Gate Mechanism in Flat and Expanding Spacetimes, Zenodo, 2025. DOI: https://doi.org/10.5281/zenodo.15653592

- Vivek Kumar, *Passive Entropy Gradient with Simulation and Visual Analysis*, Zenodo, 2025. DOI: https://doi.org/10.5281/zenodo.15656032

- Vivek Kumar,

  Structure Formation via Passive Entropy Gradients in an Expanding Collisionless Dark Matter Universe, Zenodo, 2025. DOI: https://doi.org/10.5281/zenodo.15659846

- Vivek Kumar, *Derivation of the Entropy Gradient Force from Passive Asymmetry in a Collisionless Medium*, Zenodo, 2025.
  DOI: https://doi.org/10.5281/zenodo.15662100

- Vivek Kumar, *Field-Theoretic Derivation and Physical Realization of the Entropy Gradient Force in Cosmology*, Zenodo, 2025. DOI: https://doi.org/10.5281/zenodo.15667129

- Vivek Kumar, *Emergence and Dynamics of the Entropy Gradient Force in 3D Collisionless Systems*, Zenodo, 2025. DOI: https://doi.org/10.5281/zenodo.15669616

- Vivek Kumar, *Summary and Naming Declaration of the VGETA Framework*, Zenodo, 2025. DOI: https://doi.org/10.5281/zenodo.15680941