Cosmology from the Event Density Compositional Rule

Allen Proxmire
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Abstract

We apply the Event Density (ED) compositional rule to the universe as a whole and derive a coherent cosmological history without introducing geometry, fields, or background spacetime. In the high-ED, small-gradient regime, the quadratic gradient penalty drives an exponential decay of inhomogeneities, producing an inflation-like smoothing phase. As gradients diminish, the smoothing term weakens, leaving a small but finite level of residual structure. The concave relational penalty amplifies these residual gradients and stabilizes the resulting overdensities, yielding long-lived high-ED pockets that serve as the precursors of galaxies, stars, and clusters. ED flows outward from these pockets, reducing the global average ED density and driving a slow decay of gradients; this thinning process increases the coarse-grained homogeneity scale and functions as an ED analogue of cosmic expansion. At late times, gradients vanish, structures dissolve, and the boundary term dominates, producing horizon-like behavior and a thin, nearly uniform asymptotic state. Cosmology in ED is therefore not an additional assumption but a derived consequence of the compositional rule itself.

1. Introduction

Cosmology is the first large-scale test of the Event Density (ED) framework. Once the compositional rule is fixed, the evolution of the universe is no longer an external assumption or a geometric postulate—it is a dynamical consequence of how ED combines, competes, and redistributes across finite configurations. The purpose of this paper is to show that, without introducing a metric, fields, or background spacetime, the ED rule alone generates a coherent cosmological history with recognizable large-scale features: an early exponential smoothing phase, the emergence of residual gradients, the formation of long-lived high-ED structures, global thinning, and late-time flattening with horizon-like behavior.

The central idea is simple: **the universe is a finite configuration whose ED evolves according to the same compositional law that governs all subsystems.**

When applied at cosmological scales, this rule induces a natural coarse-grained dynamics for the average ED density and the typical gradient magnitude. These two quantities— $\tilde{\rho}(t)$ and $G(t)$ —play the roles ordinarily assigned to energy density and curvature in geometric cosmology, but here they arise from the internal bookkeeping of ED itself.

A key feature of the ED rule is the presence of three competing contributions:

1. a **relational penalty** that suppresses overlap of high-ED regions,
2. a **gradient penalty** that drives rapid smoothing, and
3. a **boundary term** that dominates in extreme regimes and produces horizon-like behavior.

In ordinary settings these terms govern competition, classicality, and holography. In cosmology they acquire a new interpretation: they dictate how the universe smooths, how structure seeds survive, how overdensities stabilize, and how the global ED density thins over time.

The early universe is characterized by high ED everywhere and small but nonzero gradients. In this regime the gradient penalty dominates, forcing an exponential decay of gradients and producing an inflation-like smoothing phase. As gradients diminish, the relational term becomes comparatively more important, allowing small residual variations to seed structure. High-ED pockets form and stabilize through the concavity of the relational penalty, while the average ED density decreases as ED flows outward from these pockets. At late times, gradients on large scales approach zero, structures slowly dissolve, and boundary effects dominate the remaining dynamics, yielding a heat-death-like asymptotic state.

This paper develops these ideas systematically. We begin by specifying the cosmological specialization of the compositional rule, introduce the coarse-grained variables that track large-scale evolution, and derive the early-time exponential smoothing behavior. We then analyze the emergence of structure from residual gradients, the long-term thinning of ED, and the late-time approach to a flat, horizon-dominated regime. Throughout, no geometric assumptions are made; the familiar features of cosmology arise from the internal logic of ED alone.

2. Cosmological Setup

Cosmology in ED begins with a simple observation: the universe is itself a finite configuration. Nothing in the framework distinguishes “the universe” from any other region except its size. The same compositional rule that governs small subsystems must therefore govern the evolution of the largest possible one. This section establishes the minimal structure needed to describe that evolution without introducing geometry or external dynamical assumptions.

2.1 Finite Configurations at Cosmological Scale

Let C(t) denote the finite configuration representing the universe at an ED-time parameter t. The ED density p(x,t) is defined on the space of microconfigurations $x \in C(t)$. No metric, background spacetime, or geometric structure is assumed; the only primitive is the ED distribution itself.

The evolution of C(t) is governed entirely by the compositional rule. As ED flows, competes, and redistributes across subregions, the effective “shape” of the universe changes. Cosmological behavior is therefore encoded in the large-scale statistics of p(x,t), not in geometric fields.

2.2 Coarse-Grained Variables

Although ED is defined microscopically, cosmology concerns the large-scale, averaged behavior of the universe.

Two coarse-grained quantities capture this behavior:

Average ED density

$$\hat{p}(t) = 1 / V(t) \int_{C(t)} p(x,t)\, d\mu(x)$$

This measures the global “thickness” of the universe. In early regimes $\hat{p}(t)$ is near its maximal value; in late regimes it approaches a minimal background level.

Typical gradient magnitude

$$G(t) = \langle |\nabla p\ (x,t)| \rangle$$

This measures the degree of inhomogeneity. Large G(t) corresponds to strong local variation; small G(t) corresponds to large-scale smoothness.

Coarse-grained length scale

The typical length over which p varies appreciably is inversely related to the gradient magnitude:

$$L(t) \sim 1 / G(t)$$

This is not a geometric distance but a measure of how far one must move in configuration space before ED changes significantly.

Scale factor proxy

We define:

$$a(t) \propto L(t)$$

This is the ED analogue of the cosmological scale factor. It tracks the growth of the coarse-grained homogeneity scale, not the stretching of a metric.

2.3 Regime Assumptions

The cosmological application of ED relies on three broad empirical assumptions, each of which is consistent with the ED axioms and supported by observation:

(1) Early universe thick everywhere

At sufficiently early times,

$$p(x,t) \approx p_{max}$$

for almost all microconfigurations. The universe begins in a high-ED, nearly uniform state.

(2) Small but nonzero initial gradients

Although the early universe is thick, it is not perfectly uniform. Small fluctuations exist:

$$0 < G(0) \ll p_{max}$$

These gradients are essential for later structure formation.

(3) No geometric structure assumed

The ED framework does not posit a metric, curvature tensor, or background spacetime. Any geometric interpretation must emerge from the behavior of $p(x,t)$ and its gradients.

2.4 Cosmology as a Derived Phenomenon

With these ingredients, cosmology becomes a derived consequence of the compositional rule. The evolution of $\hat{p}(t)$ and $G(t)$ is not imposed; it follows from the interplay of:

- relational penalties that suppress overlap of high-ED regions,
- gradient penalties that drive smoothing,
- boundary terms that dominate in extreme regimes.

The remainder of the paper shows how these ingredients generate a cosmological history with recognizable features — inflation, structure formation, expansion, and late-time flattening — without invoking geometry or external dynamical laws.

3. The Compositional Rule in Cosmological Regimes

The ED compositional rule is universal: it governs how ED combines across all finite configurations, from microscopic subsystems to the universe as a whole. Cosmology requires no new principles. What changes is only the scale at which the rule is applied and the regime in which the universe finds itself. In this section we specify the cosmological specialization of the rule and justify the functional choices that drive the large-scale dynamics.

3.1 The Compositional Rule

For any two finite configurations A and B, the ED of their union is:

$$p(A \cup B) = p(A) + p(B) - \alpha\int_{A\cap B} f(p)\, d\mu - \beta\int_{A\cup B} g(|\nabla p|)\, d\mu - \gamma \int_{\partial(A\cup B)} h(|\nabla p|)\, dS.$$

This expression contains three correction terms:

- a relational penalty over the overlap $A \cap B$,
- a gradient penalty over the union $A \cup B$,
- a boundary term over $\partial(A \cup B)$.

Each term reflects a distinct physical effect: competition, smoothing, and horizon behavior. In cosmology, these effects manifest as structure formation, inflation-like smoothing, and late-time horizon dominance.

3.2 Functional Choices for Cosmology

Cosmology does not require the full generality of the ED rule. The large-scale universe occupies a specific regime: high ED, small gradients, and slow variation across enormous scales. In this regime, the following functional choices capture the essential dynamics:

Relational term

$$f(p) = p^{\gamma}, \qquad 0 < \gamma < 1.$$

This concave form ensures:

- strong competition at moderate ED,
- soft saturation at high ED,
- stability of high-ED pockets (structure formation).

Gradient term

$$g(u) = u^2.$$

This quadratic penalty is the simplest choice that:

- drives rapid smoothing,
- produces exponential decay of gradients,
- yields an inflation-like phase without geometry.

Boundary term

h(u) increasing, saturating.

The boundary term must:

- reward or penalize sharp gradients at large-scale boundaries,

- dominate in extreme regimes (holographic behavior),
- remain finite even when gradients become large.

A saturating form ensures that horizons behave like stable, finite-cost boundaries.

3.3 Why These Choices Are Natural in Cosmology

These functional forms are not arbitrary. They are the simplest choices that satisfy the ED axioms and reproduce the qualitative features of the observed universe.

Concavity of p^γ

Concavity ensures that:

- small overdensities grow (structure seeds),
- large overdensities stabilize (galaxies, stars),
- competition remains strong but not pathological.

This is the ED analogue of gravitational instability.

Quadratic gradient penalty

The choice $g(u)=u^2$ is uniquely suited to cosmology:

- it produces exponential smoothing,
- it suppresses small-scale noise,
- it yields a natural inflation-like epoch.

No geometric assumptions are needed; the exponential behavior arises from the internal logic of ED.

Saturating boundary term

A saturating h(u) ensures:

- finite cost for horizon-scale gradients,
- area-law behavior in extreme regimes,
- stable boundary layers in late-time cosmology.

This is the same mechanism that produces black hole horizons in ED-06.

3.4 Cosmology as a Special Regime of the Universal Rule

With these choices, the compositional rule becomes:

$$p(A \cup B) = p(A) + p(B) - \alpha\int_{A\cap B} p^\gamma \, d\mu - \beta\int_{A\cup B} |\nabla p|^2 \, d\mu - \gamma \int_{\partial(A\cup B)} h(|\nabla p|) \, dS.$$

This is the cosmological specialization of the ED rule.

It is not a new law; it is the same universal rule, evaluated in the regime where:

- ED is high,
- gradients are small,
- boundaries are large,
- and the universe is nearly homogeneous.

The remainder of the paper shows how this rule generates the familiar large-scale history of the universe: early exponential smoothing, residual gradients, structure formation, global thinning, and late-time flattening.

4. Early Universe: ED Inflation

The early universe in ED is characterized by two empirical facts: the ED density is near its maximal value everywhere, and the gradients of p(x,t) are small but nonzero. In this regime the gradient penalty in the compositional rule dominates the dynamics. This dominance forces a rapid decay of gradients and produces an exponential smoothing phase that plays the role of cosmological inflation. Crucially, this behavior arises without introducing a metric, a scalar field, or any geometric structure. It is a direct consequence of the ED rule itself.

4.1 Dominance of the Gradient Term

In the early universe, the compositional rule reduces to its gradient-dominated form.

With $p(x,t) \approx p_{max}$ and $0 < G(0) \ll p_{max}$, the relational penalty $\int p^{\gamma}$ is nearly constant across the universe, while the boundary term is negligible because gradients are small everywhere. The only term that varies significantly across configurations is:

$$\beta \int_{C(t)} |\nabla p(x,t)|^2 \, d\mu.$$

This term penalizes inhomogeneity. When applied across the entire universe, it drives the system toward configurations with smaller gradients. The early universe therefore evolves by minimizing this quadratic gradient cost.

4.2 Coarse-Grained Gradient Dynamics

To track the large-scale effect of this penalty, we consider the evolution of the typical gradient magnitude:

$$G(t) = \langle |\nabla p\,(x,t)| \rangle.$$

The gradient penalty induces a diffusion-like smoothing behavior. At leading order, the coarse-grained evolution of G(t) takes the form:

$$dG \,/\, dt = -\lambda_1 \, G(t),$$

where $\lambda 1 > 0$ is an effective smoothing rate determined by β and the typical ED scale. This equation is not assumed; it is the natural coarse-grained limit of the quadratic gradient penalty in a nearly uniform, high-ED regime.

The key point is that the decay rate is proportional to the gradient itself.

This is the hallmark of exponential smoothing.

4.3 Exponential Decay of Gradients

Solving the gradient decay equation yields:

$$G(t) = G(0)\, e^{-\lambda 1 t}.$$

Thus, any initial inhomogeneity is rapidly suppressed. The universe becomes exponentially smoother on large scales, even though no geometric expansion has been introduced. The smoothing is a dynamical consequence of the ED rule.

This exponential decay is the ED analogue of inflation:

- it is rapid,
- it is driven by a simple term in the compositional rule,
- and it does not require a scalar field, potential, or metric.

The universe smooths because ED penalizes gradients.

4.4 Emergent Scale Factor

The coarse-grained length scale L(t) over which p(x,t) varies appreciably is inversely related to the gradient magnitude:

$$L(t) \sim 1 / G(t).$$

As gradients decay exponentially, the homogeneity scale grows exponentially:

$$L(t) \propto e^{\lambda_1 t}.$$

We define the ED scale factor by:

$$a(t) \propto L(t).$$

Thus:

$$a(t) \propto e^{\lambda_1 t}.$$

This is an inflation-like expansion, but it is not geometric.

It is the growth of the coarse-grained homogeneity scale induced by the ED rule.

4.5 Interpretation

The ED inflation phase has three essential features:

1. It is universal.
    Any high-ED, small-gradient configuration undergoes exponential smoothing.
2. It is dynamical.
    No special initial conditions or fields are required.
3. It is finite.
    As gradients decay, the gradient penalty weakens, and the exponential phase naturally ends.

This provides a clean, non-geometric explanation for why the universe is smooth on large scales and why inflation ends without fine-tuning.

5. Post-Inflation: Residual Gradients and Seeds

The exponential smoothing of the early universe does not drive the ED distribution to perfect uniformity. Instead, the ED rule ensures that a small but finite level of inhomogeneity survives the inflation-like phase. These residual gradients play the role of primordial seeds: they define flow directions, generate curvature-like behavior, and initiate the formation of long-lived high-ED structures. In this section we explain why gradients do not vanish, how they persist, and why their survival is essential for the later evolution of the universe.

5.1 Why Gradients Do Not Vanish

The gradient penalty $\beta \int |\nabla p|^2$ drives rapid smoothing, but its influence weakens as gradients decay. Once $G(t)$ becomes sufficiently small, the penalty becomes negligible compared to the other terms in the compositional rule.

The universe enters a regime where:

$$dG / dt \approx -\lambda 1 G(t) \qquad \text{only while } G(t) \text{ is not too small.}$$

As $G(t)$ approaches zero, the effective smoothing rate $\lambda 1$ decreases. The system no longer "feels" the gradient penalty strongly enough to eliminate the remaining inhomogeneity. The exponential decay slows, and the universe asymptotically approaches a state with:

$$0 < G(t_{post}) \ll 1.$$

This is a stable fixed point of the early-time dynamics: gradients become small, but not zero.

5.2 Residual Gradients as Structural Degrees of Freedom

These surviving gradients are not noise. They are the first nontrivial degrees of freedom in the post-inflation universe. They determine:

- preferred directions of ED flow,
- the locations of future overdensities,
- the initial curvature-like behavior,
- the seeds of structure formation.

In ED, gradients are not geometric objects; they are differences in the local density of becoming. Yet they play a role analogous to curvature perturbations in standard cosmology: they determine how ED redistributes and where it accumulates.

Residual gradients therefore encode the universe's first large-scale structure.

5.3 Competition Amplifies Small Differences

Once the gradient penalty weakens, the relational penalty becomes comparatively more important. With $f(p)=p\gamma$ concave, the relational term:

$$\alpha \int p^{\gamma}$$

has two key effects:

1. It amplifies small overdensities.
   Regions with slightly higher p experience a larger relational penalty, which slows their outward ED flow. This creates a positive feedback loop: small differences grow.
2. It stabilizes high-ED pockets.
   Because $p\gamma$ grows sublinearly, the penalty saturates at high ED, allowing overdense regions to persist as metastable structures.

Thus, the same concave relational term that governs competition at small scales becomes the engine of structure formation at cosmological scales.

5.4 Residual Gradients as the Origin of Structure

The ED rule therefore predicts:

- Inflation-like smoothing eliminates large gradients.

- Residual gradients survive because the smoothing term weakens.
- Competition amplifies these residual gradients.
- Concavity stabilizes the resulting overdensities.

This sequence yields a natural, deterministic mechanism for the emergence of structure:

- galaxies,
- stars,
- clusters,
- and other high-ED islands.

No stochastic fluctuations, quantum fields, or inflationary potentials are required.
Structure arises from the internal logic of ED.

5.5 Comparison to Standard Cosmology

In standard cosmology:

- inflation smooths the universe,
- quantum fluctuations seed perturbations,
- gravity amplifies them.

In ED cosmology:

- the gradient penalty smooths the universe,
- residual gradients survive deterministically,
- the relational penalty amplifies them.

The roles are analogous, but the mechanisms are entirely different.
ED cosmology replaces geometric assumptions with compositional dynamics.

6. Structure Formation from Relational Concavity

The end of the inflation-like smoothing phase leaves the universe in a state that is nearly uniform but not perfectly so. Small residual gradients survive, and these gradients encode the first nontrivial structure in the ED distribution. In this section we show how the relational term in the compositional rule amplifies these small differences and stabilizes the resulting overdensities, producing long-lived high-ED structures. This mechanism is deterministic, universal, and requires no geometric assumptions. It is the ED analogue of gravitational instability.

6.1 The Relational Penalty as a Driver of Structure

The relational term in the compositional rule is:

$$\Phi_{rel}(A,B) = \alpha \int_{A\cap B} p(x)^\gamma \, d\mu(x), \quad 0 < \gamma < 1.$$

This term penalizes overlap of high-ED regions. In cosmology, where the universe is nearly uniform, the relational penalty becomes sensitive to small differences in $p(x,t)$. Two key features of the concave form p^γ drive structure formation:

Sensitivity at moderate ED

1. When p is high but not maximal, the derivative $d(p^\gamma) / dp$ is large.
   Small differences in p produce disproportionately large differences in the relational penalty.

2. Saturation at high ED
   As p approaches its upper bound, pγ grows sublinearly.
   The penalty increases more slowly, allowing high-ED pockets to persist.

These two features — sensitivity and saturation — are the essential ingredients of ED structure formation.

6.2 Amplification of Residual Gradients

Let $p(x,t) = \hat{p}(t) + \delta p(x,t)$, where δp represents the small residual variations that survive the inflation-like phase. The relational penalty responds to these variations as:

$$p\gamma = \hat{p}^{\gamma} + \gamma\hat{p}^{\gamma-1}\delta p + O(\delta p^2).$$

Because $0 < \gamma < 1$, the coefficient $\gamma\hat{p}^{\gamma-1}$ is large when $\hat{p}$ is high.

This means:

- even tiny δp produce significant differences in the relational penalty,
- regions with slightly higher p experience a noticeably larger penalty,
- this slows their outward ED flow relative to their surroundings.

The result is a positive feedback loop:

- slightly higher p → slower outflow → accumulation of ED → even higher p.

This is the ED analogue of gravitational instability.

6.3 Stabilization of High-ED Pockets

As overdensities grow, the concavity of p^{γ} becomes crucial.

Because pγ grows sublinearly:

- the relational penalty increases more slowly at high ED,
- the cost of maintaining a high-ED region saturates,
- overdense pockets become metastable.

This stabilization mechanism is purely compositional:

- no potential wells,
- no metric curvature,
- no gravitational force.

High-ED pockets persist because the relational penalty stops increasing fast enough to push ED out of them.

These pockets are the ED precursors of:

- galaxies,
- stars,
- clusters,
- and other long-lived structures.

6.4 Competition as a Universal Mechanism

The same relational term that governs competition in small systems governs structure formation in cosmology.

The mechanism is identical:

- competition: high-ED regions suppress each other's growth,
- stabilization: concavity prevents runaway behavior,
- localization: ED accumulates where outflow is slowest.

In cosmology, this produces a universe that is:

- smooth on large scales (due to gradient decay),
- structured on intermediate scales (due to relational concavity),
- stable on small scales (due to saturation).

This is a unified explanation for the coexistence of homogeneity and structure.

6.5 Emergent Structure Without Geometry
In standard cosmology:

- inflation smooths the universe,
- quantum fluctuations seed perturbations,
- gravity amplifies them,
- dark matter stabilizes structures.

In ED cosmology:

- the gradient penalty smooths the universe,
- residual gradients survive deterministically,
- the relational penalty amplifies them,
- concavity stabilizes structures.

The roles are analogous, but the ontology is entirely different.
Structure emerges from the internal logic of ED, not from geometric fields.

6.6 Summary
The ED rule predicts that:

1. Residual gradients survive the inflation-like phase.
2. The relational penalty amplifies these gradients.
3. Concavity stabilizes the resulting overdensities.
4. High-ED pockets form and persist as long-lived structures.

This mechanism is deterministic, universal, and requires no geometry.
It is the ED explanation for why the universe contains galaxies, stars, and clusters rather than being perfectly smooth.

7. Global Thinning and Expansion

The ED universe expands not because space stretches, but because ED thins.

As high-ED pockets form and stabilize, ED flows outward from these regions into the surrounding configuration. This outward flow reduces the average ED density $\hat{\rho}(t)$ while increasing the coarse-grained homogeneity scale $L(t)$. The result is an emergent expansion law: the universe becomes more uniform on large scales as its global ED content decreases. This section develops the coarse-grained dynamics of thinning and shows how they give rise to an ED analogue of cosmological expansion.

7.1 ED Flow Out of High-ED Regions

Once structure begins to form, the universe contains:

- high-ED pockets (proto-structures),
- low-ED surroundings,
- small but persistent gradients between them.

The compositional rule dictates that ED flows from regions of higher ED to regions of lower ED, moderated by the relational and gradient penalties. This flow reduces the global average ED density:

$$\hat{p}(t) = (1 / V(t)) \int_{C(t)} p(x,t)\, d\mu(x).$$

The key point is that **ED flow is not geometric.**
It is a redistribution of the density of becoming across the configuration.

As ED leaves high-ED pockets, the universe becomes globally thinner.

7.2 Coarse-Grained Thinning Dynamics

The rate at which $\hat{p}(t)$ decreases is controlled by the gradients that remain after the inflation-like phase. At leading order, the coarse-grained evolution of $\hat{p}(t)$ takes the form:

$$d\hat{p} / dt \approx -\lambda_2\, G(t)^2,$$

where $\lambda^2 > 0$ is an effective thinning coefficient determined by the interplay of the relational and gradient penalties.

This equation has a simple interpretation:

- No gradients → no thinning.
  If $G(t) = 0$, the universe is perfectly uniform and ED cannot flow.

- Small gradients → slow thinning.
  As $G(t)$ becomes small, thinning slows dramatically.

- Residual gradients → long-term evolution.
  The small but finite gradients that survive inflation drive the slow decrease of $\hat{p}(t)$ over cosmological timescales.

Thus, the universe thins because it is not perfectly smooth.

7.3 Expansion as Growth of the Homogeneity Scale

As ED thins, the typical gradient magnitude decreases further.

This increases the coarse-grained homogeneity scale:

$$L(t) \sim 1 / G(t).$$

Since the ED scale factor is defined by:

$$a(t) \propto L(t),$$

we obtain:

$$a(t) \propto 1 / G(t).$$

During the inflation-like phase, G(t) decays exponentially, giving exponential growth of a(t).
After inflation, G(t) decays more slowly, giving slower growth of a(t).

This is the ED analogue of the transition from inflation to standard expansion.

7.4 ED Expansion vs. Metric Expansion

In standard cosmology:

- the metric stretches,
- distances increase,
- energy density dilutes.

In ED cosmology:

- the ED distribution thins,
- gradients decrease,
- the homogeneity scale grows.

The two descriptions are not equivalent, but they are phenomenologically parallel:

Standard Cosmology	ED Cosmology
Metric expansion	Growth of L(t)
Dilution of energy density	Thinning of $\hat{p}(t)$
Curvature evolution	Gradient evolution
Inflation	Exponential smoothing

ED cosmology reproduces the qualitative behavior of expansion without invoking geometry.

7.5 Long-Term Behavior of $\hat{p}(t)$

As the universe evolves:

- high-ED pockets slowly lose ED to their surroundings,
- gradients between pockets and background decrease,
- thinning slows as G(t) approaches zero.

In the long-time limit:

$$\hat{p}(t) \to p_{min}, \qquad G(t) \to 0.$$

The universe approaches a globally thin, nearly uniform state.
This is the ED analogue of a heat-death-like future (ontological flatness).

7.6 Summary

Global thinning is the ED mechanism behind cosmic expansion:

1. ED flows outward from high‑ED pockets.
2. Average ED density decreases as a result.
3. Gradients decrease, increasing the homogeneity scale.
4. The ED scale factor grows, first exponentially, then slowly.
5. Thinning slows as gradients vanish.
6. The universe approaches a flat, low‑ED state.

Expansion is therefore not a geometric assumption but a dynamical consequence of the ED rule.

8. Late‑Time Universe: ED Heat Death (Flatness) and Horizon Dominance

As the universe evolves under the ED compositional rule, the combined effects of smoothing, thinning, and structure formation drive it toward a qualitatively different regime. High‑ED pockets slowly dissolve, gradients on large scales approach zero, and the boundary term in the compositional rule becomes the dominant contributor to the dynamics. In this section we describe the late‑time behavior of the ED universe, showing how it approaches a thin, nearly uniform state with horizon‑like boundaries and minimal internal structure. This is the ED analogue of cosmological heat death.

8.1 Asymptotic Flattening of the ED Distribution

The long‑term evolution of the universe is governed by the decay of gradients.

As ED flows outward from high‑ED pockets, the typical gradient magnitude G(t) decreases. The thinning equation:

$$d\hat{p} / dt \approx -\lambda 2\, G(t)^2$$

implies that thinning slows dramatically as G(t) becomes small.

In the limit $t \to \infty$:

$$G(t) \to 0, \qquad \hat{p}(t) \to p_{min}.$$

The ED distribution becomes nearly uniform across the entire configuration.

This is the ED analogue of a flat, low‑curvature universe.

The key point is that this flattening is dynamical, not geometric.
It arises from the internal logic of ED flow, not from the evolution of a metric.

8.2 Dissolution of High‑ED Structures

High‑ED pockets — the ED precursors of galaxies, stars, and clusters — are metastable.

They persist for long periods because the relational penalty saturates at high ED.
But they are not eternal.

As the universe thins:

- the contrast between high‑ED pockets and the background decreases,
- gradients at the boundaries of these pockets weaken,
- the relational penalty becomes less effective at stabilizing them,

- ED slowly leaks out of the pockets into the surrounding configuration.

Over sufficiently long timescales, all high-ED structures dissolve.

The universe becomes a nearly uniform sea of low ED.
This is the ED analogue of the dissolution of bound structures in a heat-death scenario.

8.3 Emergence of Horizon-Like Behavior
As gradients vanish in the bulk, the only significant contributions to the compositional rule come from the boundary term:

$$\gamma \int_{\partial C(t)} h(|\nabla p|)\, dS.$$

In the late-time universe:
- gradients inside the configuration are negligible,
- gradients at the boundary remain finite,
- the boundary term dominates the ED of the entire configuration.

This produces horizon-like behavior:

1. Boundary dominance
   The ED of the universe becomes concentrated in a thin layer near its boundary.
2. Area-law scaling
   Because h(u) saturates, the boundary contribution scales with the area of the boundary, not its volume.
3. Stability of the boundary layer
   The saturating form of h(u) ensures that the boundary remains stable even as internal gradients vanish.

This is the cosmological analogue of the horizon behavior studied in ED-06.

8.4 The ED Heat-Death State
The asymptotic state of the ED universe is characterized by:
- uniform low ED in the bulk,
- vanishing gradients across almost all of the configuration,
- dominant boundary contributions,
- minimal internal structure,
- slow or negligible further evolution.

This state is not static — ED continues to flow, but the flow becomes arbitrarily slow.
The universe approaches a fixed point of the compositional dynamics.

In this regime:
- the ED scale factor a(t) grows without bound,
- but the growth carries no new structure or complexity,
- and the universe becomes effectively featureless.

This is the ED analogue of cosmological heat death.

8.5 Summary

The late-time universe in ED is the natural endpoint of the compositional rule:

1. Gradients vanish as ED thins.
2. High-ED structures dissolve over long timescales.
3. Boundary terms dominate, producing horizon-like behavior.
4. The universe approaches a uniform, low-ED state.
5. Evolution slows, approaching a fixed point.

This asymptotic regime is not imposed; it is the inevitable consequence of the ED rule applied to a finite configuration over long timescales.

9. Summary and Implications

Cosmology in ED is not an additional layer placed on top of the compositional rule. It is the first large-scale consequence of that rule. By applying the same local bookkeeping law that governs all finite configurations to the universe as a whole, we obtain a coherent cosmological history with familiar large-scale features — but without invoking geometry, fields, or external dynamical assumptions. The universe evolves because ED evolves.

The central results of this paper can be summarized as follows:

(1) Early exponential smoothing (ED inflation)
In the high-ED, small-gradient regime, the quadratic gradient penalty dominates the dynamics. This produces an exponential decay of gradients and an exponential growth of the coarse-grained homogeneity scale. The universe becomes smooth on large scales through the internal logic of ED, not through the stretching of a metric or the dynamics of a scalar field.

(2) Survival of residual gradients
The smoothing term weakens as gradients decay, leaving a small but finite level of inhomogeneity. These residual gradients are not noise; they are the first structural degrees of freedom in the universe. They define flow directions, seed curvature-like behavior, and initiate the formation of overdensities.

(3) Structure formation from relational concavity
The concave relational penalty p^{γ} amplifies small differences in ED and stabilizes the resulting overdensities. High-ED pockets form and persist as metastable structures. This mechanism is deterministic, universal, and requires no geometry. It is the ED analogue of gravitational instability.

(4) Global thinning as expansion
As ED flows outward from high-ED pockets, the average ED density decreases. This thinning drives a slow decay of gradients and a corresponding growth of the homogeneity scale. The ED scale factor grows because the universe becomes more uniform on large scales, not because space stretches.

(5) Late-time flattening and horizon dominance
As gradients vanish, high-ED structures dissolve and the boundary term dominates the ED of the universe. The universe approaches a thin, nearly uniform state with horizon-like boundaries and minimal internal structure. This is the ED analogue of cosmological heat death.

9.1 Conceptual Implications

The results of ED-05 show that:

- Cosmology is not geometric.
  Large-scale behavior emerges from the compositional rule, not from a metric.

- Inflation, structure formation, and expansion are unified.
  They arise from different regimes of the same rule.

- The universe is a finite configuration.
  Its evolution is governed by the same principles as any subsystem.

- Horizon behavior is not special.
  It is the natural outcome of boundary dominance in extreme regimes.

This unification is not imposed; it is discovered.

9.2 Outlook

The cosmological behavior derived here is robust across a wide family of functional choices. The next steps are to:

- refine the functional forms f,g,h,
- determine the regime thresholds more precisely,
- explore observational consequences,
- and connect ED cosmology to effective geometric descriptions.

The ED framework provides a new way to understand the universe: not as a geometric object evolving under field equations, but as a finite configuration whose internal density of becoming shapes its large-scale history.