Geometry from Entropy Flow: Renormalization, Plenum Dynamics, and the Emergence of Physical Structure

Flyxion

March 18, 2026

Abstract

Modern theoretical physics increasingly suggests that spacetime and gravitational dynamics may emerge from deeper informational or thermodynamic processes. Renormalization group theory, effective action methods in quantum field theory, and entropy-based approaches to gravity all point toward a picture in which physical laws evolve under coarse-graining and information flow across scales.

This paper develops this picture through the Relativistic Scalar–Vector Plenum (RSVP) framework, a field-theoretic ontology in which the universe is characterized by a scalar density field Φ, a vector flow field $\mathbf{v}$, and an entropy field S. We argue that renormalization group flow, entropy-driven relaxation, and emergent geometry are unified aspects of a single dynamical structure.

We derive field equations from a candidate action functional, establish conservation laws and linear stability conditions, and formalize the framework within a hierarchy running from discrete event calculi (Spherepop) through continuous plenum dynamics to geometric and categorical structures. We prove that symbolic collapse grammar models are recovered as overdamped binary limits of RSVP field theory, and position the framework relative to asymptotic safety, holographic renormalization, and emergent gravity.

1 Introduction

Classical physics traditionally assumes that the laws governing the universe are independent of scale. However, developments in quantum field theory have revealed that effective physical laws depend on the energy scale at which phenomena are observed.

The renormalization group provides the mathematical framework for understanding this dependence. Under coarse-graining, microscopic degrees of freedom are integrated out, producing effective theories that describe large-scale behavior.

At the same time, several modern approaches to quantum gravity have suggested that spacetime itself may emerge from deeper information processing or thermodynamic structures. Jacobson's derivation of Einstein's equations from horizon thermodynamics [6], Verlinde's entropic gravity proposal [7], and the holographic principle [42, 41] all point in this direction.

The Relativistic Scalar–Vector Plenum (RSVP) framework proposes an alternative cosmological picture in which the universe is described as a dynamical plenum characterized by three interacting fields: a scalar density field Φ, a vector flow field $\mathbf{v}$, and an entropy field S. In this view, cosmic evolution reflects the redistribution of density, flow, and entropy rather than geometric expansion of spacetime.

The purpose of this paper is to explore structural connections between renormalization group theory and the entropy-driven field dynamics proposed in RSVP. We derive explicit field equations, establish conservation laws, analyze the linear stability of homogeneous backgrounds, and situate the framework within several active research programs in theoretical physics.

2 Spherepop as a Discrete Event Calculus

Before introducing the continuous RSVP field description, it is useful to consider a complementary discrete perspective in which physical processes are described as elementary events.

In the Spherepop framework, the fundamental objects are localized interaction events—*pops*—representing transitions between configurations of a system. Each event is characterized by a finite region of influence and a transformation rule acting on local state variables: a density transfer, a directed flow contribution, and an entropy increment.

A Spherepop configuration is a network of such events, with adjacency relations encoding causal or interaction structure. Composition of events is associative and admits an identity (the null event), making the event algebra a monoid. Crucially, large-scale structure does not arise from any single event but from the collective organization of many such transitions.

Definition 1 (Spherepop Event)**.** A Spherepop event e is a triple

$$e = (\rho(e),\, \mathbf{j}(e),\, s(e)), \tag{1}$$

where $\rho(e) \in \mathbb{R}$ is a density transfer, $\mathbf{j}(e) \in \mathbb{R}^n$ is a momentum-like flow contribution, and $s(e) \geq 0$ is the entropy increment associated with the event.

When coarse-grained over a region $B_\ell(x)$ of scale ℓ, the collective statistics of events define smooth fields:

$$\Phi_\ell(x,t) = \langle \rho(e_i) \rangle_{B_\ell(x)}, \tag{2}$$

$$\mathbf{v}_\ell(x,t) = \langle \mathbf{j}(e_i) \rangle_{B_\ell(x)}, \tag{3}$$

$$S_\ell(x,t) = \langle s(e_i) \rangle_{B_\ell(x)}. \tag{4}$$

In this sense, Spherepop provides a microscopic event grammar whose continuum limit is captured by the RSVP plenum fields. The relationship is formalized in Theorem 1.

3 Emergent Structure from Localized Updates

A useful analogy for understanding the emergence of macroscopic structure from localized processes arises from version control systems, in particular the internal structure of Git repositories.

In Git, the fundamental objects are not directories or hierarchical containers, but rather snapshots of file paths. A repository state is defined by a tree structure in which each file is associated with a path. Crucially, directories are not stored as independent entities. Instead, they are inferred from the common prefixes of file paths. The introduction of a file at path `a/b/c.txt` implicitly defines the nested directory structure a/b, even though no explicit object corresponding to these directories exists. The apparent hierarchy is therefore not primary, but emerges from the collective organization of individual file entries.

This behavior reflects three deeper principles that parallel the RSVP framework. The first is the absence of primitive containers: structure is not encoded as independent objects but arises from relationships between local elements. The second is event-based construction: each commit introduces localized changes, and global structure is the cumulative result of these events. The third is the nonexistence of empty structure: a directory has no independent meaning in the absence of files, existing only insofar as it is supported by underlying content.

In Spherepop dynamics, the fundamental objects are localized events that modify state in bounded regions, and no global geometric structure is assumed a priori. Under coarse-graining, the discrete event structure gives rise to continuous fields $(\Phi, \mathbf{v}, S)$. Just as directories in a Git repository are projections of file paths, spacetime geometry in RSVP may be interpreted as a projection of underlying field organization. In both cases the apparent hierarchy is not fundamental but emergent, and global structure is reconstructed from local data whose persistence depends on the coherence of the underlying configuration.

The path structure of a repository may be given a precise categorical formulation. Let $\mathcal{P}$ denote the set of file paths, viewed as a partially ordered set under prefix inclusion: $p \leq q$ if and only if p is a prefix of q. Treating $(\mathcal{P}, \leq)$ as a category in which objects are paths and there exists a unique morphism $p \to q$ whenever $p \leq q$, a repository snapshot becomes a functor

$$\mathcal{F} : \mathcal{P} \to \mathbf{Set}, \tag{5}$$

assigning to each path the corresponding file content, with restriction maps reflecting prefix inclusion. The global structure of the repository is encoded not in explicit containers but in the functorial assignment of data to paths. This categorical picture closely parallels the RSVP framework, where the plenum may be viewed as a functor

$$\mathcal{P}_{\text{space}} : U \mapsto (\Phi, \mathbf{v}, S)|_U, \tag{6}$$

assigning field configurations to regions U. In both cases, global structure emerges from the compatibility of local assignments.

This analogy also clarifies an important conceptual constraint: just as one cannot meaningfully define a directory without specifying its contents, macroscopic geometry in RSVP cannot be prescribed independently of the underlying field dynamics.

4 Sheaf-Theoretic Interpretation of Emergent Structure

The emergence of hierarchical structure from local data can be made precise using the language of sheaf theory [29, 54]. The file-path example provides a concrete illustration.

Consider the set of file paths $\mathcal{P}$ equipped with the prefix topology, in which open sets correspond to collections of paths sharing a common prefix. For each such open set $U \subset \mathcal{P}$, define $\mathcal{F}(U)$ as the set of file contents restricted to paths in U. Restriction maps

$$\rho_{UV} : \mathcal{F}(U) \to \mathcal{F}(V), \qquad V \subset U, \tag{7}$$

define a presheaf on the space of paths. This presheaf satisfies the sheaf gluing condition: if local data assignments on overlapping path sets $\{U_i\}$ agree on intersections $U_i \cap U_j$, then there exists a unique global assignment on $\bigcup_i U_i$.

In this framework, what is ordinarily interpreted as a directory structure corresponds to an open set in the topology together with its associated local data. A directory is not a fundamental object, but a derived construct whose existence depends entirely on the presence of compatible sections over that region.

This construction mirrors the sheaf-theoretic formulation of the RSVP plenum introduced in Section 31. There, spacetime is covered by open sets $\{U_i\}$, each assigned local field data $(\Phi, \mathbf{v}, S)|_{U_i}$. Restriction maps ensure consistency across overlaps, and global solutions arise by gluing compatible local sections. The analogy can be made precise:

$$\text{Paths} \longleftrightarrow \text{Spacetime regions}, \qquad \text{File data} \longleftrightarrow \text{Field configurations}. \tag{8}$$

From this perspective, geometry itself may be interpreted as a derived object arising from the organization of local sections. Just as the directory tree is reconstructed from compatible file assignments, the effective geometric structure of spacetime in RSVP emerges from the coherent assembly of plenum field configurations. Sheaf theory provides the natural mathematical language for expressing this principle across both informational and physical domains.

5 Field-Theoretic Foundations of RSVP

The Relativistic Scalar–Vector Plenum (RSVP) framework provides a continuum description of collective dynamics arising from the underlying event processes of Section 2.

Definition 2 (Plenum State)**.** A *plenum state* is a smooth assignment of fields

$$X^A = (\Phi,\, \mathbf{v},\, S) \tag{9}$$

defined on a spacetime domain $\Omega \times \mathbb{R}$, where $\Phi(x,t) \in \mathbb{R}$ encodes local density, $\mathbf{v}(x,t) \in \mathbb{R}^n$ encodes directed transport, and $S(x,t) \in \mathbb{R}_{\geq 0}$ encodes entropy density.

An *event* in the continuum description corresponds to a localized reconfiguration of these fields. In contrast to the discrete Spherepop picture, events in RSVP are not primitive objects but emergent features of field dynamics: a pop becomes a region where $\partial_t S > 0$ and $|\nabla \cdot \mathbf{v}|$ is locally significant.

The evolution of the system is governed by coupled partial differential equations

$$\partial_t X^A = F^A(X, \nabla X), \tag{10}$$

derived from an action functional as in Section 14, or equivalently interpreted as a gradient flow on the entropy–coherence functional $\mathcal{R}$ introduced in Appendix B. This formulation places RSVP within the standard framework of classical and quantum field theory while retaining a direct conceptual link to its underlying event-based interpretation.

Remark 1. The three-field structure $(\Phi, \mathbf{v}, S)$ is the minimal content required for a theory in which density, transport, and thermodynamic state are simultaneously dynamical. Any coarser description—such as a scalar-only or entropy-only field—loses either the directionality of flow or the local thermodynamic degree of freedom.

6 Renormalization Group Flow

In quantum field theory, coupling constants evolve with energy scale. If g_i denotes a coupling parameter, its scale dependence is governed by the beta function [1, 14, 15]

$$\mu \frac{dg_i}{d\mu} = \beta_i(g). \tag{11}$$

This equation defines a trajectory in the space of possible field theories, sometimes called *theory space*.

Fixed points occur when

$$\beta_i(g^*) = 0. \tag{12}$$

At these points, the theory becomes scale invariant. Such fixed points play a central role in critical phenomena [21] and in modern approaches to quantum gravity such as asymptotic safety [3, 4].

7 Effective Actions and Quantum Geometry

Quantum field theories are often summarized using the effective action Γ_{eff}, which incorporates all quantum corrections to classical dynamics [17, 19].

For gravitational systems coupled to matter fields, the semiclassical field equations can be written schematically as

$$\frac{\delta \Gamma_{\text{eff}}}{\delta g_{\mu\nu}} = 0. \tag{13}$$

The effective action typically contains contributions from classical geometry, quantum fluctuations of matter fields, anomaly terms, and nonlocal corrections.

Studying how Γ_{eff} evolves under renormalization group flow has become an important strategy in attempts to understand the ultraviolet structure of quantum gravity [18, 4].

8 Entropy and Information Flow

Entropy plays a fundamental role in both statistical mechanics and modern gravitational physics [36, 37, 38].

In information theory, entropy is defined as

$$S = -\mathrm{Tr}(p \log p). \tag{14}$$

In gravitational physics, entropy appears in black hole thermodynamics through the Bekenstein–Hawking relation [8, 9],

$$S_{BH} = \frac{A}{4G}. \tag{15}$$

These relationships have motivated the hypothesis that gravitational dynamics may have a thermodynamic origin [12, 40].

9 The Geometry of Theory Space

Recent work has emphasized that theory space itself can possess geometric structure [2, 5]. In two-dimensional conformal field theory, Zamolodchikov demonstrated that the space of coupling constants carries a natural metric.

Under renormalization group flow, couplings follow trajectories on this curved manifold. The curvature of theory space reflects interactions between operators and influences the stability of fixed points.

This geometric viewpoint suggests that RG flow can be interpreted as a kind of dynamical motion on a curved parameter manifold, closely analogous to Ricci flow on a Riemannian manifold [23, 22].

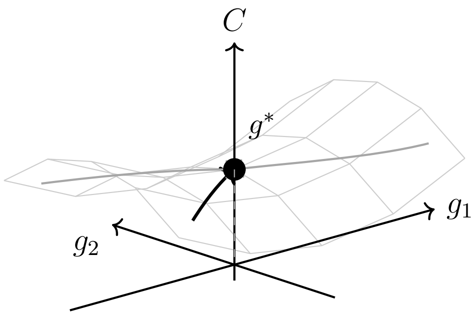

Figure 1: Renormalization group trajectories on a curved theory-space manifold. The vertical coordinate is the monotonic c-function $C(g)$. Multiple trajectories from different UV starting points flow downward on this surface, converging toward the scale-invariant fixed point g^* at the minimum.

10 Gradient Flows and Irreversibility

Several results indicate that renormalization group flow behaves like a gradient flow with respect to certain monotonic quantities [2, 16]. In two dimensions, the c-theorem establishes the existence of a function that decreases along RG trajectories. More generally, RG evolution may be written as

$$\frac{dg^i}{d\tau} = -G^{ij}\frac{\partial C}{\partial g^j}, \tag{16}$$

where C is a monotonic functional and G^{ij} is a metric on theory space. This structure resembles thermodynamic evolution, in which systems move toward states of reduced free energy.

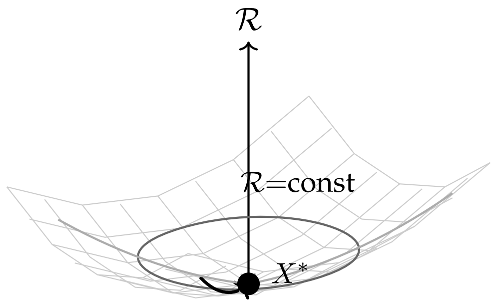

Figure 2: Gradient flow on the entropy–coherence functional $\mathcal{R}$. The paraboloid surface represents $\mathcal{R}$ over plenum field space. Three descent trajectories from different initial conditions converge to the minimum X^*, which corresponds to a stationary plenum regime. Level sets of $\mathcal{R}$ are shown as closed curves on the bowl.

11 The RSVP Plenum Framework

The RSVP framework proposes that the universe can be described as a continuous plenum governed by three interacting fields: a scalar density field Φ, a vector flow field $\mathbf{v}$, and an entropy field S. Rather than treating spacetime curvature as fundamental, RSVP interprets geometry as an emergent description of the organization of these fields.

The dynamical evolution of the plenum can be expressed schematically as

$$\partial_t \Phi = F_\Phi(\Phi, \mathbf{v}, S), \tag{17}$$

$$\partial_t \mathbf{v} = F_v(\Phi, \mathbf{v}, S), \tag{18}$$

$$\partial_t S = F_S(\Phi, \mathbf{v}, S). \tag{19}$$

These equations describe redistribution processes within the plenum.

12 RSVP as a Geometric Flow

A useful mathematical interpretation is to treat RSVP dynamics as a gradient flow on a functional $\mathcal{R}$ defined over field space. Let $X^A = (\Phi, \mathbf{v}, S)$ denote the collective fields. Then the dynamics may be written as

$$\partial_t X^A = -G^{AB} \frac{\delta \mathcal{R}}{\delta X^B}. \tag{20}$$

This formulation places RSVP within the broader family of geometric flows that includes renormalization group evolution, Ricci flow [23], and thermodynamic relaxation processes.

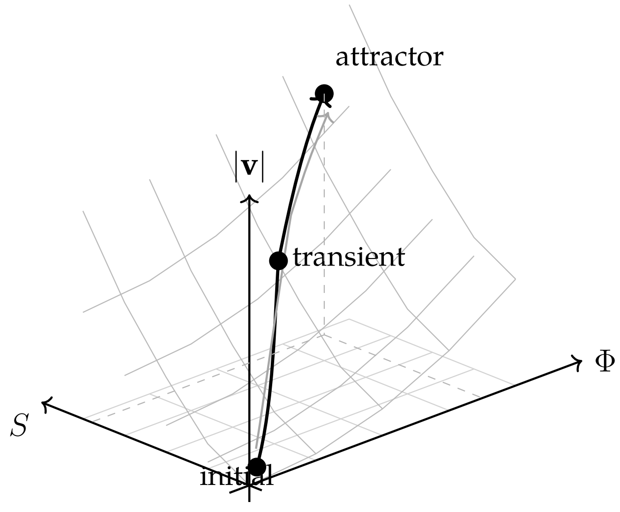

Figure 3: Three-dimensional RSVP configuration manifold with coordinates $(\Phi, |\mathbf{v}|, S)$. The manifold curves upward, reflecting increasing coherence. The bold trajectory represents entropy-driven evolution from an initial nonequilibrium state toward a coherent attractor regime; the lighter trajectory shows a neighboring orbit converging to the same attractor.

13 Construction Principles for the RSVP Action

The form of the RSVP action is constrained by several physical and structural requirements, which we state explicitly before writing it down. This prevents the Lagrangian from appearing as an arbitrary ansatz.

Locality requires that the Lagrangian density depend only on the fields and their first derivatives at a point. This excludes nonlocal integral kernels at leading order.

Rotational and translational invariance restrict the allowed scalar combinations of fields. In particular, the vector sector must appear through scalars such as $\mathbf{v}^2$, $(\nabla \times \mathbf{v})^2$, and $\mathbf{v} \cdot \nabla\Phi$.

Minimal coupling between sectors requires that interaction terms couple density, flow, and entropy at the lowest order consistent with the symmetries, yielding three distinct coupling constants λ_1, λ_2, λ_3 rather than a single universal coupling.

Entropy production positivity requires that the entropy balance equation derived from the action admits a non-negative source term $\sigma \geq 0$, consistent with the second law of thermodynamics.

Vorticity suppression is motivated by the requirement that small-scale turbulent flow be energetically penalized relative to large-scale coherent structures. This is encoded by the term $\kappa(\nabla \times \mathbf{v})^2$.

These five requirements uniquely determine the minimal action functional up to the choice of potentials $V(\Phi)$ and $U(S)$ and the values of the coupling constants.

14 A Candidate RSVP Action Functional

To place the RSVP framework in closer analogy with conventional field theory, we introduce an action functional governing the dynamics of the plenum fields [35, 44]. Let the fundamental variables be $\Phi(x,t)$, $\mathbf{v}(x,t)$, and $S(x,t)$.

A minimal action functional may be written as

$$\mathcal{A}_{RSVP} = \int d^4x \left[\mathcal{L}_\Phi + \mathcal{L}_v + \mathcal{L}_S + \mathcal{L}_{\text{int}}\right], \tag{21}$$

with sector Lagrangians

$$\mathcal{L}_\Phi = \frac{1}{2}(\partial_\mu \Phi)(\partial^\mu \Phi) - V(\Phi), \tag{22}$$

$$\mathcal{L}_v = \frac{1}{2}\rho(\Phi)\,\mathbf{v}^2 - \kappa(\nabla \times \mathbf{v})^2, \tag{23}$$

$$\mathcal{L}_S = \frac{1}{2}\alpha(\nabla S)^2 - U(S), \tag{24}$$

and interaction terms

$$\mathcal{L}_{\text{int}} = \lambda_1 S\,\nabla \cdot \mathbf{v} + \lambda_2 \Phi S + \lambda_3 \mathbf{v} \cdot \nabla \Phi. \tag{25}$$

15 Variational Derivation of the RSVP Field Equations

The dynamical equations follow from the Euler–Lagrange equations

$$\frac{\partial \mathcal{L}}{\partial \psi} - \partial_\mu \left(\frac{\partial \mathcal{L}}{\partial(\partial_\mu \psi)} \right) = 0 \tag{26}$$

applied to each field $\psi \in \{\Phi, \mathbf{v}, S\}$.

15.1 Scalar Density Field

For the scalar sector with interaction sourcing, the Euler–Lagrange equation gives

$$\partial_\mu \partial^\mu \Phi + \frac{dV}{d\Phi} = J_\Phi, \tag{27}$$

where the source term arising from the interaction Lagrangian is

$$J_\Phi = -\lambda_2 S - \lambda_3 \nabla \cdot \mathbf{v} - \frac{1}{2} \frac{d\rho}{d\Phi} \mathbf{v}^2. \tag{28}$$

This is a wave equation with a potential modified by entropy and flow couplings.

15.2 Vector Flow Field

The vector sector yields an evolution equation resembling a generalized forced Euler equation,

$$\rho(\Phi)\, \partial_t \mathbf{v} = -\nabla P_{\text{eff}} + \kappa\, \nabla^2 \mathbf{v} + \mathbf{J}_v, \tag{29}$$

where the effective pressure is

$$P_{\text{eff}} = \lambda_3 \Phi + \lambda_1 S, \tag{30}$$

and the source $\mathbf{J}_v = \lambda_1 \nabla S + \lambda_3 \nabla \Phi$ arises from coupling gradients. The term $\kappa\, \nabla^2 \mathbf{v}$ suppresses vorticity growth.

15.3 Entropy Field

For the entropy sector, variation yields

$$\alpha\, \nabla^2 S - \frac{dU}{dS} = J_S, \tag{31}$$

with entropy source

$$J_S = -\lambda_1 \nabla \cdot \mathbf{v} - \lambda_2 \Phi. \tag{32}$$

Together these three equations define the coupled dynamical system governing RSVP plenum evolution.

16 Explicit Form of the Entropy–Coherence Functional

The gradient-flow formulation of RSVP requires a concrete entropy–coherence functional $\mathcal{R}$ whose variation generates the effective field evolution. We now construct it explicitly, unifying the conservative action description with the dissipative gradient-flow picture.

Motivated by the RSVP action and the requirement of monotonic entropy production, we define

$$\mathcal{R}[\Phi, \mathbf{v}, S] = \int d^3x \Big[\tfrac{1}{2}|\nabla\Phi|^2 + \tfrac{1}{2}\rho(\Phi)|\mathbf{v}|^2 + \tfrac{1}{2}\alpha|\nabla S|^2 + V(\Phi) + U(S) - \lambda_1 S\, \nabla\cdot\mathbf{v} - \lambda_2 \Phi S\Big]. \tag{33}$$

This functional combines energetic contributions (gradient and potential terms) with entropy-flow couplings that encode irreversibility and inter-field interaction.

16.1 Functional Derivatives

The functional derivatives of $\mathcal{R}$ with respect to the fields are:

$$\frac{\delta\mathcal{R}}{\delta\Phi} = -\nabla^2\Phi + \frac{dV}{d\Phi} - \lambda_2 S + \frac{1}{2}\frac{d\rho}{d\Phi}|\mathbf{v}|^2, \tag{34}$$

$$\frac{\delta\mathcal{R}}{\delta\mathbf{v}} = \rho(\Phi)\,\mathbf{v} + \lambda_1 \nabla S, \tag{35}$$

$$\frac{\delta\mathcal{R}}{\delta S} = -\alpha\,\nabla^2 S + \frac{dU}{dS} - \lambda_1 \nabla\cdot\mathbf{v} - \lambda_2\Phi. \tag{36}$$

16.2 Gradient Flow Dynamics

With positive definite metric G^{AB}, the gradient-flow dynamics

$$\partial_t X^A = -G^{AB}\frac{\delta\mathcal{R}}{\delta X^B} \tag{37}$$

yield

$$\partial_t \Phi = \nabla^2 \Phi - \frac{dV}{d\Phi} + \lambda_2 S - \frac{1}{2}\frac{d\rho}{d\Phi}|\mathbf{v}|^2, \tag{38}$$

$$\partial_t \mathbf{v} = -\rho(\Phi)\,\mathbf{v} - \lambda_1 \nabla S, \tag{39}$$

$$\partial_t S = \alpha\,\nabla^2 S - \frac{dU}{dS} + \lambda_1 \nabla \cdot \mathbf{v} + \lambda_2 \Phi. \tag{40}$$

These equations reproduce, to leading order, the structure of the RSVP field equations derived from the action functional, with the difference that they describe dissipative relaxation toward entropy-coherent configurations.

By Theorem 3, $\mathcal{R}$ is non-increasing along trajectories,

$$\frac{d\mathcal{R}}{dt} \leq 0, \tag{41}$$

with equality only at stationary points. Thus $\mathcal{R}$ serves as a Lyapunov functional for RSVP dynamics.

Remark 2. The RSVP framework admits both a conservative formulation derived from the action functional and a dissipative formulation generated by $\mathcal{R}$. The latter may be viewed as an effective description obtained after coarse-graining over microscopic degrees of freedom, analogous to the emergence of thermodynamic behavior from underlying Hamiltonian dynamics. The action description is the reversible backbone; the gradient-flow description is its irreversible coarse-grained shadow.

17 Conservation Laws

The RSVP action possesses continuous symmetries that lead to conservation laws through Noether's theorem [25, 26].

17.1 Energy Functional

The energy density associated with the plenum fields is

$$\mathcal{E} = \frac{1}{2}|\partial_t \Phi|^2 + \frac{1}{2}|\nabla \Phi|^2 + \frac{1}{2}\rho(\Phi)|\mathbf{v}|^2 + \kappa|\nabla \times \mathbf{v}|^2 + \frac{1}{2}\alpha|\nabla S|^2 + V(\Phi) + U(S). \tag{42}$$

Under appropriate boundary conditions the total energy

$$E = \int \mathcal{E}\, d^3x \tag{43}$$

is conserved. In the gradient-flow regime the energy decreases monotonically, consistent with entropy-driven relaxation.

17.2 Entropy Transport

Entropy satisfies an advection–diffusion equation of the form

$$\partial_t S + \nabla \cdot (S\,\mathbf{v}) = D_S\,\nabla^2 S + \sigma, \tag{44}$$

where D_S is the entropy diffusion coefficient and $\sigma \geq 0$ represents local entropy production. Integration over space gives

$$\frac{d}{dt}\int S\,d^3x = \int \sigma\,d^3x \geq 0, \tag{45}$$

so total entropy is non-decreasing, consistent with the second law of thermodynamics.

18 Linear Stability Analysis

To understand the formation of large-scale structure in RSVP dynamics, consider small perturbations around a homogeneous equilibrium state [35],

$$\Phi = \Phi_0 + \delta\Phi, \quad \mathbf{v} = \delta\mathbf{v}, \quad S = S_0 + \delta S. \tag{46}$$

Linearizing the field equations around this background yields

$$\partial_t \delta\Phi = D_\Phi\,\nabla^2\delta\Phi + \lambda_2\,\delta S + \lambda_3\,\nabla\cdot\delta\mathbf{v}, \tag{47}$$

$$\partial_t \delta\mathbf{v} = -\frac{1}{\rho_0}\nabla\delta P_{\text{eff}} + \nu\,\nabla^2\delta\mathbf{v}, \tag{48}$$

$$\partial_t \delta S = D_S\,\nabla^2\delta S + \lambda_1\,\nabla\cdot\delta\mathbf{v} + \lambda_2\,\delta\Phi, \tag{49}$$

where $\nu = \kappa/\rho_0$ is an effective kinematic viscosity.

Assuming plane-wave solutions $\delta X \propto e^{i(\mathbf{k}\cdot\mathbf{x}-\omega t)}$, one obtains the dispersion relation for longitudinal modes,

$$\omega^2 = \left(D_\Phi + D_S - \frac{\lambda_1\lambda_3}{\rho_0}\right)k^2 - \lambda_2^2 + \mathcal{O}(k^4). \tag{50}$$

Instabilities occur when the effective sound-speed term becomes negative. In particular, when the coupling λ_2^2 between density and entropy fields exceeds the diffusive stabilization, long-wavelength modes become unstable, which provides a mechanism for spontaneous formation of large-scale coherent structures.

19 Spectral Representation of RSVP Fields

The plenum fields can be expanded in Fourier modes,

$$\Phi(x,t) = \int \tilde{\Phi}(k,t)\, e^{ik\cdot x}\, d^3k, \tag{51}$$

and similarly for $\mathbf{v}$ and S. In this representation coarse-graining corresponds to removing high-frequency modes $|k| > \Lambda$. The resulting effective fields obey renormalized dynamical equations in which coupling parameters depend on the cutoff scale Λ. This provides a direct connection between RSVP field evolution and renormalization group methods [1, 15].

20 Continuum Limit of Spherepop Dynamics

We now formalize the relationship between the discrete Spherepop event structure of Section 2 and the continuous RSVP field description.

20.1 Assumptions on the Event Ensemble

We assume that the Spherepop event configuration $\{e_i\}$ satisfies:

1. *Locality*: each event affects only a bounded neighborhood,
2. *Finite propagation*: interactions propagate at finite speed,
3. *Statistical regularity*: event distributions admit coarse-grained averages over sufficiently large regions.

Theorem 1 (Emergence of RSVP Field Dynamics). *Consider a sequence of Spherepop event configurations with coarse-graining scale $\ell \to 0$ and event density increasing such that macroscopic observables remain finite. Under the assumptions of locality, finite propagation speed, and statistical regularity, the coarse-grained fields $(\Phi_\ell, \mathbf{v}_\ell, S_\ell)$ converge weakly to continuous fields $(\Phi, \mathbf{v}, S)$ satisfying a system of coupled partial differential equations*

$$\partial_t X^A = F^A(X, \nabla X). \tag{52}$$

Moreover, if the microscopic event dynamics conserve total density and respect entropy production constraints, the limiting equations take the form of a gradient flow

$$\partial_t X^A = -G^{AB} \frac{\delta \mathcal{R}}{\delta X^B} \tag{53}$$

for a functional $\mathcal{R}$ determined by the coarse-grained statistics of the event ensemble.

Sketch. The proof follows standard arguments in hydrodynamic and kinetic limits. Local averaging defines effective fields whose evolution is determined by the net flux of conserved quantities across the boundary of $B_\ell(x)$. Locality ensures that only nearby events contribute to the flux, while finite propagation bounds the rate of change. Statistical regularity guarantees convergence of empirical averages to smooth fields as $\ell \to 0$.

Conservation of density produces a continuity equation; the momentum-like transfer $\mathbf{j}(e_i)$ defines the effective flow field $\mathbf{v}$. Entropy production at the microscopic level induces a monotonic functional $\mathcal{R}$ whose variation governs relaxation. Collecting these contributions yields a closed system for $(\Phi, \mathbf{v}, S)$, which can be written in gradient-flow form under positivity conditions on the coarse-grained metric G^{AB}. □

Remark 3. The structure of Theorem 1 closely parallels the derivation of hydrodynamics from kinetic theory and the emergence of effective field theories under renormalization group flow. In this sense, RSVP dynamics may be interpreted as the hydrodynamic limit of an underlying event-based theory.

21 Topological Structures in the Plenum

The vector flow field $\mathbf{v}$ admits conserved topological invariants [24].

Definition 3. The helicity of the plenum flow is

$$H = \int \mathbf{v} \cdot (\nabla \times \mathbf{v}) \, d^3x. \tag{54}$$

Under the RSVP evolution equations with appropriate boundary conditions, H is conserved in the inviscid limit $\kappa \to 0$. Physically, helicity measures the degree to which flow lines are linked and twisted.

The linking number of two closed vortex curves γ_1, γ_2 is given by the Gauss integral

$$L(\gamma_1, \gamma_2) = \frac{1}{4\pi} \oint_{\gamma_1} \oint_{\gamma_2} \frac{(\mathbf{r}_1 - \mathbf{r}_2) \cdot (d\mathbf{r}_1 \times d\mathbf{r}_2)}{|\mathbf{r}_1 - \mathbf{r}_2|^3}. \tag{55}$$

Vortex structures with nontrivial topology can trap entropy and density gradients, providing a mechanism for the persistence of coherent cosmic structures over long timescales.

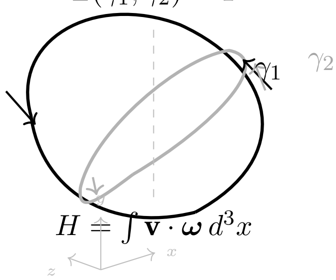

Figure 4: Two linked vortex tubes γ_1 (black) and γ_2 (gray) in the plenum flow field $\mathbf{v}$. Their topological linking number $L(\gamma_1, \gamma_2) = 1$ is a conserved invariant in the inviscid limit. The global helicity $H = \int \mathbf{v} \cdot (\nabla \times \mathbf{v})\, d^3x$ measures the total winding and is conserved under RSVP evolution when $\kappa \to 0$. Such topological structures can trap entropy gradients, stabilizing coherent cosmic configurations.

22 Curvature of Theory Space and the Zamolodchikov Metric

The geometric interpretation of renormalization group flow becomes more precise when the space of couplings is endowed with a metric structure. In two-dimensional conformal field theory, Zamolodchikov demonstrated that the space of marginal couplings carries a natural Riemannian metric defined by two-point functions of operators [2].

Let g_i denote couplings associated with operators $\mathcal{O}_i$. The Zamolodchikov metric is

$$G_{ij} \sim \langle \mathcal{O}_i(x)\, \mathcal{O}_j(0) \rangle. \tag{56}$$

Under RG flow, couplings evolve along geodesics of this curved manifold. The curvature of theory space reflects operator mixing and quantum corrections [5].

In RSVP theory, the universe evolves through a configuration space defined by $(\Phi, \mathbf{v}, S)$. If this space is endowed with an appropriate metric G^{AB}, dynamical evolution corresponds to trajectories in a curved field manifold. The geometric structure of theory space in quantum field theory may therefore have a precise analogue in the geometric structure of plenum field space.

23 Entropy, Holography, and Emergent Geometry

The connection between entropy and spacetime geometry has become a central theme in modern theoretical physics [42, 41, 10]. Black hole thermodynamics revealed that gravitational systems possess entropy proportional to horizon area [8, 9].

In the AdS/CFT correspondence, spacetime geometry in a bulk gravitational theory emerges from the entanglement structure of a boundary quantum field theory [10, 11, 49]. More broadly, Ryu–Takayanagi formula relates entanglement entropy of a boundary region to the area of a minimal bulk surface.

The RSVP framework offers a complementary interpretation. Instead of deriving geometry from boundary entanglement, RSVP treats entropy as one of the primary dynamical fields. The entropy field S interacts with density Φ and flow $\mathbf{v}$, producing large-scale structures through redistribution processes. Geometric properties of spacetime arise from the collective organization of these fields as coherent patterns stabilize.

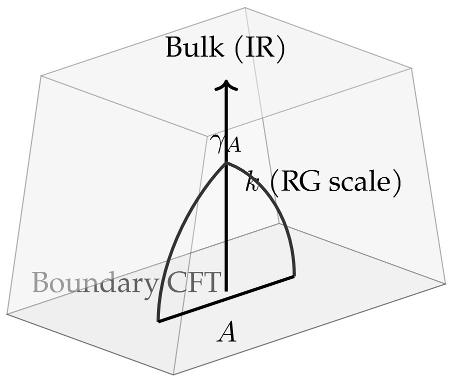

Figure 5: Holographic geometry with boundary conformal field theory at $y = 0$ and bulk Anti-de Sitter spacetime above it. The radial coordinate corresponds to the RG scale k. The arc γ_A is the Ryu–Takayanagi minimal surface in the bulk whose area computes the entanglement entropy of boundary region A. In the RSVP interpretation, the radial direction corresponds to entropy-driven smoothing across plenum scales.

24 RSVP Dynamics as Coarse-Grained Renormalization Flow

The similarity between RSVP evolution and renormalization group flow becomes clearer when coarse-graining procedures are considered.

In quantum field theory, coarse-graining integrates out short-distance degrees of freedom, corresponding to

$$\Gamma_\Lambda[\phi] \to \Gamma_{\Lambda - d\Lambda}[\phi], \tag{57}$$

where Λ is a momentum cutoff. A conceptually similar process occurs in RSVP dynamics. A coarse-graining transformation acts on the plenum fields as

$$X^A(x) \to \bar{X}^A(x) = \int K(x-y)\, X^A(y)\, dy, \tag{58}$$

where K is a smoothing kernel. The evolution of the coarse-grained fields defines a flow on the space of plenum configurations, analogous to RG flow on theory space. Large-scale cosmological behavior corresponds to infrared fixed points of the plenum evolution.

25 Renormalization Flow Derived from the RSVP Action

Following the functional renormalization group approach [4, 19], the scale dependence of the effective RSVP action can be expressed as

$$\partial_k \Gamma_k[\Phi, \mathbf{v}, S] = \frac{1}{2}\mathrm{Tr}\left[(\Gamma_k^{(2)} + R_k)^{-1} \partial_k R_k\right], \tag{59}$$

where $\Gamma_k^{(2)}$ denotes the second functional derivative and R_k is an infrared regulator. The effective action depends on all three plenum fields, so the trace runs over $(\Phi, \mathbf{v}, S)$ fluctuation modes. This equation describes how the effective interactions among density, vector flow, and entropy fields evolve as small-scale plenum fluctuations are integrated out, establishing a direct mathematical bridge between conventional RG analysis and entropy-driven plenum dynamics.

26 Entropy Production and Irreversibility

Irreversibility plays an important role in both thermodynamics and RG dynamics [38, 39, 37]. Define the local entropy production rate

$$\sigma = D_S |\nabla S|^2 / S + \kappa |\nabla \times \mathbf{v}|^2, \tag{60}$$

which combines diffusive entropy production and viscous dissipation. The entropy balance equation

$$\partial_t S + \nabla \cdot (S\,\mathbf{v}) = D_S\,\nabla^2 S + \sigma \tag{61}$$

then describes both entropy transport and production simultaneously. The positive definiteness of σ ensures irreversibility, providing a microscopic basis for the monotonic decrease of the entropy–coherence functional $\mathcal{R}$ established in Theorem 3 below.

27 Hamiltonian Formulation of RSVP Field Dynamics

An equivalent formulation of RSVP dynamics uses canonical momenta and Hamiltonian mechanics [25, 26, 27].

Define conjugate momenta

$$\Pi_\Phi = \frac{\partial \mathcal{L}}{\partial(\partial_t \Phi)} = \partial_t \Phi, \tag{62}$$

$$\mathbf{\Pi}_v = \frac{\partial \mathcal{L}}{\partial(\partial_t \mathbf{v})} = \rho(\Phi)\,\mathbf{v}, \tag{63}$$

$$\Pi_S = \frac{\partial \mathcal{L}}{\partial(\partial_t S)} = 0. \tag{64}$$

The Hamiltonian density is obtained by Legendre transform:

$$\mathcal{H} = \frac{1}{2}\Pi_\Phi^2 + \frac{|\mathbf{\Pi}_v|^2}{2\rho(\Phi)} + \frac{1}{2}|\nabla\Phi|^2 + \frac{1}{2}\alpha|\nabla S|^2 + \kappa|\nabla \times \mathbf{v}|^2 + V(\Phi) + U(S) + \mathcal{H}_{\text{int}}. \tag{65}$$

The Hamilton equations of motion

$$\partial_t X^A = \frac{\delta \mathcal{H}}{\delta \Pi_A}, \qquad \partial_t \Pi_A = -\frac{\delta \mathcal{H}}{\delta X^A} \tag{66}$$

reproduce the Euler–Lagrange equations derived in Section 9. The configuration space of plenum fields becomes a phase space equipped with the symplectic form

$$\Omega = \int d^3x \, d\Pi_A \wedge dX^A. \tag{67}$$

Remark 4. The entropy field S has vanishing canonical momentum at this order. In an extended formulation incorporating entropy production explicitly, a Lagrange multiplier for the entropy balance constraint introduces a nontrivial conjugate variable representing a chemical potential.

28 Lie Symmetry Structure of Plenum Dynamics

Continuous symmetries of the RSVP action generate conserved currents via Noether's theorem [25, 18]. Under the infinitesimal coordinate transformation $x^\mu \to x^\mu + \epsilon\xi^\mu$ together with field variations $\delta\Phi$, $\delta\mathbf{v}$, δS, the action is invariant when

$$\delta\mathcal{A}_{RSVP} = 0. \tag{68}$$

The generators of symmetry transformations form a Lie algebra

$$[T_a, T_b] = f_{ab}^{\ \ c} T_c, \tag{69}$$

where $f_{ab}^{\ \ c}$ are the structure constants. The principal symmetries of the RSVP action include spatial translation invariance, generating momentum conservation in the plenum; rotational invariance, generating angular momentum conservation for the vector flow field; and global shifts $S \to S + \text{const}$, which are broken by the potential $U(S)$ to a discrete subgroup. The study of these symmetries classifies invariant solutions and attractor configurations within RSVP dynamics.

29 Lie Algebra Cascade of Entropy Flow

Entropy transport in RSVP dynamics can be interpreted as a cascade of transformations generated by vector flow operators. The entropy field evolves according to

$$\partial_t S = \mathcal{L}_{\mathbf{v}} S + D_S \nabla^2 S + \sigma, \tag{70}$$

where $\mathcal{L}_{\mathbf{v}}$ is the Lie derivative along the flow field. Successive interactions between flow modes generate a cascade analogous to a Lie algebra action on tensor fields. Letting T_a denote generators associated with flow modes at scale a, the algebra satisfies $[T_a, T_b] = f_{ab}{}^{c} T_c$. Entropy redistribution across scales can therefore be interpreted as a sequence of Lie algebra operations progressively transferring structure from small to large scales.

30 Correspondence Between RG and RSVP

The structural similarities between RG flow and RSVP dynamics suggest a precise correspondence. In both frameworks, microscopic complexity is progressively reorganized into effective macroscopic behavior.

Renormalization Group	RSVP
Theory space trajectory	Plenum field trajectory
RG fixed point	Stationary plenum regime
Coarse-graining	Entropic smoothing
Monotonic c-function	Entropy–coherence functional $\mathcal{R}$
Zamolodchikov metric	Field-space metric G^{AB}
UV cutoff Λ	Smoothing kernel scale
Operator mixing matrix	Field coupling matrix λ_{ij}

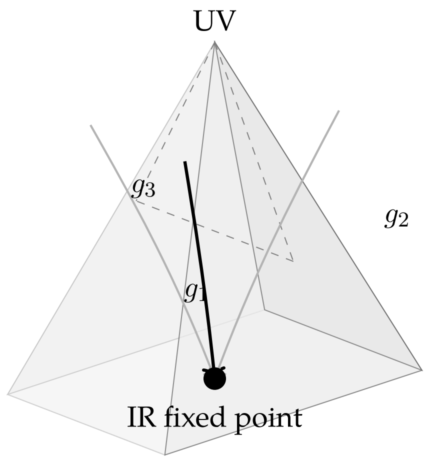

Figure 6: Theory space as a three-dimensional polyhedral cone. The apex represents the ultraviolet regime; the three faces correspond to sectors dominated by couplings g_1, g_2, g_3. Renormalization group trajectories flow along the faces of the cone, converging to the infrared fixed point at the base center.

31 Related Work

A growing body of work in theoretical physics has explored the possibility that geometry, gravitation, and physical law may arise from informational, entropic, or emergent structures. Jacobson's thermodynamic derivation of the Einstein equation showed that gravitational dynamics can be interpreted as an equation of state associated with local horizon thermodynamics [6]. Verlinde extended this direction by proposing that gravity may be understood as an entropic force [7]. Within holographic and entanglement-based approaches, Ryu–Takayanagi and developments by Van Raamsdonk strengthened the view that spacetime connectivity may be reconstructed from entanglement structure [11, 51].

In the study of renormalization and theory space, the irreversibility of RG flow and the geometry of operator manifolds suggest that physical description carries an intrinsic directional and geometric organization [2, 5]. Jaynes and Landauer each contributed foundational perspectives connecting inference, entropy, and physical law [38, 52].

The symbolic collapse grammar framework of Taylor belongs to this broad lineage but approaches it from the side of discrete symbolic emergence [53]. There, physical observables arise from motif rendering, entropy-weighted collapse, and symbolic grammar over a binary alphabet. The RSVP framework proposed here shares with such approaches the conviction that physical structure is emergent and entropy-sensitive, but differs in a decisive respect: rather than taking symbolic collapse as primitive, RSVP posits continuous scalar, vector, and entropy fields whose coupled dynamics generate both geometric structure and, in suitable discrete limits, symbolic rendering rules. In this sense, RSVP is intended not as a competitor to discrete emergence models but as a possible field-theoretic completion within which they may be recovered as coarse-grained projections.

32 Symbolic Collapse Grammars as Discrete Limits of the Plenum

32.1 Overview

Symbolic collapse grammars model physical emergence as a rendering process constrained by entropy. Motifs are evaluated by an entropy cost functional; only those satisfying a threshold condition are permitted to render as physical states.

We show here that such grammars are recovered as a discrete, thresholded, overdamped limit of RSVP dynamics.

32.2 Discrete Symbolic Substrate

Let the symbolic alphabet be

$$\Sigma = \{A,\, A^{\perp}\}.$$

Define an embedding into the scalar field $\Phi(x,t)$ by

$$A \mapsto +\phi_0, \qquad A^{\perp} \mapsto -\phi_0,$$

for fixed amplitude $\phi_0 > 0$. A symbolic motif of length N,

$$w = (s_1, \ldots, s_N), \quad s_i \in \Sigma,$$

corresponds to a discrete sampling of Φ over a lattice $\{x_i\}_{i=1}^{N}$, so the symbolic substrate is equivalent to a binary-valued lattice field configuration.

32.3 Entropy Functional as Coarse-Grained Field

The symbolic entropy cost $H(w)$ is identified with the coarse-grained entropy field:

$$H(w) \approx \sum_{i=1}^{N} S(x_i, t) \;\longrightarrow\; \int_{\Omega} S(x,t)\, dV.$$

The symbolic entropy measure is therefore the discrete projection of a continuous entropy density.

32.4 Collapse Operator as Thresholded Dynamics

The symbolic collapse rule

$$\hat{M}(w) = \begin{cases} \text{rendered}, & H(w) < H_c, \\ \varnothing, & \text{otherwise} \end{cases}$$

is reproduced by the local collapse indicator

$$\chi(x,t) = \Theta\big(S_c - S(x,t) - \alpha\, \nabla \cdot \mathbf{v}(x,t)\big),$$

where Θ is the Heaviside function. The global symbolic condition $H(w) < H_c$ is the integrated constraint $\int_{\Omega} S\, dV < H_c$, which is an observable derived from field dynamics rather than a primitive rule.

32.5 Variational Embedding and the RSVP Lagrangian

To make the discrete-limit argument variational, we record the full RSVP Lagrangian density:

$$\begin{aligned}\mathcal{L}_{RSVP} = &\frac{1}{2}(\partial_t\Phi)^2 - \frac{c_\Phi^2}{2}|\nabla\Phi|^2 - U(\Phi) \\ &+ \frac{\rho_v}{2}|\partial_t\mathbf{v}|^2 - \frac{\nu_v^2}{2}|\nabla\mathbf{v}|^2 - \frac{m_v^2}{2}|\mathbf{v}|^2 \\ &+ \frac{\rho_S}{2}(\partial_t S)^2 - \frac{c_S^2}{2}|\nabla S|^2 - W(S) \\ &+ \kappa\, S\Phi + \alpha\,\mathbf{v}\cdot\nabla\Phi + \beta\,\mathbf{v}\cdot\nabla S - \gamma\, S\,\nabla\cdot\mathbf{v} - \delta\,\Phi^2 S, \end{aligned} \tag{71}$$

with quartic potentials $U(\Phi) = \frac{\lambda}{4}\Phi^4 - \frac{\mu_\Phi^2}{2}\Phi^2$ and $W(S) = \frac{\lambda_S}{4}S^4 - \frac{\mu_S^2}{2}S^2$. Adding a Rayleigh dissipation functional

$$\mathcal{R}_{dis} = \int \left(\tfrac{\sigma_\Phi}{2}(\partial_t\Phi)^2 + \tfrac{\sigma_v}{2}|\partial_t\mathbf{v}|^2 + \tfrac{\sigma_S}{2}(\partial_t S)^2\right) d^n x$$

and passing to the overdamped limit $\sigma \to \infty$ reduces the second-order system to a first-order gradient flow, recovering the effective RSVP evolution equations.

32.6 Reduction Theorem

Theorem 2 (Overdamped Binary Reduction)**.** *Consider the RSVP Lagrangian above with Rayleigh dissipation. In the simultaneous limits*

(i) $\sigma_\Phi, \sigma_v, \sigma_S \to \infty$ (overdamped),

(ii) $\Phi(x,t) \in \{+\phi_0, -\phi_0\}$ (binary scalar),

(iii) $\mathbf{v}(x,t) \to 0$ (suppressed flow),

(iv) $S(x,t) \to S_i$ piecewise constant, $\partial_t(\Phi, S) \to 0$ (quasi-static),

the RSVP system reduces to a symbolic collapse grammar over $\Sigma = \{A, A^\perp\}$ with rendering rule determined by a thresholded entropy functional.

Proof. In the overdamped limit, inertial terms vanish and the Euler–Lagrange equations reduce to gradient-flow form

$$\sigma_q\,\partial_t q \approx -\frac{\delta L}{\delta q},$$

so the system evolves toward local minima of the effective energy functional $E[\Phi, \mathbf{v}, S]$.

Under the binary constraint on Φ, the field reduces to a discrete-valued function on a partition $\{\Omega_i\}$, identified with a symbolic string w. Since $\mathbf{v} \to 0$, all transport and flow-coupling terms vanish. The entropy field becomes piecewise constant, so the total entropy reduces to the finite sum $H(w) = \sum_i S_i|\Omega_i|$.

The RSVP collapse indicator reduces to the global condition $\sum_i S_i < H_c$, which reproduces the symbolic collapse rule. □

Corollary 2.1 (Loss of Geometric Information)**.** *The reduction to symbolic collapse dynamics eliminates entropy gradients ∇S, vector flow $\mathbf{v}$, and continuous scalar variation. Any metric of the form $g_{ij} \sim \partial_i S \partial_j S + v_i v_j + \Phi^2 \delta_{ij}$ reduces to a trivial or piecewise constant structure. Therefore symbolic grammars constitute a strictly lower-dimensional representation of plenum dynamics: they are projections, not equivalents.*

Remark 5. The relationship between RSVP and symbolic collapse grammars mirrors the relationship between fluid mechanics and cellular automata models of fluids. The automaton captures some macroscopic features correctly but loses continuous structure. The field theory is the generating substrate; the automaton is a compressed shadow.

33 Comparison with Modern Approaches to Quantum Gravity

33.1 Asymptotic Safety

The asymptotic safety program proposes that quantum gravity may be defined by a nontrivial ultraviolet fixed point of the renormalization group [3, 4]. Within this framework, the renormalization group flow of the effective action Γ_k is studied using the functional equation

$$\partial_k \Gamma_k = \frac{1}{2} \mathrm{Tr} \left[(\Gamma_k^{(2)} + R_k)^{-1} \partial_k R_k \right]. \tag{72}$$

Asymptotic safety describes a trajectory in theory space approaching a stable fixed point in the ultraviolet. RSVP by contrast concerns physical field trajectories rather than coupling-space trajectories, but both pictures involve dynamical evolution on a high-dimensional manifold governed by flow equations.

33.2 Emergent Gravity

Jacobson demonstrated that Einstein's equations can be derived from the Clausius relation applied to local Rindler horizons [6], while Verlinde has proposed that gravity may emerge as an entropic force [7]. RSVP shares the philosophical direction that geometry is not fundamental, interpreting geometric phenomena as emergent consequences of plenum field organization. However, whereas emergent gravity programs begin with quantum entanglement or horizon thermodynamics, RSVP begins with a continuous field description of density, flow, and entropy.

33.3 Holographic Renormalization

In AdS/CFT, the radial coordinate of an Anti-de Sitter spacetime corresponds to the energy scale of a boundary quantum field theory [10, 11, 43]. Renormalization group flow in the boundary theory is interpreted geometrically as radial motion in the bulk. In RSVP theory, entropy-driven smoothing may play an analogous role, describing large-scale structure as the macroscopic manifestation of deeper field dynamics.

34 Sheaf-Theoretic Locality of the Plenum

Physical field theories are inherently local: large-scale behavior arises from the consistent assembly of local data. The natural mathematical language for this is sheaf theory [29, 30].

Let $\mathcal{U} = \{U_i\}$ be an open cover of spacetime. On each patch U_i define local plenum fields

$$(\Phi_i, \mathbf{v}_i, S_i) \in \mathcal{F}(U_i), \tag{73}$$

where $\mathcal{F}$ is the presheaf of RSVP field configurations. Restriction maps

$$\rho_{ij} : \mathcal{F}(U_i) \to \mathcal{F}(U_i \cap U_j) \tag{74}$$

encode compatibility of field data across overlapping regions. If the compatibility conditions are satisfied on all overlaps, the local configurations glue to produce a global field configuration. The RSVP plenum may thus be viewed as the sheaf

$$\mathcal{P} : U \mapsto (\Phi, \mathbf{v}, S)|_U. \tag{75}$$

Entropy transport and vector flow become morphisms between sections of this sheaf, and large-scale cosmic structure emerges when local field sections assemble coherently across spacetime.

35 Spectral Sequences and Entropy Cascades

The redistribution of entropy and density across scales resembles cascade processes in turbulence and RG flow [34, 20]. Let $\mathcal{H}_k$ denote a hierarchy of field modes ordered by characteristic scale k, defining a filtration

$$\mathcal{H}_0 \subset \mathcal{H}_1 \subset \cdots \subset \mathcal{H}_n. \tag{76}$$

Spectral sequence techniques track how entropy propagates across these layers. The pages $E_r^{p,q}$ of the associated spectral sequence carry differential operators

$$d_r : E_r^{p,q} \to E_r^{p+r,q-r+1} \tag{77}$$

representing inter-scale entropy transfers. Under repeated application of these differentials the sequence converges

$$E_r^{p,q} \Rightarrow H^{p+q}(\mathcal{P}), \tag{78}$$

representing the large-scale cohomological structure of the plenum field configuration. Microsopic fluctuations cascade through intermediate scales before stabilizing into macroscopic cosmological structures.

36 Categorical Structure of Coarse-Graining

Renormalization and coarse-graining processes admit a categorical interpretation [30, 29]. Let $\mathcal{C}$ denote a category whose objects are field configurations and whose morphisms represent dynamical evolution. A coarse-graining transformation defines a functor

$$\mathcal{F} : \mathcal{C}_{micro} \to \mathcal{C}_{macro}, \tag{79}$$

mapping microscopic configurations to effective macroscopic states. Renormalization group flow corresponds to iterated application of such functors $\mathcal{F}_\Lambda : \mathcal{C} \to \mathcal{C}$. The RSVP plenum evolution can be interpreted similarly: the fields $(\Phi, \mathbf{v}, S)$ define objects in a configuration category, while entropy-driven smoothing corresponds to morphisms reducing fine-scale structure.

37 Symmetric Monoidal Categorical Formulation of Plenum Dynamics

The category **Plenum** has objects $X = (\Phi, \mathbf{v}, S)$ representing local plenum configurations and morphisms $f : X \to Y$ representing entropy-coherence transformations. It naturally carries a symmetric monoidal structure: given two independent regions X and Y, their joint configuration is

$$X \otimes Y, \tag{80}$$

with monoidal unit $\mathbf{1} = (0, 0, 0)$ (the vacuum plenum). Entropy redistribution processes correspond to monoidal morphisms

$$\mu : X \otimes Y \to Z \tag{81}$$

merging local plenum states into larger coherent structures. Coarse-graining operations then define symmetric monoidal functors

$$\mathcal{C}_\lambda : \mathbf{Plenum} \to \mathbf{Plenum}, \tag{82}$$

formalizing the compositional nature of large-scale structure formation.

38 Functorial Relationship Between RG and RSVP Dynamics

Let $\mathcal{T}$ denote the category of quantum field theories parameterized by couplings g_i, and let $\mathcal{P}$ denote the category of plenum configurations. Renormalization defines a flow functor

$$\mathcal{R}_\Lambda : \mathcal{T} \to \mathcal{T} \tag{83}$$

and entropy-driven plenum evolution defines

$$\mathcal{E}_t : \mathcal{P} \to \mathcal{P}. \tag{84}$$

A conceptual bridge between the frameworks may be expressed as a functor $\mathcal{F} : \mathcal{T} \to \mathcal{P}$. If this functor exists and is natural, one has the commutative diagram:

$$\begin{array}{ccc} \text{Microscopic QFT} & \xrightarrow{\mathcal{R}_\Lambda} & \text{Effective QFT} \\ \Big\downarrow \mathcal{F} & & \Big\downarrow \mathcal{F} \\ \text{Plenum Microstate} & \xrightarrow[\mathcal{E}_t]{} & \text{Plenum Macrostate} \end{array}$$

If such a functorial relationship holds, RG flow and entropy-driven plenum dynamics may be viewed as different representations of a single deeper transformation on physical state spaces.

39 Morse-Theoretic Interpretation of Renormalization Flow

Renormalization group flow can often be interpreted as a gradient flow on a manifold of couplings [2, 5]. Suppose there exists a scalar functional $C(g)$ on theory space $\mathcal{T}$ such that

$$\frac{dg^i}{d\tau} = -G^{ij}\frac{\partial C}{\partial g^j}. \tag{85}$$

If C is a Morse function, its critical points

$$\nabla C = 0 \tag{86}$$

coincide with RG fixed points. The Hessian

$$H_{ij} = \frac{\partial^2 C}{\partial g^i \partial g^j} \tag{87}$$

determines stability: positive eigenvalues correspond to relevant perturbations and negative eigenvalues to irrelevant operators [16].

A parallel structure appears in RSVP dynamics. If the entropy–coherence functional $\mathcal{R}$ acts as a Morse function on plenum field space, then stationary configurations correspond to critical points of $\mathcal{R}$, and the stability of these states is determined by the second variation $\delta^2\mathcal{R}$. Morse theory may therefore be useful for classifying stable and unstable regimes of RSVP cosmological dynamics [26, 25].

40 Derived Stack Structure of Plenum Field Space

Modern approaches to quantum field theory describe configuration spaces using derived stacks, which capture symmetry quotients and constraint relations [30, 29, 31]. Because the RSVP fields are defined modulo symmetry transformations, the true configuration space is a quotient

$$\mathcal{M} \simeq [\mathcal{F}/\mathcal{G}], \tag{88}$$

where $\mathcal{F}$ is the space of raw field configurations and $\mathcal{G}$ is the symmetry group. Derived geometry enters when considering fluctuations: the tangent complex of the derived stack captures linearized dynamics and constraints simultaneously.

The RSVP action becomes a function on the derived stack

$$\mathcal{A}_{RSVP} : \mathcal{M} \to \mathbb{R}. \tag{89}$$

Classical solutions correspond to critical points, while the derived tangent complex encodes their perturbations. This viewpoint provides a bridge between RSVP field theory and modern geometric approaches including derived symplectic geometry.

41 Derived Symplectic Structure of Plenum Field Space

Spaces of solutions to field equations often carry natural derived symplectic structures [29, 28]. A derived symplectic form of degree k on the plenum configuration space is a closed 2-form

$$\omega : \mathbb{T}_{\mathcal{M}} \wedge \mathbb{T}_{\mathcal{M}} \to \mathbb{R}[k] \tag{90}$$

defined on the tangent complex. A natural candidate in the RSVP framework arises from the pairing between density fluctuations and vector flow modes,

$$\omega = \int d^3x \left(\delta\Phi \wedge \delta(\nabla \cdot \mathbf{v}) + \delta S \wedge \delta\sigma \right), \tag{91}$$

where σ represents entropy production modes. This defines a Poisson bracket on observables,

$$\{F, G\} = \omega^{-1}(dF, dG), \tag{92}$$

and the resulting Hamiltonian flow

$$\partial_t X^A = \{X^A, \mathcal{R}\} \tag{93}$$

describes entropy-driven redistribution consistent with both the gradient-flow and Hamiltonian interpretations.

42 AKSZ Quantization of the RSVP Action

The Batalin–Vilkovisky (BV) formalism provides a systematic method for quantizing field theories with gauge symmetries [29, 28]. To quantize the RSVP theory within this framework, the field space is extended to include ghost fields and antifields, producing an extended space $\mathcal{M}_{BV}$. The BV formalism introduces an odd symplectic structure

$$\omega_{BV} = \int d^3x \, \delta X^A \wedge \delta X^*_A, \tag{94}$$

where X^*_A are antifields. The master action

$$\mathcal{S}_{BV} = \mathcal{A}_{RSVP} + \text{ghost terms} + \text{gauge-fixing terms} \tag{95}$$

must satisfy the BV master equation

$$(\mathcal{S}_{BV}, \mathcal{S}_{BV}) = 0, \tag{96}$$

where $(\cdot, \cdot)$ denotes the BV antibracket. Entropy flow constraints and vector field conservation laws may appear as gauge symmetries whose resolution requires ghost degrees of freedom. The BV framework thus provides a natural pathway toward quantizing the RSVP theory.

43 Gromov–Hausdorff Convergence and Cosmological Smoothing

The entropy-driven smoothing of the RSVP plenum admits a precise geometric interpretation using Gromov–Hausdorff convergence [32, 33]. The Gromov–Hausdorff distance between metric spaces (X, d_X) and (Y, d_Y) is

$$d_{GH}(X, Y) = \inf_Z d_H^Z(\varphi(X), \psi(Y)), \tag{97}$$

where φ, ψ are isometric embeddings into a common metric space Z and d_H is the Hausdorff distance. Interpreting plenum configurations at different times as metric spaces (X_t, d_t) whose metric is induced by density and entropy gradients, cosmic evolution corresponds to a sequence

$$(X_0, d_0) \to (X_1, d_1) \to \cdots \to (X_\infty, d_\infty) \tag{98}$$

converging in the Gromov–Hausdorff sense toward a smoother configuration. This provides a rigorous framework for the intuition that the universe evolves toward large-scale structural regularity through entropy-driven redistribution.

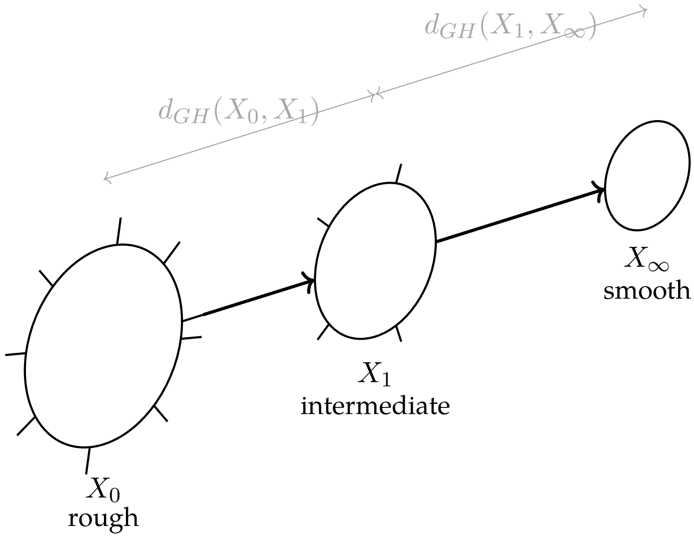

Figure 7: Gromov–Hausdorff convergence of plenum configurations. The metric space X_0 represents an initial rough, fluctuating plenum geometry. Entropy-driven smoothing progressively reduces the Gromov–Hausdorff distance, yielding the intermediate state X_1 and eventually the entropy-coherent attractor X_∞. The spikes indicate microscopic inhomogeneities that are progressively absorbed.

44 Covariant Relativistic Formulation of RSVP Dynamics

To connect RSVP with relativistic physics, we express the plenum dynamics in covariant form [44, 45]. With spacetime coordinates x^μ and metric $g_{\mu\nu}$, the flow field becomes a four-vector $v^\mu(x^\mu)$ and the fields Φ, S remain scalars. A relativistic RSVP action is

$$\mathcal{A} = \int d^4x \sqrt{-g}\, \mathcal{L}(\Phi, v^\mu, S), \tag{99}$$

with

$$\mathcal{L} = \frac{1}{2}\nabla_\mu\Phi\,\nabla^\mu\Phi + \frac{1}{2}\rho(\Phi)\,v_\mu v^\mu + \frac{1}{2}\alpha\,\nabla_\mu S\,\nabla^\mu S + \lambda_1 S\,\nabla_\mu v^\mu + \lambda_2\Phi S - V(\Phi, S). \quad (100)$$

The Euler–Lagrange equations yield

$$\nabla_\mu\nabla^\mu\Phi = \frac{\partial V}{\partial\Phi} - \lambda_2 S, \quad (101)$$

$$\rho(\Phi)\,v^\mu + \lambda_1\,\nabla^\mu S = 0, \quad (102)$$

$$\nabla_\mu\nabla^\mu S = -\lambda_1\,\nabla_\mu v^\mu + \frac{\partial V}{\partial S}. \quad (103)$$

In regimes where coherent field configurations emerge, the effective geometry perceived by observers may resemble curved spacetime, suggesting a pathway toward recovering gravitational phenomena as collective behavior of the plenum fields.

45 Observable Cosmological Consequences

For RSVP to function as a physical theory it must produce observable predictions differing from standard cosmology.

Within the RSVP framework, photons propagating through a slowly evolving plenum may lose energy according to

$$\frac{dE}{dt} = -\gamma\,\nabla S\cdot\mathbf{v}, \quad (104)$$

producing an effective redshift

$$1 + z = \exp\left(\int \gamma\,\nabla S\cdot\mathbf{v}\,dt\right). \quad (105)$$

This mechanism associates cosmological redshift with entropy-driven energy redistribution rather than metric expansion.

Density gradients in the Φ field could also bend photon trajectories, producing gravitational lensing effects without requiring fundamental spacetime curvature. Entropy-driven smoothing may furthermore influence the formation of cosmic structure, offering alternative explanations for large-scale clustering patterns observed in galaxy surveys. Future work must determine whether these predictions can be made quantitatively consistent with cosmological data [13, 44, 46].

46 Homogeneous and Isotropic Cosmological Limit

To connect RSVP dynamics with large-scale cosmology, we consider the homogeneous and isotropic limit of the plenum fields. The purpose of this reduction is not to impose a standard Friedmann–Lemaître–Robertson–Walker geometry at the outset, but to show how an effective cosmological description may arise from symmetry-restricted plenum dynamics.

46.1 Symmetry Reduction of the Plenum Fields

On sufficiently large scales, assume that the plenum is spatially homogeneous and isotropic. Then the scalar density and entropy fields depend only on time,

$$\Phi = \Phi(t), \qquad S = S(t), \tag{106}$$

and in a comoving frame the flow field takes the form $v^\mu = (v^0(t), 0, 0, 0)$, so that spatial gradients vanish.

46.2 Effective Cosmological Metric

The emergent metric ansatz reduces to a diagonal form

$$ds^2 = -N^2(t)\, dt^2 + a^2(t)\, \delta_{ij}\, dx^i dx^j, \tag{107}$$

where $a^2(t) = A(\Phi, S)$ is the derived scale factor and $N^2(t)$ incorporates flow and entropy-rate corrections. The effective cosmological scale factor is thus a collective variable derived from the scalar and entropy content of the plenum.

46.3 Friedmann-Like Equations

Varying the symmetry-reduced action and expressing dynamics through $a(t)$ yields a Friedmann-like relation,

$$H^2 = \frac{\kappa_{\text{eff}}}{3}\, \rho_{\text{plenum}} + \Delta_{\text{ent}}, \tag{108}$$

where $H = \dot{a}/a$ is the effective Hubble rate,

$$\rho_{\text{plenum}} = \frac{1}{2}\dot{\Phi}^2 + \frac{1}{2}\alpha \dot{S}^2 + \frac{1}{2}\rho(\Phi)(v^0)^2 + V(\Phi, S) - \lambda_2 \Phi S, \tag{109}$$

and Δ_{ent} collects correction terms arising from the entropy–flow coupling. A parallel acceleration equation takes the form

$$\frac{\ddot{a}}{a} = -\frac{\kappa_{\text{eff}}}{6}\big(\rho_{\text{plenum}} + 3p_{\text{plenum}}\big) + \Xi_{\text{ent}}, \tag{110}$$

where p_{plenum} is the effective pressure generated by the plenum fields and Ξ_{ent} collects entropy-driven corrections.

46.4 Redshift and Attractor Cosmologies

In the RSVP framework, the quantity $a(t)$ is an emergent collective variable, so cosmological redshift may be interpreted either as propagation through an effective geometry with time-dependent scale factor, or as a manifestation of entropy-driven redistribution in the underlying plenum. A particularly important case arises when $a(t)$ is approximately constant while the entropy and flow fields continue to evolve: the large-scale geometry is then effectively static while photons accumulate redshift through entropy-coupled propagation.

Because RSVP dynamics admit a gradient-flow interpretation, the homogeneous cosmological solutions may be interpreted as trajectories in a reduced phase space flowing toward critical points of $\mathcal{R}$. A stationary cosmology corresponds to a critical point satisfying $\delta\mathcal{R}/\delta\Phi = \delta\mathcal{R}/\delta S = \delta\mathcal{R}/\delta v^0 = 0$, and different cosmological histories correspond to different basins of attraction.

47 A Toy Redshift Law and Luminosity Distance

47.1 Entropy-Driven Redshift

Consider a photon of energy $E(t)$ propagating through a homogeneous plenum with time-dependent entropy field $S(t)$ and flow component $v^0(t)$. Motivated by the coupling structure of the RSVP action, the photon energy obeys

$$\frac{dE}{dt} = -\gamma\,\Theta(t)\,E, \tag{111}$$

where the effective attenuation rate is

$$\Theta(t) = \alpha_1\dot{S}(t) + \alpha_2 v^0(t) + \alpha_3\nabla_\mu v^\mu. \tag{112}$$

Solving yields

$$1 + z = \frac{E(t_{\text{em}})}{E(t_{\text{obs}})} = \exp\left(\gamma \int_{t_{\text{em}}}^{t_{\text{obs}}} \Theta(t)\, dt\right). \tag{113}$$

If $\Theta(t) = \Theta_0$ is approximately constant, then $1 + z = e^{\gamma\Theta_0\Delta t}$, reducing at small redshift to $z \approx \gamma\Theta_0\Delta t$. If the dominant contribution is entropy relaxation, then $1 + z = \exp(\gamma\alpha_1[S(t_{\text{obs}}) - S(t_{\text{em}})])$, so redshift directly measures the cumulative entropy difference encountered during propagation.

47.2 Luminosity Distance

Using the standard definition $F = L/(4\pi d_L^2)$ and accounting for both energy loss and arrival-rate suppression by a factor $(1 + z)^{-2}$, the luminosity distance is

$$d_L(z) = (1 + z)\, r(z), \tag{114}$$

where $r(z) = \int_{t_{\text{em}}}^{t_{\text{obs}}} c_{\text{eff}}(t)/a(t)\, dt$ is the propagation distance. In the constant-Θ approximation,

$$d_L(z) = \frac{c_{\text{eff}}}{\gamma\Theta_0}(1 + z)\ln(1 + z), \tag{115}$$

with small-redshift expansion

$$d_L(z) \approx \frac{c_{\text{eff}}}{\gamma\Theta_0}\left(z + \frac{z^2}{2} + \mathcal{O}(z^3)\right), \tag{116}$$

reproducing a linear Hubble-like law with effective scale $H_{\text{eff}} \equiv \gamma\Theta_0$.

47.3 Modified Reciprocity Relation

The angular-diameter distance d_A is determined by the geometric spreading of null congruences and is insensitive to entropy-driven energy loss at leading order, giving $d_A(z) = r(z)/(1 + z_{\text{geom}})$. Since the total redshift decomposes as $(1 + z) = (1 + z_{\text{geom}})(1 + z_{\text{ent}})$, one obtains the modified reciprocity relation

$$d_L = (1 + z_{\text{ent}})\,(1 + z_{\text{geom}})^2\, d_A. \tag{117}$$

When entropy-driven attenuation is absent ($z_{\text{ent}} = 0$), this reduces to the standard Etherington relation $d_L = (1 + z)^2 d_A$. Precision measurements comparing luminosity distances and angular-diameter distances therefore provide a direct test of the RSVP framework: any systematic deviation from the standard $(1 + z)^2$ ratio signals the presence of non-metric contributions to redshift.

48 Parameter Estimation Framework for RSVP Cosmology

48.1 Parametrization

We introduce a minimal parametrization of the attenuation rate as a function of redshift,

$$\Theta(z) = H_0 + \beta z + \mathcal{O}(z^2), \tag{118}$$

where H_0 plays the role of an effective Hubble scale and β captures deviations from linear behavior. The luminosity distance becomes

$$d_L(z;\theta) = (1+z)\int_0^z \frac{c_{\text{eff}}}{\gamma\Theta(z')}\,dz', \tag{119}$$

where $\theta = (H_0, \beta, \ldots)$ is the parameter vector. For the simplest case $\Theta = H_0$, this reduces to equation (115). The corresponding distance modulus is

$$\mu(z;\theta) = 5\log_{10}\left(\frac{d_L(z;\theta)}{10\,\text{pc}}\right). \tag{120}$$

48.2 Likelihood and Comparison with ΛCDM

Given a dataset of supernovae $\{z_i, \mu_i, \sigma_i\}$, a Gaussian likelihood takes the standard form

$$\mathcal{L}(\theta) \propto \exp\left(-\frac{1}{2}\sum_i \frac{[\mu_i - \mu(z_i;\theta)]^2}{\sigma_i^2}\right). \tag{121}$$

In the standard ΛCDM model, the luminosity distance is

$$d_L^{\Lambda\text{CDM}}(z) = (1+z)\int_0^z \frac{c}{H(z')}\,dz', \tag{122}$$

with $H(z)$ determined by the Friedmann equations. The RSVP model replaces the expansion rate $H(z)$ with the attenuation function $\gamma\Theta(z)$, yielding the same integral structure but a different physical interpretation. Both models can be fitted to the same datasets and compared by standard model-selection criteria.

At low redshift, the RSVP model mimics the standard linear Hubble law. At higher redshift, the logarithmic corrections in equation (115) predict deviations from ΛCDM that grow with z and can in principle be distinguished using supernova, baryon acoustic oscillation, and cosmic chronometer data. Violations of the standard reciprocity relation provide an additional independent diagnostic.

49 Emergent Metric Structure from Plenum Fields

49.1 Effective Metric Ansatz

To establish a connection between RSVP dynamics and geometric descriptions of spacetime, we construct an effective metric from the plenum fields. A natural symmetric rank-2 tensor built from the available field content is

$$g_{\mu\nu}^{\text{eff}} = A(\Phi, S)\,\eta_{\mu\nu} + B(\Phi, S)\,v_\mu v_\nu + C(\Phi, S)\,\nabla_\mu S\,\nabla_\nu S, \tag{123}$$

where $\eta_{\mu\nu}$ is the background Minkowski metric and A, B, C are scalar functions encoding how density and entropy modify effective geometry. The first term represents isotropic scaling determined by the local plenum state; the second and third terms introduce anisotropy due to flow and entropy gradients.

49.2 Metric as a Pullback from Field Space

A more fundamental origin of this metric arises from the pullback construction. At each spacetime point x^μ, the fields define a map $X : x^\mu \mapsto X^A(x^\mu)$ from spacetime into the plenum configuration space $\mathcal{M}$. The effective spacetime metric is then obtained as the pullback of the field-space metric G_{AB} along this map:

$$g_{\mu\nu}^{\text{eff}} = G_{AB}(X)\,\partial_\mu X^A\,\partial_\nu X^B, \tag{124}$$

giving schematically

$$g_{\mu\nu}^{\text{eff}} \sim (\partial_\mu\Phi)(\partial_\nu\Phi) + \rho(\Phi)(\partial_\mu v^\alpha)(\partial_\nu v_\alpha) + \alpha(\partial_\mu S)(\partial_\nu S) + \cdots \tag{125}$$

The ansatz from the previous subsection is a low-order approximation to this pullback, obtained by truncating higher-derivative terms. This construction is analogous to induced metrics in sigma models, and it unifies the geometric and dynamical aspects of RSVP: the same metric G_{AB} governs both gradient flow in field space and the induced geometry of spacetime.

49.3 Induced Connection and Effective Field Equations

Given $g_{\mu\nu}^{\text{eff}}$, the Levi-Civita connection and curvature tensor are derived quantities reflecting spatial and temporal variations of the plenum fields. In a slow-variation regime where higher-order derivative terms may be neglected, variation of the effective action with respect to the metric yields an equation of the form

$$G_{\mu\nu}(g_{\text{eff}}) = \kappa_{\text{eff}}\, T^{(\Phi,v,S)}_{\mu\nu} + \mathcal{O}(\nabla^2 X), \tag{126}$$

where $T^{(\Phi,v,S)}_{\mu\nu}$ is the effective stress-energy tensor built from the plenum fields and κ_{eff} is an effective coupling. This has the same structural form as Einstein's field equations, but with both metric and stress-energy arising from the same underlying plenum fields. In regimes where entropy gradients are small and flow is negligible, the metric reduces to a conformally rescaled form $g^{\text{eff}}_{\mu\nu} \approx A(\Phi)\, \eta_{\mu\nu}$ and the equations reduce to scalar-field-driven gravity models. More general configurations introduce anisotropic and dissipative corrections leading to deviations from standard general relativity.

50 Lattice Discretization of RSVP Field Dynamics

Because the RSVP equations resemble nonlinear transport and diffusion systems, lattice discretization provides a practical route to numerical exploration. On a cubic lattice with spacing Δx and time step Δt, the scalar density field is represented at lattice sites $\Phi_{i,j,k}(t)$, vector flow components are stored on lattice edges $v^x_{i+1/2,j,k}$, $v^y_{i,j+1/2,k}$, $v^z_{i,j,k+1/2}$, and the entropy field at lattice sites $S_{i,j,k}(t)$. The discretized evolution equations are

$$\Phi^{t+1}_{i,j,k} = \Phi^{t}_{i,j,k} + \Delta t \left(-\nabla_h \cdot (\Phi \mathbf{v}) + D_\Phi\, \nabla_h^2 \Phi \right), \tag{127}$$

$$S^{t+1}_{i,j,k} = S^{t}_{i,j,k} + \Delta t \left(-\nabla_h \cdot (S \mathbf{v}) + D_S\, \nabla_h^2 S + \sigma \right), \tag{128}$$

where ∇_h denotes the discrete spatial derivative. Vector flow dynamics are evolved using discretized vorticity and pressure-gradient terms derived from the RSVP action. Such lattice simulations may reveal emergent phenomena including entropy-driven smoothing of density fluctuations, formation of coherent flow structures, and long-range correlations resembling gravitational clustering.

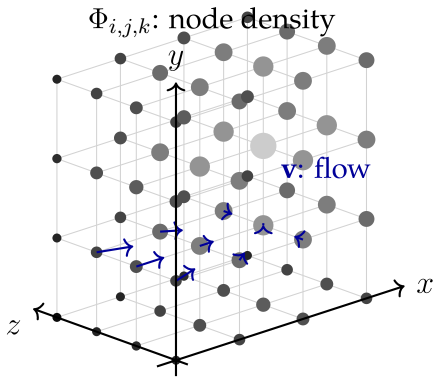

Figure 8: Lattice discretization of the RSVP plenum. Node shading encodes the scalar density field $\Phi_{i,j,k}$: darker nodes indicate higher density, forming a coherent cluster near the lattice center. Blue arrows on the central horizontal slice show vector flow field components $\mathbf{v}$, here directed inward toward the density peak. The entropy field $S_{i,j,k}$ is defined at each site and evolved simultaneously using the discretized advection–diffusion equation.

51 Future Directions

The RSVP framework remains at an early conceptual stage and requires substantial mathematical and empirical development before it can be considered a predictive physical theory.

51.1 Mathematical Development

A first priority is the construction of a fully consistent dynamical theory for the plenum fields $(\Phi, \mathbf{v}, S)$. The action functional introduced above should be generalized to ensure full covariance, stability of solutions, and compatibility with known physical constraints. Key open questions include the geometric structure of the configuration manifold; the existence of monotonic entropy–coherence functionals; classification of stationary solutions and attractor regimes; and the precise relationship between RSVP gradient flows and renormalization group dynamics.

51.2 Connections with Quantum Field Theory

A precise correspondence between RSVP field dynamics and conventional quantum field theory requires explicit coarse-graining maps between microscopic field theories and the RSVP plenum variables. One possibility is that RSVP dynamics arise as a coarse-grained description of deeper microscopic degrees of freedom, in much the same way that hydrodynamics emerges from molecular physics.

51.3 Numerical Simulation

Lattice-based simulations could model the coupled evolution of Φ, $\mathbf{v}$, and S under simplified dynamical rules. Such simulations may reveal emergent phenomena including self-organizing flow structures, entropy-driven smoothing of density fluctuations, and long-range coherence patterns resembling gravitational clustering.

51.4 Cosmological Observables

Possible avenues for observational testing include alternative interpretations of cosmological redshift, entropy-based explanations for large-scale structure formation, modified predictions for gravitational lensing patterns, and deviations from standard cosmic expansion histories.

51.5 Conceptual Foundations

If spacetime geometry emerges from entropy-driven plenum dynamics, the fundamental ontology of physics may shift from geometric objects to informational and thermodynamic processes. Exploring this possibility could clarify the relationship between gravity, information, and the large-scale structure of the universe [47, 48, 46, 50].

52 Structural Convergence Without Derivation

The preceding sections develop a formal framework in which physical structure emerges from local interactions, entropy-driven dynamics, and variational principles. An important implication of this perspective concerns the way complex theoretical expressions are generated, interpreted, and evaluated.

It is a recurring phenomenon in theoretical work that expressions of considerable structural similarity arise independently across different contexts. Functional derivatives of effective actions, entropy terms, renormalization group flows, and nonlocal kernels appear naturally in quantum field theory, statistical mechanics, and information-theoretic approaches to physics.

From the RSVP perspective, this convergence is not accidental. It reflects the fact that many systems—physical, computational, and cognitive—are governed by common principles combining local variation, global consistency, and entropy constraints. As a result, expressions that bring together effective actions, functional derivatives, entropy contributions, and flow constraints tend to reappear as structurally stable attractors in the space of possible formalisms.

Within the Spherepop interpretation, such expressions may be understood as high-level configurations toward which symbolic systems evolve under constraints of coherence and compression. However, the existence of such attractors does not guarantee that a given expression encodes a well-defined or empirically meaningful theory. Distinct derivations may lead to superficially similar forms while differing fundamentally in interpretation, domain of validity, and predictive content.

Scientific practice places central importance on derivation, not merely on final expressions. A formula acquires meaning through the sequence of transformations, approximations, and assumptions that produce it. Formally, this may be expressed as a mapping

$$\mathcal{D} : \text{assumptions} \longrightarrow \text{equations}, \tag{129}$$

where the derivation $\mathcal{D}$ encodes the structure necessary for reproducibility and comparison. Without this mapping, an expression remains underdetermined, admitting multiple incompatible interpretations or failing to connect to any well-defined dynamical system.

This phenomenon has implications for both human and machine-generated theoretical work. In particular, the appearance of a highly structured expression should not be taken as evidence of a unified theory in the absence of a transparent derivation. Within RSVP, this is understood as a distinction between *structural plausibility*—convergence toward common symbolic patterns—and *derivational validity*—the existence of a well-defined generative process linking assumptions to predictions.

53 Derivation as a Path in Theory Space

We now make the notion of derivation precise by modeling it as a path in a suitably defined space of theories [2, 5].

Let $\mathcal{T}$ denote the space of admissible theoretical configurations, where a point

$\tau \in \mathcal{T}$ consists of a specification of fields, symmetries, action functional, and constraints:

$$\tau = (\mathcal{F}, \mathcal{S}, \mathcal{A}, \mathcal{C}). \tag{130}$$

A derivation is then a path in theory space,

$$\gamma : [0, 1] \to \mathcal{T}, \tag{131}$$

with $\gamma(0) = \tau_{\text{initial}}$ and $\gamma(1) = \tau_{\text{final}}$. Each infinitesimal segment of the path corresponds to a well-defined transformation—variation, coarse-graining, field redefinition, symmetry reduction, or quantization—so derivation is not merely a sequence of symbolic steps but a structured trajectory through the space of admissible theories.

Different derivations may lead to the same final expression while traversing distinct regions of theory space, explaining why structurally similar equations arise from different theoretical contexts while encoding different physics. The derivation process may be formalized as a functor

$$\mathcal{D} : \mathcal{C}_{\text{assumptions}} \to \mathcal{C}_{\text{theories}}, \tag{132}$$

mapping a category of assumptions and transformations to a category of resulting theories, with composition of transformations corresponding to composition of morphisms.

Within the Spherepop framework, derivations correspond to event histories: each transformation along γ is represented by a discrete event e_i, so

$$\gamma \;\longleftrightarrow\; (e_1, e_2, \ldots, e_n). \tag{133}$$

A valid derivation therefore corresponds to a well-formed event trace, while an isolated expression without history corresponds to a terminal state with no accessible generative path.

To quantify proximity between theories, one equips $\mathcal{T}$ with a metric or divergence functional $d(\tau_1, \tau_2)$ measuring differences in predictions, symmetries, or information content. Paths minimizing this functional correspond to efficient derivations, analogous to geodesics in theory space. This connects naturally to renormalization group flows, which may be interpreted as gradient flows with respect to such a metric [2, 5].

54 Homotopy Classes of Derivations

Having modeled derivations as paths in theory space, we now refine this structure by introducing an equivalence relation based on continuous deformation.

Let $\gamma_1, \gamma_2 : [0,1] \to \mathcal{T}$ be two derivations connecting the same initial and final theories. We say that γ_1 and γ_2 are *homotopic* if there exists a continuous family

$$H : [0,1] \times [0,1] \to \mathcal{T} \tag{134}$$

with $H(s,0) = \gamma_1(s)$, $H(s,1) = \gamma_2(s)$, $H(0,t) = \tau_{\text{initial}}$, and $H(1,t) = \tau_{\text{final}}$ for all t. Two derivations are thus equivalent if one can be continuously deformed into the other without leaving the space of admissible theories.

The set of equivalence classes $[\gamma]$ under homotopy captures the essential structure of a derivation independent of inessential choices such as intermediate parameterizations or auxiliary representations. From a physical standpoint, two derivations are equivalent if they correspond to transformations that preserve all observable predictions, as with field redefinitions, gauge transformations, and changes of renormalization scheme.

Not all derivations connecting the same endpoints are homotopic. Obstructions may arise from topological features of theory space or from singularities encountered along intermediate steps, indicating genuine distinctions between theories that cannot be removed by continuous deformation.

The collection of theories and derivations naturally forms a higher categorical structure: theories are objects, derivations are 1-morphisms, and homotopies between derivations are 2-morphisms. Iterating this construction leads to an ∞-groupoid of theories in which all higher equivalences are encoded systematically [30]. Within Spherepop, homotopies between derivations correspond to transformations of event sequences that preserve overall outcomes, so homotopy classes of derivations correspond to equivalence classes of event traces.

55 Variational Principles on Theory Space

We now complete the framework by defining a variational principle on the space of derivations.

Define a functional $\mathcal{S}_{\text{der}}[\gamma]$ assigning a cost to each derivation path:

$$\mathcal{S}_{\text{der}}[\gamma] = \int_0^1 \Big[\lambda_1 \|\dot{\gamma}(s)\|^2 + \lambda_2 \,\mathcal{U}(\gamma(s)) + \lambda_3 \,\mathcal{I}(\gamma(s))\Big]\, ds, \tag{135}$$

where $\|\dot{\gamma}\|$ measures the rate of change in theory space, $\mathcal{U}$ is a potential encoding inconsistency or instability, and $\mathcal{I}$ measures informational cost. A valid or optimal derivation is a path that extremizes $\mathcal{S}_{\text{der}}$:

$$\delta\mathcal{S}_{\text{der}}[\gamma] = 0. \tag{136}$$

Such paths are geodesics in theory space with respect to an effective metric induced by the functional, representing the most efficient transformations between theories under the chosen criteria.

In many cases this functional induces a gradient flow

$$\frac{d\gamma^A}{ds} = -G^{AB}\frac{\partial \mathcal{F}}{\partial \gamma^B}, \tag{137}$$

which is directly parallel to the RSVP dynamics of plenum fields, establishing a correspondence between physical evolution and the evolution of theoretical descriptions. The informational term $\mathcal{I}$ may be interpreted as measuring the entropy or complexity of intermediate representations: paths that introduce unnecessary structure incur higher cost, while paths maintaining coherence are favored. This aligns with the RSVP interpretation of physical dynamics as entropy-constrained evolution.

The existence of a variational principle explains why certain formal structures recur across different contexts. These structures correspond to low-action regions in theory space, making them natural endpoints of many distinct derivational paths—but a low-action endpoint does not uniquely determine the path taken to reach it, reinforcing the necessity of explicit derivational specification.

56 Constraint Before Content

The preceding development has introduced a layered framework in which physical systems, symbolic structures, and theoretical constructions are all described in terms of constrained evolution. We articulate the unifying principle underlying these constructions.

In traditional formulations, physical theories are presented in terms of objects—fields, particles, or states—together with equations governing their behavior. The RSVP framework suggests instead that constraint is primary, and that objects arise as secondary manifestations of constraint satisfaction. The dynamics of the plenum are governed by

$$\delta\mathcal{R} = 0, \tag{138}$$

which determines admissible configurations of the fields $(\Phi, \mathbf{v}, S)$. Spacetime geometry, matter distributions, and interaction patterns are emergent solutions to this constraint, not independently specified inputs.

An analogous structure appears at the level of theory construction. Derivations are paths $\gamma \subset \mathcal{T}$ constrained by consistency, coherence, and informational criteria. The variational principle

$$\delta\mathcal{S}_{\text{der}}[\gamma] = 0 \tag{139}$$

selects preferred derivations, while homotopy classes organize equivalences between them. Theoretical objects—equations, models, and formalisms—are endpoints of constrained processes in theory space, not primitive entities.

This principle manifests in both continuous and discrete settings: in RSVP through gradient flows in field space, in Spherepop through admissible event histories. In both frameworks, valid states arise from sequences of transformations subject to global consistency conditions.

The recurrence of similar formal structures across independent contexts—whether in physics, computation, or symbolic reasoning—follows from shared constraint landscapes. Certain configurations act as attractors because they satisfy these constraints efficiently. This explains the convergence of complex expressions across different derivations, while clarifying why such convergence does not, by itself, establish theoretical equivalence.

Across all levels of description, structure arises not as a primitive given but as the outcome of constrained evolution. Physical systems evolve along paths minimizing an action functional; theoretical derivations follow paths minimizing a derivational cost; symbolic systems organize themselves under constraints of coherence and entropy. In this sense the distinction between physics, computation, and theory construction becomes one of representation rather than principle: constraint precedes content, and content emerges as its realization.

57 Conclusion

Renormalization group theory, effective action methods, and entropy-based approaches to gravity all emphasize the role of information flow in shaping physical laws. The RSVP framework extends this perspective by proposing that the universe itself may evolve through entropy-driven field dynamics within a plenum.

We have derived the RSVP field equations from a candidate action functional, established conservation laws, analyzed linear stability, and connected the framework to renormalization group theory, asymptotic safety, holographic renormalization, sheaf-theoretic locality, derived geometry, and Gromov–Hausdorff convergence. The structural similarities between RG flow and RSVP evolution are not merely analogical but suggest that modern quantum field theory may already contain the mathematical tools needed to formalize such a framework.

Further work is needed to establish rigorous derivations, make contact with empirical predictions, and explore the connections with derived algebraic geometry and categorical field theory.

Appendices

A Notation and Symbol Glossary

For clarity, we summarize the principal symbols used throughout this manuscript.

Symbol	Meaning
$\Phi(x,t)$	Scalar density field of the plenum
$\mathbf{v}(x,t)$	Vector flow field describing directional transport
$S(x,t)$	Entropy field governing thermodynamic redistribution
$\mathcal{A}_{RSVP}$	Action functional defining plenum dynamics
$\mathcal{L}$	Lagrangian density of the RSVP theory
$\mathcal{R}$	Entropy–coherence functional generating gradient flow
G^{AB}	Metric on plenum field configuration space
g_i	Coupling constants in renormalization group theory
Γ_{eff}	Effective quantum action
Γ_k	Wilsonian effective action at scale k
G_{ij}	Zamolodchikov metric on theory space
H	Helicity invariant of the vector flow field
d_{GH}	Gromov–Hausdorff distance between metric spaces
$E_r^{p,q}$	Spectral sequence terms for scale cascade
$\mathcal{P}$	Sheaf of plenum field configurations
$\mathcal{C}_\lambda$	Coarse-graining functor on plenum states
ω_{BV}	BV odd symplectic form on extended field space
Π_Φ, $\mathbf{\Pi}_v$, Π_S	Canonical momenta of plenum fields
λ_1, λ_2, λ_3	Interaction coupling constants

B Core Mathematical Results

Theorem 3 (Gradient Flow Structure). *Let $\mathcal{R}[\Phi, \mathbf{v}, S]$ be the entropy–coherence functional defined on plenum field space with G^{AB} a positive definite metric. If the field dynamics satisfy*

$$\partial_t X^A = -G^{AB}\frac{\delta \mathcal{R}}{\delta X^B}, \tag{140}$$

then $\mathcal{R}$ is non-increasing along solution trajectories.

Proof. Computing the time derivative of $\mathcal{R}$ yields

$$\frac{d\mathcal{R}}{dt} = \int \frac{\delta \mathcal{R}}{\delta X^A} \, \partial_t X^A \, d^3x. \tag{141}$$

Substituting the gradient flow equation gives

$$\frac{d\mathcal{R}}{dt} = -\int G^{AB} \frac{\delta \mathcal{R}}{\delta X^A} \frac{\delta \mathcal{R}}{\delta X^B} \, d^3x. \tag{142}$$

Positive definiteness of G^{AB} implies the integrand is non-negative pointwise, so

$$\frac{d\mathcal{R}}{dt} \le 0, \tag{143}$$

with equality if and only if $\delta\mathcal{R}/\delta X^A = 0$ everywhere. □

Proposition 1 (Stationary Plenum States)**.** *Configurations satisfying*

$$\frac{\delta \mathcal{R}}{\delta X^A} = 0 \tag{144}$$

correspond to stationary solutions of the RSVP field equations and to critical points of the entropy–coherence functional.

Proposition 2 (Scale Hierarchy and Effective Flow)**.** *If the plenum fields admit a multiscale decomposition*

$$X = \sum_k X_k \tag{145}$$

via the Fourier expansion, then coarse-graining transformations

$$X \mapsto \bar{X}_\Lambda = \int_{|k|<\Lambda} \tilde{X}(k) \, e^{ikx} \, d^3k \tag{146}$$

define a renormalization-like flow on the space of effective plenum descriptions, with the infrared limit corresponding to stationary plenum regimes.

Proposition 3 (Entropy Monotonicity)**.** *Let $\sigma \ge 0$. Then the total entropy $\int S \, d^3x$ is non-decreasing along solutions of the RSVP entropy balance equation, consistent with the second law of thermodynamics.*

C Step-by-Step Derivation of the Covariant Field Equations

For completeness we derive the covariant RSVP field equations (101)–(103) in detail.

The covariant Lagrangian is

$$\mathcal{L} = \frac{1}{2}\nabla_\mu\Phi\,\nabla^\mu\Phi + \frac{1}{2}\rho(\Phi)\,v_\mu v^\mu + \frac{1}{2}\alpha\,\nabla_\mu S\,\nabla^\mu S + \lambda_1 S\,\nabla_\mu v^\mu + \lambda_2\,\Phi S - V(\Phi, S). \quad (147)$$

Variation with respect to Φ

The terms in $\mathcal{L}$ depending on Φ or $\nabla_\mu\Phi$ are

$$\frac{1}{2}\nabla_\mu\Phi\,\nabla^\mu\Phi + \frac{1}{2}\frac{d\rho}{d\Phi}\,v_\mu v^\mu\,\Phi + \lambda_2\,\Phi S - V(\Phi, S). \quad (148)$$

The Euler–Lagrange equation $\nabla_\mu(\partial\mathcal{L}/\partial(\nabla_\mu\Phi)) = \partial\mathcal{L}/\partial\Phi$ gives

$$\nabla_\mu\nabla^\mu\Phi = \frac{\partial V}{\partial\Phi} - \lambda_2 S. \quad (149)$$

Variation with respect to v^μ

The dependence on v^μ is

$$\frac{1}{2}\rho(\Phi)\,v_\mu v^\mu + \lambda_1 S\,\nabla_\mu v^\mu. \quad (150)$$

Integrating by parts in the action to move the derivative off v^μ, the Euler–Lagrange equation yields

$$\rho(\Phi)\,v^\mu + \lambda_1\,\nabla^\mu S = 0. \quad (151)$$

Variation with respect to S

The terms depending on S or $\nabla_\mu S$ are

$$\frac{1}{2}\alpha\,\nabla_\mu S\,\nabla^\mu S + \lambda_1 S\,\nabla_\mu v^\mu + \lambda_2\,\Phi S - V(\Phi, S). \quad (152)$$

The Euler–Lagrange equation gives

$$\alpha\,\nabla_\mu\nabla^\mu S = -\lambda_1\,\nabla_\mu v^\mu - \lambda_2\,\Phi + \frac{\partial V}{\partial S}. \quad (153)$$

Setting $\alpha = 1$ these reproduce equations (101)–(103).

References

[1] K. G. Wilson and J. Kogut, *The Renormalization Group and the ϵ Expansion*, Physics Reports **12**, 75–199 (1974).

[2] A. B. Zamolodchikov, *Irreversibility of the Flux of the Renormalization Group in a 2D Field Theory*, JETP Letters **43**, 730–732 (1986).

[3] S. Weinberg, *Ultraviolet Divergences in Quantum Theories of Gravitation*, in *General Relativity: An Einstein Centenary Survey*, Cambridge University Press (1979).

[4] M. Reuter, *Nonperturbative Evolution Equation for Quantum Gravity*, Physical Review D **57**, 971–985 (1998).

[5] W. H. Pannell and A. Stergiou, *Gradient Flows and the Curvature of Theory Space*, arXiv:2502.06940 (2025).

[6] T. Jacobson, *Thermodynamics of Spacetime: The Einstein Equation of State*, Physical Review Letters **75**, 1260–1263 (1995).

[7] E. Verlinde, *On the Origin of Gravity and the Laws of Newton*, Journal of High Energy Physics **2011**, 29 (2011).

[8] J. D. Bekenstein, *Black Holes and Entropy*, Physical Review D **7**, 2333–2346 (1973).

[9] S. W. Hawking, *Particle Creation by Black Holes*, Communications in Mathematical Physics **43**, 199–220 (1975).

[10] J. Maldacena, *The Large-N Limit of Superconformal Field Theories and Supergravity*, Advances in Theoretical and Mathematical Physics **2**, 231–252 (1998).

[11] S. Ryu and T. Takayanagi, *Holographic Derivation of Entanglement Entropy*, Physical Review Letters **96**, 181602 (2006).

[12] T. Padmanabhan, *Thermodynamical Aspects of Gravity: New Insights*, Reports on Progress in Physics **73**, 046901 (2010).

[13] S. Carroll, *Spacetime and Geometry: An Introduction to General Relativity*, Cambridge University Press (2019).

[14] C. Callan, *Broken Scale Invariance in Scalar Field Theory*, Physical Review D **2**, 1541–1547 (1970).

[15] J. Polchinski, *Renormalization and Effective Lagrangians*, Nuclear Physics B **231**, 269–295 (1984).

[16] J. Cardy, *Scaling and Renormalization in Statistical Physics*, Cambridge University Press (1996).

[17] M. Peskin and D. Schroeder, *An Introduction to Quantum Field Theory*, Addison–Wesley (1995).

[18] S. Weinberg, *The Quantum Theory of Fields*, Cambridge University Press (1995).

[19] J. Zinn-Justin, *Quantum Field Theory and Critical Phenomena*, Oxford University Press (2002).

[20] K. Wilson, *The Renormalization Group: Critical Phenomena and the Kondo Problem*, Reviews of Modern Physics **47**, 773 (1975).

[21] M. E. Fisher, *Renormalization Group Theory: Its Basis and Formulation in Statistical Physics*, Reviews of Modern Physics **70**, 653 (1998).

[22] G. Perelman, *The Entropy Formula for the Ricci Flow and Its Geometric Applications*, arXiv:math/0211159 (2002).

[23] R. Hamilton, *Three-Manifolds with Positive Ricci Curvature*, Journal of Differential Geometry **17**, 255 (1982).

[24] V. Arnold and B. Khesin, *Topological Methods in Hydrodynamics*, Springer (1998).

[25] T. Frankel, *The Geometry of Physics*, Cambridge University Press (2011).

[26] M. Nakahara, *Geometry, Topology and Physics*, Taylor & Francis (2003).

[27] J. Baez and J. Munian, *Gauge Fields, Knots and Gravity*, World Scientific (1994).

[28] D. Freed and M. Hopkins, *Reflection Positivity and Invertible Topological Field Theories*, Geometry & Topology **25**, 1165 (2021).

[29] K. Costello and O. Gwilliam, *Factorization Algebras in Quantum Field Theory*, Cambridge University Press (2017).

[30] J. Lurie, *On the Classification of Topological Field Theories*, Current Developments in Mathematics (2009).

[31] M. Kontsevich and Y. Soibelman, *Deformation Theory I*, arXiv:math/0707.3579.

[32] M. Gromov, *Metric Structures for Riemannian and Non-Riemannian Spaces*, Birkhäuser (1999).

[33] C. Villani, *Optimal Transport: Old and New*, Springer (2009).

[34] L. Onsager, *Statistical Hydrodynamics*, Nuovo Cimento **6**, 279 (1949).

[35] L. Landau and E. Lifshitz, *Fluid Mechanics*, Pergamon Press (1987).

[36] L. Landau and E. Lifshitz, *Statistical Physics*, Pergamon Press (1980).

[37] H. Callen, *Thermodynamics and an Introduction to Thermostatistics*, Wiley (1985).

[38] E. T. Jaynes, *Information Theory and Statistical Mechanics*, Physical Review **106**, 620 (1957).

[39] E. T. Jaynes, *Information Theory and Statistical Mechanics II*, Physical Review **108**, 171 (1957).

[40] T. Padmanabhan, *Gravity and the Thermodynamics of Horizons*, Physics Reports **406**, 49 (2005).

[41] L. Susskind, *The World as a Hologram*, Journal of Mathematical Physics **36**, 6377 (1995).

[42] G. 't Hooft, *Dimensional Reduction in Quantum Gravity*, arXiv:gr-qc/9310026 (1993).

[43] D. Harlow, *Jerusalem Lectures on Black Holes and Quantum Information*, Reviews of Modern Physics **88**, 015002 (2016).

[44] C. Misner, K. Thorne, and J. Wheeler, *Gravitation*, W. H. Freeman (1973).

[45] R. Wald, *General Relativity*, University of Chicago Press (1984).

[46] R. Penrose, *The Road to Reality*, Jonathan Cape (2004).

[47] J. Butterfield and C. Isham, *Spacetime and the Philosophical Challenge of Quantum Gravity*, Physics Meets Philosophy at the Planck Scale (2001).

[48] N. Seiberg, *Emergent Spacetime*, arXiv:hep-th/0601234 (2006).

[49] B. Swingle, *Entanglement Renormalization and Holography*, Physical Review D **86**, 065007 (2012).

[50] S. Carroll, *The Biggest Ideas in the Universe*, Dutton (2022).

[51] M. Van Raamsdonk, *Building up Spacetime with Quantum Entanglement*, General Relativity and Gravitation **42**, 2323–2329 (2010).

[52] R. Landauer, *Irreversibility and Heat Generation in the Computing Process*, IBM Journal of Research and Development **5**, 183–191 (1961).

[53] T. S. Taylor, *Symbolic Collapse Grammar and Entropic Rendering: A Foundational Model of Physical Emergence*, International Journal of Quantum Foundations **11**, 395–443 (2025).

[54] M. Kashiwara and P. Schapira, *Sheaves on Manifolds*, Springer (1990).

[55] S. Amari, *Information Geometry and Its Applications*, Springer (2016).

[56] T. Cover and J. Thomas, *Elements of Information Theory*, Wiley (2006).