Metamatter and the Phase Origin of Classical Matter and Spacetime

Abstract

We propose a phase-based framework for the origin of classical matter, space, and time grounded in the concept of **metamatter** and its ensemble, fractal dynamics. In contrast to standard approaches, spacetime is not postulated as a fundamental background but emerges as an effective regime of partial actualization resulting from a sequence of phase transitions.

The theory is formulated in terms of competing entropy and negentropy contributions unified by an **effective phase functional**

$$\mathcal{F} = S - \alpha N,$$

which governs the direction of evolution, self-organization, and the selection of stable regimes through dissipation. Within this framework, quantum mechanics, nonlocality, entanglement, dark matter, dark energy, and gravity are interpreted as manifestations of different phases or projections of the same underlying ensemble dynamics.

Holography, black holes, and cosmological limits are described as boundary or reverse phase regimes in which local spacetime description breaks down while information remains preserved beyond geometric representation. The resulting phase cycle

$$0D \to 1D \to 2D \to 3+1D \to 0D$$

provides a unified picture of cosmological evolution and its limiting states.

The proposed scheme does not constitute a complete field theory but establishes a rigorous ontological and formal foundation for its future construction, offering a coherent pre-field-theoretic framework for the fractal dynamics of matter.

Keywords:

- **Metamatter**
- **Phase transitions**
- **Emergent spacetime**
- **Origin of time**
- **Origin of space**

- **Fractal dynamics**
- **Quantum mechanics foundations**
- **Dark matter**
- **Dark energy**
- **Holography**
- **Black holes**
- **Negentropy and self-organization**
- **Phase ontology**
- **Foundations of physics**

1. Introduction

Modern theoretical physics is built upon two remarkably successful yet conceptually disconnected frameworks: quantum mechanics and general relativity. Despite their empirical power, both theories presuppose spacetime as a given structure, within which physical processes unfold. Quantum theory operates on a fixed background, while general relativity dynamizes geometry itself, yet neither explains **why spacetime exists at all**, nor how its dimensionality, causal structure, and temporal direction originate.

This conceptual gap becomes especially acute in the presence of unresolved foundational problems: the measurement problem, nonlocal correlations and Bell-type constraints, the nature of dark matter and dark energy, the cosmological constant problem, and the status of information in black hole physics. These issues suggest that spacetime and classical matter may not be fundamental, but emergent.

In this work, we advance a different perspective: **spacetime and classical matter arise as phase-dependent regimes of a deeper physical substrate**, which we denote as *metamatter*. Metamatter is not introduced as an additional substance or field, but as a pre-geometric, ensemble-based form of physical reality whose internal dynamics precede localization, metric structure, and classical causality.

1.1. From geometric dynamics to phase dynamics

Standard approaches to quantum gravity typically attempt to quantize spacetime geometry or to embed gravity into quantum field frameworks. While mathematically sophisticated, such strategies often retain spacetime as a primary object, merely modifying its dynamics or quantization rules.

By contrast, the present approach treats geometry itself as **a phase of matter**, not its foundation. Dimensionality, locality, and temporal ordering are interpreted as emergent properties that arise through **phase transitions in the ensemble dynamics of metamatter**, rather than as axioms of the theory.

This shift replaces geometric dynamics with **phase dynamics** as the central organizing principle.

1.2. Ensemble ontology and fractal dynamics

A key assumption underlying our framework is that fundamental evolution does not proceed through isolated degrees of freedom, but through **ensembles of correlated configurations**. This view is inspired by the work of I. Prigogine, who emphasized that irreversible processes and self-organization emerge at the level of ensembles rather than individual constituents.

In the present context, metamatter is structured as **ensembles of fractal configurations**, whose evolution is governed by the competition between entropy-producing and negentropy-generating processes. These ensembles undergo selective stabilization through dissipation, giving rise to ordered regimes without external fine-tuning.

As a result, the emergence of structure is not an exception to thermodynamic evolution but a natural consequence of it.

1.3. Phase structure and dimensional emergence

We propose that the observable universe corresponds to one branch of a universal phase sequence,

$$0D \;\rightarrow\; 1D \;\rightarrow\; 2D \;\rightarrow\; 3+1D,$$

where each step represents a **qualitative change in the mode of actualization** rather than a geometric expansion in a pre-existing space.

- The **0D phase** corresponds to a fully symmetric, non-local, information-complete state without spatial or temporal extension.
- The **1D phase** underlies quantum coherence and superposition.
- The **2D phase** encodes relational and holographic structures.
- The **3+1D phase** realizes stable locality, classical matter, and physical time.

Black holes and cosmological limits implement the reverse transitions, completing the phase cycle.

1.4. Scope and aims of the present work

The goal of this paper is not to present a complete field theory, but to establish a **coherent ontological and formal foundation** upon which such a theory may be constructed. Specifically, we aim to:

1. formulate a phase-based origin of spacetime and classical matter;
2. introduce entropy and negentropy as fundamental drivers of phase selection;
3. reinterpret quantum mechanics, gravity, and dark components as phase manifestations;
4. resolve standard conceptual paradoxes by relocating information beyond geometric description.

The structure of the paper reflects this aim: early sections introduce the ontological framework, followed by formal phase dynamics, cosmological implications, and a final synthesis.

2. Metamatter and Pre-Geometric Dynamics

2.1. Metamatter as a pre-geometric physical substrate

In the present framework, *metamatter* denotes a pre-geometric physical substrate that precedes the emergence of spacetime, particles, and fields. It is not a hidden form of classical matter, nor an additional entity supplementing existing theories. Rather, metamatter represents a **mode of physical existence prior to localization, metric structure, and classical causality**.

At this level, there are no spatial coordinates, no trajectories, and no externally defined temporal parameter. Physical distinction is not encoded by position or motion, but by **relations within ensembles of configurations**. What later appears as spacetime structure is here present only implicitly, as potential organization.

2.2. The 0D phase: complete potentiality

The deepest regime of metamatter is the **0D phase**, corresponding to a fully symmetric and maximally compact informational state. The designation “0D” does not imply emptiness or absence, but rather the absence of spatial and temporal extension.

In the 0D phase:

- information is not destroyed but fully compressed;
- no ordering of events exists;
- no localization or separation is defined.

This phase may be described as an **absolute informational singularity**, not in the sense of divergence, but in the sense of maximal potentiality without actualized structure.

2.3. Fractal dynamics without spacetime

Although spacetime is absent at the 0D level, the system is not static. Its evolution is governed by **fractal ensemble dynamics**, characterized by recursive self-relations and scale-independent structure.

Here, "dynamics" does not mean motion through space or evolution in time. Instead, it refers to **reconfigurations of relational structure**, in which ensembles explore different modes of internal organization without external parameters.

This justifies the introduction of a *fractal dynamical parameter* (denoted in later sections as τ), which precedes physical time and does not possess a fixed direction.

2.4. Ensemble evolution and irreversibility

A crucial feature of metamatter dynamics is that meaningful evolution occurs at the **ensemble level**, not at the level of isolated configurations. Individual configurations have no privileged status; stability and selection arise only through collective behavior.

Irreversibility enters the theory not as a fundamental axiom, but as a **statistical and ensemble-dependent phenomenon**. As ensembles grow in complexity, certain reconfigurations become dynamically suppressed, leading to effective directionality.

This mechanism provides the precondition for the emergence of physical time without assuming it a priori.

2.5. Transition from potentiality to partial actualization

The transition from the 0D phase to higher-dimensional regimes corresponds to the onset of **partial actualization**. Rather than unfolding into a pre-existing space, metamatter undergoes a qualitative change in how relational distinctions are stabilized.

This first transition marks the emergence of a **1D phase**, which underlies quantum coherence and superposition. Importantly, dimensionality here is not geometric but functional: it reflects the number of independent relational degrees of freedom that have become dynamically distinguishable.

2.6. Conceptual consequences

The pre-geometric interpretation of metamatter has several immediate consequences:

1. spacetime is not fundamental but emergent;
2. locality is a phase-dependent property, not a universal principle;
3. information is primary with respect to geometry;
4. physical laws are effective descriptions of stable regimes.

These points form the conceptual backbone for the phase-based interpretation developed in subsequent chapters.

3. Entropy, Negentropy, and Phase Selection

3.1. Beyond entropy as disorder

In conventional thermodynamics, entropy is often associated with disorder or loss of structure. While this interpretation is adequate for closed systems near equilibrium, it becomes insufficient for describing **far-from-equilibrium processes**, self-organization, and the emergence of complexity.

Within the present framework, entropy is treated not as a universal measure of disorder, but as a **global indicator of irreversible dissipation** associated with partial actualization of metamatter. Crucially, entropy growth does not preclude the emergence of structure.

3.2. Negentropy as a structural driver

To account for the observed growth of complexity and hierarchical organization, we introduce **negentropy** as an independent and necessary contribution.

Negentropy characterizes the capacity of ensembles to:

- form stable correlations,
- maintain coherence across scales,
- generate structured configurations resistant to dissipation.

Negentropy is not defined as “negative entropy” in a literal sense, but as a **structural functional** describing the degree of organized relational content within an ensemble.

3.3. Ensemble dynamics and Prigogine’s perspective

Following the insights of Ilya Prigogine, irreversible evolution and structure formation occur at the level of **ensembles**, not isolated constituents. Dissipative structures arise when systems operate far from equilibrium, sustained by the balance between dissipation and organizing flows.

In the context of metamatter, this balance is generalized: ensembles of fractal configurations evolve under competing entropy-producing and negentropy-generating processes, leading to **selective stabilization of certain phase regimes**.

Self-organization thus appears as a natural outcome of ensemble dynamics rather than an exception to thermodynamic principles.

3.4. The effective phase functional

The competition between entropy and negentropy is captured by the **effective phase functional**

$$\boxed{\mathcal{F} = S - \alpha N,}$$

where:

- S denotes the entropic contribution associated with irreversible dissipation;
- N denotes the negentropic contribution associated with structural organization;
- $\alpha > 0$ is a phase sensitivity parameter that quantifies the efficiency of structure formation relative to dissipation.

The functional $\mathcal{F}$ is not a free energy in the thermodynamic sense. Rather, it serves as a **generalized phase potential** governing the direction and stability of ensemble evolution.

3.5. Phase selection and critical regimes

Phase evolution is governed by the variational condition

$$\delta\mathcal{F} = \delta S - \alpha\,\delta N.$$

Depending on the balance between the two contributions, different regimes emerge:

- $\delta\mathcal{F} > 0$: entropy-dominated evolution, suppression of structure;
- $\delta\mathcal{F} < 0$: negentropy-dominated evolution, growth of complexity;
- $\delta\mathcal{F} = 0$: **critical regime**, corresponding to a phase transition.

Critical regimes play a central role in dimensional emergence, localization, and the onset of classical behavior.

3.6. Directionality without fundamental time

Importantly, the effective direction of evolution does not require a fundamental time parameter. Directionality arises statistically through ensemble selection: once certain configurations become dynamically favored, alternative paths are increasingly suppressed.

This mechanism provides a natural origin for irreversibility and temporal ordering **without assuming time as a primitive concept**.

3.7. Conceptual implications

The introduction of entropy and negentropy as competing functionals leads to several key implications:

1. structure formation is thermodynamically natural;
2. complexity emerges without fine-tuning;
3. phase transitions replace dynamical laws as the primary organizing principle;
4. physical time and locality arise as stabilized outcomes of ensemble selection.

These results prepare the ground for the analysis of dimensional emergence and the transition to observable spacetime.

4. Phase Transitions and Dimensional Emergence

4.1. Dimensionality as a phase property

In the present framework, dimensionality is not assumed as a background attribute of space. Instead, it is treated as a **phase-dependent property of metamatter actualization**. Each effective dimension corresponds to a distinct regime of stabilized relational structure within ensembles.

Dimensional emergence is therefore not a geometric unfolding but a **qualitative transition in the mode of organization**, governed by entropy–negentropy balance and ensemble selection.

4.2. The 0D → 1D transition: onset of coherence

The transition from the 0D phase to the 1D phase represents the first act of partial actualization. In this regime, fully symmetric potentiality gives way to a minimal form of distinction.

The 1D phase is characterized by:

- the emergence of coherent relational ordering,
- the appearance of superposition-like structures,
- the absence of metric localization.

This phase underlies the essential features of quantum coherence. Importantly, "one-dimensional" here does not denote a spatial line, but a **single independent relational degree of freedom** stabilized against full symmetry.

4.3. The 1D → 2D transition: relational extension and holography

As negentropic processes become dominant, ensemble dynamics allow for the stabilization of an additional independent relational degree of freedom. This transition defines the **2D phase**.

The 2D regime introduces:

- relational extension without volumetric locality,
- surface-like encoding of information,
- the structural basis for holographic descriptions.

At this stage, information becomes distributable across relational layers, while still lacking full spatial volume. This provides a natural pre-geometric origin for holographic principles observed in gravitational systems.

4.4. The 2D → 3+1D transition: localization and classical matter

The emergence of the 3+1D phase corresponds to a critical transition in which dissipation stabilizes locality and causal order. Relational degrees of freedom become sufficiently constrained to support:

- localized objects,

- persistent trajectories,
- classical matter with well-defined properties,
- physical time as a directed sequence of actualizations.

This transition marks the birth of **classical spacetime**, not as a fundamental arena, but as a dynamically selected and stabilized phase.

4.5. Physical time as a phase-stabilized parameter

In the 3+1D regime, physical time $t$emerges as an effective parameter ordering actualized configurations. It is not identical to motion or change itself, but to the **consistent sequencing of stabilized states**.

Thus, physical time is:

- directional,
- irreversible,
- phase-dependent.

Its apparent universality reflects the robustness of the 3+1D phase, not its fundamentality.

4.6. Phase transitions as critical phenomena

Each dimensional transition corresponds to a **critical regime** where the effective phase functional

$$\mathcal{F} = S - \alpha N$$

changes its extremal structure.

Near criticality:

- fluctuations increase,
- multiple modes of organization compete,
- small perturbations can determine macroscopic outcomes.

This behavior explains why early cosmological epochs are sensitive to initial conditions without invoking fine-tuning.

4.7. Cyclic completion and reverse transitions

Dimensional emergence is not irreversible in principle. Under extreme conditions—such as gravitational collapse or cosmological limits—the system may undergo **reverse phase transitions**, returning from 3+1D to lower-dimensional regimes.

This completes the universal phase cycle:

$$0D \rightarrow 1D \rightarrow 2D \rightarrow 3 + 1D \rightarrow 0D.$$

Black holes and horizon phenomena are interpreted as local manifestations of such reverse transitions.

4.8. Conceptual summary

Dimensionality, locality, and physical time are emergent features arising from phase transitions in ensemble dynamics. Geometry is not fundamental but **selected**, stabilized by dissipation and negentropic structure formation.

This perspective reframes the origin of spacetime as a problem of phase dynamics rather than geometry or quantization.

5. Quantum Mechanics as a 1D Phase Projection

5.1. Quantum theory without fundamental spacetime

In standard formulations, quantum mechanics is defined on a fixed spacetime background, with time entering as an external parameter. While operationally successful, this approach obscures the physical origin of quantum phenomena such as superposition, entanglement, and nonlocal correlations.

Within the phase-based framework developed here, quantum mechanics is interpreted not as a fundamental theory of microscopic objects, but as an **effective description of a 1D phase of metamatter actualization**, preceding full localization and classical causality.

5.2. The 1D phase and incomplete actualization

The defining feature of the 1D phase is **incomplete actualization**. Configurations are not fully distinguished or localized; instead, they exist as coherent relational possibilities within an ensemble.

This incomplete actualization naturally gives rise to:

- linear superposition of states,
- interference phenomena,
- probabilistic outcomes upon further phase transitions.

Superposition does not represent coexistence of mutually exclusive realities, but reflects the **absence of sufficient phase constraints** to enforce a unique classical configuration.

5.3. Entanglement as ensemble coherence

Entanglement arises when multiple configurations belong to the same coherent ensemble and cannot be factorized into independent subsystems.

In the present interpretation:

- entangled states are **structurally unified**, not dynamically connected;
- correlations do not propagate through space, as spatial separation is not yet fully defined;
- measurement reveals, rather than transmits, correlations.

Thus, entanglement is a manifestation of **ensemble-level coherence** characteristic of the 1D phase.

5.4. Nonlocality and the absence of metric structure

Quantum nonlocality is often regarded as paradoxical because it appears to violate relativistic locality. This paradox dissolves once it is recognized that the 1D phase lacks a well-defined metric structure.

Without stable spatial distances:

- the notion of "here" and "there" is phase-dependent,
- correlations need not respect spatial separation,
- locality is not violated because it has not yet emerged.

Nonlocality is therefore a signature of **pre-local phase structure**, not a breakdown of causality.

5.5. Bell-type constraints and phase realism

Bell's theorem demonstrates the incompatibility of quantum correlations with local hidden-variable models. In the present framework, this result is reinterpreted as a constraint on **classical locality**, not on realism per se.

Reality at the 1D phase level is:

- ensemble-based rather than object-based,
- relational rather than point-like,
- nonlocal with respect to emergent spacetime.

Bell inequalities thus mark the boundary beyond which classical intuitions about separability and locality cease to apply.

5.6. Measurement as a phase transition

Measurement is not treated as a special or external process. Instead, it is interpreted as a **local phase transition** from the 1D regime toward higher-dimensional actualization.

During measurement:

- coherence is partially lost,
- ensemble structure collapses into a localized configuration,
- physical time ordering becomes enforced.

The apparent randomness of outcomes reflects sensitivity to microscopic phase fluctuations near criticality.

5.7. The Schrödinger equation as an effective description

The Schrödinger equation is understood as an **effective dynamical law governing ensemble coherence** within the 1D phase. Its linearity reflects the absence of full phase constraints, while its probabilistic interpretation arises from incomplete actualization.

Importantly, this equation is not fundamental but emergent, valid only within the stability domain of the 1D regime.

5.8. Conceptual summary

Quantum mechanics emerges as a consistent and universal description of a **pre-classical phase of reality**, characterized by coherence without localization and correlations without geometry.

Superposition, entanglement, and nonlocality are not anomalies but **natural consequences of phase structure**, disappearing as full actualization proceeds.

6. Dark Matter and Dark Energy as Incomplete Actualization

6.1. Beyond particle-based interpretations

Standard cosmology interprets dark matter and dark energy as additional components introduced to reconcile theory with observation. Despite their phenomenological success, these approaches face persistent difficulties, including the absence of direct detection and the cosmological constant problem.

Within the present framework, dark components are not treated as new substances or fields. Instead, they arise **inevitably** as consequences of incomplete phase actualization within the ensemble dynamics of metamatter.

6.2. The 2D phase as a structural energy layer

The **2D phase** corresponds to a regime in which relational structure is stabilized without full volumetric localization. Unlike the 1D phase, the 2D regime supports extended relational networks, yet lacks the constraints required for particle-like behavior.

This phase possesses:

- structured energy without localized mass,
- persistent correlations without trajectories,
- gravitational influence without direct detectability.

Accordingly, the 2D phase functions as a **structural energy layer** embedded within the cosmological evolution.

6.3. Dark matter as nonlocal structural ensembles

Dark matter is identified with ensembles that remain stabilized at the 2D level and do not undergo the transition to full 3+1D localization.

In this interpretation:

- dark matter is not composed of particles,
- its gravitational effects arise from structural energy,

- its distribution reflects ensemble history rather than baryonic motion.

This naturally explains why dark matter halos exhibit stability, universality, and partial independence from visible matter.

6.4. Structural autonomy and delayed response

Because dark matter originates from nonlocal 2D ensembles, it does not instantaneously follow the redistribution of baryonic matter. Instead, it responds through **phase-mediated reconfiguration**, governed by ensemble dynamics rather than local forces.

This structural autonomy accounts for:

- observed offsets between baryonic and dark matter distributions,
- lag effects in merging systems,
- nontrivial halo morphology.

6.5. Dark energy as a global phase regime

Dark energy is interpreted not as a field or fluid, but as a **global phase condition** reflecting the fraction of metamatter that remains unactualized with respect to 3+1D localization.

Its effects include:

- accelerated expansion,
- large-scale homogeneity,
- weak coupling to local structure.

In this sense, dark energy parametrizes the **degree of incomplete actualization** at cosmological scales.

6.6. Relation to the cosmological constant

Within this framework, the cosmological constant Λemerges as an effective parameter describing the balance between fully actualized and non-actualized phases.

This reinterpretation resolves the discrepancy between quantum vacuum estimates and observed values by recognizing that only a limited fraction of underlying structural energy contributes to 3+1D geometry.

6.7. Negentropy and structural selection

Negentropic processes play a central role in determining which ensembles undergo full localization and which remain at the 2D level.

- localized matter corresponds to negentropy-dominated stabilization,
- dark matter reflects structurally stable but nonlocalized regimes,
- dark energy reflects the global persistence of unactualized degrees of freedom.

Thus, dark components are not anomalies but **necessary outcomes of phase selection**.

6.8. Observational implications

This phase-based interpretation yields several testable implications:

1. absence of a universal dark matter particle;
2. dependence of halo structure on formation history;
3. phase-delayed response of dark matter to baryonic dynamics;
4. large-scale acceleration decoupled from local density.

These features distinguish the present framework from standard ΛCDM extensions.

6.9. Conceptual summary

Dark matter and dark energy arise naturally as manifestations of **incomplete phase actualization** within the ensemble dynamics of metamatter. They are structural, relational, and phase-dependent phenomena, rather than independent physical substances.

7. Black Holes, Holography, and Reverse Phase Transitions

7.1. Extreme regimes of phase dynamics

In the phase-based framework developed here, black holes and cosmological limits are not anomalies but **extreme regimes of phase dynamics**. They mark conditions under which the stability of the 3+1D phase breaks down and the system undergoes **reverse phase transitions** toward lower-dimensional modes of actualization.

Such regimes reveal the limits of geometric description and expose the deeper structure of metamatter dynamics.

7.2. Black holes as phase defects

A black hole is interpreted as a **local phase defect** in which full 3+1D localization becomes unsustainable.

In this regime:

- spatial localization progressively collapses,
- causal structure becomes incomplete,
- effective dimensionality is reduced.

The classical singularity does not represent a physical divergence but indicates the **failure of the 3+1D phase description** beyond a critical threshold.

7.3. Horizons as phase boundaries

The event horizon is not a material surface but a **phase boundary** separating distinct regimes of actualization.

Across this boundary:

- classical spacetime coordinates lose operational meaning,
- information ceases to be representable within local geometry,
- ensemble correlations persist in nonlocal form.

This interpretation naturally aligns with holographic descriptions, where information content scales with boundary structure rather than volume.

7.4. Information preservation and the absence of paradox

Within the present framework, **information is never destroyed**. Instead, it transitions between phase regimes.

During gravitational collapse:

- information exits the 3+1D geometric description,
- but remains encoded in lower-dimensional ensemble structure,
- inaccessible to observers restricted to classical spacetime.

Thus, the black hole information paradox arises from identifying information with local geometric degrees of freedom rather than with ensemble relations.

7.5. Holography as a phase property

Holography emerges naturally from the 2D phase, where relational structure is stabilized without volumetric localization.

In this sense:

- holographic encoding is not a postulate,
- it reflects the persistence of 2D ensembles under extreme conditions,
- black hole horizons provide physical realizations of this regime.

Holography is therefore a **phase-dependent property**, not a fundamental principle imposed on spacetime.

7.6. Reverse phase transitions and the return to 0D

Under sufficient compression or loss of negentropic stabilization, the system may undergo reverse transitions:

$$3+1D \ \rightarrow \ 2D \ \rightarrow \ 1D \ \rightarrow \ 0D.$$

The 0D phase represents a state of complete potentiality in which:

- localization is fully absent,
- temporal ordering is undefined,
- informational content is maximally compact.

Black holes implement local realizations of this return, while cosmological limits may realize it globally.

7.7. Cosmological implications

The existence of reverse phase transitions implies that cosmological evolution is not strictly linear but **cyclic in phase space**.

Expansion, collapse, and horizon phenomena correspond to different branches of the same universal phase cycle, governed by entropy–negentropy balance and ensemble selection.

7.8. Conceptual summary

Black holes and holographic phenomena are not exceptions to physical law but **windows into pre-geometric regimes** of reality. They reveal that spacetime is a phase-dependent construct, reversible under extreme conditions.

8. Ontological Status of Space, Time, and Matter

8.1. Ontology beyond geometric primitives

The present framework rejects the assumption that space and time are primitive constituents of reality. Instead, they are treated as **effective ontological modes** arising from phase-stabilized configurations of metamatter.

Ontology is therefore not grounded in geometry, but in **modes of actualization**. Geometry, causality, and temporal ordering appear only once certain ensemble configurations become dynamically stable.

8.2. Metamatter as the primary ontological content

Metamatter constitutes the primary ontological level. It is neither spatial nor temporal in the classical sense, yet it is not abstract or immaterial. Rather, it represents a **pre-geometric physical substrate** whose internal relational dynamics give rise to all subsequent structures.

Crucially, metamatter is not one among many possible substances. It exhausts physical content at the fundamental level; all observed entities are **phase-dependent manifestations** of this same substrate.

8.3. Fractal dynamics as the mode of existence

The existence of metamatter is intrinsically **dynamic**, but this dynamism is not equivalent to motion through space or evolution in time. Instead, it takes the form of **fractal ensemble dynamics**, characterized by recursive reconfiguration and scale-independent relational structure.

Fractal dynamics provides the ontological bridge between complete potentiality and partial actualization, enabling complexity to arise without external ordering principles.

8.4. Physical time as an emergent ordering

Physical time does not precede matter. It emerges as a **macroscopic ordering of actualized configurations** once dissipation stabilizes causal relations.

Time, in this sense, is not an independent entity but a **phase-dependent parameter** that tracks irreversible ensemble selection. Its directionality reflects statistical suppression of alternative configurations rather than a fundamental arrow embedded in reality.

8.5. Space as relational differentiation

Similarly, space is not a container in which matter resides. It is a **relational differentiation** between stabilized configurations.

In pre-geometric phases, there are:

- no coordinates in the classical sense,
- no metric distances,
- no trajectories.

Instead, structure is encoded through **hierarchical relations, correlations, and degrees of actualization**. Spatial geometry emerges only when these relations admit a consistent metric representation.

8.6. Non-differentiation of space and time in deep phases

At sufficiently deep levels of metamatter dynamics, the distinction between space and time loses meaning. They form a **hybrid relational structure**, in which ordering and differentiation are inseparable.

The later separation into spatial and temporal dimensions is a consequence of phase transitions, not an intrinsic feature of the fundamental ontology.

8.7. Matter and dynamics as inseparable

Matter and dynamics cannot be separated. There is no matter without dynamical actualization, and no dynamics without material content.

Physical laws are therefore not imposed on matter from outside, but emerge as **regularities of stabilized ensemble behavior** within specific phase regimes.

8.8. Ontological economy and explanatory closure

The proposed ontology is economical: it introduces no additional substances, fields, or dimensions beyond those required by phase dynamics. At the same time, it is explanatorily powerful, providing unified interpretations of quantum phenomena, gravity, dark components, and cosmological limits.

Space, time, and matter are not competing primitives, but **mutually dependent modes** within a single phase-structured reality.

8.9. Conceptual summary

Reality is not fundamentally geometric. It is **phase-structured**.

Metamatter constitutes the primary content; fractal ensemble dynamics its mode of existence; space and time its stabilized expressions.

This ontological shift reframes physics not as the study of objects in spacetime, but as the study of **how spacetime itself becomes possible**.

9. Synthesis, Limits, and Outlook

9.1. Unified phase picture

This work has developed a unified phase-based picture of physical reality in which classical matter, space, and time emerge as **stabilized regimes of metamatter actualization**. The fundamental structure is not geometric but relational and ensemble-based, governed by fractal dynamics and phase selection.

The central result is the identification of a universal phase cycle,

$$0D \rightarrow 1D \rightarrow 2D \rightarrow 3+1D \rightarrow 0D,$$

which describes both cosmological evolution and its limiting regimes. Each transition corresponds to a qualitative change in the mode of actualization rather than to geometric expansion or contraction.

9.2. Resolution of foundational problems

Within this framework, several long-standing conceptual problems receive a unified and non-ad hoc interpretation:

- **Quantum superposition and entanglement** arise from incomplete actualization in the 1D phase.
- **Nonlocality** reflects the absence of metric structure in pre-geometric regimes.
- **Dark matter** corresponds to structurally stabilized 2D ensembles without particle-like localization.
- **Dark energy** reflects a global phase condition associated with incomplete actualization at cosmological scales.
- **Gravity** emerges as a geometric response to fractal ensemble tension rather than as a fundamental interaction.
- **Black hole information paradoxes** dissolve once information is decoupled from local geometric representation.

These phenomena are not independent mysteries but manifestations of the same underlying phase structure.

9.3. Role of entropy, negentropy, and dissipation

A central organizing principle of the theory is the competition between entropy and negentropy, captured by the effective phase functional

$$\mathcal{F} = S - \alpha N.$$

Entropy drives irreversible dissipation and suppresses unstable configurations, while negentropy enables self-organization and the growth of hierarchical structure. Dissipation acts as a selective mechanism that stabilizes particular phases without fine-tuning.

This balance provides a natural origin for temporal directionality, dimensional emergence, and the persistence of classical regimes.

9.4. Ontological implications

The proposed framework implies a significant ontological shift. Space and time are not fundamental containers of reality but **phase-dependent modes of differentiation and ordering**. Matter is not a static substance but a dynamic pattern of actualization.

Physical laws emerge as regularities of stabilized ensemble behavior within specific phase regimes, rather than as universal prescriptions imposed at the fundamental level.

9.5. Limits of the present work

The theory presented here is intentionally **pre-field-theoretic**. While it establishes a coherent ontological and formal foundation, it does not yet provide a complete dynamical field formulation or detailed quantitative predictions.

Further development is required to:

- construct a field-theoretic realization of metamatter dynamics,
- derive effective equations in specific phase regimes,
- connect the framework with precision cosmological and quantum experiments.

9.6. Outlook

Despite these limitations, the phase-based approach outlined in this work offers a promising direction for unifying quantum theory, gravity, and cosmology without introducing additional fundamental substances or dimensions.

By treating spacetime itself as an emergent phase, the framework opens a new conceptual path toward a deeper understanding of physical reality and provides a natural starting point for a future **field theory of metamatter**.

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