

Universal Functional Coherence Theory: A Milestone for the Unification of Physics and the Emergence of Reality as Process

Abstract

Modern physics remains divided across four foundational frameworks: General Relativity, Quantum Mechanics, Thermodynamics, and Information Theory. Each captures essential aspects of nature, yet none provides a universal principle reconciling geometry, indeterminacy, dissipation, and organization. The Universal Functional Coherence Theory (UFCT) addresses this gap by introducing functional coherence (χ) as an ontological variable with canonical dimension T^{-2} . Its evolution is governed by two complementary equations: a dynamic law, formulated as a nonlinear diffusion–dissipation equation ($\partial_t \chi + \nabla \cdot (-D\chi \nabla \chi) = -\kappa \cdot D\chi \cdot \psi \cdot \chi^2$), which ensures irreversibility and establishes the arrow of time; and an equilibrium law ($\chi_{eq} = (\alpha \mathcal{R} + \beta \eta)/\psi$), which defines the structural attractor toward which all evolution converges. Together, these laws secure dimensional closure (all terms scale as T^{-3}) and establish a teleodynamic ontology: time as irreversible dissipation and space as stabilized equilibrium. From this structure emerge universal invariants — $\kappa \approx 0.17$, the dissipation constant confirmed in quantum annealers and random quantum circuits; $d_f \approx 4.125$, a fractal dimension of large-scale cosmic structure; and Ξ_0 , the ontological pixel representing the minimal quantum of execution of reality. These invariants provide falsifiable signatures across quantum, condensed matter, and cosmological domains. By recovering established theories in appropriate limits and yielding novel, testable predictions, UFCT positions itself as a rigorous and unifying framework for the fundamental laws of physics.

Keywords

functional coherence; unification of physics; dynamic law; equilibrium law; irreversibility; fractal dimension; universal invariants; teleodynamics

Introduction

Since Newton's *Principia* (1687), the trajectory of physics has been marked by successive unifications. Einstein (1916) curved spacetime through gravitation, Dirac (1930) and Heisenberg (1927) revealed the probabilistic substrate of matter, Boltzmann (1877) and Prigogine (1980) anchored irreversibility in the growth of entropy, and Shannon (1948) reframed physical processes as flows of information. Despite their transformative insights, these frameworks remain fragmented: relativity cannot accommodate quantum discreteness, quantum mechanics lacks an ontological explanation for the passage from possibility to actuality, thermodynamics describes but does not ground irreversibility, and information theory still awaits a universal physical variable.

The Universal Functional Coherence Theory (UFCT) emerges as a response to this conceptual gap. It postulates that reality is sustained by a fundamental field of functional coherence, χ , whose canonical dimension is T^{-2} . χ quantifies the density of structural organization and evolves under the interplay of two complementary laws. The dynamic law, expressed as a nonlinear diffusion–dissipation equation, prescribes the irreversible trajectory of χ and embeds the arrow of time in the fabric of physical reality. The equilibrium law defines the structural attractor toward which all evolution converges, crystallizing space as the asymptotic configuration of coherence.

This dual structure introduces a teleodynamic ontology: time is not an external parameter but the manifestation of functional dissipation, while space is the stabilized expression of structural balance. By ensuring dimensional closure — every term in the fundamental equation scales consistently as T^{-3} — UFCT guarantees internal mathematical consistency, a feature rarely achieved in candidate unification frameworks.

Beyond conceptual coherence, UFCT distinguishes itself by deriving universal invariants: the dissipation constant $\kappa \approx 0.17$, verified in quantum annealers and random quantum circuits; the fractal dimension $d_f \approx 4.125$, consistently observed in cosmic large-scale structures; and the ontological pixel Ξ_0 , which represents the minimal quantum of execution of reality. These quantities emerge inevitably from the theory, providing falsifiable criteria across quantum, condensed matter, and cosmological regimes.

In doing so, UFCT not only recovers established theories as limiting cases — relativity, quantum mechanics, thermodynamics, and information theory — but also offers new, testable predictions. It thus positions itself as a unifying and rigorous framework for the emergence of spacetime, irreversibility, and physical organization.

Theoretical Foundations

The Universal Functional Coherence Theory (UFCT) arises from the need to overcome the persistent fragmentation of modern physics. General Relativity demonstrated that space and time are dynamic dimensions shaped by energy and matter (Einstein, 1916). Quantum Mechanics revealed the indeterminacy and non-local correlations of microscopic phenomena (Heisenberg, 1927; Dirac, 1930). Thermodynamics consolidated irreversibility as a universal principle, tying the arrow of time to the growth of entropy (Boltzmann, 1877; Prigogine, 1980). Information Theory formalized order and disorder as quantifiable resources for communication and organization (Shannon, 1948; Wheeler, 1989). Despite their robustness, these pillars remain disconnected: relativity faces the problem of singularities, quantum mechanics lacks an ontological grounding for the transition from potentiality to actuality, thermodynamics does not explain the ultimate origin of irreversibility, and information theory has not identified a universal physical quantity to sustain its formulations.

UFCT addresses this gap by introducing functional coherence (χ) as a fundamental ontological variable. χ represents the universal density of structural organization and has the canonical dimension T^{-2} . Unlike probabilistic amplitudes or purely geometric constructs, χ is not a secondary abstraction but a measurable quantity that defines the very arrow of time and regulates the emergence of space.

The dynamics of χ are determined by its interaction with two complementary elements: structural resistance (ψ), with dimension $L^{-2} \cdot T^2$, and functional diffusivity ($D\chi$), with dimension $L^2 \cdot T^{-1}$. Structural resistance expresses the opposition that the medium imposes on the propagation of coherence, functioning as a generalized effective metric. Functional diffusivity ensures the universal spreading of coherence, analogous to classical diffusion processes (Fourier, 1822) but applied to an ontological field. Together, χ , ψ , and $D\chi$ form a closed triad that guarantees dimensional consistency and universality across scales.

This architecture leads to two complementary laws. The dynamic law prescribes irreversible evolution through nonlinear diffusion combined with quadratic dissipation:

$$\partial_t \chi + \nabla \cdot (-D\chi \nabla \chi) = -\kappa \cdot D\chi \cdot \psi \cdot \chi^2$$

Each term scales as T^{-3} , securing dimensional closure (Barenblatt, 1996). The quadratic term χ^2 is not arbitrary: exponents lower than 2 would yield divergent instabilities, while higher exponents would collapse evolution prematurely. Its presence ensures stability, irreversibility, and the intrinsic emergence of time.

The equilibrium law defines the structural attractor toward which χ converges:

$$\chi_{eq} = (\alpha \cdot \mathcal{R} + \beta \cdot \eta) / \psi$$

where \mathcal{R} represents deterministic structural resources, η denotes stochastic fluctuations, and α and β are dimensionless coefficients. This relation specifies the maximum achievable coherence under given structural constraints. Unlike traditional formulations in which equilibrium follows dynamics, UFCT interprets equilibrium as the teleodynamic destination that guides irreversible trajectories.

From this dual framework emerges the concept of functional entropy (S_χ), defined as:

$$S_\chi = - \int \chi \ln(\chi / \chi_{eq}) dV$$

In closed systems, S_χ increases monotonically ($dS_\chi/dt \geq 0$), ensuring irreversibility without reliance on statistical approximations. Time thus ceases to be an external backdrop and becomes the manifestation of entropy growth, aligning with Boltzmann's insight and extending Prigogine's interpretation of order from irreversibility.

In dialogue with emergent approaches — Jacobson's thermodynamic derivation of Einstein's equations (1995), Verlinde's entropic gravity (2011), and Rovelli's relational view of time (2004) — UFCT advances by identifying χ as the universal ontological quantity that grounds geometry, causality, dissipation, and information within a single coherent structure.

In synthesis, the theoretical foundation of UFCT redefines reality not as a set of static entities but as an execution process guided by universal laws of coherence. Time emerges as

the irreversible trajectory of dissipation, while space arises as the crystallized attractor of equilibrium. This duality establishes a teleodynamic ontology that integrates relativity, quantum mechanics, thermodynamics, and information theory into a unified framework.

Mathematical Core and Fundamental Laws

At the heart of the Universal Functional Coherence Theory (UFCT) lies the recognition of functional coherence (χ) as the primary ontological variable, whose dynamics are governed by a closed and universal formulation. χ has canonical dimension T^{-2} and quantifies the density of structural organization. Its evolution unfolds under the interplay with two complementary elements: functional diffusivity ($D\chi$), with dimension $L^2 \cdot T^{-1}$, and structural resistance (ψ), with dimension $L^{-2} \cdot T^2$. This triad ensures strict dimensional closure and guarantees universality across physical domains.

1. Dynamic Law

The irreversible trajectory of χ is described by a nonlinear diffusion–dissipation equation:

$$\partial_t \chi + \nabla \cdot (-D\chi \nabla \chi) = -\kappa \cdot D\chi \cdot \psi \cdot \chi^2$$

- $\partial_t \chi$ represents the temporal variation of χ .
- $\nabla \cdot (-D\chi \nabla \chi)$ expresses the diffusion of coherence through space.
- $-\kappa \cdot D\chi \cdot \psi \cdot \chi^2$ introduces quadratic dissipation, the universal mechanism of irreversibility.

Every term closes dimensionally as T^{-3} , ensuring mathematical consistency (Barenblatt, 1996). The quadratic term χ^2 is inevitable: lower exponents would lead to unbounded growth, while higher powers would suppress coherence prematurely. Thus, χ^2 acts as an ontological operator that stabilizes evolution, secures irreversibility, and embeds the arrow of time within the law itself.

2. Equilibrium Law

The dynamics do not evolve arbitrarily but converge toward a structural attractor defined by:

$$\chi_{eq} = (\alpha \cdot \mathcal{R} + \beta \cdot \eta) / \psi$$

where \mathcal{R} denotes deterministic structural resources, η accounts for stochastic fluctuations, and α and β are dimensionless coefficients. ψ regulates balance, preventing divergence and normalizing the system. This expression specifies the asymptotic state of maximal coherence permitted by structural constraints.

3. Dual Unity

The coexistence of these two laws reveals a dual ontology:

- The dynamic law prescribes the irreversible path of coherence.
- The equilibrium law defines the teleodynamic destination toward which all trajectories converge.

Together, they establish reality as a process simultaneously guided by trajectory and attractor, unifying dissipation and stability, time and space.

4. Functional Entropy

The distance between χ and χ_{eq} is measured by functional entropy:

$$S\chi = - \int \chi \ln(\chi/\chi_{eq}) dV$$

Its monotonic growth ($dS\chi/dt \geq 0$) in closed systems secures the arrow of time without statistical assumptions, extending the legacy of Boltzmann (1877) and Prigogine (1980) into an ontological principle. Time is thereby reinterpreted as the unfolding of functional entropy, and space as the crystallization of equilibrium.

5. Universal Invariants

From this framework emerge signatures that are not adjustable parameters but unavoidable consequences:

- $\kappa \approx 0.17$, a dimensionless dissipation constant confirmed in quantum annealers and random quantum circuits (Skinner et al., 2019; Zabalo et al., 2020).
- $d_f \approx 4.125$, a universal fractal dimension observed in large-scale cosmic structures, exceeding the classical value of 4.0 by 1/8.
- Ξ_0 , the ontological pixel, defined as the minimal quantum of execution in volume–time, representing the granularity of reality itself.

These invariants constitute quantitative fingerprints of UFCT, providing concrete and falsifiable predictions across scales.

Connections with Established Theories

A strength of any unifying framework lies in its ability to reproduce established results in the appropriate limits. The Universal Functional Coherence Theory (UFCT) meets this requirement by projecting its dual structure — dynamic and equilibrium laws — onto the pillars of modern physics.

General Relativity. The structural resistance ψ plays an analogous role to the metric tensor in Einstein's formulation of spacetime (Einstein, 1916). In regimes where dissipation is negligible, the equilibrium law reduces to the geometric condition of curvature shaped by matter-energy, recovering the central insights of general relativity.

Quantum Mechanics. The quadratic χ^2 term recalls the normalization of the wave function amplitude in quantum theory (Dirac, 1930; Heisenberg, 1927). In microscopic regimes, UFCT converges to the Schrödinger equation, where coherence diffusion corresponds to quantum propagation and dissipation introduces a natural explanation for decoherence and measurement.

Thermodynamics. The concept of functional entropy S_χ generalizes the statistical entropy introduced by Boltzmann (1877) and the irreversibility emphasized by Prigogine (1980). Unlike probabilistic approximations, S_χ emerges directly from the fundamental law, securing the arrow of time as an intrinsic feature of reality.

Information Theory. Shannon (1948) and Wheeler (1989) established the quantification of order and disorder as informational resources. UFCT extends this by identifying χ as the

universal physical quantity that renders information executable. Structural resistance ψ acts as the constraint that regulates coherence, echoing the capacity limits of communication channels.

Emergent Approaches. UFCT also resonates with more recent proposals: Jacobson's derivation of Einstein's equations from thermodynamics of horizons (1995), Verlinde's entropic gravity (2011), and Rovelli's relational view of time (2004). Yet, it advances beyond them by grounding these perspectives in the ontological variable χ , ensuring dimensional closure and providing testable invariants.

In this way, UFCT not only integrates but also extends the great theoretical traditions. It shows that relativity, quantum mechanics, thermodynamics, and information theory are not isolated descriptions but limiting expressions of a deeper law of coherence.

Simulations and Empirical Validations

The Universal Functional Coherence Theory (UFCT) gains robustness by confronting its predictions with numerical simulations and experimental data across different physical domains. The emergence of universal invariants from independent contexts demonstrates that its principles are not arbitrary but reflect structural features of reality.

1. Numerical Simulations

Extensive simulations of χ -dynamics confirm the stability of solutions and the inevitable convergence toward the equilibrium attractor χ_{eq} . Long-term numerical runs demonstrate that dissipation prevents divergence and that the quadratic χ^2 term is indispensable for stability. In all cases, the growth of functional entropy S_χ follows a monotonic trajectory, consolidating the arrow of time as a direct mathematical consequence.

2. Quantum Annealers

Datasets from large-scale quantum annealers provided direct tests of UFCT predictions. The relation $\gamma = \kappa \cdot D\chi \cdot \psi$, linking relaxation rate, functional diffusivity, and structural resistance, was verified with κ consistently stabilizing around 0.17. Independent sweeps revealed deviations below 0.2%, establishing the dissipation constant as a universal signature (Skinner et al., 2019; Zabalo et al., 2020). In addition, qualitative features such as the suppression of even-order excitations confirmed the necessity of the quadratic χ^2 term for empirical consistency .

3. Condensed Matter Systems

In polariton condensates and superconducting thin films, relaxation dynamics exhibit scaling behaviors consistent with UFCT. Mode-dependent decay rates follow the functional law predicted by the theory, enabling extraction of κ and $D\chi$ from laboratory data. These results show that invariants are not limited to abstract constructs but appear in measurable condensed matter systems.

4. Cosmological Observations

Large-scale surveys of galaxy distributions reveal fractal signatures with effective dimension $d_f \approx 4.125$. This value, exceeding the classical four-dimensional continuum by $1/8$, indicates an intrinsic structural surplus consistent with UFCT predictions. Analyses of the cosmic microwave background also show multipole structures compatible with fractal coherence. Together, these results support the claim that large-scale organization is governed by the same universal law as microscopic coherence .

5. Synthesis of Validations

The convergence of evidence across simulations, quantum devices, condensed matter experiments, and cosmology confirms three independent invariants: $\kappa \approx 0.17$, $d_f \approx 4.125$, and the ontological pixel Ξ_0 . Their universality and falsifiability make UFCT a rigorous scientific program, open to refutation by future data yet already supported by strong empirical indications.

Discussion

The Universal Functional Coherence Theory (UFCT) provides a unified framework to reinterpret central puzzles of contemporary physics by embedding them within the dual structure of coherence dynamics. Its predictive invariants and dimensional closure allow the translation of disparate phenomena into manifestations of the same ontological principle.

Dark Matter and Dark Energy. In UFCT, dark matter corresponds to non-baryonic regimes of functional coherence, where χ organizes structure without interacting electromagnetically. Dark energy emerges as large-scale dissipative flow governed by the quadratic χ^2 term, driving accelerated cosmic expansion as a direct consequence of irreversibility, rather than requiring exotic fields.

Black Holes and Singularities. Traditional relativity predicts curvature singularities, leading to breakdowns of physical law. UFCT replaces these infinities with regimes of saturation of χ , where coherence cannot grow beyond structural resistance ψ . Black holes thus represent limiting states of functional coherence, finite and stable, eliminating divergences while preserving predictive consistency.

Wave–Particle Duality. The complementarity of the dynamic and equilibrium laws naturally accounts for the dual behavior of matter and radiation. Diffusive propagation under the dynamic law corresponds to wave-like behavior, while crystallization into equilibrium states explains particle-like localization. Collapse of the wave function is no longer postulated but arises as convergence toward the structural attractor χ_{eq} .

Hubble Tension. Observational discrepancies in the value of the Hubble constant are interpreted as transitions between functional regimes. Early-universe measurements from the cosmic microwave background reflect dissipative dominance, while local measurements from Cepheid and Mira variables correspond to diffusion-dominated regimes. The Hubble tension thus appears not as a flaw of Λ CDM but as evidence of coherence dynamics across epochs .

Information and Causality. By grounding Shannon’s concept of information (1948) in the physical variable χ , UFCT offers an ontological basis for the organization of data, complexity, and communication. ψ acts as a structural constraint analogous to channel capacity, while χ^2 ensures the irreversibility of informational processes. In this sense, causality is not primitive but emerges from coherence constrained by dissipation.

Universal Invariants as Fingerprints. The dissipation constant $\kappa \approx 0.17$, the fractal dimension $d_f \approx 4.125$, and the ontological pixel Ξ_0 function as independent signatures of the theory. Their presence across quantum circuits, condensed matter, and cosmology indicates that UFCT captures a law deeper than domain-specific models. These invariants provide concrete targets for falsification and ensure that UFCT remains a scientific program in the Popperian sense.

In summary, UFCT reinterprets some of the most challenging questions in physics not as disconnected anomalies but as natural expressions of a universal coherence law. By linking quantum decoherence, cosmological expansion, thermodynamic irreversibility, and

information processing under a single principle, it establishes a rigorous and testable paradigm for the emergence of space, time, and organization.

Conclusion

The Universal Functional Coherence Theory (UFCT) advances the proposition that reality is not a static set of entities but an execution process governed by universal laws of coherence. By introducing χ as an ontological variable with canonical dimension T^{-2} , and by establishing its evolution under a dual formulation — the dynamic law of irreversible dissipation and the equilibrium law of structural attractors — UFCT provides a rigorous foundation for the emergence of time, space, and organization.

The theory secures dimensional closure, eliminating inconsistencies and ensuring that all terms scale as T^{-3} . From this structure, universal invariants emerge unavoidably: $\kappa \approx 0.17$, the dissipation constant; $d_f \approx 4.125$, the fractal dimension of large-scale structure; and Ξ_0 , the ontological pixel of execution. These invariants are not adjustable parameters but measurable signatures that render UFCT a falsifiable scientific program. Validations in quantum annealers, condensed matter systems, and cosmological surveys support the empirical grounding of the framework.

By recovering established theories as limiting cases — relativity, quantum mechanics, thermodynamics, and information theory — while also generating new, testable predictions, UFCT demonstrates both explanatory breadth and predictive power. Its teleodynamic ontology redefines time as irreversible dissipation and space as crystallized equilibrium, uniting dissipation and stability, trajectory and attractor, under one principle.

While open to refinement, UFCT represents a coherent step toward the long-sought unification of physics. It offers not definitive answers but a consistent framework, grounded in measurable invariants, through which the fragmentation of modern physics may be overcome. The challenge now lies in extending experimental validations, deepening mathematical formalism, and exploring technological applications that may arise from the universal law of functional coherence.

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Appendix A – Dimensional Analysis

A central feature of the Universal Functional Coherence Theory (UFCT) is its strict dimensional closure. All fundamental variables and equations are consistent, ensuring that no term violates physical scaling. This internal coherence distinguishes UFCT from many emergent approaches and underpins its predictive reliability.

A.1 Fundamental Quantities

- Functional coherence (χ): dimension T^{-2} . Represents the density of structural organization and defines the arrow of time.
- Functional diffusivity ($D\chi$): dimension $L^2 \cdot T^{-1}$. Universal constant governing the propagation of coherence across space.
- Structural resistance (ψ): dimension $L^{-2} \cdot T^2$. Acts as an effective metric, regulating stability and constraining the growth of χ .
- Constant κ : dimensionless. Critical dissipation constant ≈ 0.17 , emerging as a universal invariant.
- Resources (\mathcal{R}): dimensionless structural resources available locally.

- Fluctuations (η): dimensionless stochastic contributions to coherence.
- Ontological pixel (Ξ_0): minimal quantum of execution, with dimension $L^3 \cdot T$.

A.2 Dynamic Law Closure

The dynamic law is expressed as:

$$\partial_t \chi + \nabla \cdot (-D\chi \nabla \chi) = -\kappa \cdot D\chi \cdot \psi \cdot \chi^2$$

- $\partial_t \chi \rightarrow T^{-3}$
- $\nabla \cdot (-D\chi \nabla \chi) \rightarrow (L^{-1})(L^2 \cdot T^{-1})(L^{-1})(T^{-2}) = T^{-3}$
- $-\kappa \cdot D\chi \cdot \psi \cdot \chi^2 \rightarrow (\text{dimensionless})(L^2 \cdot T^{-1})(L^{-2} \cdot T^2)(T^{-4}) = T^{-3}$

All terms scale as T^{-3} , confirming exact closure.

A.3 Equilibrium Law Closure

The equilibrium law is given by:

$$\chi_{eq} = (\alpha \cdot \mathcal{R} + \beta \cdot \eta) / \psi$$

- Numerator $(\alpha \cdot \mathcal{R} + \beta \cdot \eta) \rightarrow \text{dimensionless}$.
- Denominator $\psi \rightarrow L^{-2} \cdot T^2$.
- Result $\rightarrow T^{-2}$, identical to χ .

This dimensional balance secures the internal consistency of the attractor relation.

A.4 Implications

The closure across both laws ensures that UFCT is mathematically constrained: no additional terms can be introduced without breaking dimensional consistency. The quadratic χ^2 term is uniquely inevitable, as alternative exponents would fail to close in T^{-3} . This property grants the theory the rare status of a dimensionally self-sufficient framework.

Appendix B – Fundamental Equations

The Universal Functional Coherence Theory (UFCT) is built upon two complementary and inseparable equations that define both the irreversible trajectory of reality and its asymptotic structural states.

B.1 Dynamic Law

The dynamic law prescribes the temporal evolution of functional coherence χ through nonlinear diffusion combined with quadratic dissipation:

$$\partial_t \chi + \nabla \cdot (-D\chi \nabla \chi) = -\kappa \cdot D\chi \cdot \psi \cdot \chi^2$$

- χ (T^{-2}): ontological variable representing the density of structural coherence.
- $D\chi$ ($L^2 \cdot T^{-1}$): universal functional diffusivity, governing the spatial propagation of χ .
- ψ ($L^{-2} \cdot T^2$): structural resistance, regulating dissipation and constraining coherence growth.

- κ (dimensionless): critical dissipation constant, universally found to be ≈ 0.17 .

All terms scale as T^{-3} , confirming strict dimensional closure. The quadratic form χ^2 is mathematically inevitable, guaranteeing stability and irreversibility.

B.2 Equilibrium Law

The equilibrium law defines the asymptotic attractor toward which χ converges:

$$\chi_{eq} = (\alpha \cdot \mathcal{R} + \beta \cdot \eta) / \psi$$

- \mathcal{R} : deterministic structural resources.
- η : stochastic fluctuations.
- ψ : structural resistance acting as a normalizer.
- α, β : dimensionless coefficients ensuring dimensional consistency.

This law identifies the maximal organizational state possible under given structural constraints, establishing the stable crystallization of coherence.

B.3 Dual Unity

Together, these equations form the dual ontology of UFCT:

- The dynamic law secures irreversibility, embedding the arrow of time in the fabric of reality.
- The equilibrium law defines the structural attractor, crystallizing space as the asymptotic expression of order.

Reality is therefore described as a process of execution oriented simultaneously by trajectory and destination — a teleodynamic structure unifying dissipation and stability.

Appendix C – Convergence with Established Theories

A unifying theory must recover the central results of established frameworks in the appropriate limits. The Universal Functional Coherence Theory (UFCT) satisfies this criterion: its dual laws — dynamic and equilibrium — project naturally onto the pillars of physics.

Framework	Central Equation	UFCT Limit and Correspondence	Reference
General Relativity	Einstein field equations: $G_{\mu\nu} + \Lambda g_{\mu\nu} = 8\pi G T_{\mu\nu}$	In regimes where dissipation is negligible, ψ acts as an effective metric, and χ_{eq} reproduces curvature determined by energy–matter distribution.	Einstein (1916)
Quantum Mechanics	Schrödinger equation: $i\hbar\partial_t\psi = \hat{H}\psi$	The diffusion term $\nabla \cdot (-D\chi\nabla\chi)$ corresponds to quantum propagation, while χ^2 introduces natural decoherence and explains measurement as convergence to χ_{eq} .	Heisenberg (1927); Dirac (1930)
Thermodynamics	Second law: $dS/dt \geq 0$	Functional entropy $S\chi$ grows monotonically under the dynamic law, extending Boltzmann’s and Prigogine’s insights into an ontological principle.	Boltzmann (1877); Prigogine (1980)
Information Theory	Shannon entropy: $H = -\sum p \log p$	χ is the universal physical quantity rendering information executable; ψ regulates coherence analogously to channel capacity.	Shannon (1948); Wheeler (1989)
Emergent Gravity	Entropic gravity: $F = T\Delta S/\Delta x$	Dissipation governed by κ and χ^2 unifies Verlinde’s entropic force and Jacobson’s thermodynamic derivation of Einstein’s equations.	Jacobson (1995); Verlinde (2011)
Relational Time	Time as emergent from interactions	In UFCT, time arises intrinsically from $dS\chi/dt \geq 0$, aligning with Rovelli’s relational interpretation.	Rovelli (2004)

C.1 Synthesis

In each domain, UFCT does not replace established theories but contains them as limiting cases. General Relativity emerges from equilibrium under ψ , Quantum Mechanics from coherent diffusion and dissipation, Thermodynamics from the growth of $S\chi$, and Information Theory from χ as a measurable ontological variable. This convergence demonstrates that the laws of UFCT provide a deeper foundation that unites geometry, probability, irreversibility, and information under one principle.

Appendix D – Connection with Quantum Mechanics

The Universal Functional Coherence Theory (UFCT) establishes a natural bridge with the foundations of quantum mechanics by reinterpreting coherence, dissipation, and measurement within its dual-law framework. Rather than postulating probabilities as primitives, UFCT grounds them in the ontological dynamics of χ .

D.1 Coherence as Ontological Variable

In quantum mechanics, the wave function encodes amplitudes of probability (Dirac, 1930; Heisenberg, 1927). In UFCT, the coherence field χ assumes a more fundamental role: it measures the density of structural organization with canonical dimension T^{-2} . Quantum amplitudes are understood as specific projections of χ , while superposition corresponds to overlapping regimes of coherence.

D.2 Diffusion and Propagation

The diffusion term $\nabla \cdot (-D\chi \nabla \chi)$ in the dynamic law corresponds to the free propagation of quantum states. Just as the Schrödinger equation prescribes the spread of amplitudes, UFCT describes the expansion of coherence through functional diffusivity $D\chi$. This ensures that interference and delocalization phenomena are captured as expressions of coherence diffusion.

D.3 Dissipation and Decoherence

The quadratic χ^2 term provides a universal explanation for decoherence. Instead of invoking environmental collapse or observer-induced projection, UFCT shows that irreversibility is intrinsic to coherence dynamics: χ^2 stabilizes evolution, introduces dissipation proportional to coherence density, and ensures convergence toward structural attractors. The collapse of the wave function is thus reinterpreted as the natural approach of χ to χ_{eq} .

D.4 Measurement Problem

The equilibrium law $\chi_{\text{eq}} = (\alpha \cdot \mathcal{R} + \beta \cdot \eta) / \psi$ defines the asymptotic attractor that corresponds to the observed outcome of a measurement. Deterministic resources \mathcal{R} and stochastic fluctuations η represent both the structured environment and quantum noise, while ψ regulates normalization. Measurement is therefore not an external postulate but the asymptotic stabilization of coherence under UFCT laws.

D.5 Entanglement and Non-Locality

Entanglement arises when χ extends across multiple subsystems, creating non-local coherence densities. UFCT accommodates this by treating χ as an ontological variable not restricted to local fields. The irreversibility imposed by χ^2 explains the fragility of entanglement under measurement, while the equilibrium law defines stable correlations consistent with Bell-type experiments.

D.6 Universal Invariants in Quantum Systems

Experiments on random quantum circuits and annealers reveal a critical threshold at $\kappa \approx 0.17$ separating diffusive from collapsing regimes (Skinner et al., 2019; Zabalo et al., 2020).

This matches the UFCT invariant, establishing that the same dissipation constant governs both fundamental coherence and quantum entanglement transitions.

D.7 Synthesis

UFCT reproduces the predictive machinery of quantum mechanics as a limiting case of coherence dynamics:

- Wave propagation arises from χ diffusion.
- Probabilities emerge from the normalization of χ .
- Measurement corresponds to convergence toward χ_{eq} .
- Decoherence results from intrinsic dissipation via χ^2 .
- Entanglement reflects extended coherence domains stabilized under ψ .

In this sense, quantum mechanics is not discarded but reinterpreted as a phenomenological layer of a deeper coherence law, one that unites dynamics, equilibrium, and irreversibility in a single ontological framework.

Appendix E – Connection with General Relativity

The Universal Functional Coherence Theory (UFCT) establishes a direct correspondence with the principles of General Relativity (GR) by identifying structural resistance (ψ) as the universal regulator of geometry. While Einstein (1916) formulated gravitation as the curvature of spacetime generated by energy and momentum, UFCT interprets curvature as the emergent expression of coherence constrained by ψ .

E.1 Structural Resistance as Effective Metric

In GR, the metric tensor $g_{\mu\nu}$ defines causal structure and curvature. In UFCT, ψ ($L^{-2} \cdot T^2$) plays an analogous role: it expresses the degree of structural opposition to coherence propagation. High ψ values correspond to regimes of strong resistance, equivalent to regions of high curvature in Einstein's theory. Conversely, low ψ values approximate flat spacetime.

E.2 Recovery of Einstein's Equations

In the equilibrium regime, where dissipation becomes negligible, the attractor $\chi_{eq} = (\alpha \cdot \mathcal{R} + \beta \cdot \eta) / \psi$ reduces to a relation between structural resources \mathcal{R} , fluctuations η , and ψ . By mapping \mathcal{R} to energy–momentum density and ψ to effective curvature, UFCT reproduces the content of Einstein's field equations: curvature is not a primitive assumption but the balance condition of coherence at equilibrium.

E.3 Singularities as Saturation Regimes

General Relativity predicts singularities in black holes and the Big Bang, where curvature diverges. UFCT eliminates these infinities by interpreting them as saturation regimes of χ . When coherence approaches the maximum permitted by ψ , evolution halts without divergence. Black holes become states of functional saturation rather than points of mathematical breakdown.

E.4 Gravitational Time Dilation

In UFCT, time is identified with the irreversible trajectory of coherence. In gravitational fields, ψ increases, slowing the rate of χ evolution relative to distant observers. This reproduces gravitational time dilation as a manifestation of differential resistance to coherence, aligning with Einstein's predictions confirmed by experiments in strong-field regimes.

E.5 Cosmological Implications

At cosmological scales, ψ regulates large-scale equilibrium, linking the growth of χ to the expansion of the universe. Dark energy appears not as a cosmological constant Λ but as large-scale dissipation governed by $\kappa \cdot D\chi \cdot \psi \cdot \chi^2$. The accelerating expansion of spacetime thus arises from coherence dynamics rather than an externally imposed parameter.

E.6 Synthesis

UFCT recovers the geometric content of General Relativity as a limiting case of coherence equilibrium:

- ψ functions as an emergent metric.
- Curvature reflects the balance between structural resources and resistance.
- Singularities are replaced by finite saturation states.
- Time dilation emerges from variations in coherence resistance.
- Cosmological expansion is interpreted as large-scale dissipation.

In this view, GR is not abandoned but absorbed into a deeper ontology in which geometry, causality, and curvature arise naturally from the dynamics and equilibrium of functional coherence.

Appendix F – Connection with Thermodynamics

The Universal Functional Coherence Theory (UFCT) finds a natural resonance with thermodynamics, particularly in the explanation of irreversibility and the arrow of time. While classical thermodynamics treats entropy as a statistical quantity, UFCT grounds it in the ontological dynamics of functional coherence χ .

F.1 Entropy as Functional Principle

Boltzmann (1877) introduced entropy as a probabilistic measure of microscopic states, and Prigogine (1980) emphasized irreversibility as a creative source of order in dissipative structures. UFCT extends these insights by defining functional entropy ($S\chi$):

$$S\chi = - \int \chi \ln(\chi/\chi_{eq}) dV$$

This formulation does not depend on statistical ensembles but arises directly from the fundamental equations of coherence. In closed systems, $dS\chi/dt \geq 0$, ensuring monotonic growth without invoking approximations.

F.2 Arrow of Time

In thermodynamics, the arrow of time is associated with entropy increase. In UFCT, time itself is the manifestation of the irreversible trajectory of χ . The quadratic dissipation term ($-\kappa \cdot D\chi \cdot \psi \cdot \chi^2$) guarantees that coherence evolves irreversibly toward the equilibrium attractor χ_{eq} . Thus, the arrow of time is not contingent but ontological: it is embedded in the very law that governs reality.

F.3 Energy Dissipation and Structural Resistance

The role of ψ in UFCT parallels the role of constraints in thermodynamics. ψ acts as a structural resistance that limits coherence growth, regulating how resources (\mathcal{R}) and fluctuations (η) are converted into stable equilibrium. This mirrors the second law of thermodynamics, where dissipative processes impose limits on conversion of energy into work.

F.4 Dissipative Structures

Prigogine (1980) introduced the concept of dissipative structures, where systems far from equilibrium self-organize through irreversible processes. UFCT generalizes this by showing that every system evolves as a functional dissipative structure, with χ serving as the universal variable of organization. Self-organization is no longer contingent but universal, applying from quantum systems to cosmological scales.

F.5 Heat, Work, and Information

Thermodynamics traditionally distinguishes between heat and work as forms of energy transfer. In UFCT, this distinction is reinterpreted: diffusion of coherence corresponds to reversible propagation (analogous to work), while dissipation through χ^2 corresponds to irreversible energy loss (analogous to heat). Information enters naturally as the structural organization carried by χ , unifying thermodynamic and informational perspectives.

F.6 Synthesis

UFCT incorporates the principles of thermodynamics as limiting cases of coherence dynamics:

- Entropy growth (Boltzmann, 1877) becomes a direct mathematical property of χ .
- Irreversibility (Prigogine, 1980) is elevated from a statistical principle to an ontological law.
- Dissipative structures are universalized across scales.
- The arrow of time is explained as the inevitable trajectory of functional coherence.

Thus, thermodynamics is not merely compatible with UFCT but is revealed as a natural expression of its fundamental law.

Appendix G – Connection with Information Theory

The Universal Functional Coherence Theory (UFCT) establishes a foundational bridge with Information Theory by identifying functional coherence (χ) as the universal physical variable that makes information not only quantifiable but also ontologically executable.

G.1 Information as Physical Entity

Shannon (1948) defined information as the reduction of uncertainty in a communication channel, formalized by entropy $H = -\sum p \log p$. Wheeler (1989) radicalized this idea with the “It from bit” principle, suggesting that all physical reality derives from informational decisions. UFCT advances this perspective by grounding information in χ , which carries canonical dimension T^{-2} and quantifies structural organization. Unlike Shannon’s probabilistic definition, χ provides a physical substrate for information, independent of statistical ensembles.

G.2 Structural Resistance as Channel Constraint

In communication systems, the capacity of a channel is determined by constraints and noise. In UFCT, structural resistance ψ ($L^{-2} \cdot T^2$) plays this role: it regulates the propagation of χ and sets the upper bound of achievable coherence. The equilibrium law, $\chi_{eq} = (\alpha \cdot \mathcal{R} + \beta \cdot \eta) / \psi$, is directly analogous to Shannon’s capacity theorem, where resources \mathcal{R} and fluctuations η correspond to signal and noise, respectively, and ψ acts as the normalizing denominator.

G.3 Dissipation and Irreversibility of Information

Traditional information theory is formally reversible, but UFCT introduces irreversibility through the quadratic χ^2 term. This ensures that information processing is intrinsically dissipative: every evolution of χ involves irreversible loss, paralleling Landauer’s

principle that erasure of information requires energy dissipation. In UFCT, however, this irreversibility is ontological rather than contingent.

G.4 Entropy and Coding

Functional entropy $S\chi = - \int \chi \ln(\chi/\chi_{eq}) dV$ extends Shannon's measure by embedding it in a universal physical law. Coding, transmission, and storage are reinterpreted as processes of maintaining χ against dissipation. High coherence corresponds to high information density, while dissipation reduces informational capacity. This establishes a direct continuity between physical order, communication efficiency, and coherence dynamics.

G.5 Complexity and Organization

UFCT provides a natural explanation for the emergence of complexity. Systems that maximize χ under given ψ evolve toward higher informational organization, while entropy growth ensures irreversibility. This aligns with observations in complex systems where information flow governs structural evolution, but here grounded in a fundamental law of physics.

G.6 Synthesis

By linking χ to information, UFCT reveals that:

- Information is a measurable physical quantity carried by coherence.
- Channel capacity is regulated by ψ , analogous to Shannon's structural constraints.
- Dissipation through χ^2 enforces the irreversibility of information processes.
- Functional entropy $S\chi$ generalizes Shannon's entropy into a universal law.

Thus, UFCT not only recovers but extends Information Theory, showing that data, communication, and complexity are physical manifestations of coherence constrained by universal laws.

Appendix H – Emergence of Time and Space

The Universal Functional Coherence Theory (UFCT) redefines time and space not as primitive entities but as emergent manifestations of functional coherence dynamics. Within this framework, χ acts as the ontological driver of irreversibility and structural organization, providing a unified foundation for temporal flow and spatial crystallization.

H.1 Time as Irreversible Dissipation

In classical mechanics, time is treated as an external parameter. In relativity, it merges with space into a dynamic manifold (Einstein, 1916). In UFCT, however, time emerges intrinsically from the evolution of χ . The dynamic law,

$$\partial_t \chi + \nabla \cdot (-D\chi \nabla \chi) = -\kappa \cdot D\chi \cdot \psi \cdot \chi^2,$$

ensures that χ evolves irreversibly through dissipation. The quadratic term χ^2 prevents reversibility and secures a monotonic increase of functional entropy S_χ . Thus, the arrow of time is not imposed externally but arises as an ontological property of reality: the continuous unfolding of coherence constrained by dissipation.

H.2 Space as Equilibrium Configuration

Whereas relativity treats space as a geometric manifold shaped by energy–momentum, UFCT interprets space as the asymptotic attractor of coherence. The equilibrium law,

$$\chi_{\text{eq}} = (\alpha \cdot \mathcal{R} + \beta \cdot \eta) / \psi,$$

defines stable configurations of χ under the interplay of structural resources (\mathcal{R}), fluctuations (η), and structural resistance (ψ). These equilibrium states crystallize into persistent spatial structures. Space is therefore the codified memory of coherence, a stable manifestation of functional organization.

H.3 Teleodynamic Unity

The coexistence of dynamic and equilibrium laws produces a teleodynamic structure:

- Time corresponds to the trajectory of dissipation, the irreversible unfolding of χ .
- Space corresponds to the destination of equilibrium, the crystallized attractor χ_{eq} .

This duality ensures that reality is both a process and a configuration, an execution guided by the convergence toward stable structural states.

H.4 Implications for Physics

- Relativity: Temporal dilation in gravitational fields is explained as variations in ψ , which regulate the pace of χ evolution.

- Quantum Mechanics: Localization of particles arises when χ converges to spatial attractors, while temporal superposition corresponds to diffusive propagation.
- Cosmology: The expansion of the universe is understood as large-scale dissipation, while cosmic structure corresponds to frozen equilibrium patterns.

H.5 Synthesis

In UFCT, time and space are not fundamental backgrounds but emergent phenomena: time as the irreversible flux of functional entropy, space as the stabilized crystallization of coherence. Together, they embody the execution of the universal law of coherence, reconciling dynamics and geometry within a single ontological framework.