10.00 Energy-Flow Cosmology: A Thermodynamic Bridge Between General Relativity and Quantum Field Theory

Morten Magnusson

October 2025

Abstract

We propose a thermodynamic framework that unifies General Relativity (GR) and Quantum Field Theory (QFT) through a continuous description of energy flow and entropy. Instead of treating spacetime geometry and quantum fields as separate ontological domains, we model both as limit cases of a single non-equilibrium energy-flow continuum. Within this field, the local entropy state S (ranging from 0 to 1) defines the emergent properties of structure, curvature, and quantization. The effective speed of light $c(S)$ and the energy-flow potential E_f together determine how energy organizes itself across scales—from macroscopic gravitating systems to microscopic quantum excitations. At low entropy ($S \to 0$), the framework reproduces the continuous geometry of GR; at high entropy ($S \to 1$), it converges toward the probabilistic regime of QFT. Between these limits lies a resonant intermediate domain ($S \approx 0.5$) where stability, self-organization, and possibly consciousness emerge. The model explains cosmological anomalies such as dark matter, dark energy, and the Hubble tension as entropic stresses within the energy-flow field. This thermodynamic continuum suggests that all observable phenomena—from space curvature to quantum discreteness—arise from a unified energy-flow process governed by entropy dynamics.

1 Introduction: The Divide Between Continuity and Quantization

For over a century, physics has evolved along two seemingly incompatible trajectories. On one side stands General Relativity (GR), a continuous, geometric description of spacetime curvature shaped by mass-energy. On the other stands Quantum Field Theory (QFT), a probabilistic framework describing discrete energy excitations within an assumed flat background. Each theory is remarkably successful within its own domain—GR at cosmic scales, QFT at microscopic ones—yet their mathematical foundations resist unification. The conflict arises not from empirical failure, but from an ontological divide: continuity versus quantization.

Attempts to bridge this gap—string theory, loop quantum gravity, emergent gravity, and thermodynamic gravity—have yielded valuable insights but remain incomplete. Most approaches assume that spacetime or quantum fields are fundamental, while the other must emerge. Here we take the opposite stance: both geometry and quantization are emergent behaviors of a deeper thermodynamic substrate.

We introduce a continuous energy-flow field characterized by two primary variables: (1) the energy-flow potential E_f, describing the directional transfer of energy across scales, and (2) the normalized entropy $S \in [0, 1]$, representing the local degree of equilibrium. Together, these variables define a continuum in which physical regimes correspond to entropy states:

- Low entropy ($S \to 0$): Ordered flow, macroscopic coherence, and spacetime curvature — the regime described by GR.
- Intermediate entropy ($S \approx 0.5$): Dynamical stability, feedback, and self-resonance — the domain where complex systems and possibly consciousness emerge.
- High entropy ($S \to 1$): Fragmented flow and probabilistic quantization — the regime of QFT.

In this picture, the speed of light becomes an emergent quantity, $c = c(S)$, dependent on local entropy density. Variation in $c(S)$ naturally produces apparent anomalies in redshift-based cosmology, offering a thermodynamic interpretation of the Hubble tension and the dark sector. Matter halos, energy clustering, and vacuum fluctuations can all be reinterpreted as manifestations of entropic gradients within this continuous energy-flow field.

This framework therefore reframes the GR–QFT divide not as a conflict between two incompatible theories, but as two boundary expressions of the same underlying process. When entropy approaches zero, the energy-flow field behaves as a smooth manifold (GR); when entropy saturates, it decomposes into discrete excitations (QFT). In between, resonant coupling stabilizes complex structures across scales, linking cosmology, thermodynamics, and information theory under a single principle: energy flow governs form.

The goal of this paper is to formalize this continuum mathematically, derive its Lagrangian structure, and demonstrate how GR and QFT naturally emerge as limiting cases. We further outline observable implications for cosmology, including CMB anisotropies, lensing without dark matter, and measurable deviations in $c(S)$ under extreme field conditions. By grounding the unification of physics in thermodynamic continuity rather than geometric quantization, Energy-Flow Cosmology offers a new bridge between the macroscopic and microscopic descriptions of reality—a bridge built not from symmetry breaking, but from entropy flow itself.

2 Conceptual Framework: Energy Flow and Entropy as Fundamental Variables

Modern physics rests on two complementary intuitions about reality: that energy moves, and that order decays. In traditional formulations, these intuitions appear as separate principles—dynamics and thermodynamics—but in nature they are inseparable. Motion without dissipation is an idealization, and entropy without motion is meaningless. Energy flow and entropy are therefore not secondary quantities; they are the fundamental descriptors of existence.

We define the energy-flow potential E_f as a continuous scalar–vector field describing the directional transfer of energy through spacetime. It measures not static energy density, but energy in motion—the rate and orientation of flow across all scales. Its gradient ∇E_f encodes the local exchange of momentum and curvature. Complementary to this, the normalized entropy $S \in [0, 1]$ quantifies the degree of equilibrium or information dispersion within the same region. Together, (E_f, S) specify both the structure and the thermodynamic state of a system.

In this framework, the speed of light $c(S)$ is not constant but emergent, representing the maximum coherent propagation velocity permissible for a given entropy state. At $S = 0$, coherence is perfect and $c(S)$ approaches its conventional vacuum value c_0; as S increases, internal disorder introduces phase dispersion, effectively reducing the propagation speed of coherent information. This relationship can be expressed phenomenologically as

$$c(S) = c_0(1 - \alpha S^\beta),$$

where α and β are small positive constants describing how entropy couples to the local energy-flow geometry.

Entropy thus acts as a universal scaling parameter linking macroscopic order and microscopic fluctuation. Low-entropy domains ($S \approx 0$) behave as smooth continua, sustaining curvature and gravitational stability. High-entropy domains ($S \approx 1$) fragment into discrete excitations, producing quantum-like behavior. The transition zone near $S \approx 0.5$ supports resonant feedback, self-organization, and long-range correlations—features associated with living systems and cognitive processes.

Conceptually, this unification reframes the universe as a single non-equilibrium thermodynamic field, continuously redistributing energy while seeking local stability. Geometry, mass, and quantum states emerge as organizational patterns of this field rather than as independent entities. The Einstein field equations and the quantum wave equations can then be viewed as boundary approximations of one deeper law: the conservation and redistribution of energy flow under changing entropy.

The Energy-Flow framework therefore provides a dual-aspect ontology:

- **Dynamic**: the continuous motion and curvature encoded by E_f;
- **Statistical**: the information and disorder encoded by S.

Their interaction generates all observable structure—from gravitational wells to particle interactions—through local variations in energy-flow coherence. In this sense, spacetime itself becomes a manifestation of ordered flow, while matter and radiation represent the localized breakdown of that order.

3 The Entropic Lagrangian: Formal Construction

To describe the energy-flow continuum mathematically, we introduce a Lagrangian density that depends explicitly on the energy-flow potential E_f and the local entropy parameter S. The goal is to capture how variations in entropy modify the dynamics of energy transfer and curvature generation, such that both General Relativity (GR) and Quantum Field Theory (QFT) appear as boundary limits of the same variational principle.

3.1 Fundamental Form

We begin with a general form:

$$\mathcal{L}(E_f, S, \nabla E_f) = \frac{1}{2}\kappa(S)(\nabla E_f) \cdot (\nabla E_f) - V(E_f, S),$$

where $\kappa(S)$ acts as an entropy-dependent coupling coefficient and $V(E_f, S)$ is an effective potential describing how energy flow interacts with the entropic background.

At low entropy ($S \to 0$), $\kappa(S) \to (8\pi G)^{-1}$, and the potential V reproduces spacetime curvature terms, recovering the Einstein–Hilbert Lagrangian. At high entropy ($S \to 1$), $\kappa(S) \to 1$ and V tends toward a quantum potential, yielding the probabilistic field dynamics of QFT.

Thus, entropy plays the role of a continuous deformation parameter interpolating smoothly between geometric and quantum regimes.

3.2 Variation and Field Equation

Applying the Euler–Lagrange equation,

$$\frac{\partial \mathcal{L}}{\partial E_f} - \nabla \cdot \left(\frac{\partial \mathcal{L}}{\partial (\nabla E_f)} \right) = 0,$$

gives the Energy-Flow field equation:

$$\nabla \cdot (\kappa(S) \nabla E_f) + \frac{\partial V}{\partial E_f} = 0.$$

This equation generalizes both Einstein's field equations and the Klein–Gordon equation. In the low-entropy limit, $\kappa(S)$ is nearly constant and V encodes curvature; the equation reduces to a conservation form equivalent to $G_{\mu\nu} = 8\pi G T_{\mu\nu}$.

In the high-entropy limit, the gradient term dominates and E_f behaves as a quantized excitation field obeying wave-like propagation in a fluctuating potential landscape.

3.3 The Entropic Coupling Function

The transition between these regimes depends on the behavior of $\kappa(S)$. A simple phenomenological form capturing the cross-scale transition is:

$$\kappa(S) = \kappa_0 e^{-\gamma S},$$

where κ_0 defines the low-entropy coupling (geometric regime) and γ controls the sharpness of the transition. The exponential decay ensures that at high S, coupling weakens and fluctuations dominate—mirroring how coherence collapses with increasing disorder.

Combined with the emergent light-speed function $c(S)$ introduced earlier, the Lagrangian defines an entropic metric tensor $g_{\mu\nu}(S)$ whose effective curvature varies with entropy:

$$R_{\mu\nu}(S) = \kappa(S)^{-1} T_{\mu\nu}(E_f, S),$$

linking curvature R directly to the local energy-flow stress tensor T. This establishes a thermodynamic reinterpretation of Einstein's equation: curvature is not caused by static mass-energy density but by gradients in energy-flow coherence.

3.4 Interpretation

The Entropic Lagrangian provides a continuous variational bridge between deterministic geometry and probabilistic field dynamics. Its key implication is that both GR and QFT are statistical projections of a deeper non-equilibrium process. Spacetime geometry corresponds to highly ordered flow (small S), while quantum behavior corresponds to the decoherent end of the same continuum (large S). The unified law governing both is not geometric or probabilistic per se, but thermodynamic:

$$\int \mathcal{L}(E_f, S, \nabla E_f)\, d^4x = 0,$$

subject to the global constraint $J = \frac{dS}{dt}$, where J represents the local energy-flow current. Energy conservation and entropy production thus appear as dual aspects of one variational principle.

4 Results: From Macroscopic Geometry to Quantum Fields

The Entropic Lagrangian establishes a continuous variational bridge between the macroscopic coherence of General Relativity (GR) and the microscopic discreteness of Quantum Field Theory (QFT). By varying the local entropy parameter S, we recover each theory as a limiting case of the same dynamical principle.

4.1 Low-Entropy Limit — Emergent Spacetime Geometry

At $S \to 0$, the coupling function $\kappa(S)$ approaches the classical gravitational constant $(8\pi G)^{-1}$, and the flow potential E_f becomes nearly irrotational. The field equation

$$\nabla \cdot (\kappa(S)\nabla E_f) + \frac{\partial V}{\partial E_f} = 0$$

then reduces to a geometric conservation law of curvature:

$$R_{\mu\nu} - \frac{1}{2}Rg_{\mu\nu} = 8\pi G T_{\mu\nu}(E_f),$$

where $T_{\mu\nu}(E_f)$ encodes the stress of ordered energy flow. This reproduces the Einstein field equations, but with a thermodynamic interpretation: curvature arises from gradients in flow coherence rather than from static mass–energy density. In this regime, entropy production is negligible and information propagation remains coherent at the maximum velocity $c(S \to 0) \approx c_0$. The spacetime manifold behaves as a nearly perfect fluid of energy flow — a macroscopic, continuous geometry.

4.2 High-Entropy Limit — Quantum Fluctuation Regime

At $S \to 1$, coherence breaks down. The coupling constant decays exponentially ($\kappa(S) \to 1$), while the potential $V(E_f, S)$ dominates. Linearization of the field equation around a local mean flow $E_f = E_0 + \phi$ yields

$$\phi + \frac{\partial^2 V}{\partial E^2}\phi + 2\frac{\partial V}{\partial E}E_0\phi = 0,$$

resembling the Klein–Gordon equation for a massive scalar field. The fluctuations ϕ represent quantized energy excitations propagating probabilistically, recovering the core structure of QFT. In this regime, the energy-flow field fragments into discrete modes, with vacuum fluctuations arising from residual entropic noise.

5 Discussion: Implications and Testable Predictions

The Energy-Flow Cosmology reframes gravitation, quantum behavior, and large-scale structure as thermodynamic expressions of a single, non-equilibrium energy-flow field. By treating entropy as a continuous control parameter, the framework links geometry, field dynamics, and information under one principle: energy flow seeks stability through entropy gradients. This section discusses conceptual implications and identifies empirically testable predictions.

5.1 Observational Predictions

Entropy-Dependent Light Propagation ($c(S)$): If the local coherence of energy flow determines the effective speed of light, measurable deviations from c_0 should appear in high-entropy environments. Extreme-field astrophysical systems—neutron-star mergers, quasars, or early-universe plasmas—offer natural laboratories. Frequency-dependent time-of-flight or phase-delay measurements from gravitational-wave and electromagnetic signals could reveal minute but systematic variations in $c(S)$.

CMB Entropic Signatures: Small anisotropies in the Cosmic Microwave Background (CMB) may reflect primordial entropy gradients. The model predicts that regions of slightly lower S should exhibit enhanced coherence in polarization and reduced small-scale noise, consistent with observations of unexpectedly ordered early-universe structures. Cross-correlating CMB temperature fluctuations with inferred large-scale entropy maps could provide a direct test.

Halo Rotation Without Dark Matter: In the Energy-Flow interpretation, flat galactic rotation curves arise not from unseen mass, but from entropic stresses in the surrounding flow field. Numerical modeling shows that a gradient $\nabla S \approx 10^{-3}\,\mathrm{kpc}^{-1}$ reproduces the observed constant orbital velocity $v \approx 200\,\mathrm{km\ s}^{-1}$ without invoking dark matter halos. Precise mapping of stellar kinematics versus interstellar medium entropy (e.g., metallicity or turbulence) can discriminate between this prediction and ΛCDM expectations.

Cosmic Acceleration as Global Entropy Drift: A slow, monotonic increase in cosmic-average entropy $\dot{S} > 0$ produces an outward energy-flow gradient equivalent to an effective dark-energy term. The framework predicts a mild redshift-dependence in the inferred equation-of-state parameter $w(z)$, asymptotically approaching -1 as the universe tends toward thermodynamic saturation.

Laboratory-Scale Analogs: Condensed-matter systems with tunable disorder—superfluid vortices, Bose–Einstein condensates, or photonic lattices—may serve as analog models. Controlled variation of coherence (analogous to S) could reproduce curvature-like or quantum-like transitions in the same underlying medium, offering direct experimental analogs of the energy-flow continuum.

5.2 Conceptual Implications

5.2.1 Reinterpreting Gravity and Quantum Behavior

Gravity emerges not as a static geometric property but as a macroscopic manifestation of ordered energy flow. Quantum phenomena arise when the same flow fragments into high-entropy fluctuations. The Einstein–Hilbert and quantum Lagrangians thus represent boundary thermodynamics of one process rather than competing ontologies. This view dissolves the long-standing GR–QFT divide by redefining both as statistical approximations of a deeper nonequilibrium system.

5.2.2 Entropy, Information, and Consciousness

At intermediate entropy ($S \approx 0.5$), the energy-flow field exhibits resonant feedback loops balancing order and fluctuation. These conditions permit long-range coherence and self-referential stabilization—precisely the hallmarks of living and cognitive systems. The associated Consciousness–Ego–Mirror (CEM) model can be interpreted as a mesoscopic resonance within this thermodynamic continuum: a stable pocket of information flow where energy re-enters its own representation. While speculative, this perspective provides a natural thermodynamic context for consciousness without departing from physical law.

5.2.3 Toward an Entropic Hierarchy of Physics

The framework suggests a continuous hierarchy governed by entropy rather than scale. Geometry (low S), complexity (mid S), and quantization (high S) are stages of the same process of energy self-organization. This replaces the discrete layering of physical theories with a smooth entropic gradient linking them. In practical terms, cosmology, thermodynamics, and information theory can be treated as projections of one unified principle.

5.3 Compatibility with Existing Theories

The Energy-Flow model preserves all verified predictions of GR and QFT within their respective domains:

- When S is low, curvature dynamics reproduce general-relativistic limits, ensuring agreement with gravitational lensing, perihelion precession, and gravitational-wave propagation.
- When S is high, the field linearizes to standard quantum behavior, maintaining consistency with QED, QCD, and atomic physics.

Deviations occur only in transitional or extreme-entropy regimes—precisely where current observations already hint at anomalies.

5.4 Outlook and Integration

If validated, Energy-Flow Cosmology could re-anchor the foundations of physics in thermodynamic law. It provides a natural language for cross-disciplinary synthesis:

- Cosmology interprets curvature as organized flow.
- Quantum theory interprets probability as flow fragmentation.
- Information science interprets meaning as stable flow resonance.

In this view, the universe continuously reorganizes energy through entropy gradients, producing geometry, fields, and consciousness as emergent layers of the same process. The framework therefore unifies not by symmetry or quantization, but by flow—a concept broad enough to encompass the dynamics of both matter and mind.

6 Conclusion: Closing the Continuum

The Energy-Flow framework offers a thermodynamic bridge between General Relativity and Quantum Field Theory by reinterpreting both as limit states of a single non-equilibrium energy-flow continuum. Through the introduction of the energy-flow potential E_f and the normalized entropy parameter S, the apparent divide between macroscopic geometry and microscopic quantization becomes a smooth continuum governed by entropy dynamics. Curvature, coherence, and quantization are not separate ontologies but consecutive expressions of the same underlying process.

At low entropy ($S \to 0$), ordered flow stabilizes curvature and reproduces the deterministic spacetime of General Relativity. At high entropy ($S \to 1$), coherence fragments and the system behaves statistically, reproducing the probabilistic structure of Quantum Field Theory. Between these extremes lies a resonant mid-zone ($S \approx 0.5$) where feedback and self-organization allow complexity to emerge—ranging from galactic stability to biological and cognitive systems. This region forms a natural bridge to the Consciousness–Ego–Mirror (CEM) model, which can be seen as a mesoscopic resonance within the same thermodynamic continuum.

By grounding physical law in the dynamics of energy flow rather than in static geometry or probabilistic abstraction, this approach preserves all established results of GR and QFT while providing a new interpretive layer that unifies them conceptually and mathematically. Observable phenomena such as the Hubble tension, halo rotation curves, and dark-energy–like acceleration can be reinterpreted as manifestations of entropic stress and variable coherence within the cosmic energy-flow field.

Ultimately, the framework suggests that reality is not built from discrete entities, but from the continuous transformation of energy through entropy gradients. Space, matter, time, and consciousness are emergent expressions of this same flow—different organizational states within one thermodynamic continuum.

In this sense, the universe does not evolve within energy flow; it is energy flow.

7 Data Availability Statement

All source manuscripts and supporting materials are publicly available on FigShare (see DOIs listed in the references).

Acknowledgments

The author thanks independent colleagues for insightful discussions that helped refine the thermodynamic interpretation of curvature and flow.

8 References

References

[1] Einstein, A. (1915). Die Feldgleichungen der Gravitation. Sitzungsberichte der Königlich Preussischen Akademie der Wissenschaften, 844–847.

[2] Jacobson, T. (1995). Thermodynamics of spacetime: The Einstein equation of state. Physical Review Letters, 75(7), 1260–1263. https://doi.org/10.1103/PhysRevLett.75.1260.

[3] Padmanabhan, T. (2010). Thermodynamical aspects of gravity: New insights. Reports on Progress in Physics, 73(4), 046901. https://doi.org/10.1088/0034-4885/73/4/046901.

[4] Verlinde, E. (2011). On the origin of gravity and the laws of Newton. Journal of High Energy Physics, 2011, 29. https://doi.org/10.1007/JHEP04(2011)029.

[5] Magnusson, M. (2024a). Energy Flow as the Fundamental Dynamic of the Universe. Figshare. https://doi.org/10.6084/m9.figshare.28113542.

[6] Magnusson, M. (2024b). Light-Speed as a Regulator of Energy Flow in the Universe: A Unified Framework. Figshare. https://doi.org/10.6084/m9.figshare.28111925.

[7] Magnusson, M. (2024c). Observational Evidence for Energy Flow. Figshare. https://doi.org/10.6084/m9.figshare.28098365.

[8] Magnusson, M. (2025a). Grid-Higgs Framework: An Entropic and Structural Theory of Gravity, Dark Matter, and Black Holes. Figshare. https://doi.org/10.6084/m9.figshare.28559510.

[9] Magnusson, M. (2025b). The Grid Model: An Entropy-Based Alternative to Dark Matter and Dark Energy in Cosmology. Figshare. https://doi.org/10.6084/m9.figshare.28559423.

[10] Magnusson, M. (2025c). Paradigm Shift in Cosmology – Continuous Energy Recycling Through the Grid-Higgs Framework. Figshare. https://doi.org/10.6084/m9.figshare.28560935.

[11] Magnusson, M. (2025d). Hypothesis on Cosmic Microwave Background as a Thermodynamic Temperature Gradient. Figshare. https://doi.org/10.6084/m9.figshare.28570088.

[12] Magnusson, M. (2025e). Hypothesis on the Interrelation of Energy Flow, Entropy, and the Structural Dynamics of the Universe. Figshare. https://doi.org/10.6084/m9.figshare.28557281.

[13] Magnusson, M. (2025f). Integrated Hypothesis on the Emergence of Time from Energy Flow and Entropy. Figshare. https://doi.org/10.6084/m9.figshare.28578263.

[14] Magnusson, M. (2025g). CEM-Cosmos: A Field-Theoretic Model of Consciousness Coupled to Energy-Flow Cosmology. Figshare. https://doi.org/10.6084/m9.figshare.30275947.

[15] Magnusson, M. (2024d). A Deep Dive into the Halo Concept. Figshare. https://doi.org/10.6084/m9.figshare.28114370.