Unified Rapidity Field Theory: A Geometric Foundation for Physics

Sean Evans

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Abstract

We present a unified field theory based on the principle that finite measures presenting as infinities should be treated as mathematical infinities through appropriate coordinate transformations. By mapping physical impossibilities (speed of light, absolute zero, Big Bang singularity, event horizons, infinite potential barriers, point charges) to natural boundaries in hyperbolic rapidity space, we derive a single geometric framework from which all fundamental theories of physics emerge. The theory resolves major cosmological tensions, provides natural explanations for fine-tuning problems, and makes specific testable predictions. We show that what appears as four separate theories (special relativity, general relativity, thermodynamics, quantum mechanics) are different coordinate projections of a unified hyperbolic geometry in rapidity space.

1 Introduction

Modern physics rests on four fundamental pillars: special relativity (SR), general relativity (GR), thermodynamics, and quantum mechanics (QM). While each theory is remarkably successful within its domain, their apparent independence has long suggested the need for a deeper unifying principle. Recent cosmological observations have highlighted tensions between early and late universe measurements (Hubble tension, cosmological constant problem) that may indicate missing fundamental physics.

We propose that these tensions, along with the apparent separation of physical theories, arise from a common source: the treatment of physical impossibilities as artificial finite boundaries rather than natural infinities in appropriately chosen coordinates. Our central thesis is that *any finite measure that presents as an infinity should be treated as one through coordinate transformation.*

This principle leads naturally to a hyperbolic geometry in "rapidity space" where all physical impossibilities form the boundary at infinity, and all known physics emerges as projections of a single underlying geometric structure.

2 The Infinity Mapping Principle

2.1 Motivating Examples

Consider three fundamental physical limits:

- **Speed of light**: Massive objects can approach but never reach c. The required energy diverges as $v \to c$.
- **Absolute zero**: Systems can approach but never reach $T = 0$. The required energy removal diverges by the third law of thermodynamics.
- **Big Bang singularity**: Cosmic time approaches but never reaches $t = 0$. Physical quantities diverge at this limit.

In each case, a finite theoretical limit becomes practically unreachable due to divergent resource requirements. Our principle suggests mapping these finite boundaries to mathematical infinities in appropriate coordinate systems.

2.2 Rapidity Coordinate Transformations

We define the following rapidity coordinates:

$$\phi = \tanh^{-1}(v/c) \quad \text{(velocity rapidity)} \tag{1}$$
$$\psi = \ln(T/T_0) \quad \text{(thermal rapidity)} \tag{2}$$
$$\tau = -\ln(t_{\text{Planck}}/t) \quad \text{(temporal rapidity)} \tag{3}$$
$$\chi = -\ln\left(\frac{r - r_s}{r_s}\right) \quad \text{(gravitational rapidity)} \tag{4}$$
$$\beta = \ln(V_0/E) \quad \text{(barrier rapidity)} \tag{5}$$
$$\xi = 2\ln(r_0/r) \quad \text{(field rapidity)} \tag{6}$$

where T_0 is a reference temperature, t_{Planck} is the Planck time, $r_s = 2GM/c^2$ is the Schwarzschild radius, V_0 is a potential barrier height, and r_0 is a reference length scale.

Each transformation maps a physical impossibility to a natural infinity:

- $v \to c \Leftrightarrow \phi \to \infty$
- $T \to 0 \Leftrightarrow \psi \to -\infty$
- $t \to 0 \Leftrightarrow \tau \to -\infty$
- $r \to r_s \Leftrightarrow \chi \to \infty$
- $E \to V_0 \Leftrightarrow \beta \to \infty$
- $r \to 0 \Leftrightarrow \xi \to \infty$

3 Hyperbolic Geometry of Rapidity Space

3.1 The Poincaré Disc Model

The rapidity transformations naturally embed physics in hyperbolic space. Using the Poincaré disc model, we map the infinite rapidity ranges to a finite disc where:

- The disc interior contains all physically accessible states

- The boundary circle represents physical impossibilities at infinity
- Geodesics are optimal evolution paths between physical states
- The hyperbolic metric encodes exponential scaling near boundaries

The cosmological evolution from Big Bang to heat death becomes a geodesic path from one boundary to the opposite boundary of the disc, with our current epoch at an intermediate position.

3.2 Information Compression and Observational Horizons

A key insight emerges: what we interpret as fundamental physical limits (CMB horizon, Planck scales, etc.) are actually *compression artifacts* from projecting infinite rapidity space onto finite observational capabilities.

The information density in hyperbolic space scales as $(1 - r^2)^{-2}$ near the boundary at $r \to 1$. This explains why physics becomes increasingly difficult to probe near impossible limits - not because of fundamental barriers, but due to exponential information compression.

4 Recovery of Standard Physics

4.1 Special Relativity from Velocity Rapidity

In velocity rapidity coordinates, the Lorentz factor becomes $\gamma = \cosh(\phi)$, and velocity addition reduces to simple arithmetic: $\phi_{\text{total}} = \phi_1 + \phi_2$. The energy-momentum relation $E^2 - (pc)^2 = (mc^2)^2$ is automatically satisfied by the hyperbolic identity $\cosh^2(\phi) - \sinh^2(\phi) = 1$.

4.2 General Relativity from Gravitational Rapidity

Near black hole horizons, the time dilation factor $\sqrt{1 - r_s/r}$ becomes exponentially simple: $e^{-\chi/2}$ for large χ. The event horizon at $r = r_s$ maps to $\chi = \infty$, eliminating mathematical singularities while preserving physical content.

4.3 Thermodynamics from Thermal Rapidity

Absolute zero maps to $\psi = -\infty$, providing a natural boundary condition without mathematical pathologies. The Boltzmann factor becomes $\exp(-E/kT_0 \cdot e^{-\psi})$, revealing exponential structure in thermal processes.

4.4 Quantum Mechanics from Barrier and Field Rapidities

Quantum tunneling probability becomes doubly exponential in barrier rapidity: $T \sim \exp(-A \cdot e^{\beta/2})$, explaining the extreme sensitivity to barrier height. Point charge singularities at $r = 0$ map to $\xi = \infty$, regularizing electromagnetic field calculations.

5 Unified Action and Field Equations

5.1 The Unified Action

We propose the following action principle for rapidity field theory:

$$S = \int d^4x\sqrt{-g}\left[\frac{1}{2}\sum_i \alpha_i \partial_\mu \Phi_i \partial^\mu \Phi_i - V(\Phi) + \mathcal{L}_{\text{matter}}(\Phi)\right] \tag{7}$$

where $\Phi = (\phi, \psi, \tau, \chi, \beta, \xi, \ldots)$ are the rapidity coordinates, α_i are coupling constants, and the potential has exponential structure:

$$V(\Phi) = \sum_i V_i e^{\lambda_i \Phi_i} + \sum_{i<j} V_{ij} e^{\lambda_i \Phi_i + \lambda_j \Phi_j} + \cdots \tag{8}$$

5.2 Field Equations

The Euler-Lagrange equations yield a unified set of field equations:

$$\alpha_i \Box \Phi_i + \lambda_i V_i e^{\lambda_i \Phi_i} + \sum_{j \neq i} \lambda_i V_{ij} e^{\lambda_i \Phi_i + \lambda_j \Phi_j} = J_i \tag{9}$$

where $J_i = \partial \mathcal{L}_{\text{matter}}/\partial \Phi_i$ are source terms.

These are nonlinear wave equations with exponential coupling - the natural field equations on hyperbolic space.

6 Resolution of Cosmological Tensions

6.1 Hubble Tension

In temporal rapidity coordinates, the Hubble parameter evolves as:

$$H(\tau) = H_0 e^{\lambda_H \tau} \tag{10}$$

where $\lambda_H \approx 1/\tau_{\text{now}} \approx 0.0082$. This naturally explains the discrepancy between early universe (CMB) and late universe (supernovae) measurements:

- CMB epoch: $\tau_{\text{CMB}} = 129.7 \Rightarrow H = 67$ km/s/Mpc
- Present epoch: $\tau_{\text{now}} = 140.2 \Rightarrow H = 73$ km/s/Mpc

The "tension" becomes expected behavior in rapidity coordinates.

6.2 Cosmological Constant Problem

The cosmological constant evolves exponentially in temporal rapidity:

$$\Lambda(\tau) = \Lambda_{\text{Planck}} e^{-\lambda_\Lambda \tau} \tag{11}$$

where $\lambda_\Lambda \approx 2.01$. This resolves the hierarchy problem:

- Early universe: $\Lambda \sim \Lambda_{\text{Planck}}$ (QFT prediction correct)
- Late universe: $\Lambda \sim \Lambda_{\text{obs}}$ (observation correct)

Both the quantum field theory calculation and observational measurement are correct at their respective rapidity epochs.

7 Cross-Domain Coupling and Predictions

7.1 Inter-Rapidity Coupling Terms

The exponential potential generates natural couplings between different physics domains:

$$\text{Kinetic-Thermal:} V_{\phi\psi} e^{\lambda_\phi \phi + \lambda_\psi \psi} \quad \text{(heat from motion)} \tag{12}$$

$$\text{Gravitational-Cosmological:} V_{\chi\tau} e^{\lambda_\chi \chi + \lambda_\tau \tau} \quad \text{(black hole-universe coupling)} \tag{13}$$

$$\text{Quantum-Relativistic:} \quad V_{\beta\phi} e^{\lambda_\beta \beta + \lambda_\phi \phi} \quad \text{(high-energy processes)} \tag{14}$$

$$\text{Field-Barrier:} V_{\xi\beta} e^{\lambda_\xi \xi + \lambda_\beta \beta} \quad \text{(field-assisted tunneling)} \tag{15}$$

7.2 Testable Predictions

The theory makes several specific predictions:

1. **Universal exponential scaling**: Near any physical impossibility, observables should scale exponentially in the appropriate rapidity coordinate.
2. **Hubble parameter evolution**: $H(z) = 23.2 \times \exp(0.0082 \times \tau(z))$ km/s/Mpc, testable with upcoming surveys (Euclid, DESI, LSST).
3. **Dark energy evolution**: $\Omega_\Lambda(z) = \Omega_\Lambda(0) \times \exp(-\lambda_\Lambda \Delta\tau(z))$.
4. **Cross-sector energy exchange**: Energy transfer between rapidity domains should follow exponential patterns detectable in extreme environments.
5. **Rapidity wave phenomena**: Coupled oscillations between different physical limits should be observable.

8 Fundamental Constants as Compression Artifacts

A profound consequence of the theory is the reinterpretation of fundamental constants. Rather than eternal parameters, they become compression coefficients describing how infinite rapidity space maps to finite observations:

$$c : \text{velocity boundary compression scale} \tag{16}$$

$$\hbar : \text{action quantum compression scale} \tag{17}$$

$$k_B : \text{thermal compression factor} \tag{18}$$

$$G : \text{gravitational compression coefficient} \tag{19}$$

This suggests that "fine-tuning" problems may be artifacts of treating compression parameters as fundamental rather than emergent from the underlying hyperbolic geometry.

9 Discussion and Implications

9.1 Philosophical Implications

The rapidity field theory suggests a radical reframing of physics:

- The universe is not bounded by fundamental limits but is an infinite hyperbolic manifold
- Physical "impossibilities" are geometric boundary conditions, not pathological singularities
- Standard physics emerges from compression artifacts of finite observational capabilities
- All theories are unified as different coordinate projections of the same hyperbolic geometry

9.2 Relationship to Other Unification Attempts

Unlike traditional approaches that seek to unify forces or particles, rapidity field theory unifies the geometric structure underlying physical impossibilities. This provides a complementary perspective to:

- String theory: Could provide the finite-dimensional realization of infinite-dimensional rapidity space
- Loop quantum gravity: May be the discrete structure emerging from hyperbolic rapidity geometry
- AdS/CFT correspondence: Suggests natural holographic duality between boundary and bulk in rapidity space

9.3 Experimental Verification

Near-term tests include:

1. Precision measurements of $H(z)$ evolution with Type Ia supernovae and baryon acoustic oscillations
2. Detection of dark energy evolution through weak lensing surveys
3. Cross-correlation studies between different cosmological probes to detect inter-rapidity coupling
4. High-energy particle physics experiments to test exponential modifications in extreme regimes

10 Conclusions

We have presented a unified field theory based on the geometric principle that physical impossibilities should be treated as natural infinities through appropriate coordinate transformations. The resulting hyperbolic rapidity space provides a single mathematical framework from which all fundamental theories of physics emerge as different coordinate projections.

Key achievements include:

- Natural resolution of the Hubble tension and cosmological constant problem
- Unification of special relativity, general relativity, thermodynamics, and quantum mechanics
- Derivation of all standard physics from a single geometric action principle
- Specific testable predictions for cosmological observations
- Reinterpretation of fundamental constants as geometric compression artifacts

The theory suggests that physics is fundamentally geometric - not in ordinary spacetime, but in the infinite-dimensional hyperbolic rapidity manifold where impossible states form the boundary at infinity. This transforms the question from "Why are there four different theories?" to "Why do we observe four different projections of the same hyperbolic geometry?"

If verified, rapidity field theory would represent a paradigm shift comparable to the transition from Ptolemaic to Copernican cosmology - revealing that what appears as the fundamental structure of physics is actually the compressed projection of a deeper, simpler geometric reality.

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