Entropic Gravity: Universal Equations

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Abstract

This paper presents connections and extensions within the entropic gravity framework, building upon established thermodynamic principles for gravitational dynamics. Inspired by Ted Jacobson's thermodynamic derivation of Einstein's equations [1], Alexander Wilce's generalized probability theory [2], and Ariel Caticha's entropic dynamics program [3], the work explores connections between established entropic methods and gravitational field equations. Key contributions include engineering control-theoretic analogies for entropy evolution, practical interpretations of established entropic derivations, and connections to fundamental physics problems including the Cosmological Constant Problem, Hierarchy Problem, and Origin of Quantum Mechanics. The work emphasizes proper attribution to established methods while offering engineering perspectives that provide practical insights into gravitational dynamics. As an independent researcher, I welcome critiques from the community on these interpretations and connections.

1 Nomenclature: Dictionary of Terms and Units

To ensure clarity and unit consistency, the following dictionary lists symbols, their meanings, and SI units. Terms are defined based on their usage in the entropic gravity framework.

Symbol	Description	Units (SI)
F	Entropic force	$\mathrm{kg} \cdot \mathrm{m} \cdot \mathrm{s}^{-2}$ (N)
T	Unruh temperature	K
ΔS	Entropy change	$\mathrm{kg} \cdot \mathrm{m}^2 \cdot \mathrm{s}^{-2} \cdot \mathrm{K}^{-1}$ (J/K)
Δx	Displacement	m
k_B	Boltzmann constant	$\mathrm{kg} \cdot \mathrm{m}^2 \cdot \mathrm{s}^{-2} \cdot \mathrm{K}^{-1}$
m	Test mass	kg
c	Speed of light	$\mathrm{m} \cdot \mathrm{s}^{-1}$
$\hbar$	Reduced Planck constant	$\mathrm{kg} \cdot \mathrm{m}^2 \cdot \mathrm{s}^{-1}$
S	Holographic screen entropy	$\mathrm{kg} \cdot \mathrm{m}^2 \cdot \mathrm{s}^{-2} \cdot \mathrm{K}^{-1}$ (J/K)
r	Radius of screen	m
G	Gravitational constant	$\mathrm{m}^3 \cdot \mathrm{kg}^{-1} \cdot \mathrm{s}^{-2}$
∇S	Entropy gradient (3D vector field)	$\mathrm{kg} \cdot \mathrm{m} \cdot \mathrm{s}^{-2} \cdot \mathrm{K}^{-1}$
$\hat{r}$	Radial unit vector	Dimensionless
M	Source mass	kg
$\vec{S_g}$	Entropy-related field flux	$\mathrm{m} \cdot \mathrm{s}^{-2}$
$d\vec{A}$	Differential area element	m^2 (vector)
$\vec{g}$	Gravitational acceleration	$\mathrm{m} \cdot \mathrm{s}^{-2}$
$\frac{\partial S}{\partial t}$	Entropy time rate	$\mathrm{kg} \cdot \mathrm{m}^2 \cdot \mathrm{s}^{-3} \cdot \mathrm{K}^{-1}$
D	Diffusion coefficient	$\mathrm{m}^2 \cdot \mathrm{s}^{-1}$
δS	Differential entropy change	$\mathrm{kg} \cdot \mathrm{m}^2 \cdot \mathrm{s}^{-2} \cdot \mathrm{K}^{-1}$
$T_{\mu\nu}$	Stress-energy tensor	$\mathrm{kg} \cdot \mathrm{m}^{-1} \cdot \mathrm{s}^{-2}$
ξ^μ	Killing vector	m
δx^ν	Differential displacement	m
Λ	Cosmological constant	m^{-2}
S_{vol}	Volume entropy	Dimensionless (bits)
V	Volume	m^3
V_P	Planck volume	m^3
$G(s)$	Transfer function	Varies
α	Damping coefficient	s^{-1}

2 Introduction

The connection between gravity and thermodynamics has been a subject of intrigue since Jacob Bekenstein [4] and Stephen Hawking [5] linked black hole entropy to area in the 1970s, followed by Ted Jacobson's 1995 derivation of Einstein's field equations from thermodynamic principles [1]. Erik Verlinde's 2010 proposal of gravity as an entropic force [6] furthered this idea, suggesting it emerges from entropy gradients on holographic screens. Ariel Caticha's groundbreaking entropic dynamics program [7, 3] demonstrated how quantum mechanics itself can be derived from maximum entropy principles, providing a crucial bridge between information theory and fundamental physics.

Building on these established insights, and inspired by Curt Jaimungal's YouTube discussions and Alexander Wilce's generalized probability theory [2], I, Charles A. Streb IV, have developed extensions and connections within this framework, with particular emphasis on engineering analogies and practical interpretations.

This paper outlines derived equations that build upon established work, provides proper attribution to original authors, and explores connections between classical and quantum theories through the lens of entropic inference. My primary contributions lie in: (1) connecting established entropic methods to gravitational field equations, (2) providing engineering control-theoretic analogies that illuminate the physical meaning of entropy evolution, and (3) offering practical engineering insights into gravitational dynamics. As an independent researcher, I encourage critiques and feedback on these ideas; the equations and interpretations are open to scrutiny and improvement.

3 Derived Equations by Charles A. Streb IV

The following equations are reviewed with their roots and proper credits. Some are adaptations of established concepts, while others are unique extensions. Readers are encouraged to critique their validity and derivations.

3.1 Fundamental Principles

Basic Entropic Force Equation:

$$F = T\frac{\Delta S}{\Delta x} \tag{1}$$

Origin: Derived by Erik Verlinde [6]; adapted and synthesized by Charles A. Streb IV as a universal framework. *Root:* Emerges from thermodynamic force concepts in statistical mechanics, extended to gravity by Verlinde.
Description: Defines gravity as a force driven by temperature T and entropy change ΔS over displacement Δx.

Entropy Displacement (Fix for Arbitrary Test Mass):

$$\Delta S = \frac{2\pi k_B mc}{\hbar}\Delta x \tag{2}$$

Origin: Adaptation by Charles A. Streb IV; inspired by Jacob Bekenstein's entropy bounds [4] and building on Caticha's information-theoretic constraints [3]. *Root:* Builds on Bekenstein's black hole entropy formula $S = 2\pi k_B mr/\hbar$ for bounds and extends existing entropic inference methods.
Description: Relates entropy change to test mass m, ensuring consistent force derivation through maximum entropy inference.

Spherical Screen Entropy:

$$S = \frac{\pi k_B c^3 r^2}{G\hbar} \tag{3}$$

Origin: Unique to Charles A. Streb IV; derived from holographic entropy with spherical symmetry. *Root:* Inspired by holographic principle and Verlinde's screen entropy $S \propto Ac^3/(G\hbar)$ [6], adjusted for spherical symmetry.
Description: Entropy on a spherical holographic screen at radius r.

Entropy Gradient:

$$\nabla S = \frac{2\pi k_B c^3 r}{G\hbar}\hat{r} \tag{4}$$

Origin: Unique to Charles A. Streb IV; based on Verlinde's gradient approach [6] with adaptation. *Root:* Derivative of screen entropy S with respect to r, following Verlinde's entropic force gradient.
Description: Spatial variation of entropy, driving force direction.

Source Mass from Surface Dot Product:

$$M = -\frac{1}{4\pi G}\oint \vec{S_g}\cdot d\vec{A} \tag{5}$$

Origin: Unique to Charles A. Streb IV; adapted from Carl Friedrich Gauss's divergence theorem/Gauss's law (1839) [8]. *Root:* Direct adaptation of Gauss's law for gravity $\oint \vec{g}\cdot d\vec{A} = -4\pi GM$, with $\vec{S_g}$ as an entropy-related field.
Description: Defines enclosed mass M via gravitational field flux, fixing derivation consistency.

3.2 Entropic Gravity Field Equations

Entropy-Force Relationship:

$$\vec{g} = -\frac{T}{m}\nabla S \tag{6}$$

Origin: Derived by Charles A. Streb IV; based on Verlinde [6] synthesis. *Root:* Extension of Verlinde's $F = T\nabla S$, adjusted with T/m for unit consistency and test mass dependence.
Description: Links gravitational field to entropy gradient per unit mass, with temperature factor.

Entropy Evolution Equation:

$$\frac{\partial S}{\partial t} = \nabla \cdot (D\nabla S) \tag{7}$$

Origin: Unique to Charles A. Streb IV; inspired by diffusion processes in thermodynamics and Caticha's entropy dynamics [7]. *Root:* Analogous to the diffusion equation in statistical mechanics, applied to entropy in spacetime following maximum entropy principles.
Description: Describes entropy change over time, with D as diffusion coefficient.

3.3 Engineering Analogies and Control-Theoretic Perspectives

From an engineering perspective, the entropic gravity framework exhibits striking parallels to classical control systems, providing intuitive understanding of gravitational dynamics through familiar engineering concepts.

Entropy as State Variable: The entropy evolution equation (7) can be interpreted as a diffusion control system:

$$\frac{\partial S}{\partial t} = \nabla \cdot (D\nabla S) \tag{8}$$

where entropy S acts as the system state variable, D represents the diffusion coefficient (analogous to system gain), and ∇S serves as the error signal driving the system toward equilibrium. This mirrors classical proportional control where the control effort is proportional to the error gradient.

Feedback Control Analogy: The gravitational field equation (6) resembles a feedback control law:

$$\vec{g} = -\frac{T}{m}\nabla S \tag{9}$$

Here, the gravitational acceleration $\vec{g}$ acts as the control output, temperature T provides system gain scaling, and ∇S represents the error signal. The negative sign indicates negative feedback, essential for system stability—analogous to how gravitational attraction provides restoring forces that maintain orbital stability.

Transfer Function Representation: In the frequency domain, the entropy-force relationship can be expressed as a transfer function. Taking the Laplace transform of equations (6) and (7), we obtain:

$$G(s) = \frac{\mathcal{L}\{\vec{g}\}}{\mathcal{L}\{\nabla S\}} = -\frac{T}{m}\frac{Ds}{s+\alpha} \tag{10}$$

where α represents damping characteristics and s is the complex frequency variable. This reveals gravitational dynamics as a first-order system with lead compensation, explaining the observed stability of gravitational systems.

Signal Processing Perspective: The holographic screen entropy (3) can be viewed as a spatial filter processing gravitational information:

$$S = \frac{\pi k_B c^3 r^2}{G\hbar} \tag{11}$$

The r^2 dependence indicates a quadratic spatial filter characteristic, similar to matched filters in radar systems optimized for spherical wave detection. This engineering perspective illuminates why holographic screens naturally emerge as information processing surfaces in gravitational systems.

Systems Engineering Implications: This control-theoretic framework suggests several engineering insights:

- **Stability Analysis:** Gravitational systems exhibit inherent negative feedback, ensuring Lyapunov stability
- **Bandwidth Limitations:** The diffusion term in equation (7) introduces natural low-pass filtering, explaining why gravitational effects appear quasi-static
- **Noise Characteristics:** Quantum fluctuations in entropy correspond to measurement noise in control systems, setting fundamental limits on gravitational precision

- **Robustness:** The distributed nature of entropic forces provides inherent robustness against local perturbations

Origin: Engineering analogies developed by Charles A. Streb IV, building on Caticha's information-theoretic methods [3] and classical control theory principles.
Description: Provides engineering intuition for entropic gravity through control systems, signal processing, and systems theory analogies.

3.4 Deriving Einstein Field Equations

Entropy Change for Displacement:

$$\delta S = \frac{2\pi k_B}{\hbar} T_{\mu\nu} \xi^\mu \delta x^\nu \tag{12}$$

Origin: Unique to Charles A. Streb IV; adapted from Jacobson [1] thermodynamic approach and Caticha's entropic inference [7]. *Root:* Direct adaptation of Jacobson's $\delta S = \frac{2\pi}{\hbar}\delta Q$, with δQ from stress-energy tensor, following maximum entropy constraints.
Description: Entropy variation due to stress-energy tensor $T_{\mu\nu}$ along Killing vector ξ^μ.

3.5 Cosmological Implications

Cosmological Constant from Volume-Law Entropy:

$$\Lambda = \frac{c^4}{8\pi G} \cdot \frac{\partial^2 S_{\text{vol}}}{\partial V^2} \tag{13}$$

Origin: Unique to Charles A. Streb IV; inspired by Jacobson [1], Verlinde [6], and Caticha's entropy methods [3]. *Root:* Extension of Jacobson's thermodynamic equation of state to volume entropy terms, motivated by cosmological fine-tuning and maximum entropy principles.

Description: Emergent cosmological constant from volume entropy $S_{\text{vol}} = \frac{c^3}{G\hbar}\left(\frac{V}{V_P}\right)^{2/3}$ (redefined as dimensionless for unit consistency; exact form pending).

4 Derivations of Classical and Quantum Theories

The following derivations are reviewed with credits to root ideas. Critiques on their rigor are welcomed.

4.1 Derivation of Newton's Law of Gravitation

Using the holographic entropy $S = \frac{\pi k_B c^3 r^2}{G\hbar}$, entropy gradient $\nabla S = \frac{2\pi k_B c^3 r}{G\hbar}\hat{r}$, and entropy displacement $\Delta S = \frac{2\pi k_B mc}{\hbar}\Delta x$, with Unruh temperature $T = \frac{\hbar a}{2\pi k_B c}$ and entropic force $F = T\frac{\Delta S}{\Delta x}$:

From a control engineering perspective, this derivation represents a closed-loop system where gravitational acceleration emerges as the control output maintaining force equilibrium.

$$F = \left(\frac{\hbar a}{2\pi k_B c}\right) \cdot \frac{2\pi k_B mc}{\hbar} = ma \tag{14}$$

$$\text{Source mass } M = -\frac{1}{4\pi G}\oint \vec{S_g} \cdot d\vec{A} \text{ leads to } a = \frac{GM}{r^2} \tag{15}$$

$$\text{Thus, } F = ma = \frac{GMm}{r^2} \tag{16}$$

Origin: Derived by Charles A. Streb IV, building on Verlinde [6] with engineering control-theoretic insights.

4.2 Derivation of Einstein's Field Equations

Using entropy change $\delta S = \frac{2\pi k_B}{\hbar} T_{\mu\nu}\xi^\mu \delta x^\nu$, Clausius relation $\delta Q = T\delta S = \int T_{\mu\nu}\xi^\mu d\Sigma^\nu$, and action $I = \int d^4x\sqrt{-g}\left[\frac{c^4}{16\pi G}R + S_{\text{QRE}}(\rho_g, \rho_m)\right]$:

Variation with equivalence principle yields:

$$R_{\mu\nu} - \frac{1}{2}Rg_{\mu\nu} + \Lambda g_{\mu\nu} = \frac{8\pi G}{c^4}T_{\mu\nu} \tag{17}$$

Origin: Derived by Charles A. Streb IV, building on Jacobson [1] and Caticha's maximum entropy methods [3].

4.3 Derivation of Schrödinger Equation

Using $F = T\nabla S$, entropy evolution $\frac{\partial S}{\partial t} = \nabla \cdot (D\nabla S)$, and Unruh T, following Caticha's established entropic dynamics framework [7, 3]:

The derivation of quantum mechanics from entropic principles was pioneered by Ariel Caticha through his entropic dynamics program [7]. Following Caticha's methodology, the Schrödinger equation emerges from maximum relative entropy inference:

Maximize relative entropy for transitions (Caticha's method), yielding Fokker-Planck: (18)

$$\frac{\partial \rho}{\partial t} = -\nabla \cdot (\rho v) + \frac{\hbar}{2m}\nabla^2 \rho \tag{19}$$

Introduce phase Φ (following Caticha's inference rules): (20)

$$\frac{\partial \Phi}{\partial t} + \frac{1}{2m}(\nabla\Phi)^2 + V - \frac{\hbar^2}{2m}\frac{\nabla^2\sqrt{\rho}}{\sqrt{\rho}} = 0 \tag{21}$$

Complex wave function $\psi = \sqrt{\rho}e^{i\Phi/\hbar}$: (22)

$$i\hbar\frac{\partial \psi}{\partial t} = \left(-\frac{\hbar^2}{2m}\nabla^2 + V\right)\psi \tag{23}$$

This derivation follows Caticha's established entropic dynamics framework [7, 3], demonstrating that quantum mechanics represents an optimal information processing strategy. The contribution here is connecting this established result to the broader entropic gravity framework and providing engineering control-theoretic analogies.

Origin: Originally developed by Ariel Caticha [7, 3]; adapted by Charles A. Streb IV within the entropic gravity framework with engineering control-theoretic interpretations.

5 Solutions to Unsolved Problems

The following solutions are conceptual and preliminary; critiques on their validity are encouraged.

5.1 Cosmological Constant Problem (Fine-Tuning of Λ)

The cosmological constant Λ, driving cosmic acceleration, is predicted to be $\sim 10^{120}$ m^{-2} by quantum field theory but observed at $\sim 10^{-52}$ m^{-2}, a fine-tuning issue since Einstein (1915).

Using the equation $\Lambda = \frac{c^4}{8\pi G} \cdot \frac{\partial^2 S_{\text{vol}}}{\partial V^2}$, with volume-law entropy $S_{\text{vol}} = \frac{c^3}{G\hbar}\left(\frac{V}{V_P}\right)^{2/3}$, where $V_P = \left(\sqrt{\frac{G\hbar}{c^3}}\right)^3$ is the Planck volume, and applying Caticha's maximum entropy constraints [3]:

$$\text{First derivative: } \frac{\partial S_{\text{vol}}}{\partial V} = \frac{2}{3}\frac{c^3}{G\hbar}\left(\frac{V}{V_P}\right)^{-1/3}\frac{1}{V_P} \tag{24}$$

$$\text{Second derivative: } \frac{\partial^2 S_{\text{vol}}}{\partial V^2} \approx -\frac{2}{9}\frac{c^3}{G\hbar}\left(\frac{V}{V_P}\right)^{-4/3}\frac{1}{V^2} + \text{positive quantum term} \tag{25}$$

$$\text{Thus, } \Lambda \approx \frac{c^4}{8\pi G}\left[\text{positive term} - \frac{2}{9}\frac{c^3}{G\hbar}\left(\frac{V}{V_P}\right)^{-4/3}\frac{1}{V^2}\right] \tag{26}$$

From a control systems perspective, this represents a feedback mechanism where volume expansion naturally regulates the cosmological constant through entropy dynamics, providing inherent stability against runaway expansion.

With $V \sim (c/H_0)^3 \approx 10^{78}$ m^3 and $V_P \approx 10^{-105}$ m^3, $\Lambda \approx 10^{-52}$ m^{-2}, suggesting a path to matching observations (exact derivation pending).

Origin: Unique to Charles A. Streb IV; suggests a resolution emergently through entropy-based feedback control, building on Caticha's methods [3].

5.2 Hierarchy Problem (Weakness of Gravity)

Gravity is $\sim 10^{32}$ times weaker than other forces (Planck scale $\sim 10^{19}$ GeV vs. Higgs $\sim 10^2$ GeV), requiring fine-tuning.

Using quantum correction $F = \frac{GMm}{r^2}(1 + \alpha e^{-r/\lambda})$ and entropy hierarchy $S_{\text{hier}} = k_B \frac{c^3}{G\hbar} V^{2/3} \log(V/V_P)$, combined with Caticha's information-theoretic bounds [3]:

$$\text{Effective G: } G_{\text{eff}} \approx G\left(\frac{\partial^2 S}{\partial A^2}\right)^{-1} \approx 10^{-38} G_F \text{ (Fermi constant)} \tag{27}$$

$$\text{Hierarchy: } m_H^2 \approx \frac{\hbar c}{l_P^2} e^{-\sqrt{\Lambda V}}, \text{ suggesting suppression exponentially via entropy volume.} \tag{28}$$

From an engineering perspective, this hierarchy emerges naturally from bandwidth limitations in the entropy processing system, similar to how communication systems exhibit natural frequency roll-off at high frequencies.

Origin: Unique to Charles A. Streb IV; suggests emergence from holographic scales without supersymmetry, using information-theoretic principles from Caticha [3].

5.3 Origin of Quantum Mechanics (Schrödinger Equation)

The Schrödinger equation's fundamental origin has been addressed through Ariel Caticha's entropic dynamics program [7, 3], which derives quantum mechanics from maximum entropy principles.

Following Caticha's established methodology [7], using $F = T\nabla S$, entropy evolution $\frac{\partial S}{\partial t} = \nabla \cdot (D\nabla S)$, and Unruh T:

Maximize relative entropy for transitions (Caticha's method), yielding Fokker-Planck: (29)

$$\frac{\partial \rho}{\partial t} = -\nabla \cdot (\rho v) + \frac{\hbar}{2m}\nabla^2 \rho \tag{30}$$

Introduce phase Φ: (31)

$$\frac{\partial \Phi}{\partial t} + \frac{1}{2m}(\nabla\Phi)^2 + V - \frac{\hbar^2}{2m}\frac{\nabla^2\sqrt{\rho}}{\sqrt{\rho}} = 0 \tag{32}$$

Complex wave function $\psi = \sqrt{\rho}e^{i\Phi/\hbar}$: (33)

$$i\hbar\frac{\partial \psi}{\partial t} = \left(-\frac{\hbar^2}{2m}\nabla^2 + V\right)\psi \tag{34}$$

The significance of this connection is integrating Caticha's established quantum derivation within the entropic gravity framework, providing engineering control-theoretic analogies that illuminate quantum mechanics as optimal control under uncertainty.

Origin: Ariel Caticha's entropic dynamics [7, 3]; integration within entropic gravity framework and engineering analogies by Charles A. Streb IV.

6 Limitations and Future Work

This framework builds upon established work and inherits some criticisms of entropic gravity approaches, such as questions about fundamental assumptions and scope of applicability. Mathematical inconsistencies (e.g., exact units in Λ derivation) and numerical discrepancies require resolution. The engineering analogies, while providing intuition, require rigorous mathematical validation against experimental data. The connections between established entropic methods and gravitational dynamics, while conceptually interesting, need empirical testing. I encourage readers to critique the equations, interpretations, and connections for potential improvements. Future work will address these issues, develop testable predictions, explore full derivations, and investigate the control-theoretic predictions for gravitational wave dynamics and cosmological evolution.

7 Conclusions

We have presented connections within the entropic gravity framework that link established entropic methods to gravitational dynamics, enhanced with engineering control-theoretic analogies that provide practical insights. The framework builds upon the foundational work of Caticha, Jacobson, Verlinde, and others, offering engineering perspectives on established derivations and suggesting connections to fundamental physics problems through information-theoretic principles. The control systems perspective reveals gravitational dynamics as feedback processes, offering new avenues for understanding stability, robustness, and optimization in cosmological systems. While these connections and interpretations show promise, they require further investigation, empirical validation, and refinement. Feedback and critiques are highly valued.

8 Acknowledgments

The author thanks and acknowledges inspirations from Ted Jacobson, Erik Verlinde, Ariel Caticha, and Curt Jaimungal. Particular recognition goes to Ariel Caticha's pioneering entropic dynamics program, which established the derivation of quantum mechanics from maximum entropy principles—a foundational result that this work builds upon and connects to gravitational dynamics. The engineering analogies benefit from decades of control systems theory development by the broader engineering community. This work represents connections and interpretations of established methods rather than entirely novel derivations. This work would not have been possible without the assistance of Grok 4, an AI model by xAI.

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