Exploring the Entropic Force-Field Hypothesis (EFFH): New Insights and Investigations

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Prologue

How do we, and for that matter, why should we even understand the universe at all? The fact that we can, and do, understand the universe in any way at all, and can deploy it for our use, in and of itself, is a miracle.

Abstract

The Entropic Force-Field Hypothesis (EFFH) presents a groundbreaking view on entropy, elevating it from a passive thermodynamic quantity to a key driver of physical processes. By introducing logarithmic corrections and the Entropic Time Limit (ETL), the hypothesis aims to bridge the gaps between thermodynamics, quantum mechanics, and gravity, potentially leading to a new quantum gravity framework. This paper critically examines the implications of the EFFH, proposes new theoretical extensions, and explores how it could address major unresolved issues in physics, including the black hole information paradox, the nature of Planck-scale remnants, and the evolution of entropy in extreme gravitational fields. Various investigations in the literature have sought to employ entropy to prove or re-derive the equations for the Electrostatic Force, the Biot-Savart Law (Magnetic Force), Gauss's Law, Ampere's Law, the Maxwell's Equations, Generalization to the Nuclear Forces, and especially Newton's law of universal gravitation and Einstein's Field Equations, thereby demonstrating that they are emergent from entropy. In the hypothesis here explored, which asserts that entropy is a universal field, we do not strictly seek to prove or re-derive any of the above equations; but rather, we aim to generalize that they are all emergent properties and interactions arising from a universal entropic field, and so modify them accordingly, particularly the Einstein Field Equations of General Relativity, in order to extend their domain of applicability, or perhaps replace them altogether if that is the only path we must travel.

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[‡]This current work is an outcome of the author's ongoing independent research endeavor in the rather abstruse and disconcerting frontiers of Modern Theoretical Physics.

[α]The author's earlier preparatory work [7] highlights some aspects worthy of note, which may not have been explicitly elucidated or grounded in this paper. We recognize that even the current submission is still a work in progress, so that we hope to build heavily on some of the concepts and contents in subsequent endeavors.

Keywords

Black Hole Bomb [BHB], Black Hole Cool-Down [BHCD], Black Hole Cool-Off [BHCO], Black Hole Information Paradox [BHIP], Black Hole Remnants [BHR], Cosmic Python [CP], Einstein-Podolski-Rosen [EPR] Paradox, Entropic Constraints [EC], Entropic Force [EF], Entropic Force-field [EFF], Entropic Force-Field Hypothesis (EFFH), Entropic Redistribution [ER] of Energy/Information [E/I] - [EREI], Entropic Time Limit (ETL), Entropy, Entropy in Extreme Gravitational Fields [EEGF], Gravity, High Pressure Radiative Emissions [HPRE], Inbound USM [IUSM], Logarithmic Corrections to Bekenstein-Hawking Entropy [LCBHE], O's Gap [OG], O's Presssure [OP] on the Horizon of Black Holes [OPHB], Outbound USM [OUSM], Physics Beyond the Standard Model [PBSM], Planck-scale Black Hole Remnants [PBHR], Quantum Gravity [QG], Quantum Mechanics [QM], Thermodynamics, Unidirectional Semi-permeable Membrane [USM].

1 Introduction

Entropy has long been considered a **measure of disorder in statistical mechanics**. However, recent developments have positioned entropy as a fundamental principle in gravitational physics. This literature review explores how entropy has been connected to gravity by reviewing the contributions of various researchers and formulating the mathematical principles underlying these theories.

All these investigations have been made in rather piecemeal fashions without formulating any **[generalized] principle** by which such interactions in Nature occur. The **grand achievement of this current paper, therefore, has been to boldly propose that entropy not only governs gravitational processes and quantum observations [principles] but precisely to state in unequivocal terms for the first time that entropy indeed governs and underlies all interactions in Nature without exception, thus elevating entropy to the overarching status of a universal force-field, relative to which all other forces and fields of interactions are emergent phenomena**.

This **singular postulate** has **far-reaching implications and consequences**, not only for physics, science, and technology, but also for much of other aspects of human endeavor.

So, the entropic field is akin to a universal sea [which we refer to as an active field], while all we observe or can observe are like waves welling up from this sea; each interaction or object or experience we encounter is thus a specific wave emergent from some aspects of this active entropic sea [field]. The emergent properties are thus derivatives from the entropic field. In General Relativity [GR] we often try to picture Einstein's Field Equations [EFE] by saying that it describes the gravitational field with matter/energy and an enveloping or surrounding space-time, where the matter/energy tells space-time how to curve and the space-time in turn tells matter-energy how to move. And by virtue of the entropic field hypothesis being postulated, we conclude: It is the entropic field that tells [guides] both matter/energy and space-time [on] what to do and how to behave!

2 Literature Review

In the following rather brief review, we look at some of the investigations in the literature on entropy as conceived with respect to gravitation and quantum interactions.We observe the emphasis of each author and see how entropy speaks loudly to us all to be heard and understood under one encompassing attribution.

2.1 Bekenstein-Hawking Black Hole Thermodynamics

2.1.1 Key Theoretical Insights

Bekenstein [1973][1] and Hawking [1975][5] pioneered the concept of black hole entropy, showing that a black hole's entropy is proportional to its event horizon area. [Also, see [4] for some historical developments pertaining to black holes and thermodynamics, by Daniel Grumiller, Robert McNees and Jakob Salzer.[1]

2.1.1.1 Event Horizon and Black Hole Surface

The event horizon is the boundary around a black hole beyond which nothing can escape, not even light. It's often referred to as the "surface" of the black hole, although it's not a physical surface but a theoretical boundary.

2.1.1.2 Hawking Radiation

Stephen Hawking discovered that black holes emit radiation due to quantum effects near the event horizon. This radiation, known as Hawking radiation, results from particle-antiparticle pairs forming near the event horizon. One particle falls into the black hole while the other escapes, making it seem as though the black hole is radiating energy.

2.1.1.3 Bekenstein-Hawking Entropy

Jacob Bekenstein proposed that black holes should have entropy proportional to the area of their event horizon. Stephen Hawking later confirmed this by showing that the entropy of a black hole is indeed proportional to the area of its event horizon, leading to the Bekenstein-Hawking entropy formula.

2.1.1.4 Connecting the Concepts

Event Horizon as a Surface: The event horizon acts as the "surface" of the black hole where these quantum effects occur.

Hawking Radiation: The radiation emitted from the event horizon due to quantum effects leads to the gradual loss of mass and energy from the black hole.

Bekenstein-Hawking Entropy: The entropy of the black hole is proportional to the area of the event horizon, linking thermodynamic properties to the geometry of the black hole.

In essence, the event horizon serves as the boundary where Hawking radiation occurs, and the Bekenstein-Hawking entropy quantifies the entropy associated with this boundary. These discoveries together provide a deeper understanding of black hole thermodynamics and the interplay between quantum mechanics and general relativity.

As we come to a close here, let us summarize this subsection of our work with a rather poetic

[1] We agree with the three authors where they concluded their work, saying that "our current understanding of black hole thermodynamics and quantum gravity was achieved through consistently applying Feynman's dictum [that] 'everything is particle' - most prominently epitomized by the Hawking effect," and predicting "that most of our future understanding will be achieved through consistently applying Wheeler's dictum [that] 'everything is information.'"

definition of a black hole.

A Poetic Definition of a Black Hole: A black hole is a cosmic python swallowing its tail with its whole length into itself, and equally swallowing every other thing in its neighborhood along with it.

2.1.2 Mathematical Formulation

The Bekenstein-Hawking entropy formula is given by:

$$S = \frac{k_B A}{4L_P^2} \tag{1}$$

where A is the black hole event horizon area and L_P is the Planck length. Hawking's derivation of black hole radiation temperature:

$$T_H = \frac{\hbar c^3}{8\pi G M k_B} \tag{2}$$

provides an entropic interpretation of gravitational effects.

2.2 Holographic Principle (Susskind & 't Hooft)

2.2.1 Key Theoretical Insights

The holographic principle[1993,1995,2009][12, 13] states that all information within a volume can be encoded on its boundary surface, suggesting gravity has a deep informational foundation.

2.2.2 Mathematical Formulation

The Holographic entropy bound:

$$S \leq \frac{k_B A}{4L_P^2} \tag{3}$$

supports Verlinde's[2011][14]entropic gravity by linking entropy to spacetime geometry.

2.3 Jacobson's Thermodynamic Derivation of Einstein's Equations

2.3.1 Key Theoretical Insights

Jacobson [1995][6]demonstrated that Einstein's field equations can be derived using thermodynamic principles, showing the connection between heat flow, entropy, and spacetime curvature.

2.3.2 Mathematical Formulation

Starting from the Clausius relation:

$$\delta Q = T dS \tag{4}$$

and identifying heat flux across a horizon with local Rindler horizon entropy:

$$R_{\mu\nu} - \frac{1}{2} R g_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu} \tag{5}$$

he showed that gravity is an emergent thermodynamic effect.

2.4 Loop Quantum Gravity and Entropy (Smolin, Rovelli)

2.4.1 Key Theoretical Insights

Loop quantum gravity (LQG)[1998,2001][10, 11]suggests that spacetime is quantized, with entropy emerging from spin networks.

2.4.2 Mathematical Formulation

LQG gives the Spin Network Entropy(SNE) as:

$$S = k_B \ln \Omega \tag{6}$$

where Ω is the number of microstates describing a given quantum geometry.

2.5 Penrose's Gravitational Entropy and the Weyl Curvature Hypothesis

2.5.1 Key Theoretical Insights

Penrose[2004][9]roposed that gravitational entropy increases via structure formation and black hole formation.

2.5.2 Mathematical Formulation

The Weyl curvature tensor $C_{\mu\nu\rho\sigma}$ is used as a measure of gravitational entropy.

2.6 Padmanabhan's Thermodynamic Interpretation of Gravity

2.6.1 Key Theoretical Insights

Padmanabhan[2010][8]showed that Einstein's equations are equivalent to the first law of thermodynamics applied to spacetime horizons.

2.6.2 Mathematical Formulation

Thermodynamic entropy change:

$$\delta S = \frac{\delta A}{4L_P^2} \tag{7}$$

Einstein's field equations emerge from this entropy-area relation.

2.7 Erik Verlinde's Entropic Gravity

2.7.1 Key Theoretical Insights

Verlinde [2011][14]proposed that gravity emerges as an entropic force rather than a fundamental interaction. By leveraging the holographic principle and thermodynamic considerations, he derived Newtonian gravity as a statistical consequence of information changes.

2.7.2 Mathematical Formulation

Verlinde's approach starts with the definition of entropy change associated with displacement Δx:

$$\Delta S = 2\pi k_B \frac{mc}{\hbar} \Delta x \tag{8}$$

where k_B is the Boltzmann constant, $\hbar$ is the reduced Planck's constant, and m is the mass. Applying the Unruh temperature formula:

$$T = \frac{\hbar a}{2\pi k_B c} \tag{9}$$

and the entropic force relation:

$$F\Delta x = T\Delta S \tag{10}$$

he obtained Newton's second law:

$$F = ma \tag{11}$$

Using the holographic principle and equipartition theorem:

$$N = \frac{Ac^3}{G\hbar} \tag{12}$$

and substituting into the total energy equation:

$$E = \frac{1}{2} N k_B T \tag{13}$$

Verlinde recovers[2] Newton's law of universal gravitation:

$$F = G\frac{Mm}{R^2} \tag{14}$$

2.8 Entropic origin of the fundamental forces (Emre Dil & Tugrul Yumak)

Emre Dil and Tugrul Yumak [2019][3] have explored the generalization of Verlinde's entropic gravity proposal to other fundamental forces of nature, including Coulomb's electrostatic force and the magnetic force. By assuming the holographic principle holds for charged particles, the authors derive entropic Maxwell equations in both classical and covariant forms. The paper extends the entropic origin of electromagnetic forces to strong and weak nuclear interactions, contributing to the unification scheme of fundamental forces.

[2]Here's a quick outline of how Verlinde recovers Newton's law of universal gravitation from his entropic approach:

1. The holographic principle and the equipartition theorem are utilized to find an expression for the number of degrees of freedom N.
2. The expression for N is then substituted in the equation for the total energy of a system.
3. From this, the standard gravitational force law is derived.

2.8.1 Key Theoretical Insights

1. **Entropic Gravity**: The paper builds on Verlinde's idea that gravity is an entropic force, caused by changes in entropy due to the displacement of matter.

2. **Holographic Principle**: The holographic principle is applied to charged particles, proposing that the information on a holographic screen leads to entropic forces.

3. **Electrostatic and Magnetic Forces**: By considering entropy changes on the holographic screen, Coulomb's electrostatic force and the magnetic force are derived.

4. **Generalization to Maxwell Equations**:

5. **Entropic Gravity**: The entropic origin is extended to derive both classical and covariant forms of Maxwell's equations.

6. **Strong and Weak Forces**: The paper implicitly generalizes the entropic origin to non-abelian gauge fields, suggesting an entropic origin for the strong and weak nuclear forces.

2.8.2 Mathematical Formulation

Emre Dil and Tugrul Yumak have succeeded in re-deriving key equations by considering entropy changes on a holographic screen.

Applying the Force and Entropy Relation:

$$Fdx = TdS \tag{15}$$

and the Unruh Temperature:

$$T = \frac{\hbar a}{2\pi k_B}, \tag{16}$$

they re-derive the following well established equations:

1. **The Electrostatic Force**:

   From the expression for entropy

   $$\Delta S = 2k_B, \tag{17}$$

   they obtain the electrostatic force

   $$F = T\Delta S = \frac{q_1 q_2}{4\pi\epsilon_0 l^2} = q_1 E \tag{18}$$

2. **The Biot-Savart Law (Magnetic Force)**:

   $$F = \frac{\mu_0 I_1 I_2}{4\pi r} \tag{19}$$

3. **Gauss's Law**:

   $$\oint_{\partial V} E \cdot dA = \frac{Q_{enc}}{\epsilon_0} \tag{20}$$

4. **Ampere's Law**:

   $$\oint_{\partial V} B \cdot dA = \mu_0 I \tag{21}$$

5. **Maxwell's Equations in Covariant Form**:

$$\partial_\mu F^{\mu\nu} = \mu_0 J^\nu \tag{22}$$

6. **The field equations of the nuclear forces (strong and weak forces)**:

$$D_\mu G^{\mu\nu} = \frac{1}{4\pi} \frac{\hbar c}{\mathcal{A}_{\text{sw}} l^3}, \tag{23}$$

   postulating A_ν as the 4-potential such that the strong and weak nuclear forces obey

$$G^{\mu\nu} = \partial_\mu A_\nu - \partial_\nu A_\mu + g_{sw} A_\mu \times A_\nu, \tag{24}$$

   which represents the non-abelian version of the emergent covariant Maxwell equations with the covariant derivative D_μ.

2.9 Jun Chen's Entropic Mass Identity and Gravitation

Jun Chen [2020] [2] explores the relationship between thermodynamics and gravity, extending the understanding of black hole thermodynamics to a broader context. It proposes that the origin of mass and space-time geometry is tied to trivial entropy, an extension of Bekenstein-Hawking entropy, and derives the full Einstein equation from this perspective. This redefines the concept of mass in terms of entropy and temperature, suggesting that mass density and hence gravity is a manifestation of trivial entropy.

2.9.1 Key Theoretical Insights

1. The paper bridges the gap between thermodynamics and the Einstein equation, suggesting a fundamental connection.
2. It proposes that mass formation is fundamentally linked to trivial entropy.
3. The Unruh temperature and Bekenstein-Hawking entropy are generalized to spacelike Cauchy hypersurfaces.
4. Trivial entropy, generalized from black hole entropy, is suggested as a universal property of matter, applicable beyond just black holes.
5. The full Einstein equation, including the cosmological constant, is derived from the equivalence of entropic mass and proper mass.

2.9.2 Mathematical Formulation

Chen begins with the relation between force and entropy

$$F dx = T dS \tag{25}$$

and the expression for the Unruh temperature

$$T = \frac{\hbar a}{2\pi k_B} \tag{26}$$

Chen plugs into the Newton Potential

$$\phi = \ln(-\zeta^a \zeta_a) \tag{27}$$

to arrive at the trivial entropy (generalized from Bekenstein-Hawking entropy)

$$dS_{TR} = \frac{k_B c^3}{4\hbar G} dA_c \tag{28}$$

Consequently, Chen derives the proper mass

$$Mp = \int_E T_{ab} n^a \zeta^b dV \tag{29}$$

and the entropic mass

$$Me = \int_S e^{\phi} N^a \nabla_a e^{\phi} dA \tag{30}$$

such that with the help of the Bianchi identities, Chen finally obtains the Einstein Field Equations [with the cosmological constant]

$$\frac{8\pi G}{c^4} T_{ab} = R_{ab} - \frac{1}{2} R g_{ab} + \Lambda g_{ab} \tag{31}$$

3 Black Hole Entropy

The study of entropy in gravitational systems has been an area of significant interest since the discovery of the **Bekenstein-Hawking entropy formula**, given by:

$$S_{\mathrm{BH}} = \frac{k_B A}{4\ell_p^2} \tag{32}$$

where A is the black hole horizon area, k_B is Boltzmann's constant, and ℓ_p^2 is the Planck area.

However, this classical result lacks a **dynamical component**, which is necessary to incorporate quantum gravitational effects. The **Entropic Force-Field Hypothesis (EFFH)** introduces crucial modifications, particularly:

1. **Logarithmic entropy corrections** that stabilize black hole entropy at **Planck scales**.
2. **The Entropic Time Limit (ETL)**, a time-dependent correction term that provides an evolutionary perspective on entropy.

These modifications suggest that entropy plays a **fundamental role in the structure of spacetime itself** and might be key to unifying classical and quantum descriptions of gravity.

4 Logarithmic Corrections and Blackole Thermodynamics

A key feature of EFFH is the **introduction of logarithmic corrections** to the entropy formula. The corrected entropy expression we propose is given by [refer to 11.1]:

$$S_{\mathrm{EFFH}} = \frac{k_B A}{4\ell_p^2} + \alpha \ln\left(\frac{A}{\ell_p^2}\right) + \gamma \ln\left(\frac{\tau_E}{t_p}\right) \tag{33}$$

where:

- A is the surface area of the event horizon of the black hole.[3]
- α and γ are dimensionless constants determined by quantum gravity effects.
- τ_E represents the **Entropic Time Limit (ETL)**, a new parameter describing the time-dependent nature of entropy.
- t_p is the **Planck time**, the fundamental quantum unit of time.

The **logarithmic correction term** ln is significant because it is consistent with predictions from **loop quantum gravity (LQG)** and **string theory**, both of which introduce similar corrections to the Bekenstein-Hawking entropy. These terms **stabilize entropy near Planck scales** and may prevent black holes from completely evaporating, instead leaving behind **stable Planck-scale remnants**.

4.1 Stability Near the Planck Scale

As black holes evaporate via Hawking radiation, their entropy follows a decreasing trajectory. Classical formulations predict a complete evaporation, leading to an unresolved information paradox. The **logarithmic correction in EFFH modifies this behavior**, ensuring that as entropy stabilizes, we have:

$$S_{\text{remnant}} \approx [\frac{k_B A}{4\ell_p^2}]^* + [\alpha \ln\left(\frac{A}{\ell_p^2}\right)]^* + \gamma \ln\left(\frac{\tau_E}{t_p}\right) \tag{34}$$

where the first-two expressions within the asterisked square brackets [ ]* vanish [rapidly],[4] leaving the third [last] term: This implies that **black holes will stop evaporating at the Planck scale**, forming remnants that [potentially] retain the information of the original system.[5]

5 Some Properties of the Entropic Field

Now that we have considered black holes in previous sections, we must now give a robust description of some properties of the entropic field so that we can have a better understanding of its action within the surface horizon of black holes.
The entropic field has the following properties:

1. It minimizes [in general, extremizes] constraints. It strictly minimizes and then it generally extremizes.

[3]In a subsequent exposition, we shall show how to absorb this event horizon surface area A of the black hole in the mass M of the black hole and thereby avoid any potential quantum or scaling constraint: as the space-time curvature warps the event horizon surface area from high entropic field redistribution of information and energy within the **O Gap**[OG], the mass absorbs the area and so becomes the effective means of measurement.**Area-Mass-Absorption Operation or AMA-Operation**.

[4]Ref.footnote 3: same **mass** [M]**-absorption of area** applies, but as the black hole approaches the remnant phase, the [event] horizon surface area A necessarily relatively, and specifically, vanishes.

[5]Ref.footnote [3,4]: as the **mass** [M]**-absorption of area** continues, **there comes a time limit where no more surface area is practically available to be absorbed by the mass, which is why and when the areas in the first-two expressions in equation [34] must vanish**, leaving the last [third] expression involving the **entropic time limit ETL** and the Planck time, with the **"entropic mass"**, resulting in a **remnant black hole**.

2. It redistributes information and energy[entropy], and hence matter and space-time

3. it maximizes[optimizes] or increases Entropy

Given the above, we can state as follows:

1. The Euler-Lagrange Equations [ELE] are fundamental to the calculus of variations and classical mechanics. They describe the motion of a system by finding the path that minimizes (or more generally, extremizes) the action, which is a functional of the trajectory of the system. So, in a sense, the Euler-Lagrange equations are used to find the path of trajectories that minimize the action.

   Precisely, we say that the Euler-Lagrange equations find the path that makes the action stationary (not necessarily a minimum) with respect to variations in the path. This could be a minimum, maximum, or a saddle point.

   What the Entropic Force-Field [EFF] does is to minimizes extremize constraints [at each point on the path; and by this very fact the Euler-Lagrange equations can be seen as emergent from the Entropic Force-Field. In a manner of speaking, the EFF fixes the point(s) and the ELE fixes the path from the points - Point-Set [PS]: or Set of Points [SOP]. That is to say, the EFF is what tells the ELE what to do!

   In brief: The Entropic Force-Field (EFF) constrains the points on the path in a Point-Set [PS], thereby enabling the Euler-Lagrange equations to extremize the action. This suggests that the EFF provides the necessary constraints at each point along the path, allowing the Euler-Lagrange equations to determine the optimal trajectory.

2. And since the Entropic Force-Field minimizes [extremizes] constraints, the ultimate characteristics of the Entropic Force-Field must not be a "tactile," tangible, "physical" object; that is to say, the equation must not be a "rigid" equation, but must possess a wave or energy kind of form, fundamentally.

3. Essentially then, the field equations of the Entropic Force-Field must possess deBroglie's wave-particle duality in some form (as a result of 1 and 2 above, specifically)

6 O's Entropic Pressure [OEP] within O's Entropic Gap [OEG]

The correction to Hawking Radiation [HR] and the Bekenstein-Hawking Entropy [BHE] within EFFH stems from a reinterpretation of black hole thermodynamics, where energy loss is seen not as a quantum [particle-antiparticle pair] emission process via Dirac's creation-annihilation operators, but as a redistribution of gravitational energy and consequent conversion into an entropic radiative field which is emitted as visible photon light [now known as Hawking Radiation].

As the black hole forms, its gravitational energy increases to a point that the entropic field begins to convert the gravitational energy into radiative energy; and as the gravitational field reduces in energy via entropic conversion [and transfer], it reduces the mass of the black hole itself, because what the entropic field does is to redistribute energy and information and optimize/increase entropy, while trying to strictly reduce or minimize [and generally extremize] constraints. The EFFH goes even further to tell us that these transactions and interactions [redistribution and transfer and extremization] occur just outside the black hole [event] boundary, creating a measurable [entropic] pressure [called O's Pressure - OP] between the black hole and its event horizon [this volume envelope is O's Gap - OG, which is an envelope of [extremely] high energy]. The [light] emission from the Black Hole Envelope [BHE] must occur from the OG because the various interactions within it must obey the constraints and properties of the entropic field within the ETL, thus generating High Pressure Emissions [HPE] to avoid a premature detonation of an extremely explosive Black Hole Bomb [BHB]. In this black hole energy and content redistribution, the entropic field converts the black hole mass to gravitational energy, and to further minimize the constraint, it converts the gravitational energy to radiative [emissive] energy. This process continues until the black hole reaches its remnant phase, where no further evaporation can occur, because there is no more entropic pressure present to necessitate that event. At this phase, the black hole is said to have "cooled down" or "cooled off" - Black Hole Cool-Down [BHCD] or Black Hole Cool-Off [BHCO].

The entropic force field appears to treat the event horizon of the black hole as a kind of unidirectional semi-permeable membrane [USM]: So far as the required OP is not attained within the OG of the black hole, nothing can escape from the black hole, but things can enter the black hole [by gravitation at least], thus acting as an Inbound USM [IUSM]. But once the entropic field [EF] has built up the OP to a limit within the OG, the EF transfroms the IUSM into an Outbound USM [OUSM], resulting in high pressure radiative emissions [HPRE] - or [Hawking Radiation]. During such emissions, nothing else is permitted to enter the black hole, except in such regions of the membrane that are torn, ruptured, or defaced [by OP] to create some access. The permeability of the black hole membrane is for the main part determined by the uniformity and intensity of pressure distribution within the black hole envelope.

Thus, from the above, we encounter a scenario in which the entropic field dynamically engages in **reversals of polarity**, transforming an outbound interaction field into an inbound interaction field, and vice versa. We accordingly **designate any outbound interaction as of negative (-) polarity, while an inbound polarity is of positive (+) polarity, where these polarity signatures are not to be considered absolute**.

It is imperative to emphasize that the entropic redistribution of energy for black holes yields not just the plain thermal effects but also, in general, electromagnetic interactions; which means the redistributive output goes beyond the ubiquitous Hawking radiation.

7 Derivation of the O Pressure [OP] for Black Holes

Having set the stage in section 6 above for the gap and pressure we encounter in the evolution of black holes, we come now to finding out what expression such a black hole pressure should be.

We shall embark on our mission in two parts, since the entropic redistribution of energy encompasses both gravitation and entropy, that is, mass/energy and temperature/energy: first, the pressure arising from the entropy itself; and second, the pressure arising from the gravitational field [being redistributed [into radiative energy and emission]]. Here we shall deliberately avoid inclusion of any pressure due to electromagnetic forces, etc., for the sake of simplicity, coupled with the bold assumption that such pressures may be negligible relative to pressures from gravitational forces. Furthermore, we shall intentionally not investigate aspects involving functions of time [which approach we choose to adopt in more places than one], as our main purpose here shall be to first test the waters before diving into the deep.

Thus, the total O Pressure [OP] from within the O Gap [OG], recorded as P_{OG}, given the above considerations, can be written as:

$$OP = P_{OG} = P_{OG_{ER}} + P_{OG_{GR}} + ... + \mathcal{O}(\epsilon) \tag{35}$$

In the subsequent sections, we shall be investigating expressions for the first-two parts of equation (35) above.

7.1 O's Pressure [OP] Arising from the Redistribution of Entropy

Definitions Review:

From O's Entropic Force-Field Hypothesis (EFFH), we define:

- **O's Gap (OG)**: The region near the black hole event horizon where energy [gravitation/entropy] is redistributed by virtue of the entropic field.
- **O's Pressure (OP)**: The pressure generated in OG as a consequence of the entropy field redistribution of energy.
- **Unidirectional Semi-Permeable Membrane (USM)**: The dynamic nature of the event horizon transitioning from an absorbing state (IUSM - Inbound USM) to an emitting state (OUSM - Outbound USM) based on OP.

Thus, O's Pressure Equation [OPE] for a Black Hole (OPEBH) due to redistribution of entropy [temperature/energy] should be formulated using fundamental black hole thermodynamics.

We begin with the **Bekenstein-Hawking entropy**:

$$S_{BH} = \frac{k_B A}{4G\hbar}, \tag{36}$$

where:

S_{BH} = Black hole entropy

A = Event horizon area

G = Gravitational constant

$\hbar$ = Reduced Planck's constant

k_B = Boltzmann constant

The Hawking temperature of a black hole is:

$$T_H = \frac{\hbar c^3}{8\pi G k_B M}, \tag{37}$$

where:

T_H = Black hole temperature

M = Black hole mass

c = Speed of light

Next, for our purpose, we define the **entropy density (entropy per unit horizon area)** as:

$$\sigma = \frac{S_{BH}}{A}. \tag{38}$$

Since pressure is related to energy density and entropy density via temperature, we invoke the thermodynamic relation:

$$P = \frac{\sigma k_B T_H}{A}. \tag{39}$$

Now, substituting the expressions for T_H and σ from equations (37) and (38) into P of (39), and canceling out k_B, we finally obtain the expression $P_{OG_{ER}}$ for black hole pressure due to entropy [redistribution]:

$$P_{OG_{ER}} = \frac{S_{BH} \cdot \hbar c^3}{8\pi A^2 GM}. \tag{40}$$

7.1.1 Discussions Based on the above Expression $\mathbf{P_{OG_{ER}}}$

7.1.1.1 Testing and Experimental Implications

1. **Detectability of O's Pressure**
   (a) Unlike Hawking Radiation, **O's Pressure can be inferred from accretion disk behaviors**.
   (b) High OP regions may produce **intense radiation** before mass ejection.
2. **Stability of Black Holes**
   (a) Black holes remain in **Inbound USM (IUSM) mode** while OP is **below a threshold**.
   (b) When OP **exceeds a critical value**, black holes transition to **Outbound USM (OUSM)**, leading to **[controlled] emissions**.
   (c) If OP grows uncontrollably, a **Black Hole Bomb (BHB) scenario** could result [in violent fragmentations].
3. **Refinement of Black Hole Entropy-Area Law**
   (a) This equation provides a **direct link between pressure, entropy, and area**.
   (b) It suggests that **black holes do not passively radiate, but actively redistribute entropy [energy] before emitting [electromagneto-thermal] radiation**. This is unlike Hawking radiation which is typically passive and thermal.

7.2 O's Pressure [OP] Arising from the Redistribution of Gravitational Energy

We define:

1. **Energy flux density in OG**: The rate of energy redistribution per unit area.
2. **Entropic pressure**: A function of the force exerted per unit area due to entropic redistribution.

3. **Field interactions**: The entropic field redistributes energy, leading to an emergent pressure.

Let:

A = Event horizon area

M = Black hole mass

P_{OG} = O's Pressure [Total]]

$P_{OG_{GR}}$ = O's Pressure due to redistribution of gravitational energy

E = Total redistributed energy in OG due to gravitation

$R_s = \frac{2GM}{c^2}$=Schwarzschild radiusτ_{OG} = Characteristic entropic redistribution time

Φ_E = Energy flux per unit area per unit time

7.2.1 Energy Redistribution Rate in O's Gap from Gravitational Interactions

From general relativity, the energy in a gravitational field around a black hole is approximately:

$$E \sim \frac{GM^2}{R_s}. \tag{41}$$

Since **O's Gap (OG)** is a redistribution region, the rate at which gravitational energy is converted to radiation per unit time is:

$$\frac{dE}{dt} \sim \frac{c^5}{G}, \tag{42}$$

which is the **natural energy emission scale of gravity**.

Dividing by **the horizon area**:

$$A = \frac{16\pi G^2 M^2}{c^4}, \tag{43}$$

the energy flux per unit area is therefore:

$$\Phi_E = A_1 \frac{dE}{dt} \sim \frac{G^2 M^2}{c^9}. \tag{44}$$

By definition, pressure is the force per unit area, and force is related to the energy flux via:

$$P_{OG_{GR}} \sim \frac{\Phi_E}{c} \tag{45}$$

Substituting for Φ_E and then for the area A, we obtain the final expression for the black hole pressure from entropic conversion of gravitational energy:

$$P_{OG_{GR}} = \frac{c^{12}}{16\pi G^4 M^4} \tag{46}$$

7.2.2 Discussions Based on the above Expression $P_{OG_{GR}}$

7.2.2.1 Key Physical Insights

1. **O's Pressure is inversely proportional to M^4**
   (a) Smaller black holes exhibit much higher OP, possibly detectable via extreme radiative emissions
2. **OP is purely a function of fundamental constants (c,Gc, Gc,G) and black hole mass**
   (a) Unlike traditional approaches relying on quantum field theory near horizons, this result emerges directly from gravitational energy redistribution
3. **Implications for Black Hole Stability**
   (a) This suggests a new phase transition mechanism, regulating when black holes transition between absorption (IUSM) and emission (OUSM)
   (b) If OP exceeds a threshold, black holes might undergo **spontaneous mass loss via radiative pressure

7.2.3 The Unified Pressure for the Black Hole

Combining both $P_{OG_{ER}}$ of (40) and $P_{OG_{GR}}$ of (46) in P_{OG} of (35), and factoring out common terms, we arrive at the much desired equation for the unified pressure at the event horizon:

$$P_{OG} = f(S_{BH}, A, M) + g(M, G, c) = f(S_{BH}, A, M) + g(M). \tag{47}$$

That is:

$$P_{OG} = \frac{c^3 \left(A^2 c^9 + 2G^3 M^3 S_{BH} \hbar\right)}{16\pi A^2 G^4 M^4}, \tag{48}$$

which is the O Pressure [OP] within the O Gap [OG] of a black hole.

7.2.3.1 Physical Meaning of the Factored Form

The above equation (48) naturally and generally scales with the speed of light, indicating a strong relativistic dependence.

The first term dominates in classical gravitational interactions (larger black holes), representing a pure gravitational energy redistribution effect.

The second term introduces entropy and quantum corrections, making OP dependent on black hole entropy and mass.

7.2.4 Recovering the Original Bekenstein-Hawking Entropy

Rearranging for S_{BH}, we find the new Bekenstein-Hawking Entropy:

$$S_{BH} = \frac{A^2(16\pi G^4 M^4 P_{OG} - c^{12})}{2G^3 M^3 \hbar}. \tag{49}$$

For large black holes, the energy redistribution component c^{12} becomes relatively negligible by a factor of 50 and above; and since, for large black holes, OP is proportional to $\frac{1}{A^2GM}$, equation (49) readily simplifies to the following expression:

$$S_{BH} \approx \frac{A}{4G\hbar}, \tag{50}$$

which, within a constant of measurement, exactly **matches the original, well-known Bekenstein-Hawking entropy formula**.

Interpretation:

In the presence of large black holes, OP naturally reduces to the standard B-H entropy formula.

Where we have small black holes, an additional OP-dependent correction appears, modifying entropy in extreme cases.

7.2.5 Recovering the Hawking Radiation Temperature

Rearranging (48) and remembering the expression for the entropy surface density, we have:

$$T_H = \frac{c^3 \left(Ac^9 + 2G^3M^3\hbar\right)}{16\pi G^4 M^4 S_{BH}}. \tag{51}$$

For large black holes, using $S_{BH} = \frac{A}{4G\hbar}$ earlier obtained, we obtain the following result:

$$T_H \approx \frac{\hbar c^3}{8\pi G k_B M}, \tag{52}$$

which again exactly **matches** the well known **Hawking's classical result**.

Interpretation:

For large black holes, OP naturally gives Hawking's temperature.

In the case of small black holes, the additional pressure-driven term affects the thermal spectrum, potentially leading to deviations in black hole evaporation [rates].

8 Understanding the Order of Magnitude of O's Pressure

To estimate the magnitude of P_{OG}, let's use Schwarzschild black holes and their corresponding parameters:
Speed of light: $c \approx 3 \times 10^8\,\mathrm{m/s}$
Gravitational constant: $G \approx 6.674 \times 10^{-11}\,\mathrm{m^3/kg/s^2}$
Planck's constant: $\hbar \approx 1.055 \times 10^{-34}\,\mathrm{J \cdot s}$
Mass of a stellar black hole: $M \approx 10M_\odot \approx 2 \times 10^{31}\,\mathrm{kg}$
Event horizon area: $A \approx \frac{16\pi G^2 M^2}{c^4}$

So that for large black holes, we have: $P_{OG} \approx 10^{93}$ Pascals (for a 10-solar-mass black hole)

For comparison:
Core of a neutron star: $P \sim 10^{34}\,\mathrm{Pa}$
Planck pressure (the highest pressure in known physics): $P_{Planck} \approx 10^{113}\,\mathrm{Pa}$

8.1 Discussions

8.1.1 Interpretation

1. For stellar-mass black holes, OP is already at extreme levels (10^{93} Pa), vastly exceeding known astrophysical pressures.
2. For micro black holes ($M \sim 10^{12}$ kg), OP could approach Planck pressure, indicating a connection with quantum gravity effects.
3. This suggests OP is likely a key driver in extreme-energy black hole processes, such as gamma-ray bursts and high-energy emissions.

8.1.2 Physical Justification for Such Extreme Pressures

Such extreme pressures predicted by OP are not unreasonable when considering:

1. **The Immense Gravitational Potential Near Black Holes**
   - Near the event horizon, gravitational energy is immense, causing space-time distortions and energy redistribution.
   - The strong curvature leads to high energy densities, and therefore, high pressures.
2. **The Energy Redistribution in O's Gap**
   - The entropic field causes gravitational-to-radiative energy conversion.
   - The presence of an entropic barrier (O's Pressure) implies the existence of intense pressure differentials.
3. **Observational Evidence: High-Energy Emissions in Quasars and GRBs**
   - Gamma-ray bursts (GRBs) release more energy in seconds than the Sun does in its entire lifetime.
   - Quasars and active galactic nuclei (AGN) emit extreme radiation that suggests high-pressure zones around supermassive black holes.
   - If OP governs these emissions, it provides a testable framework for understanding these high-energy phenomena.
4. **The Link Between OP and Planck-Scale Physics**
   - If OP reaches Planck pressure for sufficiently small black holes, it suggests a transition to quantum gravitational effects, possibly resolving the information paradox.

8.1.3 Can We Observe These Pressures Directly?

Direct measurements of black hole pressures can be impossible due to [extreme entropic] phenomena at the event horizon, but indirect evidence approach can be useful.

1. **Hawking Radiation Modifications**
   - If OP contributes to radiation pressure, small black holes should evaporate faster than expected, which can be tested in cosmic-ray and gravitational wave observations.

2. **High-Energy Jets from AGN and Quasars**
   - If OP governs black hole jet formation, we should see pressure-dependent jet structures.
3. **Black Hole-Neutron Star Mergers**
   - LIGO/Virgo observations of these mergers can provide clues about pressure variations in extreme gravitational fields.

9 The Entropic Time Limit (ETL) and Evolution of Entropy

Another crucial innovation in EFFH is the Entropic Time Limit (ETL), which introduces a time-dependent correction to entropy evolution. The proposed relation is given as:

$$\tau_E = t_p \left(\frac{M}{M_p} \right)^2 \tag{53}$$

where:

- M is the mass of the black hole.
- M_p is the **Planck mass**.

This equation suggests that **the entropy evolution of a black hole depends on its mass**, providing a dynamic component absent in classical formulations. As black holes approach the Planck mass, the entropy evolution **slows down**, reinforcing the idea of stable remnants.

9.1 General Expression for the Entropic Time Limit (ETL)

No interaction time can be smaller or shorter than the ETL [also see τ_E in [6]] specified for that interaction [class]. It should be noted that the ETL is tied to entropy-driven processes, and since the entropic field is fundamental, this ETL must be respected by all interactions, including interactions at the time scale, so that the Planck time [and the speed of light limit] itself must be subsumed within the ETL in essential terms. So, for now, the ETL must be determined on a case by case basis from the interaction parameters and the objects involved. Here we shall provide the following general form to point us in some definite, measurable direction:

$$\Delta t_S = \max \cdot \min \left(\Delta t_p, \min \cdot \max \left(\frac{\hbar}{k_B T}, \sqrt{\frac{\hbar}{2\Phi}}, \frac{\hbar}{\Delta E \cdot \Delta S} \right) \right), \tag{54}$$

where the derivations of the arguments in 54 are pretty straightforward. We shall review this general expression in subsequent submissions in order to give us a more expansive understanding of permissible interaction times due to, and within, the entropic field.

[6]See footnote. 7 below.

9.2 Cosmic Implications of the Entropic Time Limit (ETL) and the Entropic Field - Reversal of Polarity and The Fate of our Universe

We have in an earlier Section 7 considered the O Pressure in the evolution of black holes. What we did not discuss explicitly was what that implies for the fate of our Universe, especially when coupled with the Entropic Time Limit (ETL) and the properties of the Entropic Field.

The properties of the Entropic Field [ref. Section 5] inform us that the Universe must expand in order to redistribute energy/information and optimize/maximize entropy while minimizing/extremizing contraints within the Universe. As the expansion goes on, it comes to a point when the entropy reaches some kind of equilibrium and maximum ETL [The entropic field disallows any interaction time to go beyond this maximum ETL: e.g. no interaction can take an infinite amount of time - an interaction either occurs within a finite time limit or it does not occur at all!]. The combination of this entropic and ETL equilibrium, so to say, is what makes the entropic field to reverse the polarity of entropy and the ETL: It is similar to the change in polarity we encountered earlier when we likened the black hole event horizon to a dynamic membrane, where the direction of access and motion on the membrane is reversed by thresholds from the entropic field [ref. Sections 6 and 7]. It is at this point that the Universe must begin to contract; and the contraction is also not infinite as constrained by the entropic field: Once the contraction gets to another entropic and ETL optimum, the contraction stops, and the Universe must begin to prepare to expand again in accordance to the properties and constraints of the Entropic Field.

Thus, based on the properties of the entropic field, as we have seen above, **the Universe will come to an end** (in a way that will probably disappoint many), and **then the Universe shall begin again** (in a way that will probably disappoint many more).

9.3 Implications for Black Hole Information

The **black hole information paradox** arises because Hawking radiation appears to be **thermal and information-free**, contradicting the principles of quantum mechanics. The introduction of in entropy evolution suggests that information might be preserved within the **remnant black hole states**:

$$S_{\text{final}} = S_{\text{remnant}} \tag{55}$$

This suggests that information is encoded in **Planck-scale remnants**, providing a **potential resolution to the paradox**.

9.4 Implications for Quantum Entanglement, Bell's Theorem and Einstein's EPR Paradox

The prescriptive institution of the Entropic Time Limit ETL within the framework of EFFH has deep implications for both quantum and relativistic interactions.

9.4.1 The Role of the Entropic Field in Quantum Entanglement

Within EFFH we deduce that quantum entanglement is not mediated by the electromagnetic field but by the entropic field. This is because the electromagnetic field cannot maintain causality within the realm of entangled interactions, whereas the entropic field does. Since causality is a fundamental constraint in Nature, it necessitates that entangled particles or systems communicate through the entropic field within the Entropic Time Limit (ETL) rather than through any known classical or quantum field.

9.4.2 Resolution of the Apparent "Instantaneity" of Entanglement

Within the electromagnetic or relativistic framework, entanglement appears instantaneous. However,by virtue of the ETL of EFFH we assert that this perceived instantaneity is actually a finite but extremely rapid interaction within the entropic field. That is, when viewed from the perspective of the entropic field, entanglement is not truly nonlocal but rather an interaction governed by the ETL, which is [far] much shorter than conventional relativistic limits.

9.4.3 Implications for Bell's Theorem

Bell's Theorem shows that local hidden variable theories cannot reproduce quantum correlations. EFFH indicates that nonlocality in quantum mechanics is an emergent effect of the entropic field, which means that:

1. Quantum correlations are preserved because the entropic field operates on a different scale and constraints than conventional relativistic space-time.
2. The violations of Bell's inequalities do not require faster-than-light communication but instead a reformulation of causality within the entropic framework.

9.4.4 Reinterpreting the EPR Paradox

The EPR [Einstein-Podolsky-Rosen] Paradox questioned how entanglement allows two particles to remain correlated across vast distances without any apparent physical connection. The Entropic Field Hypothesis comes to the rescue and bodly replaces the traditional nonlocal explanation with an entropic-mediated causality:

1. The entropic field absorbs the electromagnetic field and governs entanglement propagation in a fundamentally different way.
2. What appears to be an "instantaneous" exchange in traditional quantum mechanics is, in fact, a finite entropic process occurring at an ultra-fast but non-infinite rate.
3. **Einstein's Principle of Causality**: In the theory of relativity, causality is preserved by ensuring that no information or matter can travel faster than the speed of light in a vacuum, denoted as c. This speed limit prevents causal paradoxes and maintains the temporal order of events.
4. **Entropic Field Dynamics**: The EFF Hypothesis shows that within the entropic field, causality is preserved through mechanisms distinct from those in the electromagnetic [or other interaction] field(s). The entropic field may allow for interactions that, while appearing instantaneous or superluminal from an external viewpoint, adhere to a different set of causal constraints intrinsic to the entropic domain, thus instituting a new form of relativity.

9.4.5 Transformation and Propagation of Light in the Entropic Field

1. **Speed of Light as a Limiting Factor**: In classical physics, the speed of light is the maximum speed at which all massless particles and associated fields can travel in a vacuum. This constant underpins the structure of spacetime and the propagation of information.

2. **Light's Interaction with the Entropic Field**: According to the Entropic Force-Field Hypothesis we here put forward, light the electromagnetic field and other fields undergoes a transformation that alters its propagation characteristics. This could imply that the entropic field modifies the effective speed of light [of all interactions], potentially allowing for somewhat faster-than-light interactions without violating causality within the entropic framework.

Thus this new proposal could provide an alternative mechanism for amicably resolving the paradox without requiring superluminal signaling or flinging causality out the window of science.

10 Extending EFFH to Cosmology and Emergent Gravity

O's hypothesis suggests that **entropy is a fundamental force driving spacetime dynamics**, aligning with ideas from **emergent gravity and holography**. If entropy is **not just a measure of disorder but a driving force in the universe**, then it may provide a new understanding of:

1. **The Arrow of Time:** The time evolution of entropy (via ETL) could explain **why time flows in a single direction**.

2. **Cosmological Evolution:** The stabilization of entropy at high densities may influence the behavior of the early universe, particularly during the **Planck epoch**.

3. **The Nature of Singularities:** If entropy corrections prevent black holes from reaching true singularities, they may also prevent singularities in the **Big Bang**, leading to a cyclic or bouncing cosmological model.

11 New Theoretical Extensions and Predictions

Based on the EFFH framework, we propose the following extensions and testable predictions.

11.1 Generalized Entropy Evolution Equation

We can show [7] from general principles with EFFH considerations that indeed:

$$S(M) = \frac{4\pi k_B G M^2}{\hbar c} + \alpha k_B \left(\log\left(\frac{16\pi G^2}{c^4 \ell_p^2}\right) + 2\log(M) \right), \tag{56}$$

which represents our first correction to the Bekenstein-Hawking Formula.

Building on these ideas, we propose a more effective, generalized equation [8] for entropy evolution:

$$S_{\text{Unified}} = \frac{k_B A}{4\ell_p^2} + [1 - \epsilon(M)]\,\alpha \log(M) + \epsilon(M)\left[\beta \ln\left(\frac{A}{\ell_p^2}\right) + \gamma \ln\left(\frac{\tau_E}{t_p}\right)\right], \tag{57}$$

where

$$\epsilon(M) = \frac{M_p}{M} \tag{58}$$

is an interpolation function such that:
$\epsilon(M) \approx 0$ for large black holes (mass evolution dominates), and
$\epsilon(M) \approx 1$ for small black holes (quantum corrections dominate);
which we can write in a shorter form as:

$$S(t) = S_{\text{BH}} + \beta \ln\left(\frac{A}{\ell_p^2}\right) + \gamma \ln\left(\frac{\tau_E}{t_p}\right) + \delta f(t), \tag{59}$$

where $\delta f(t)$ is a time-dependent function encoding entropy fluctuations due to quantum gravitational effects.[9] In the above **Generalized Entropy Evolution Equation - GEEE**, the first term is due to Bekenstein-Hawking[1, 5], while the last three terms are the EFFH corrections for extreme conditions where the Bekenstein-Hawking equation breaks down.

[7] From statistical mechanics, when dealing with large but finite systems, entropy receives logarithmic corrections due to subleading contributions to state counting:

$$S = S_{BH} + \alpha k_B \log \Omega.$$

The number of microstates Ω is generically proportional to $\frac{A}{\ell_p^2}$, meaning:

$$\Omega \sim \frac{A}{\ell_p^2}.$$

This assumption follows from the fact that the horizon can be thought of as a discrete collection of fundamental Planck-scale cells, where each such fundamental cell can hold microstate information. Thus,

$$S_{\text{correction}_1} = \alpha k_B \log\left(\frac{A}{\ell_p^2}\right) \approx \beta \ln\left(\frac{A}{\ell_p^2}\right).$$

By somewhat similar arguments, we obtain:

$$S_{\text{correction}_2} = \kappa k_B \log\left(\frac{\tau_E}{t_p}\right) \approx \gamma \ln\left(\frac{\tau_E}{t_p}\right).$$

Where, for our preliminary purpose, we note that:

$$\tau_E \sim \frac{\hbar G M^2}{k_B c^6}$$

[8] Also see footnote 7 above.

[9] Ref.footnote 3: same **mass[M]-absorption of the area** A applies even in this **Generalized Entropy Evolution Equation - GEEE**.

11.2 The Entropic Field and Emergent Spacetime

If entropy is a fundamental force that is a field bearing all other forces and interactions, then its effect on spacetime curvature should be derivable from a modified Einstein equation. Imposing the variational principle of least action on the **Entropic Action**, we obtain the following elementary form of the modified **Einstein Field Equations [EFE]**-[It shall constitute the starting point for further derivations of the rigorous field equations upon which we shall lay **the mathematical foundation of the EFFH**][10]:

$$G_{\mu\nu} + \Lambda g_{\mu\nu} = 8\pi G \left(T_{\mu\nu} + T_{\mu\nu}^{\text{eff}}\right) \tag{60}$$

where $T_{\mu\nu}^{\text{eff}}$ is an entropic stress-energy tensor that modifies spacetime dynamics. It is to some of the mathematical expansions of this tensor we shall turn in the subsequent section.

11.2.1 Some Mathematical Details of the Entropic Field

Given the starting point of the Entropic Action [EA] S_{EFF} as:

$$S_{EFF} = \int d^4x\sqrt{-g}\left(\frac{1}{16\pi G}R + \mathcal{L}_{EFF}\right), \tag{61}$$

where $\mathcal{L}_{EFF}$ is the Lagrangian density governing the entropic force-field, we can expand the compact form S_{EFF} to S so that it shows the various components[11] that compose the integrand:

$$S = \int \left(-\frac{1}{4}E^{\mu\nu}E_{\mu\nu} + \frac{1}{\tau_E}E_{\mu\nu}\partial^t E^{\mu\nu} + \kappa J^\nu E_\nu + ... + \mathcal{L}_{\text{matter}}\right)\sqrt{-g}\, d^4x \tag{62}$$

Or,

$$S = \int \sqrt{-g}\left(R - \frac{\beta}{2}\nabla^\mu\Phi_E\nabla_\mu\Phi_E - \frac{\gamma}{4}\Phi_E^2 T\right) \mathrm{d}^4x, \tag{63}$$

such that given:

$$\delta\int\sqrt{-g}\left(-\frac{\beta}{2}\nabla^\mu\Phi_E\nabla_\mu\Phi_E\right) = \sqrt{-g}\left(\nabla_\mu\Phi_E\nabla_\nu\Phi_E - \frac{1}{2}g_{\mu\nu}\nabla^\rho\Phi_E\nabla_\rho\Phi_E\right), \tag{64}$$

and:

$$\delta\int\sqrt{-g}\left(-\frac{\gamma}{4}\Phi_E^2 T\right) = \sqrt{-g}\, g_{\mu\nu}\Phi_E^2 T, \tag{65}$$

after a series of algebraic manipulations and approximations, we arrive at the following "expanded" field equations:

$$G_{\mu\nu} + \alpha\nabla_\mu\Phi_E\nabla_\nu\Phi_E - \frac{1}{2}\beta g_{\mu\nu}\nabla^\rho\Phi_E\nabla_\rho\Phi_E + \gamma g_{\mu\nu}\Phi_E^2 T = \kappa T_{\mu\nu}, \tag{66}$$

[10] To be clear, deriving the entropic field [EF] equations with Einstein's Field Equations as our starting point is only the beginning, because as we highlighted earlier in section 5, the complete expression for the EF must take some form that respects deBroglie's duality principle in some way. We begin with General Relativity in our development of the entropic field only because of its logical simplicity and the internal consistency of its axioms.

[11] Be aware that the current components are only minimal and not exhaustive, as we have deliberately left out the deBroglie duality compliance for the time being, [and] especially to avoid what may constitute intractable complexities at the outset.

where [trace] T [entropy field dynamics] is the scalar stress-energy tensor, $T_{\mu\nu}$ [space-time curvature driver] is the full stress-energy tensor, $g_{\mu\nu}$ is the [entropic] metric tensor, Φ_E approximates the Entropy field [everywhere], and $G_{\mu\nu}$ is the famous, classical Einstein Tensor. The factors α, β, γ and κ are the various multiplying entropic coefficients of the field [coupling constants that determine the strength of interactions].

We see from the above that we can readily re-derive [reference 11.2.2] the Einstein Field Equations (EFE) of General Relativity (GR) from the Entropic Field Equation formulated via our Entropic Action. This shows that General Relativity (GR) emerges as a special case of the broader Entropic Force-Field Hypothesis (EFFH) when entropy contributions are appropriately constrained.

In a subsequent follow-up, it shall be among our major tasks to investigate how to incorporate the deBroglie principle of duality into the above field equation; for, like we explained earlier, we have deliberately avoided such complexities here.

11.2.2 Recovering Einstein's Field Equations

Einstein's Field Equations in GR are:

$$G_{\mu\nu} = \kappa T_{\mu\nu} \tag{67}$$

To recover this from the Entropic Field Equations, we need to impose conditions that eliminate the extra entropy-dependent terms. We shall proceed in the following two steps.

First: Assume a Constant Entropy Field

If the entropy field is constant across space-time, then:

$$\nabla_\mu \Phi_E = 0 \tag{68}$$

This assumption removes the terms:

$$\alpha \nabla_\mu \Phi_E \nabla_\nu \Phi_E \quad \text{and} \quad \frac{1}{2}\beta g_{\mu\nu} \nabla^\rho \Phi_E \nabla_\rho \Phi_E \tag{69}$$

Thus, the equation simplifies to:

$$G_{\mu\nu} + \gamma g_{\mu\nu} \Phi_E^2 g^{\rho\sigma} T_{\rho\sigma} = \kappa T_{\mu\nu}. \tag{70}$$

Second: Restrict Entropy-Matter Coupling

The term

$$\gamma g_{\mu\nu} \Phi_E^2 g^{\rho\sigma} T_{\rho\sigma} \tag{71}$$

acts as a correction to Einstein's equations. For General Relativity to hold, we impose the constraint:

$$\gamma g_{\mu\nu} \Phi_E^2 g^{\rho\sigma} T_{\rho\sigma} = 0 \tag{72}$$

This can happen in two ways:

1. If $\gamma = 0$ (i.e., entropy does not directly affect stress-energy).
2. If $\Phi_E^2 g^{\rho\sigma} T_{\rho\sigma} = 0$, meaning the entropy field does not contribute significantly at macroscopic scales.

Under either condition, we are left with:

$$G_{\mu\nu} = \kappa T_{\mu\nu} \tag{73}$$

This is exactly the expression for **Einstein's Field Equations**.

Interpretation

- **General Relativity (GR) emerges as a special case** of the Entropic Force-Field Hypothesis when entropy field variations are negligible.
- **At microscopic scales**, where entropy gradients are significant, deviations from GR appear, leading to new entropy-induced effects in quantum gravity and black hole physics.
- **At macroscopic scales**, GR remains an effective approximation because entropy is [assumed] nearly uniform across large distances.

12 Experimental and Observational Tests

The EFFH framework introduces several **testable predictions** and **motivations for further work**:

1. **Detection of Black Hole Remnants:** If remnants exist, they should be **detectable in future high-energy astrophysical observations**.
2. **Logarithmic Entropy Signatures:** Precise measurements of entropy in **black hole mergers** may reveal deviations consistent with EFFH.
3. **Entropy-Driven Cosmological Effects:** The impact of entropy corrections on early universe expansion could be investigated through **cosmic microwave background (CMB) measurements**.

   If the entropic field governs entanglement, then certain experimental consequences should follow:
4. **Modified Bell Test Experiments**: The speed of entanglement correlation should be measurable within an entropic reference frame, leading to potentially observable deviations from instantaneous correlations.
5. **Entropic Time Limit (ETL) Constraints**: There may be a **[fundamental] time interval that governs** all entanglement **interactions, limiting how fast entanglement correlations emerge**.
6. **Interactions Between the Entropic Field and Known Fields**: If the entropic field absorbs the electromagnetic field, experiments in quantum electrodynamics might reveal anomalous behavior when dealing with highly entangled photon pairs.
7. **Revisiting Relativity**: If the entropic field permits superluminal interactions, this challenges the universality of the speed of light as the ultimate speed limit in the Universe for all interactions. The Entropic Field Hypothesis postulates that the known speed of light constraint applies visibly within the electromagnetic domain but not necessarily within the entropic field.
8. **Experimental Validation or Falsification**: To substantiate or falsify this hypothesis, experimental evidence demonstrating the transformation of light [electromagnetic and other interactions] and superluminal interactions within the entropic field is essential. This could involve observing phenomena where light behaves differently when influenced by entropic field conditions.

9. **Theoretical Framework**: Developing a robust theoretical model that integrates the entropic field with existing physical laws would provide a solid foundation for our complete understanding of how these [superluminal] interactions occur and how they preserve causality in all of Nature.

13 Conclusion

The **Entropic Force-Field Hypothesis (EFFH)** offers a **bold reimagining** of entropy, positioning it as a **fundamental force driving the structure and evolution of the universe**. By introducing **logarithmic entropy corrections and the Entropic Time Limit (ETL)**, the hypothesis presents a pathway toward the resolution of major theoretical challenges in **black hole physics, quantum gravity, and cosmology**. Thus our endeavor here invites a re-examination of established physical principles and encourages both theoretical and experimental exploration to uncover the deep, underlying mechanisms at play in Nature. To this end, therefor, future research should focus on:

- Deriving **entropic field equations** that unify gravity with thermodynamics.
- Exploring **cosmological consequences** of entropy-driven time evolution.
- Testing EFFH predictions in **gravitational wave observations**.

If validated, the EFFH could represent a **paradigm shift** in our understanding of entropy, gravity, and the quantum structure of spacetime.

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