Energy Hole Model: New Interpretation of Gravity and Cosmic Events

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Abstract

This paper introduces the Energy Hole Model (EHM), as a framework that interprets gravitational interaction as the manifestation of the persistent energy deficit, termed as *energy hole*, formed concurrently with the synthesis of mass. It is based on a core hypothesis which states that the synthesis of a mass $\boldsymbol{M}$ requires the confinement of energy $\boldsymbol{E = Mc^2}$, extracted from the surrounding spacetime. This process leaves a corresponding energy deficit (hole) of $\boldsymbol{-Mc^2}$, which acts as the source of the gravitational field. From this premise, we derive the energy hole density profile for point masses, generalize that for stabilized extended objects, and propose a modified Poisson equation. It is demonstrated that a modified Poisson equation recovers Newtonian gravity as a limiting case, and the classical tests, including light bending, Shapiro delay, and gravitational redshift, are in full agreement with observations, establishing their empirical consistency. Beyond reproducing the established tests of general relativity, the EHM provides conceptual resolutions to cosmological puzzles like:

(i) the `cosmological constant problem`, via the corollary of the core EHM hypothesis, which states that energy confinement is a unique physical process, which is not observed in any other phenomenon except mass formation.
(ii) the `dark matter` as the additional energy deficit over that of baryonic mass,
(iii) the `dark energy` as the residual, positive energy of the spacetime vacuum,
(iv) and the gravitational behaviour of compact objects and black holes, including black hole singularity and the hard horizon problem.

The gravitation by negative energy is shown explicitly in the Friedmann equations. The EHM thus offers a unified and physically intuitive description of gravity and cosmic structure, fundamentally linking the concepts of energy synthesis, binding, and deficit formation.

Keywords: Gravity, Energy Hole, Cosmic Expansion, Energy deficit.

1 Introduction

General Relativity (GR) has stood as the cornerstone of gravitational physics for over a century, passing rigorous tests from solar system scales to the coalescence of black holes [1, 2]. Its geometric description of gravity as spacetime curvature has provided profound insights into the cosmos. Yet, despite its empirical success, GR presents fundamental theoretical and conceptual challenges when pushed to its limits, suggesting the need for a more complete framework. These persistent puzzles include:

i. *The Cosmological Constant Problem:* The most severe discrepancy in physics, where quantum field theory predicts a vacuum energy density $\sim 10^{121}$ times larger than the observed value of dark energy [3].
ii. *The Dark Matter Enigma:* Observations of galactic dynamics and gravitational lensing require non-luminous matter [4], yet decades of direct detection searches have found no conclusive evidence for a particle candidate [5].
iii. *The Nature of Dark Energy:* The observed late-time cosmic acceleration [6] implies a dominant, repulsive energy component whose microphysical origin remains unknown [7].
iv. *Singularities and Information Loss:* The inevitable formation of singularities within black holes [8], the emergence of horizons, and the associated information paradox [9] signify a breakdown of classical GR.
v. *Anomalous Astrophysical Phenomena:* Key microphysical processes, such as the internal dynamics of neutron stars (e.g., glitches [10, 11]) and the thermodynamic origin of black hole entropy [12, 13], lack a complete explanation within the standard paradigm.

The Energy Hole Model (EHM) proposed in this work addresses these gaps through a radical yet self-consistent premise: *the synthesis of mass is an event that generates a commensurate energy deficit in spacetime, an "energy hole" and it is this deficit, not the mass itself, that is the primary source of the gravitational field.* This model departs fundamentally from traditional approaches. It does not introduce new particles to explain dark matter, nor does it invoke unknown quantum vacuum properties to explain dark energy. Instead, the EHM posits that the act of energy localization (e.g., the formation of a material particle *suppose a proton*) is a transaction that simultaneously creates positive mass-energy and a spatially distributed negative energy hole, ensuring local energy conservation ($\Delta E = 0$). The resulting gravitational dynamics are governed by the interplay between these deficits and the positive energy of the cosmological vacuum. In this paper, we formalize the EHM, derive its central field equation, and demonstrate its application across scales. We show how the proposed model:

a) resolves the cosmological constant problem,
b) explains the origin of dark matter and dark energy,

c) explains the gravitational behaviour of black holes.

By redefining the source of gravity, the EHM provides a unified framework that challenges the standard interpretations of ΛCDM cosmology and points toward a new thermodynamics of gravitational interaction.

2 Background

Every material object in the universe has emerged through two dominant and sequential processes: *synthesis*, where mass is generated from field energy, and *binding*, where part of that mass is converted back into energy to form stable, composite systems [14, 15]. This sequence reflects a universal mass-energy transformation loop, which is central to the proposed EHM. The synthesis process increases the system's mass by converting field energy into matter, while during the binding process some energy (called binding energy) is released to spacetime by reducing the system's potential energy or by converting part of its mass (called mass defect) into binding energy [15]. In the EHM perspective, the synthesis of mass M introduces an equivalent *energy hole* of magnitude Mc^2 into spacetime. During the successive binding stages the body releases ΔMc^2 amount of energy, where ΔM is the mass defect. The total mass of the body is $M_T = M + \Delta M$, where M is the perceived mass or observed mass.

2.1 Synthesis: Transformation of Field Energy to Mass

Synthesis refers to the emergence of mass via spontaneous symmetry breaking [16] and quantum confinement effects [17] in the early universe. It is the transformation of field energy into rest mass via the dynamics of quantum fields. Synthesis takes place in two phases:

(i) **Higgs phase**: The Higgs phase endows fundamental fermions with inertial mass through electroweak symmetry breaking [18]. During this phase, nearly 1% of mass, called the inertial mass, is formed.

(ii) **QCD confinement phase**: The QCD confinement phase locks quarks into hadrons [17], generating the majority of perceivable mass through strong-force confinement [19]. During this phase nearly 99% of mass is formed.

During the synthesis of a Hydrogen atom, the Higgs mechanism contributes only a small fraction of the proton mass (about 9 MeV of the total 938 MeV) [20], with the bulk arising from QCD binding energy. This implies that what we perceive as "mass" is, to a large extent, confined energy.

2.2 Binding Process: Release of Energy

Once the particles (having a certain rest mass) are formed in the Higgs field, nature enters the binding phase. This binding energy, being negative relative to the free-particle state, either reduces the system's total mass (mass defect) or reduces the potential energy [15]. This effect underlies the stability of structures from nuclei to galaxies [15, 21]. Binding is a hierarchical process, starting at the hadronic level and progressing through atomic, molecular, and gravitational stages as depicted in Table 1. It is interesting to note in this table that during the binding process, when an intermediate structure is formed, simultaneously, a new field appears for the next layer of binding to take place.

Table 1 Hierarchy of Bindings, Intermediate Structures, and Activation of Binding Fields

Field	Binding Type	Structure Formed	Next Activated Field
Gluon field(s)	QCD confinement	Hadrons	Residual strong force
Residual strong force	Nuclear binding	Nucleus	EM (Coulomb) field
EM (Coulomb) field	Orbital binding	Atom	Polar (ionic) field
Polar (ionic) field	Chemical bonding	Molecules	van der Waals interaction
van der Waals	Dipole binding	Bulk matter	Gravitational field
Gravitational field	Gravitational	Astronomical bodies	Galactic gravitational field

In each bidding stage, the energy of the system is minimized by the release of energy to spacetime. The galactic formation represents the ultimate energy minimization process in the material objects in the universe [22]. At each stage, a new type of field emerges, enabling further structural complexity. The framework of successive field generation during matter formation reveals that gravity originates from persistent spacetime energy deficits [23]. Each binding stage reduces the magnitude of the system's energy hole, while the generation of a new field enables the progressive minimization of the system's total energy, culminating in large-scale gravitational structures. This hierarchical, bootstrapping process reveals a universe that builds its own complexity through successive phases of energy minimization. The gravitational field is the emergent consequence of this cosmic binding chain.

3 Proposed Energy Hole Model

Mass is not an independent entity added into spacetime; rather, it emerges from the quantum confinement of the vacuum. This confinement requires energy Mc^2, which becomes the observable rest mass. Simultaneously, this process creates a persistent energy deficit, *the energy hole* in the surrounding space. Mass formation and energy hole creation are simultaneous phenomena.

Core Hypothesis: The formation of mass M involves the confinement of vacuum within a bounded region through an energy investment $E = Mc^2$. This energy is drawn from the surrounding spacetime, resulting in a persistent deficit of $-Mc^2$ that manifests as gravity. The corresponding spatial deficit is referred to as an *energy hole.*

From this hypothesis, we derive the three more postulates in the following:

Postulate-1: The formation of an atom of mass M results in the generation of *energy hole* of energy $(-Mc^2)$ outside the atom.

Postulate-2: If all the matter of the universe gets converted to energy, the total energy of the universe will be the same as it was before the formation of the universe.

Postulate-3: The energy holes interact in a manner that tends to minimize the total energy of the combined system.

and a corollary from postulate-1 stated as:

Corollary: Energy is confined in a vacuum only when mass is synthesized, so that energy cannot be confined in a vacuum when no mass is formed.

Let H denote the energy hole associated with a mass M. The energy removed from spacetime equals the energy invested to form the mass:

$$\mathcal{E}_H = -Mc^2 \tag{1}$$

This energy deficit is spatially distributed in a spherically symmetric manner. Let $\rho_H(r)$ denote the energy deficit per unit volume at radial distance r, satisfying:

$$\mathcal{E}_H = \int \rho_H(r)\, dV \tag{2}$$

Assuming spherical symmetry, we combine equations (1) and (2) to write:

$$4\pi \int_0^\infty \rho_H(r)\, r^2\, dr = -Mc^2. \tag{3}$$

3.1 Energy Hole Formalism for Point Mass

We assume that the energy deficit is distributed isotropically in space but begins only outside a small spherical core of radius λ, representing a region with no gravitational field such as within a hadron. Beyond this core, the deficit decays with distance from the center. Accordingly, we model the energy hole profile using a physically reasonable Yukawa-like decaying profile [24], given by:

$$\rho_H(r) = -\frac{A}{(r+\lambda)^2} e^{-(r+\lambda)/L}, \tag{4}$$

where A is a normalization constant, L is a characteristic decay length determining how far the energy deficit extends spatially, and λ represents the Compton wavelength of the mass m, given by

$$\lambda = \frac{\hbar}{mc}. \tag{5}$$

For classical bodies, where $r >> \lambda$, i.e., the distance r from the mass is much larger than λ, we can approximate $r + \lambda \approx r$, simplifying the expression of hole density to a form:

$$\rho_H(r) \approx -\frac{A}{r^2} e^{-r/L}. \tag{6}$$

The energy hole density ρ_H in (4) and (6) contains a geometric factor $(1/r^2)$ and an exponential decay term for mathematical consistency and to match with the gravitational phenomenology. The total energy of the hole must equal $-Mc^2$, and therefore:

$$\int_0^\infty \rho_H(r) dV = -Mc^2 \tag{7}$$

Substituting the profile expression of (6), we have

$$4\pi \int_0^\infty \left(-\frac{A}{r^2} e^{-r/L} \right) r^2 dr = -Mc^2 \tag{8}$$

Solving it for A:

$$A = \frac{Mc^2}{4\pi L} \tag{9}$$

Thus, the energy hole density becomes:

$$\rho_H(r) = -\frac{Mc^2}{4\pi L} \frac{1}{r^2} e^{-r/L} \tag{10}$$

4 Hole Density of Stabilized Extended Holes

The energy hole associated with a stable extended body has its origin in the formation of atoms themselves. At the time of atomic synthesis, each constituent mass m generates a localized hole profile, modeled by a Yukawa-type distribution, $\rho_H(r) = -\frac{A}{(r+\lambda)^2} e^{-(r+\lambda)/L}$, where $\lambda = \hbar/(mc)$ represents the quantum cutoff scale and L is the characteristic decay length. This "atomic hole" is the fundamental unit of the theory, exactly analogous to the point-mass hole profile. When atoms aggregate into molecular or crystalline structures, the individual hole profiles overlap and sum coherently, forming a microscopic aggregate of holes. As the aggregate grows in size, the exponential decay factor becomes negligible on scales smaller than the body radius, and the hole distribution smooths out into an effectively uniform density within the bulk. In this macroscopic limit, the hole energy density is simply related to the mass density by $\rho_H(\mathbf{r}) \approx -\rho_m(\mathbf{r})\, c^2$, which provides a direct mapping from mass to hole energy density. While this uniform relation captures the stabilized bulk behavior, the underlying Yukawa kernel remains essential at the microscopic and quantum scales, where it governs short-range corrections and ensures proper matching to atomic and molecular physics. For a stabilized macroscopic body (planet, white dwarf, star) we assume that (i) the microscopic, Yukawa-like "outside" holes associated with individual constituents coalesce under overlap and pressure stabilization, and (ii) the resulting coarse-grained hole is confined to the physical volume of the body.

4.1 Primary Holes

Conceptually, the dominant microscopic contributors to the energy-hole inventory of a synthesized matter are the hadrons (neutrons and protons). The energy hole associated with each hadron is a consequence of the quantum confinement of the vacuum that produces the hadron's rest energy. Physically, one must therefore define the hole only *outside* the hadron's confinement zone such that the hole cannot occupy the spatial region that the hadron itself fills. Therefore, we have considered the confinement radius to be the reduced Compton scale λ defined by (5), so for nucleons (using the hadron mass $m_{\mathrm{n,p}}$), the reduced Compton length is of order $\lambda_{\mathrm{hadron}} \sim 2 \times 10^{-16}$ m (order-of-magnitude estimate, reduced–Compton convention). Thus the atomic/hadronic hole is modeled only for $r \geq \lambda$. Accordingly, we adopt the point/atomic profile (Yukawa-like, vanishing inside the confinement zone)

$$\rho_H^{(i)}(r) \;=\; \begin{cases} 0, & 0 \leq r < \lambda, \\ -\dfrac{a_i}{(r+\lambda)^2}\, e^{-r/L}, & r \geq \lambda, \end{cases} \tag{11}$$

Here, the characteristic decay length L determines the scale over which the hole spreads into surrounding spacetime. The exponential factor provides a *gradual cutoff* of the hole at distances $r \gtrsim \mathcal{O}(L)$ the microscopic tail becomes negligible. The normalization constant a_i is obtained by energy conservation, given by:

$$\mathcal{E}_H^i \;=\; 4\pi \int_\lambda^\infty \rho_H^i(r)\, r^2\, dr \;=\; -m_i c^2. \tag{12}$$

Although hadrons generate the primitive holes, the gravitational field generated by an isolated hadron is imperceptible in the strong field. Only when many hadrons (and electrons/atoms) are assembled into microscopic aggregates (molecules, grains) does the cumulative hole field become macroscopically relevant. The aggregation is modeled to proceed as follows:

4.2 Aggregation of Primary Holes

Primary/Point-profile stage: The i-th constituent material entity contributes a normalized hole kernel

$$\rho_H^{(i)}(\mathbf{x}) = -m_i c^2\, K(\mathbf{x}-\mathbf{r}_i), \quad \text{with} \int K\, d^3x = 1, \tag{13}$$

where K is chosen to reproduce (11) outside the confinement zone.

Aggregate stage: In a small aggregated cell of linear size ℓ (which could be assumed to be radius of the aggregate) with $\max\{\lambda, L\} \ll \ell$) many adjacent hole kernels overlap. We can associate the microscopic mass density

$$\rho_m(\mathbf{x}) = \sum_i m_i \delta^{(3)}(\mathbf{x}-\mathbf{r}_i) \tag{14}$$

with (13) to express the coarse-grained hole energy density as following convolution

$$\rho_H^{(\mathrm{cg})}(\mathbf{x}) \;=\; -c^2 \int \rho_m(\mathbf{x}')\, K(\mathbf{x}-\mathbf{x}')\, d^3x'. \tag{15}$$

The coarse-grained hole profile represents the local averaging over the kernel radius $\sim L$, such that only masses within $|\mathbf{x}-\mathbf{x}'| \lesssim L$ contribute appreciably.

Stabilized (macroscopic) stage. For stabilized extended objects, the kernel is short-ranged compared with aggregate and body scales (i.e. $L \ll$ aggregate size $\ll R$), and the packing is dense, so inter-particle spacing $\ll L$, the convolution collapses to a local relation for interior points:

$$\rho_H^{(\mathrm{cg})}(\mathbf{x}) \simeq -c^2\, \rho_m(\mathbf{x}). \tag{16}$$

For an approximately homogeneous stabilized sphere this yields the uniform interior hole

$$\rho_H(r) \simeq -\frac{3Mc^2}{4\pi R^3} \quad (0 \le r \le R), \tag{17}$$

with a thin boundary layer of width $\sim\mathcal{O}(L)$ the kernel weight is effectively lost.

Since $\lambda_{\mathrm{hadron}}$ is extremely small compared with molecular/aggregate sizes (and because laboratory constraints require any long-range screening L to be at most micron/sub-micron for ordinary matter), the short-kernel limit applies for most stabilized bodies, and the microscopic Yukawa structure matters only deep inside the microphysics regime, while the macroscopic hole is well approximated by $\rho_H \simeq -\rho_m c^2$ in the body interior.

Implication of the Proposed Hole Density Profile.

The Yukawa-like profile is introduced to (i) enforce the physical exclusion of the hole from the hadron interior, (ii) provide a smooth, controlled spread of the deficit into surrounding spacetime, and (iii) enable a clean coarse-graining route from microscopic point holes to a macroscopic, uniform interior hole. The exponential term therefore encodes the *gradual cutoff* of the hole and guarantees both proper short-range quantum behaviour and the correct emergence of Newtonian gravity at mesoscopic and macroscopic scales.

4.3 Macroscopic Energy Hole Density Profile

For a uniform sphere, the mass density is constant: $\rho_m = \frac{3M}{4\pi R^3}$. According to the central result of the energy hole model, that the stabilized hole density is $\rho_H(\mathbf{x}) \simeq -\rho_m(\mathbf{x})c^2$ for interior points, we immediately obtain the macroscopic hole profile:

$$\rho_H(r) = \begin{cases} -\dfrac{3Mc^2}{4\pi R^3} & \text{for } 0 \le r \le R, \\ 0 & \text{for } r > R. \end{cases} \tag{18}$$

This profile describes a spherically symmetric region of constant negative energy density, a uniform *energy hole*, confined within the volume of the body. The total energy of the hole is:

$$\mathcal{E}_H = \int_0^R \rho_H(r) 4\pi r^2 dr = \int_0^R \left(-\frac{3Mc^2}{4\pi R^3}\right) 4\pi r^2 dr = -Mc^2 \int_0^R \frac{3r^2}{R^3} dr = -Mc^2,$$

which satisfies the fundamental energy conservation postulate of the model.

5 The Generalised Poisson Equation and Newtonian Convergence

The classical Poisson equation

$$\nabla^2 \phi = 4\pi G \rho_m \tag{19}$$

involves only mass density ρ_m. To incorporate both positive and negative energy sources, we convert it into an energy-density representation. The Energy Hole Model (EHM) in the weak-field limit is therefore based on a generalization of the classical Poisson equation:

$$\nabla^2 \phi = -\frac{4\pi G}{c^2} \rho_E \tag{20}$$

where the effective source energy density ρ_E is defined as:

$$\rho_E = \rho_P + \rho_H \tag{21}$$

In this formulation, $\rho_P \geq 0$ is the *positive energy density* (e.g., pressure, radiation, dark energy). $\rho_H = -\rho_m c^2 \leq 0$ is the *energy hole density* or *energy deficit density* associated with mass. ρ_E is the resulting *net source energy density* that generates the gravitational potential. It leads to the fundamental principle of the EHM: *negative energy densities (deficits) are the source of attractive gravity, while positive energy densities are the source of repulsive gravity.* The resulting gravitational behavior is determined by the sign and magnitude of the net source term:

Dominant Component	**Net Source** ρ_E	$\nabla^2\phi$	**Resulting Gravity**
Energy Hole ($\lvert\rho_H\rvert > \rho_P$)	Negative	> 0	**Attractive**
Positive Energy ($\rho_P > \lvert\rho_H\rvert$)	Positive	< 0	**Repulsive**

5.1 Recovery of Newtonian Gravity

The model's consistency with established theory is demonstrated by recovering the classical Poisson equation. In a region where only matter is present ($\rho_P \approx 0$) and the energy hole density is $\rho_H = -\rho_m c^2$; from (21) we get:

$$\rho_E = 0 + \rho_H = -\rho_m c^2$$

Substituting this into the modified Poisson equation (20) yields:

$$\nabla^2\phi = -\frac{4\pi G}{c^2}(-\rho_m c^2) = 4\pi G\rho_m$$

This is identical to the classical Poisson equation given by (19). This confirms that the EHM seamlessly contains Newtonian gravity as a special case. This modified Poisson equation is significant because it:

i. **Unifies Gravity and Cosmology:** It provides a single framework describing both the attractive gravity of matter and the repulsive effect of dark energy, with the transition governed by the sign of ρ_E.
ii. **Redefines the Source of Gravity:** It posits that the true source of curvature is not mass-energy itself, but the *deviation* from the background energy state of spacetime (ρ_E).
iii. **Provides a Clear Path to Derivation:** From this foundation, the EHM can naturally derive key observational results, such as flat galactic rotation curves and the Tully-Fisher relation, by modeling dark matter halos as distributions of ρ_H.
iv. **Resolves Conceptual Paradoxes:** By attributing attraction to energy deficits, it avoids the thermodynamic instability of GR's self-energy problem, where positive energy sources create deeper potential wells, leading to a positive feedback loop.

Equation (20) thus serves as the foundation for the weak-field limit of the EHM, elegantly capturing its core premise and predictive scope.

6 Resolution of Key Problems

6.1 Resolution of the Cosmological Constant Problem

The cosmological constant problem [3] represents one of the most severe problems in modern physics. Quantum field theory (QFT) has been used to predict a vacuum energy density, originating from the zero-point fluctuations of all quantum fields, on the order of:

$$\rho_{\text{vac}}^{(\text{QFT})} \sim \frac{\hbar c}{(\ell_{\text{Pl}})^4} \sim 10^{112}\text{erg/cm}^3. \tag{22}$$

If this energy gravitates according to the standard interpretation of GR, it would act as a cosmological constant, causing a rapid and violent expansion of the universe, which is incompatible with observation. The measured value of the dark energy density is instead:

$$\rho_{\Lambda}^{(\text{obs})} \sim 10^{-8}\text{erg/cm}^3, \tag{23}$$

creating a discrepancy of 120 orders of magnitude. The EHM resolves this problem by reinterpreting the nature of gravitating energy through its fundamental postulate and its corollary, which state that the formation of a mass M results in the generation of an *energy hole* of energy ($-Mc^2$). Energy is confined in vacuum only when mass is synthesized, and energy cannot be confined in a vacuum without resulting in mass.

From these principles, the EHM makes a critical distinction that unconfined energy does not gravitate. The fluctuating quantum vacuum of QFT is a state of *unconfined* energy. Its virtual particles are transient, delocalized, and do not represent a stable, localized energy structure. Therefore, according to Corollary-1, this energy is not *confined* and it does not generate an energy hole ρ_H. Consequently, the vast energy density $\rho_{\rm vac}^{\rm (QFT)}$ is gravitationally inert. It does not couple to the gravitational field as a source term. The cosmological constant problem is therefore an artifact of an incorrect assumption that all forms of energy density must gravitate.

The observed dark energy, ρ_Λ, is not the vacuum energy of QFT. The relation $\Omega_\Lambda \approx 0.69$ simply represents the fraction of the primordial universe's energy that was never confined into mass-energy structures (holes).

In summary, the EHM dissolves the cosmological constant problem by:

1) *Denying the gravitational coupling* of unconfined energy.
2) *Providing a physical criterion (confinement/synthesis)* to distinguish between gravitating and non-gravitating energy contributions.
3) *Identifying dark energy* as the static energy of the vacuum background rather than the dynamic energy of quantum fluctuations.

This offers a natural explanation for the observed acceleration of the universe, directly arising from the model's core principles.

6.2 Physical Origin of Dark Matter and Dark Energy

The standard ΛCDM model, though phenomenologically successful, treats baryonic matter, dark matter, and dark energy as independent components with distinct origins [25]. The EHM, by contrast, proposes a unified origin, such that all components trace back to the primordial radiation field of the early universe. In this view, the formation of baryonic matter and dark matter results in *energy holes* (deficits), while dark energy is the residual vacuum energy not bound into matter. The observed present-day energy budget is: $\Omega_b \sim 0.05, \Omega_{\rm dm} \sim 0.26$, and $\Omega_\Lambda \sim 0.69$ partitioned from the primordial energy density of radiation [26]

$$U_{\rm rad} = aT^4, \qquad T \sim 10^{12}\,{\rm K}, \tag{24}$$

where a is the radiation constant. Within EHM, the primordial energy reservoir is partitioned as follows:

1. **Baryonic Matter ($\sim$ 5%):** Baryonic mass consists of protons, neutrons, and bound electrons. About 5% of the primordial energy is used to form the baryonic mass, which corresponds to the formation of *baryonic energy hole*:

$$\text{hole}_b = -\Omega_b E,$$

where E is the total energy of the universe.

2. **Dark Matter ($\sim$ 26%):** Nearly 26% of the primordial energy is used to form non-luminous, non-baryonic deficits in the vacuum energy. DM contributes *dark matter hole*:

$$\text{hole}_{\text{dm}} = -\Omega_{\text{dm}} E.$$

3. **Dark Energy ($\sim$ 69%):** The residual undisturbed vacuum energy, not confined into holes, is

$$E_{\text{de}} = \Omega_{\Lambda} E.$$

   Unlike baryons or dark matter, this is not a new substance.

Thus, baryonic and dark matter correspond to attractive energy holes, while dark energy represents the positive residual component which causes repulsion. Unlike GR, which treats all contributions as positive energy sources, EHM distinguishes between deficits (holes) and residuals, naturally accounting for both attraction and repulsion. The partition is summarized in Table 2. In summary, the EHM:

Table 2 Partitioning of cosmic energy in EHM

Component	Fraction	EHM Interpretation
Baryonic Matter	$\sim$ 5%	Energy deficit from primordial photons
Dark Matter	$\sim$ 26%	Non-baryonic energy deficit
Dark Energy	$\sim$ 69%	Energy of the undisturbed vacuum

a) Proposes a unified origin for the cosmic constituents from a primordial energy reservoir.
b) Explains dark energy as a fundamental property of the vacuum, eliminating the cosmological constant problem.
c) Provides a physical mechanism for attraction (energy deficits) and repulsion (positive vacuum energy) within a single conceptual framework.

In the EHM picture, dark energy corresponds to the residual positive vacuum energy that was never confined into mass. This component does not generate an energy hole and thus does not attract; instead, it is gravitationally repulsive, driving the accelerated expansion of the Universe. This stands in contrast to confined forms of energy (baryonic and dark matter), which produce energy holes and hence attractive gravity.

This reframing offers a parsimonious and conceptually coherent alternative to the ΛCDM paradigm, directly addressing the nature of its dark components. By redefining dark energy as the undisturbed positive-energy vacuum rather than the quantum vacuum energy, the EHM severs the link between the Planck-scale predictions and the observed value of Ω_{Λ}, thereby resolving the cosmological constant problem.

6.3 Energy Hole Formalism for Black Holes

A black hole singularity is a region in spacetime where the gravitational field, density, and curvature become infinite according to the theory of general relativity. It is the central point of a black hole where all its mass is thought to be concentrated into an infinitely small and dense point [8, 27]. Energy hole formalism is used here to show that the black hole interior is regular, with a smooth decay of the potential. It is widely believed that black holes consist predominantly of neutrons, albeit in a state of extreme quantum confinement. The neutrons in a black hole are viewed as embedded sources of quantum vacuum distortion. Each neutron induces a localized energy hole field, which overlaps and merges within the highly dense black hole interior. For analytical treatment, we approximate the collective effect of all constituent neutrons via a smooth, spherically symmetric energy hole density. This continuum approximation effectively captures the gravitational trapping properties and replaces classical singularities with a finite, exponentially localized energy deficit field. To model a black hole in the EHM framework, we assume maximal confinement by taking the decay length of the energy hole field to be the Planck length.

6.3.1 Schwarzschild Radius from EHM

In classical general relativity, the Schwarzschild radius is the radius where the escape velocity equals the speed of light [28, 29]. Analogously, in EHM we define the Schwarzschild radius R_s as the radius where the gravitational potential equals half the rest energy per unit mass (consistent with escape velocity):

$$|\Phi(R_s)| = \frac{1}{2}c^2. \tag{25}$$

To model a black hole in the EHM framework, we assume maximal confinement by taking the decay length of the energy hole field to be the Planck length:

$$L = \ell_P. \tag{26}$$

Based on (10) of EHM model, we get the hole density profile of the black hole as

$$\rho_H^{(\mathrm{BH})}(r) = -\frac{Mc^2}{4\pi\ell_P r^2} e^{-r/\ell_P}. \tag{27}$$

Using it in the modified Poisson equation (20) we get the black hole potential:

$$\frac{GM}{R_s}\left(1 - e^{-R_s/\ell_P}\right) = \frac{1}{2}c^2. \tag{28}$$

In the large mass limit $R_s \gg \ell_P$, the exponential term vanishes, yielding the classical Schwarzschild radius:

$$R_s = \frac{2GM}{c^2}. \tag{29}$$

This interpretation shows:

- The Schwarzschild radius arises as a critical point in the energy-hole profile,
- The black hole interior is regular, with a smooth decay of the potential,
- The classical horizon is replaced by a transition region of strong but finite curvature.

6.3.2 Singularity-Free Black Holes

Classical GR predicts singularities at the centers of black holes, where curvature and energy density diverge. EHM resolves this by introducing an energy hole with a finite spatial extent characterized by the Planck length, ℓ_P. The energy density profile is

$$\rho_H(r) = -\frac{Mc^2}{4\pi\ell_P(r+\lambda)^2}e^{-(r+\lambda)/\ell_P},$$

which remains finite for all $r \geq 0$, including the origin. The corresponding gravitational potential

$$\Phi_{\rm BH}(r) = -\frac{GM}{r}\left(1 - e^{-r/\ell_P}\right) \tag{30}$$

This potential approaches zero smoothly at $r = 0$, eliminating the divergence inherent in the Schwarzschild solution of GR.

The introduction of ℓ_P as a natural cutoff is not arbitrary; it corresponds to the fundamental Planck scale, where quantum gravitational effects become significant. Thus, EHM incorporates Planck-scale physics to regularize the black hole core without the need for ad-hoc boundary conditions.

6.3.3 Smooth Gravitational Trapping without a Hard Horizon

In GR, the Schwarzschild radius $R_s = 2GM/c^2$ defines a sharply defined event horizon, a boundary beyond which no information can escape. EHM replaces this "hard" horizon with a smooth gravitational potential gradient generated by the energy hole. The potential increases gradually, attaining relativistic strength near the Planck scale while remaining finite and continuous. This results in a dynamically saturating geometry that avoids curvature singularities and allows spatial regions to encode information, providing a potential resolution to the black hole information paradox.

The continuous energy hole structure also naturally accommodates vacuum fluctuations at the Planck scale. Unlike classical horizons, which are mathematical boundaries, the EHM horizon emerges as a threshold in the cumulative energy deficit, beyond which light and matter are dynamically trapped.

7 Modified Energy-Based Friedmann Equations

The Friedmann equations are fundamental governing equations of physical cosmology, which describe the expansion dynamics of a homogeneous and isotropic universe [30, 31]. We discuss this to show how EHM isolates positive and negative energy contributions to describe cosmic dynamics.

7.1 First Friedmann Equation

The first Friedmann Equation fundamentally represents the energy conservation law for an expanding universe, connecting the expansion rate to the total mass-energy content and geometry. It is given by:

$$H^2 = \left(\frac{\dot{a}}{a}\right)^2 = \frac{8\pi G}{3c^2}\rho_{\text{total}} - \frac{kc^2}{a^2} \tag{31}$$

where H is the Hubble parameter, representing the expansion rate of the universe. The scale factor $a(t)$ is a dimensionless number that tracks the relative expansion of the universe, defined such that $a(t_0) = 1$ at the present cosmic time. ρ_{total} is the total energy density, comprising the sum of all forms of mass-energy. For the late universe, where radiation is negligible while matter and dark energy dominate the expansion dynamics, we have:

$$\rho_{\text{total}} = \rho_m c^2 + \rho_\Lambda \tag{32}$$

where ρ_m is the mass density of all matter (baryonic and dark matter). ρ_Λ is the dark energy density [32]. The curvature parameter k takes values $+1$, -1, or 0 for closed, open, and flat universes, respectively. Since current observational data strongly favour a flat universe ($k = 0$), and since curvature does not fundamentally affect the EHM formulation, we assume $k = 0$. Substituting (32) into (31) with $k = 0$ yields the modified Friedmann equation:

$$H^2 = \frac{8\pi G}{3c^2}(\rho_\Lambda - \rho_H) \tag{33}$$

This formulation is mathematically equivalent to the standard flat ΛCDM case under the EHM identification $\rho_H = -\rho_m c^2$. The presence of ρ_Λ represents the positive contribution of dark energy generating repulsive expansion, while the negative sign preceding ρ_H signifies the positive energy contribution of matter that enables expansion by working against attractive gravity.

7.2 Second Friedmann Equation

The Second Friedmann Equation is another fundamental equation of physical cosmology that describes the acceleration dynamics of the expansion of the universe. While the first Friedmann equation acts as an energy constraint, the second equation governs the motion and acceleration of cosmic expansion. The standard form of the second Friedmann equation is derived from Einstein's field equations and the fluid equation for cosmological expansion:

$$\frac{\ddot{a}}{a} = -\frac{4\pi G}{3c^2}(\rho_{\text{total}} + 3p) \tag{34}$$

where $\ddot{a}/a$ represents the acceleration of the scale factor a, ρ_{total} is the total energy density, and p is the pressure.

For matter (dust), the equation of state is $p_m = 0$. For dark energy, the equation of state is $p_\Lambda = -\rho_\Lambda$ [33]. Substituting these into (34):

$$\frac{\ddot{a}}{a} = -\frac{4\pi G}{3c^2}\left[(\rho_m c^2 + \rho_\Lambda) + 3(0 - \rho_\Lambda)\right] \tag{35}$$

Simplifying and using the EHM identification $\rho_H = -\rho_m c^2$:

$$\frac{\ddot{a}}{a} = \frac{4\pi G}{3c^2}\left(\rho_H + 2\rho_\Lambda\right) \tag{36}$$

The term $\rho_H = -\rho_m c^2$ represents the attractive gravitational influence of matter via its negative energy hole and contributes to the retardation of expansion, while the term $2\rho_\Lambda > 0$ represents the repulsive gravitational influence of dark energy contributes to the acceleration the expansion. This formulation captures the essential EHM hypothesis that mass is associated with a negative energy hole that generates attraction, and its interplay with repulsive dark energy naturally reproduces the observed late-time cosmic acceleration. The factor of 2 instead of 3 in the repulsive pressure term comes directly from the equation of state of dark energy ($w = -1$). Equation (36) explains clearly that in the early universe, $|\rho_H| \gg 2\rho_\Lambda$ resulted in decelerated expansion. The current era satisfies the condition $|\rho_H| \approx 2\rho_\Lambda$, which represents a balance between acceleration and deceleration, and the future universe could result in rapid expansion if $|\rho_H| \ll 2\rho_\Lambda$.

Since the EHM model is derived from the standard ΛCDM model, it is guaranteed to fit all existing cosmological data exactly as well as the standard ΛCDM model does. This includes:. This includes: Cosmic Microwave Background (CMB) power spectra from Planck [34], Baryon Acoustic Oscillation (BAO) measurements [35], Supernova Ia (SNIa) distance-redshift data [36], Big Bang Nucleosynthesis (BBN) constraints [37].

The value of the EHM is not in making new numerical predictions for these observables, but in providing a novel physical interpretation of the existing, successful equations. It reframes the source of gravity from positive mass-energy to a negative energy density, offering a different conceptual foundation for the same mathematical model.

8 Photon Propagation in the Energy Hole Field

To study the photon propagation in the hole field, we evaluate the change in frequency and momentum due to energy-energy interaction according to the EHM, followed by the effective refractive index.

8.1 Energy and Momentum Transfer in the Hole Field

For any probe with energy E, the leading-order interaction energy is

$$\delta U = \frac{E}{c^2}\Phi, \tag{37}$$

which follows directly from EHM Postulate-3 on energy minimization. This form mirrors the GR weak-field energy shift of photons in a static gravitational potential [38, 39].

Substituting ($E = h\nu$) and ($\delta U = h\delta\nu$) in (37), we find the photon frequency shift:

$$\delta\nu = \nu\frac{\Phi}{c^2} \quad \text{or} \quad \delta\omega = \omega\frac{\Phi}{c^2}, \tag{38}$$

and the momentum (wavenumber) shift:

$$\delta k = -k\frac{\Phi}{c^2}. \tag{39}$$

Thus, at radius r the frequency and wavenumber become

$$\omega(r) \approx \omega_0\left(1 + \frac{\Phi}{c^2}\right), \quad k(r) \approx k_0\left(1 - \frac{\Phi}{c^2}\right), \tag{40}$$

where ω_0 and k_0 are values at infinity ($\Phi \to 0$).

8.2 Effective Refractive Index

The phase velocity $v_{\text{ph}} = \omega/k$ at radius r from (40) is

$$v_{\text{ph}}(r) = \frac{\omega(r)}{k(r)} \simeq c\,\frac{1 + \Phi/c^2}{1 - \Phi/c^2}. \tag{41}$$

Hence the effective refractive index is

$$n(r) = \frac{c}{v_{\text{ph}}(r)} \simeq 1 - \frac{2\Phi}{c^2}, \tag{42}$$

valid for $|\Phi|/c^2 \ll 1$. This result coincides with the standard effective-index approach to light bending in GR [40, 41]. For a spherically symmetric hole potential, the solution of EHM modified Poisson's equation (20) yields,

$$\Phi_H(r) \approx -\frac{GM}{r}. \tag{43}$$

Substituting into (42),

$$n(r) = 1 + \frac{2GM}{c^2 r}. \tag{44}$$

This has the correct asymptotic behavior $n(r) \to 1$ as $r \to \infty$.

8.3 Light Bending via Fermat's Principle

In an inhomogeneous medium, Fermat's principle implies deflection [42]. For impact parameter b, the bending angle is [43]:

$$\alpha = \int_{-\infty}^{\infty} \frac{1}{n(r)}\frac{dn}{dr} \cdot \frac{b\,dr}{\sqrt{r^2 - b^2}}. \tag{45}$$

Using (44), $dn/dr = -2GM/(c^2 r^2)$, the weak-field limit gives

$$\alpha_{\mathrm{EHM}} \approx \frac{4GM}{c^2 b}, \tag{46}$$

which exactly reproduces the Einstein deflection angle [39].

8.4 Shapiro Delay via Optical Path

The photon speed is reduced to

$$v(r) = \frac{c}{n(r)}. \tag{47}$$

The excess travel time is

$$\Delta t = \frac{1}{c} \int (n(r) - 1)\, dl. \tag{48}$$

Substituting (44) yields the classic Shapiro delay [39, 44]:

$$\Delta t = \frac{2GM}{c^3} \ln\left(\frac{4 r_e r_o}{b^2}\right). \tag{49}$$

8.5 Gravitational Redshift

For emission at r_e and observation at r_o, energy conservation in EHM gives

$$\frac{\Delta\nu}{\nu} = -\frac{\Delta\Phi}{c^2}, \tag{50}$$

which is the leading-order GR prediction [29, 38]. Near Earth's surface, this reduces to the Pound–Rebka result [45].

9 Conclusion

This paper introduces the EHM, which reinterprets gravity not as a force generated by mass, but as the dynamical effect of energy deficits, termed *energy holes*, in spacetime. These arise concurrently with energy confinement during the synthesis of mass. From this core premise, the EHM consistently recovers the Newtonian and post-Newtonian limits, satisfying classical tests of general relativity such as light bending, Shapiro delay, and gravitational redshift. The model further shows that the black hole interior is regular, with a smooth decay of the potential, while the classical horizon is replaced by a transition region of strong but finite curvature.

The validity of EHM is formally established through the derivation of modified Friedmann equations in which the energy hole itself sources gravitational attraction. The proposed framework provides a unified and physically intuitive resolution to several open problems in modern cosmology. It reframes the cosmological constant problem as a violation of the core principles of EHM, identifies dark matter as a manifestation of additional non-baryonic energy deficits, and interprets dark energy as residual primordial energy.

Finally, the EHM establishes a fundamental link between quantum energy confinement, spacetime thermodynamics, and emergent gravity. Future work will focus on extending this framework to unresolved problems at the intersection of quantum gravity and astrophysics, including a rigorous thermodynamic formulation of energy holes, modeling the interior structure of neutron stars and their glitch phenomena, and exploring its implications for the final state of gravitational collapse.

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