Abstract

This paper proposes a unified conceptual framework in which a single continuous physical mechanism underlies space, time, and cosmic structure. Expansion-Defined Relativity (EDR) defines expansion of space as the physical process that sets the local rate of time. The distribution of mass-energy shapes the rate of this expansion, which causes different regions of the universe to evolve at different speeds. These differences create expansion gradients that drive large-scale behaviour and the evolution of cosmological structure. Voids accelerate as they empty; Galactic outskirts experience outward expansion gradients that raise orbital speeds; Early time-rate slowing creates the appearance of a sudden beginning; And large-scale structure emerges from expansion-driven void growth rather than matter-driven collapse. The result is a coherent physical picture in which longstanding cosmological tensions arise naturally from self-reinforcing differential expansion rates.

EDR is constructed to recover General Relativity [1] like behaviour in the weak-field regime, but offers a distinct physical foundation: gravity arises from gradients in suppressed expansion, which mirror GR's spatial warping in effect.

Although this paper does not present a completed mathematical theory, it does propose a candidate model and master equation. Its purpose is to establish a coherent conceptual framework and define the physical boundary conditions that any future formal mathematical formulation of EDR must satisfy.

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1 Introduction

EDR is a conceptual framework built around a single physical principle: the generative production of spatial substrate sets the local time-rate. The purpose of this paper is to articulate that principle, explore its physical consequences, and define the boundary conditions that any future mathematical formulation must satisfy. The focus throughout is on the internal logic of EDR itself rather than on comparisons with existing models.

Spatial expansion [2] is a physical process, the local strength of which determines how fast time runs. Where mass-energy suppresses expansion, the time-rate slows; where expansion is unhindered, the time-rate is faster. Variations in expansion shape clocks, lengths, trajectories, and cosmic evolution. These accumulate across cosmic distances, becoming significant at cosmological scales. Expansion variations also define the effective shape of the environment, meaning that the structure through which bodies move can be viewed as an emergent geometry created by expansion.

Foundational Axioms (the minimal assumptions EDR requires):

1. Expansion is a monotonic intrinsic physical property of space.
2. Mass-energy suppresses expansion.
3. The local rate of expansion sets the local rate of time; expansion and time-rate are inseparable - they are two sides of the same coin.

EDR's axioms support both Direct and Indirect Time-Coupling interpretations. While this paper focuses on the Direct interpretation for its physical clarity, the implications of this distinction, and how it allows EDR to bridge with existing GR-based frameworks, are detailed in Section 6.

Immediate Consequences (what follows directly from the axioms):

- Gravity emerges from differential expansion; time-rate differences and the resulting length deficit reproduce General Relativity (GR) like behaviour in the weak-suppression limit [1].
- Expansion produces an outward pressure; this repulsive component is masked inside bound systems and absorbed into inferred values of mass and G.
- All physical processes inherit the local expansion-defined time-rate; motion, light frequencies, and quantum phase evolution follow the local rate of expansion.

Think of expansion as the local "heartbeat" of space: clocks slow where mass suppresses this heartbeat, and clocks run faster where expansion is free. Because the local time-rate is tied directly to expansion, which in turn drives a length deficit, EDR provides a unified picture of gravitational time-rate slowing, black hole horizons, cosmic acceleration, and the large-scale structure of the universe.

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2 Conceptual Foundations of Expansion-Defined Relativity

2.1 Expansion as a Physical Quantity

Spatial substrate is generated on an ongoing basis as an intrinsic property of space itself [2]. This continual production of new space defines expansion and sets both lengths and local time-rates: regions with higher mass-energy density suppress expansion and therefore run on slower clocks and exhibit a spatial deficit, while emptier regions evolve more quickly and contain more spatial volume. Only the relative differences in expansion matter; EDR is concerned with relationships between neighbouring regions and not any absolute background.

2.2 Local Proper-Time Rates

Any physical clock - atomic, quantum, or mechanical - ticks at the pace set by this process, providing an operational definition of proper time tied to the local expansion rate. Elapsed time is simply the accumulated amount of that proper time. Because all physical processes run at this local rate, each region experiences its own physics as perfectly normal and self-consistent.

2.3 Length Deficit

Length deficits arise where regions that expand more slowly accumulate less new spatial substrate over time. When two regions with different expansion histories are compared, distances within the slower region are correspondingly shorter. Length deficit is therefore the emergent consequence of evolving in a slower-expanding environment, and the resulting difference in realised spatial extent forms part of the gentle geometric structure that emerges from the expansion process.

2.4 Emergent Gravity

Gravity emerges in proximity to mass-energy. The resulting suppressed expansion drives the linked effects of slowed local time-rate and length deficit. Reduced expansion produces slower local clock rates, and this immediate change alone causes trajectories to bend toward regions where time runs more slowly. Objects naturally take the paths that minimise accumulated proper-time and realised distance, reflecting the structure shaped by expansion. The same suppression also produces a length deficit that accumulates with elapsed time, which further steepens the effective gradient experienced by moving objects.

Conceptually, the pattern of expansion acts like a gently shaped landscape, and objects naturally follow the paths defined by this emergent geometric structure.

Local time-rate differences therefore provide the immediate expression of suppressed expansion, whilst length deficit is the long term accumulated spatial expression of the same underlying process. Together, these two manifestations of differential expansion reproduce the full gravitational behaviour attributed to curvature in General Relativity [1].

2.5 Suppression, Gradients, and Cosmic Structure

Mass-energy suppresses expansion. Voids, which experience minimal suppression, evolve on faster clocks and expand more rapidly. Regions with higher mass-energy density evolve more slowly, allowing rapidly expanding voids to grow and push matter into sheets, clusters, and filaments. This expansion-driven mechanism naturally generates the observed large-scale cosmic structure without relying on matter-dominated collapse.

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2.6 Observational Asymmetries

Each region evolves according to its own expansion-defined time-rate. Observations and interpretations made from one region of another region running at a different time-rate inevitably mix different evolutionary stages. This mismatch produces several apparent large-scale effects - behaviours that look like new components or dramatic events when interpreted through a single universal time-rate [3].

3 Physical Consequences

3.1 Gravity as Suppressed Expansion (GR Equivalent Behaviour)

Mass-energy locally suppresses expansion and the local time-rate. The combination of the instantaneous time-rate effect and the cumulative spatial deficit effect - both arising from the same suppressed expansion - shapes the surrounding environment in a way that mirrors the behaviour described by General Relativity [1]. Because the underlying geometries are equivalent, objects follow the resulting gradients exactly as they would follow GR geodesics.

The familiar geometric behaviour arises naturally from how expansion varies across space, making geometry a consequence rather than a starting point. The difference lies in interpretation:

- GR models gravity as geometric curvature of spacetime.
- In EDR, the equivalent geometry is the physical consequence of slowed time and the emergence of a length deficit near mass.

This produces identical predictions for local gravitational phenomena. EDR does not modify GR's tested predictions; it explains them physically. Locally suppressed expansion produces the same gravitational behaviour that GR attributes to curvature, while allowing new large-scale behaviour to emerge from differential expansion gradients.

EDR adds one further ingredient: spatial expansion produces an outward pressure. This pressure is stronger in regions where expansion is less suppressed (e.g. in proximity to spatial voids). In dense regions, where expansion is heavily suppressed, the outward pressure is minimal. In bound systems like the Solar System, this outward pressure is absorbed into current orbital mass estimates, making it observationally invisible. It is however conceptually important, as it underlies several large-scale phenomena discussed later.

Both the inward pull near mass and the outward expansion pressure in emptier regions arise from gradients in the rate of expansion. Because these gradients form in three-dimensional space, their influence decreases with distance following an inverse square law. The attractive effect of suppressed substrate-generation near mass and the repulsive effect of freer generation in surrounding regions therefore share the same radial scaling, and the outward component is perfectly masked inside bound systems.

3.2 Refractive Gravity, Light Bending, and GR Equivalent Geodesics

Because EDR reproduces the same curvature-equivalent behaviour that GR attributes to curved spacetime, light follows the same geodesic paths in both frameworks. The bending of light near mass is therefore identical in its observable behaviour.

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This arises because spatial expansion and the local time-rate change together. When light passes through a region where expansion is suppressed, this combined effect alters the effective optical path in a manner equivalent to GR's curved spacetime. Light simply follows the locally fastest route through this shaped environment, just as it does in any medium whose properties vary smoothly.

The result is the same deflection measured by Eddington [4]: light follows the path of least accumulated time and distance through a region where expansion is slowed. In EDR, the path of light reflects the gentle shaping of space created by expansion gradients, rather than an underlying geometric structure; this behaviour is an implicit consequence of how expansion and time-rate change in lockstep.

3.3 Emergent Gravity Consequences

The instantaneous slowing of time-rates and the accumulation of spatial deficit are two tightly coupled consequences of the same underlying expansion suppression in proximity to mass-energy. Together, these effects define the effective shape of the environment, giving rise to the geometric behaviour associated with gravitational motion.

Any stable distribution of mass-energy establishes a fixed pattern of fractional expansion-rate differences between neighbouring regions. The time-rate at each location reflects this pattern directly. The spatial deficit reflects the same pattern viewed through its accumulated expansion history. When the suppression pattern is stable, both expressions share the same characteristic scale: one reflects the immediate effect, the other reflects the long-standing imprint of that same suppression pattern.

In such regimes, the two contributions naturally become comparable in magnitude because they are both determined by the same fixed fractional differences in expansion-rate. The immediate and accumulated expressions of expansion suppression act together with similar weight. For null paths, this leads to the familiar 50:50 division between temporal and spatial contributions used in GR's description of light deflection. EDR does not impose this ratio; it arises because both contributions trace the same underlying suppression structure and therefore align in scale in stable environments. This ensures that EDR reproduces the observed GR equivalent behaviour of gravitational lensing and other null-path phenomena in weak-field environments.

A crucial point is that spatial deficit is not a static imprint left behind in space – EDR does not imply an "Ether". Spatial deficit is the expansion shortfall of the region currently experiencing suppression and therefore moves with the matter that defines that region. Because the deficit moves with the matter, no fixed background or preferred frame is introduced. Suppression patterns are dynamic: as mass-energy flows, the associated pattern of fractional expansion-rate differences is carried with it. The effective gravitational contribution from spatial deficit therefore depends on the historical stability of the local suppression pattern. Regions where the suppression pattern has remained coherent for extended periods exhibit the full spatial-deficit contribution, while regions where the pattern is still evolving exhibit a reduced and similarly evolving contribution.

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4 Apparent Phenomena

4.1 Differential Evolution

Comparing regions that evolve at different rates from a single vantage point produce several apparent large-scale effects that mirror longstanding cosmological tensions [3]:

- Apparent acceleration arises when fast-running voids are observed from slower regions.
- Apparent dark matter emerges from outward expansion gradients that, amongst other effects, raise galactic orbital velocities.
- Apparent early-time behaviour results from strong suppression in dense early environments, compressing the entire early evolution into what appears to be a sudden beginning from our faster-running vantage point.
- Apparent uniformity follows from observing regions at the same distance but at different physical ages.

These effects arise naturally when regions that evolve at different speeds are interpreted from a single vantage point and hence through a single assumed universal time-rate.

4.2 Galactic Outskirts and Apparent Dark Matter

Stars nearer the periphery of galaxies are closer to surrounding voids where expansion is higher. This creates outward expansion gradients that boost orbital velocities. No unseen mass is required [12]; the effect arises because regions at different radii are subject to different expansion-defined effects, and the resulting outward gradient increases the orbital speeds of stars in the outskirts.

4.3 Early Time Black Hole and Galaxy Formation

In early time the universe was vastly denser than today, and this high background density suppressed expansion everywhere. With expansion heavily suppressed, the environmental threshold for gravitational binding was dramatically lower. When the background expansion rate was already small, even modest local suppression produced a large fractional reduction in expansion. It is this fractional change that matters, because gravitational attraction depends on the relative difference in expansion rate between neighbouring regions, not the absolute suppression magnitude. A fixed local reduction therefore generates a far more significant gradient in early time than it does today, where the background expansion rate is much higher and small suppressions are proportionally less significant. For example, a notional 10-unit drop in expansion rate could represent a 50% reduction relative to the background rate in the early universe (a large gradient), but only a 5% reduction in the present epoch (a much smaller gradient). The resulting gradients were therefore much stronger in early time when mass-energy density was higher, granting gravity a far greater influence and allowing structures to form and grow far more readily than they can today.

Because expansion sets the rate of time, these early regions also ran on much slower clocks. Internally, all processes slowed together, so pressure, rotation and turbulence behaved normally in their own proper-time. The apparent difference arises only when these slow-clock systems are viewed from our faster-running vantage point: formation and growth that were entirely ordinary in their own time appear unusually rapid to us.

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Under these conditions, early black holes and galaxies could accumulate mass to large scales before stabilising, naturally producing the unexpectedly massive and mature systems observed at high redshift.

4.4 Black Holes as Gradient Horizons

A black hole is an extreme mass-energy dense region where expansion becomes extremely small. As density increases, expansion is progressively suppressed and time slows (i.e., the local time-rate decreases). This slowing of time also slows gravitational collapse, creating a self-reinforcing spiral that prevents total collapse to a singularity in finite real time. The interior instead becomes a region of extremely slow time.

The surface of the black hole is not a sharp surface (event horizon) but a steep gradient in expansion and time-rate. This steep gradient acts like a sharply curved region in the emergent geometry of space. Escape is not forbidden in principle; it is simply governed by the extremely slow time inside the gradient region. The horizon appears sharp only because the time-rate contrast becomes so large that outward motion becomes observationally negligible.

In principle, light may traverse outward through the gradient, but wavelengths are stretched so extremely that by the time it reaches us it lies far beyond the cosmic microwave background, rendering it observationally indistinguishable from complete confinement. Black holes therefore appear perfectly black, not because escape is impossible, but because any escaping radiation is shifted beyond detectability.

4.5 Quantum Time

Quantum phase evolution depends on proper-time. Given proper-time is defined by expansion, quantum frequencies and decay rates are not fundamental clocks but emerge from the local expansion rate itself. Time is not a coordinate but the emergent rate of spatial expansion that sets the pace of quantum phase evolution. This places quantum evolution on the same underlying time-base as gravitational and cosmological processes.

4.6 The Arrow of Time

Expansion is intrinsically monotonic: new spatial fabric is created continuously and is never destroyed. Mass-energy can slow expansion locally, but nothing undoes it. Because expansion proceeds in only one direction, the rate of proper-time inherits this one-way character. The arrow of time therefore arises directly and inevitably from the universe's expansion.

4.7 Masking of Expansion Effects in Mass and Gravitational Constant Measurements

EDR predicts a small outward expansion pressure that counterbalances the inward pull created by suppressed expansion around mass. In bound systems, both influences decrease with distance according to the same inverse-square law, so the outward component is absorbed into the net attraction. Orbital measurements therefore absorb this outward pressure into the inferred values of $M$and G, making the locally measured values effective quantities that already include the compensating term.

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This masking breaks only in the presence of a strong external expansion gradient. The Solar System provides such a case: its ~60° tilt relative to the Milky Way disc, combined with its position ~20–30 light-years above the galactic mid-plane, places it across a persistent gradient between the dense galactic interior and the surrounding intergalactic medium, producing a small directional acceleration that cannot be cancelled internally.

Historical astrometric anomalies are consistent with this external gradient perturbing the otherwise hidden masking loop. This includes the secular increase of the astronomical unit, the slow growth of the Moon's orbital eccentricity, and velocity shifts during spacecraft gravity assists.

5 Cosmological Evolution

Having described how differential expansion shapes local and apparent phenomena, we now turn to how the same generative process drives the universe's long-term physical evolution.

5.1 The Genesis of Cosmic Evolution

In the early universe, a natural dual-perspective picture emerges:

- Internal Perspective - a Finite Beginning:
  For observers inside the system, tracing the clock backwards leads to a definite start. The moment expansion rises even slightly above zero, the internal cosmic clock begins, and the first physical interaction occurs. Because internal time is counted by these ticks the universe has a finite, measurable internal age.
- External Perspective - an Eternal Origin:
  From a hypothetical outside viewpoint, the early universe is effectively static. With mass-energy at its maximum, expansion is held at an infinitesimal value, and where expansion is effectively zero, the time-rate is zero and no proper-time accumulates. The universe therefore exists in a state of timelessness until the first interaction initiates an extremely slow, gradually accelerating evolution. It need have no beginning.

This means the universe can appear young from the inside even when its underlying evolution is potentially eternal from the outside, because such suppressed regions record far less elapsed time. In this view, the Big Bang was not an explosion in a pre-existing timeline, but a smooth transition in which time itself "switched on" and accelerated. The familiar impression of a sudden beginning is simply the internal perspective of a clock accelerating away from rest.

5.2 Voids and the Cumulative Acceleration of Expansion

In low-density voids, expansion is unsuppressed and the time-rate is higher. As voids expand and eject matter, their density drops further, reducing suppression and accelerating expansion. This feedback loop produces genuine physical acceleration.

When measured from slower-running galactic clocks, this acceleration appears even stronger, creating the observed cosmic acceleration.

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5.3 Long-Term Evolution of Galaxies and Black Holes

Early-formed galaxies and black holes evolved differently from structures that formed later due to a lower threshold for gravitational binding. As the universe expanded and density fell, the background expansion strengthened and time began to run faster. Outward gradients increased as voids grew, internal support became more effective, and the outer regions of early-formed galaxies became progressively less tightly bound. Over cosmic time these galactic outskirts were gradually stripped away by expansion gradients, tidal fields, and differential evolution, leaving behind the smaller galaxies we observe in the present day.

A number of consequences follow naturally from the same gradient mechanism that shapes rotation curves, without requiring additional forces or components:

- Central black holes retain the imprint of their early growth, remaining disproportionately massive relative to their diminished host galaxies.
- Galaxies are likely to exhibit a sharper outer boundary where gravitational binding breaks down, especially as the boundary moves inwards over time towards denser regions.
- A proportion of dwarf galaxies and satellite systems would have originated from previously bound but expelled material rather than primordial collapse.
- Such satellite systems would be more likely to lack central supermassive black holes and exhibit chemical and motion signatures consistent with outer-halo origin.
- These satellites would also tend to occupy coherent spatial or orbital planes and show tidal-like chemical signatures.
- Outward drift of shed material into coherent streams and clouds would be natural.

The picture that emerges is one of continual shedding and reshaping, where the imprint of early growth remains visible even as galaxies evolve into their present forms.

5.4 Attractors to Cosmic Web Structure

Large-scale structure arises from void growth rather than matter collapse. Slight underdensities in the early universe expanded more rapidly, becoming voids where growth accelerates as suppression weakens. Matter is pushed outward into sheets, filaments, and walls.

EDR predicts that cosmic evolution naturally converges toward two attractors:

- Voids grow in regions of mass underdensity.
- Galaxies form and evolve in regions of mass overdensity.

Together, these attractors generate the familiar cosmic web. This state emerges robustly, independent of initial conditions or the precise values of EDR's underlying constants, meaning no fine-tuning is required for the universe to evolve into its observed large-scale structure.

6 Alternative Modelling Interpretation: Direct vs Indirect Time-Coupling

EDR's third axiom states that the local time-rate is inseparable from the behaviour of spatial expansion. This single axiom can be read in two ways, producing two modelling interpretations that share the same physical content.

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6.1 Direct Time-Coupling Interpretation

This is the interpretation developed throughout this paper. The local expansion rate is the local time-rate. Time is the directly realised pace of physical evolution, and the universe unfolds through a genuine process of becoming. Horizons, early-time behaviour, and the arrow of time follow naturally from this direct coupling.

6.2 Indirect Time-Coupling Interpretation

The same axioms also permit a more traditional emergent-spacetime reading. This interpretation aligns with any framework that employs the General Relativity (GR) mathematical ontology [1] - including ΛCDM, relativistic MOND-like models, emergent-gravity approaches, TeVeS-style formulations, and other metric-based theories.

In this view, expansion behaviour shapes an emergent spacetime geometry, and time is treated as a coordinate within that geometry. The physical behaviour of the universe is unchanged: suppression near mass, gradients, large-scale evolution, and all observable consequences remain identical. What differs is the ontological backdrop, not the physics.

6.3 Interpretational, not physical, difference

Both interpretations originate from the same axioms and describe the same universe. The distinction is purely one of ontological preference: whether time is taken to be directly coupled to expansion, or indirectly coupled through emergent spacetime geometry. They are empirically equivalent, making the choice of interpretation a matter of physical clarity rather than empirical prediction.

The Direct Time-Coupling interpretation is used in this paper because it provides a clearer physical account of horizons, early-time behaviour, and the arrow of time. However this is an ontological preference only - readers who prefer a GR-style spacetime ontology may adopt the Indirect Time-Coupling interpretation without altering any physical predictions.

6.4 Interpretational Differences in Extreme Regimes

Although both interpretations produce identical physical behaviour in all observable regimes, they diverge conceptually in situations where the GR mathematical ontology introduces known singular structures. These differences arise not from new physics but from the interpretational consequences of Axiom 3.

6.4.1 Black Holes under Direct vs Indirect Time-Coupling

In the Direct Time-Coupling interpretation, extreme suppression of expansion slows the local time-rate toward zero, preventing collapse from completing in finite realised time. The interior becomes a region of extremely slow evolution rather than a true singularity.

In the Indirect Time-Coupling interpretation, any model that inherits the GR global structure retains the mathematical singularity implied by the spacetime manifold.

6.4.2 Early-Time / Big-Bang Behaviour

In the Direct Time-Coupling interpretation, the apparent beginning reflects the slow-to-fast transition of the expansion-defined time-rate: the universe accelerates out of an effectively timeless state.

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In the Indirect Time-Coupling interpretation, any GR-ontology-based model recovers the familiar coordinate-time singularity, as time is treated as a coordinate within an emergent spacetime geometry.

7 Target Boundary Conditions for Mathematical Modelling

This paper deliberately avoids committing to any specific mathematical formalism for EDR. The underlying mechanism could be expressed through a scalar-like equation, a modified tensor structure, or an entirely different framework. In principle, the gravitational constant in GR [1] could be replaced with a more elaborate expression that incorporates the outward expansion pressure EDR predicts, but doing so would add further complexity to GR's already intricate machinery. By contrast, a formulation built directly around expansion - whether through a field-like equation or a reframed treatment of spacetime - may offer a far simpler route. In EDR, expansion is not treated as the motion of space through an external background or medium, but as the local emergence of new spatial substrate itself.

The purpose of this section is therefore not to prescribe the mathematics, but to define the physical outputs that any valid EDR formulation must reproduce. The following conditions set out the physical behaviour that any such formulation must be able to deliver, regardless of the mathematical route it takes.

7.1 Gravitation as a Mixture of Attraction and Repulsion

Any valid formulation of EDR must reproduce GR equivalent [1] gravitational behaviour in the weak-suppression limit, where expansion is only slightly reduced by mass-energy. At the same time, it must naturally include a repulsive component that emerges as suppression falls. This repulsive behaviour is not an added force but the direct consequence of local expansion returning toward its unsuppressed background state. As mass-energy density decreases, the attractive contribution weakens while the repulsive contribution strengthens, reaching a peak steady state in the deepest cosmic voids. Measured galaxy rotation curves and sizes provide a potential means of bounding this effect.

7.2 Effective Constants and the Masking of Expansion Pressure

Any mathematical formulation of EDR must account for the fact that the gravitational constant used in practice is not a fundamental parameter but an effective one. Because all local measurements of G and GM rely on orbital dynamics, and because those dynamics already include the outward expansion pressure predicted by EDR, the inferred values of $G$and GMincorporate this hidden repulsive contribution.

A valid EDR formulation must therefore reproduce the observed value of Gas the equilibrium result of two opposing influences: the attractive effect of suppressed expansion near mass, and the outward pressure associated with unsuppressed expansion in the surrounding region. In regions where these two components fall off together, the effective constant remains stable and GR equivalent. In regions where the balance is disturbed - such as across large-scale galactic gradients - the effective constant must shift in a way that produces the small, directional accelerations observed in high-precision astrometric data.

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This requirement ensures that any mathematical model of EDR captures both the local masking behaviour that makes GR so successful in bound systems, and the subtle departures that arise when the system is exposed to asymmetric expansion environments.

7.3 The Unitary Metric Condition

Time and space must remain explicitly tied to the same underlying process of spatial expansion. This ensures that clocks and yardsticks scale together, recovering correct light-bending and time-delay behaviour. This ensures that the familiar geometric relationships between time, distance, and motion arise naturally from expansion.

7.4 The Local Gradient Condition

The spatial distribution of expansion must vary inversely with mass-energy density. Mass acts as a local sink for expansion, creating smooth gradients in the local expansion rate that reproduce the inverse-square law of gravity. Expansion must approach a stable background value in low-density voids. These gradients are treated as continuous local variations in realised spatial extent rather than discontinuities between separate spatial regions. In the weak-suppression limit, small perturbations must reproduce Newtonian predictions.

7.5 Causality and Local Convergence Conditions

Changes in expansion must propagate at the finite cosmic speed limit [8]. The equations cannot permit instantaneous action-at-a-distance. In weak-suppression regimes, the model must converge smoothly with established calculations, accurately reproducing:

- Mercury's perihelion shift
- Gravitational redshift [5]
- Light bending
- Shapiro delay [6]
- GPS-level time dilation [7]

7.6 Cosmic Microwave Background (CMB)

Changes predicted by EDR, such as redshift and void lensing alterations, must not contradict existing highly precise measurements of the CMB.

7.7 Co-Moving Suppression and Non-Etheric Behaviour

Any valid formulation of EDR must treat spatial deficit as a co-moving property of the region currently experiencing suppressed expansion. Spatial deficit cannot be a static imprint tied to fixed spatial coordinates nor lag behind moving matter. Suppression patterns must move with the matter that defines them, ensuring that no preferred background frame or ether-like structure is introduced. Changes in suppression must propagate relationally and remain consistent with the finite causal speed limit.

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8 Candidate Mathematical Framework

Note: the following derivation is not presented as a finished theory, nor is it the only way to mathematically formalise Expansion-Defined Relativity. EDR is first and foremost a conceptual framework - a physical description of how space, time, and matter interact through differential expansion.

The equations below provide a candidate mathematical realisation of the mechanism that serves as a structural proof-of-concept. They demonstrate that spatial expansion is the physical process setting the local time-rate, and naturally yields the behaviours we observe in the universe. This is provided as a baseline to invite collaborative formalisation, whether through this scalar-field approach or alternative mappings such as fluid dynamics, tensor equations etc.

8.1 The Expansion Field

Unlike standard scalar-tensor theories which treat the scalar field as an auxiliary modification to gravity, this derivation elevates the expansion rate itself to a dynamical field (ϕ), positing that gravity is the emergent gradient of this field's suppression.

The behaviour of the expansion field (ϕ), which dictates the local expansion rate, is governed by its response to mass-energy density. $\phi(x,t)$ represents the realised local expansion rate - the physical rate at which new spatial substrate is generated. Because expansion and time-rate are inseparable, the local proper-time rate is directly proportional to ϕ.

8.2 The Master Equation

The master equation is:

$$\ddot{\phi} - \nabla^2\phi + \lambda(\phi - S) = -\beta(\rho_m - 3p_m)$$

Where:

λ is the constant defining the restoring strength of the expansion field, and controls how quickly suppressed regions recover and how far expansion-suppression effects extend.

$S$is the constant defining the natural expansion rate that space settles into in the absence of any mass-energy to interfere with it.

β is the coupling constant, defining the strength of the interaction between matter and the expansion field.

ϕ is the expansion field value (the local state of expansion).

$\ddot{\phi}$ is the acceleration of the expansion field's evolution over time.

$\nabla^2\phi$ is the spatial gradient, measuring how the expansion rate changes from one point in space to another.

$\lambda(\phi - S)$ is the restoring force, representing the field's physical tendency to relax toward its natural state (S).

$\rho_m - 3p_m$ is the source terms, where ρ_m is the density of matter-energy and p_m is its internal pressure, which together act to suppress the field.

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8.3 Emergence of the Sink Behaviour

In EDR, an ad hoc sink equation is not required. The sink behaviour - the tendency of matter to aggregate - is an emergent property of the Master Equation.

- Mechanism: Where mass-energy density (ρ_m) is high, the source term on the right becomes large and negative, forcing the expansion field $\phi$to drop below its natural state (S).
- The Sink: This localised suppression of the expansion rate creates a steep field gradient ($\nabla^2\phi$). Because the local time-rate is coupled to the expansion rate, matter effectively slides down this expansion gradient toward regions of higher suppression. This is the physical mechanism of gravity: a flow toward the sink created by the differential expansion gradient.

8.4 From Newtonian Behaviour to GR-like Dynamics

In weak-suppression environments $\phi = \phi_0 + \delta\phi$, where ϕ_0 is the background expansion rate and $\delta\phi$ is a small local deviation caused by mass-energy. Established physics is recovered across different scales through the following limit-derivations:

1. The Newtonian Limit (The Poisson Link). In the weak-field, static limit, the time-dependent term (ϕ) vanishes. The Master Equation simplifies to:

   $$-\nabla^2\phi \approx -\beta\rho_m$$

   By setting the expansion field ϕ equal to the gravitational potential Φ, this becomes:

   $$\nabla^2\Phi = 4\pi G\rho_m$$

   This confirms that the EDR field-gradient is mathematically identical to the Newtonian Poisson equation, with β mapping directly to the gravitational constant ($4\pi G$).

2. The GR Recovery (The Dynamic Limit). In high-density or high-velocity regimes, the field is no longer static. The curvature of GR is represented as the spacetime variation of the local expansion rate. By performing a perturbation analysis where $\phi = \phi_0 + \delta\phi$ (a small fluctuation in the expansion field), the Master Equation yields:

   $$\Box\delta\phi \propto T^{\mu}_{\mu}$$

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(where □ is the D'Alembertian operator and T^{μ}_{μ} is the trace of the stress-energy tensor). This is structurally consistent with the same first-order dynamical behaviour that underlies GR's tested predictions, and that the expansion field fluctuation propagates at the speed of light and couples to matter-energy density, providing the exact wave-like behavior required to replicate:

- Mercury's perihelion shift
- gravitational redshift [5]
- light bending
- Shapiro delay [6]
- GPS-level time dilation [7]

8.5 The Indirect Interpretation: ϕ as a Time-Independent Field on a GR-Style Manifold

EDR treats ϕ as the physically meaningful expansion field whose spatial variation drives all gravitational-like behaviour. In the direct time-coupling interpretation, ϕ may depend on the local physical time-rate, reflecting the underlying expansion-defined ontology.

However, readers who prefer to work within a GR-style 4D spacetime picture may adopt an alternative, indirect time-coupling interpretation in which ϕ is treated more simply. In this indirect interpretation, Λ is replaced by ϕ, which is a time-independent scalar field defined on a GR-style manifold. This time-independent treatment applies in the static limit and is not intended as a general solution to the master equation, which retains full time-dependence. No physical meaning is assigned to the GR time coordinate, and no attempt is made to represent EDR's physical notion of time-rate within the GR framework. Instead, $\phi(x)$ is understood purely as a spatial field whose gradients may be used by GR-ontology models to represent the same underlying expansion-defined behaviour.

This construction is not a new theory and does not introduce new dynamics. It is simply a way for GR-ontology models (including ΛCDM, MOND-relativistic approaches, emergent-gravity frameworks, TeVeS, and others) to represent the spatial structure of ϕ within their preferred geometric language. The physical ontology remains that of EDR; the GR-style picture is merely a representational choice. In other words, the indirect interpretation is a downstream reformulation of the same underlying ϕ field, not an alternative to it.

8.6 Exploratory AI Modelling

Preliminary exploratory modelling using AI-assisted scalar-tensor analogues suggests that screened parameter regimes may exist which are not immediately excluded by first-order Solar System constraints. However, these calculations remain unverified and require independent verification and formal analysis.

9 Falsifiable Predictions

EDR makes several concrete observationally testable predictions that follow directly from its core principles. These predictions differ from both standard General Relativity [1] and dark-matter-based cosmology and therefore offer clear opportunities for empirical validation.

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Several of these predictions can be tested directly through meta-analysis of existing datasets, while others point to longer-term observational programmes.

9.1 A Unified Galactic Gradient Signature in Solar System Astrometry

EDR predicts that the Solar System's ~60° tilt relative to the Milky Way's disc, combined with the solar system being ~20-30 light years above the galactic mid-plane, creates a persistent, directional background acceleration vector oriented perpendicular to the ecliptic. This arises from the asymmetric expansion gradient between the dense galactic interior and the low-density intergalactic medium. The presence of this predicted asymmetry can be tested via a meta-analysis of existing Lunar Laser Ranging (LLR), planetary radar ranging, and flyby Doppler datasets without requiring new observations. To the author's knowledge, the identification of these anomalies as a unified galactic gradient signature, with a consistent predicted direction and physical mechanism, has not previously appeared in published literature.

9.1.1 Directional Background Acceleration and Secular Drift in Solar System Astrometry

The internal masking loop ensures that local measurements of G and GM absorb the outward expansion pressure. However, when the Solar System is exposed to an external gradient, this balance is perturbed. EDR predicts a consistent, direction-dependent drift in orbital elements that would not be expected to arise from symmetric gravitational fields or dark matter halos [9].

Testable signatures:

a) Long-baseline astrometric datasets - including Lunar Laser Ranging (LLR) and planetary radar ranging - should reveal a consistent, direction-dependent drift in orbital elements aligned with the galactic gradient direction.

   A small, steady increase in the astronomical unit has been measured at:

   $$\dot{a} = 15 \pm 4 \frac{m}{cy}$$ [10].

   Similarly, the Moon's orbital eccentricity shows a secular increase of:

   $$\dot{e} = (5 \pm 2) \times 10^{-12} yr^{-1}$$ [9].

EDR predicts both anomalies arise from the same background acceleration vector produced by the galactic gradient.

9.1.2 Flyby Anomalies as a Function of Trajectory Orientation

EDR predicts that spacecraft passing through Earth's gravitational well will experience small, trajectory-dependent residuals depending on whether their inbound and outbound paths align with or cut across the galactic expansion gradient.

Testable signature:

a) Future Earth flybys with carefully controlled approach vectors should reproduce the pattern already seen in historical data:

   - Parallel to the gradient → measurable Δv (e.g., NEAR: +13.46 mm/s [13])
   - Perpendicular to the gradient → null result (e.g., Cassini: +0.11 mm/s [13])

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Such directional flyby behaviour would be difficult to explain naturally within standard GR or dark matter frameworks alone [13].

9.1.3 Unified Explanation for AU Drift and Lunar Eccentricity Growth

In 2011, Lorenzo Iorio demonstrated that both anomalies could be simultaneously satisfied by a single, unexplained background acceleration vector scaled to the Hubble parameter [14]. EDR identifies the galactic expansion gradient as the physical source of Iorio's empirically required acceleration vector.

Testable signature:

a) The magnitude and direction of the inferred acceleration from AU drift and lunar eccentricity growth should match each other and align with the predicted galactic gradient direction.

9.2 Rotation-Curve Asymmetries Correlated with Void Proximity

EDR predicts that galaxies near large cosmic voids experience stronger outward expansion gradients on their outer edges. This raises orbital velocities without requiring dark matter.

Testable signature:

a) Galaxies adjacent to deep voids should show systematically higher outer rotation speeds than morphologically similar galaxies embedded in denser environments [12].

9.3 Evidence of Galactic Mass Shedding since Early-Time Formation

The galactic evolutionary model predicted by EDR offers a number of simple, falsifiable predictions:

Testable signature:

a) Dwarf galaxies formed from shed material should show no evidence of central black holes and should preferentially lie in coherent spatial or orbital structures around their parent systems.
b) Coherent stellar streams and gas clouds should be observable around many galaxies, preferentially aligned in orbital planes relative to their parent systems.
c) Deep-field surveys should reveal the progressive imprint of mass shedding across successive epochs of cosmic time.

Preliminary evidence for these behaviours already exists, but systematic quantification and correlation with EDR’s predictions remain essential for validation.

9.4 Void-Driven Cosmic Acceleration Without Dark Energy

EDR predicts that cosmic acceleration is a real physical effect driven by the expansion of deep voids, amplified by differential time-rates.

Testable signature:

a) The apparent acceleration should correlate with void distribution and depth. Large-scale surveys such as DESI, Euclid, and LSST should detect anisotropies in the Hubble flow aligned with major void structures.

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9.5 Clock-Rate Differences Between Voids and Galaxies

Because expansion and time-rate are the same physical process in EDR, clocks in low-density voids should tick faster than clocks in galaxies.

Testable signature:

a) Precision timing of astrophysical clocks - pulsars, FRBs, and quasars - should reveal a small but measurable environmental dependence in frequency stability or redshift drift when comparing sources in voids versus sources in clusters.

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10 Plain-English Summary

Imagine the universe as a foam of regions that age at different rates. The bubbles are cosmic voids; the membranes are where matter collects and galaxies are found.

The central idea of EDR is that expansion does not happen in time - it creates time. Regions with more mass-energy suppress this generative process, causing their internal clocks to run more slowly, while emptier regions evolve more quickly. The familiar geometric behaviour of gravity is not assumed but emerges from how expansion is locally suppressed around matter.

When we observe these different regions from our own vantage point, we interpret them through our local time-rate, which creates several "apparent" effects:

- Apparent Acceleration: Because voids evolve on faster-running clocks, their expansion appears to us to be accelerating. In EDR, this is a real physical process driven by void growth, amplified by the time-rate contrast.
- Apparent Dark Matter: Outward expansion gradients near the edges of galaxies naturally boost orbital velocities, removing the need to invoke unseen dark matter.
- Apparent Early-Time Behaviour: In the dense, early universe, strong expansion suppression compressed the entire evolutionary history. To our faster-running clocks, this creates the appearance of a "sudden beginning," even if the underlying process is fundamentally eternal.

Large-scale structure grows from this expansion pushing matter aside, rather than from matter pulling itself together through gravity alone. Because cosmic behaviour follows from the interaction of expansion and suppression, the universe can appear young from the inside even if its underlying evolution is potentially eternal from the outside.

EDR shows how a hot, dense early phase, rapid structure formation, and today’s large-scale patterns can all arise naturally from differential expansion. It explains why gravity behaves exactly like General Relativity in testable regimes like the Solar System, while adding an outward expansion pressure that becomes visible only across large-scale gradients which shape the wider cosmos. By tying time itself to the physical generation of space, EDR turns many of the universe’s longstanding cosmological tensions into natural consequences of the framework.

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11 Glossary of Terms

Differential Expansion: Differences in local expansion rate between neighbouring regions of space. In EDR, these gradients produce the effects associated with gravitation.

Direct Time-Coupling: A conceptual interpretation of EDR in which the local rate of spatial expansion is identified as the fundamental physical process generating the local rate of time. In this view, time is a directly realised process of physical evolution, rather than an emergent coordinate within a pre-existing geometry.

EDR (Expansion Defined Relativity): The proposed physical framework in which time, gravitation, and large-scale cosmic behaviour emerge from variations in spatial expansion and its suppression by mass-energy.

Effective Gravitational Constant: Within the EDR interpretation, the observed gravitational constant behaves as an effective equilibrium parameter reflecting both attractive expansion suppression near mass and outward pressure associated with unsuppressed expansion.

Expansion: In EDR, expansion is the continual generation of spatial substrate and realised spatial extent. The local rate of this generative process determines the local rate of proper-time.

Expansion Suppression: The local reduction of expansion caused by mass-energy. In EDR, expansion suppression produces slower local time-rates, reduced spatial extent, and the gradients associated with gravitation.

Gradient: A smooth spatial difference in local expansion rate between neighbouring regions. In EDR, gravitational effects emerge from such gradients.

General Relativity (GR): Einstein's theory describing gravitation as the behaviour of spacetime geometry in the presence of mass-energy.

Indirect Time-Coupling: A conceptual interpretation of EDR compatible with General Relativity's geometric ontology. In this view, spatial expansion behaviour generates an emergent spacetime geometry, within which time is treated as a coordinate. While the underlying physical expansion-gradients remain identical to the Direct interpretation, this view frames the resulting universe through the lens of a metric-based spacetime manifold.

Length Deficit: The reduction in realised distance that develops over time in regions where expansion has been more strongly suppressed. In EDR, length deficit is the accumulated consequence of slower local expansion and accompanies local time-rate slowing.

Local Expansion Rate: The realised local condition of expansion within a region of space, determining the local rate of time and realised spatial extent.

Mass-Energy: The combined physical quantity associated with matter, radiation, and energy. In EDR, mass-energy locally suppresses expansion.

Monotonic Expansion: Expansion that proceeds continuously in one direction over cosmic time without global reversal.

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Outward Expansion Pressure: A repulsive component associated with unsuppressed expansion. In EDR, this pressure is weakest in dense regions where expansion is heavily suppressed and strongest in low-density regions where expansion is freer. Within bound systems it is normally masked inside inferred values of mass and the gravitational constant.

Proper-Time: The locally experienced passage of time measured by physical clocks. In EDR, proper-time is determined directly by the local expansion rate.

Realised Spatial Extent: The physically realised separation associated with a region of space. In EDR, realised spatial extent depends on the local expansion history: regions with stronger expansion possess greater accumulated spatial extent, while regions with suppressed expansion possess less.

Spatial Substrate: The underlying spatial structure whose continual generation constitutes expansion in EDR. The term does not imply a material medium or ether, but refers to the realised physical structure associated with spatial extent.

Time-Rate: The local rate at which physical processes evolve. In EDR, the time-rate is set directly by the local expansion rate: regions with more strongly suppressed expansion accumulate less elapsed proper-time than regions where expansion is less suppressed.

Unitary Metric: The principle that time-rate and realised spatial extent remain coupled through the same underlying expansion dynamics, ensuring that clocks and spatial measurements scale consistently.

Void: A large-scale low-density region of the universe in which expansion suppression is weak and expansion approaches its background state.

Weak Suppression Limit: The regime in which expansion suppression is small enough that EDR converges closely with Newtonian gravity and the weak-field predictions of General Relativity.

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Invitation for Collaboration

This paper sets out the core idea behind Expansion-Defined Relativity (EDR): that the rate of time is coupled with the rate of expansion, and that mass-energy slows both. The aim here isn't to present a finished theory, but to lay out a clear conceptual foundation that ties together gravity, time, cosmology, and several long-standing anomalies in a single, coherent way.

The next stage is to turn this framework into a full mathematical structure. That will need people with the right background in GR, scalar-field theory, cosmology, or related areas who can see the potential in the underlying idea and want to help shape it into something formal and testable. The candidate master equation takes a mathematically intuitive scalar wave form, making initial exploratory work accessible without the full apparatus of general relativity - a meaningful reduction in the barrier to entry.

If the core principle resonates with you - or if you can see a way to push the maths further - I'd welcome a conversation.

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