EXPANSION-DEFINED RELATIVITY (EDR)

A conceptual framework by David Suttle

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.

This paper does not present a completed mathematical theory. Its purpose is to establish a coherent conceptual framework and define the physical boundary conditions that any future mathematical formulation of EDR must satisfy.

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Zenodo Concept DOI: https://doi.org/10.5281/zenodo.20111434

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.

Foundational Axioms (the minimal assumptions EDR requires):

1. Expansion is an intrinsic physical monotonic 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.

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.

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.

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.

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.

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. The same suppression also produces a length deficit that accumulates with elapsed-time, which further steepens the effective gradient experienced by moving objects.

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.

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 difference lies in interpretation:

- GR models gravity as geometric curvature.
- In EDR, the same behaviour 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.

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.

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, 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.

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. 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.

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.

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. 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.

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 places it across a persistent gradient between the dense galactic plane 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.

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 towards denser regions over time.
- 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 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.

6.1 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.

6.2 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 GM incorporate this hidden repulsive contribution.

A valid EDR formulation must therefore reproduce the observed value of G as 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.

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.

6.3 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.

6.4 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.

6.5 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]

6.6 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.

6.7 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.

6.8 Toy Candidate Mathematical Framework

The following mathematical sketch is intended purely as an illustrative toy framework demonstrating one possible route to formalising EDR concepts. It is not presented as a completed or unique formulation of the theory. The model below adopts a scalar-field-inspired approach for conceptual simplicity, but alternative formulations based on tensor dynamics, fluid analogies, emergent geometry, or other mathematical structures may ultimately prove more appropriate.

The purpose of this section is therefore not to provide a rigorous derivation, but to establish a plausible mathematical scaffold consistent with the conceptual boundary conditions discussed throughout this paper.

6.8.1 The Unitary Metric

Time-rate and realised spatial extent are tethered to the same local expansion mechanism. The metric is expressed as:

$$ds^2 = -F(\phi)^2 c^2 dt^2 + F(\phi)^2 (dr^2 + r^2 d\Omega^2)$$

This is constructed to recover the observed coupling between light bending and Shapiro delay [6] by scaling both clocks and yardsticks through the same field.

6.8.2 The Sink Equation

$$\nabla^2 \phi = \alpha \rho$$

Mass acts as a local sink for ϕ, creating smooth gradients consistent with inverse-square gravitational behaviour in the weak-field limit. ϕ approaches a constant background value in low-density voids, providing the boundary condition for the sink equation. In the weak-field limit, small perturbations in ϕ reproduce the Newtonian potential and the inverse square law.

6.8.3 GR Recovery Condition

$F(\phi)$ is a monotonic function of ϕ, ensuring that suppressed expansion corresponds to slower time and reduced spatial scale. EDR is constructed to recover the leading weak-field phenomenology associated with the classical tests of GR. This requires:

$$F\big(\phi(r)\big)^2 \approx 1 + \frac{2\phi(r)}{c^2}$$

ensuring consistency with:

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

6.9 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.

7 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.

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

7.1 A Directional Background Acceleration Aligned With the Galactic Gradient

Because the Solar System's orbital plane is tilted by ~60° relative to the Milky Way's disc, EDR predicts a small but persistent acceleration vector perpendicular to the ecliptic. This arises from the asymmetric expansion gradient between the dense galactic interior and the low-density intergalactic medium.

Testable signature:

a) Long-baseline astrometric datasets - including Lunar Laser Ranging (LLR) and planetary radar ranging - should reveal a consistent, direction-dependent drift in orbital elements that cannot be explained by symmetric gravitational fields or dark matter halos [9].

7.2 Secular Drift in Planetary Orbits Beyond GR Predictions

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.

Testable signature:

a) A small, steady increase in the astronomical unit has been measured at $\dot{a} = 15 \pm 4\text{''} \frac{m}{cy}\text{''}$ [10].
b) Similarly, the Moon's orbital eccentricity shows a secular increase of $\dot{e} = (5 \pm 2) \times 10^{-12}\ \text{''}yr\text{''}^{-1}$ [9]

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

7.3 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])

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

7.4 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].

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.

7.5 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].

7.6 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.

7.7 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.

7.8 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.

8 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.

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.

9 Future Direction of Study

The goal of this paper has been to establish the foundations of Expansion-Defined Relativity. Because the framework treats time, gravity, and cosmic scale as emergent properties of spatial expansion, it also opens the door to potential new interpretations of longstanding questions.

Differential expansion can produce apparent acceleration, altered rotation curves, early-time compression, and large-scale structure without invoking new substances or modifying gravity. By grounding cosmic behaviour in the evolution of local time-rates, EDR attempts to provide a more intuitive physical interpretation and proposes a route by which several apparently disconnected effects emerge from the same single physical mechanism.

These ideas are exploratory and require formal modelling. But by anchoring macro- and microscopic anomalies to a single mechanism, EDR provides a coherent architectural blueprint for re-examining the universe. Such future work may explore the following directions.

9.1 Hypothesised Quantum-Scale Mechanism Underlying EDR

The core principles of EDR do not depend on any specific underlying mechanism. The framework is defined as the coupling of expansion and the time-rate, the suppression of local expansion by mass-energy, and the resulting gradients that reproduce gravitational behaviour. However, it is natural to ask whether these rules arise from a deeper quantum-scale process. The following outlines one possible mechanism. It is a speculative hypothesis, and not required for EDR validity, but it illustrates how wave-mechanical behaviour at the smallest scales might emerge from EDR.

At the quantum scale, a particle has no independent clock - its internal evolution is governed entirely by the local expansion rate. The particle behaves as a continuous wave structure embedded within a locally expanding spatial substrate. As local spatial extent increases through expansion, the particle must continually adjust its internal configuration. This adjustment follows a repeating two-step cycle:

- Micro-stretch ("stick") - expansion slightly overextends the particle's wave structure.
- Rapid relaxation ("slip") - the wave structure reconfigures back to equilibrium once the overstretch becomes unsustainable.

This cycle acts as a microscopic clock, with its frequency set by the local expansion rate. It provides a physical basis for why the local time-rate is driven by the local rate of expansion.

A useful analogy is the interaction between a violin bow and a string: the bow's continuous motion drives a repeating stick–slip pattern that sets the string's vibration and harmonics. In EDR, the expansion field plays the role of the bow, and the particle's wave structure plays the role of the string. Just as the slow drawing of a bow across a string stimulates rapid vibrations, harmonics, and sound waves, the EDR stick–slip mechanism drives rapid quantum evolution, motion, and light from even tiny increments of spatial expansion.

Crucially, the stick-slip mechanism could also provide the microscopic process through which suppression physically manifests. It does not oppose motion through space; it only resists the generation of new substrate. Uniform motion experiences no friction. Expansion suppression is therefore a local stabilising effect resisting changes in realised spatial extent, not a viscous resistance to velocity.

9.2 First and Second Laws of Thermodynamics

It is hypothesised that the Laws of Thermodynamics are emergent properties of EDR, in particular:

The First Law of Thermodynamics (energy cannot be created or destroyed, only transferred or transformed) arises because bound systems settle into equilibrium with local expansion so their internal energy becomes stable and effectively conserved.
The Second Law of Thermodynamics (entropy always increases) arises because expansion is monotonic and irreversibly increases accessible space, and any sequence of state changes in such a monotonically expanding environment cannot be undone, which makes entropy growth unavoidable.

9.3 Symmetries with Standard Model

EDR raises the possibility that some features of the Standard Model may emerge from deeper expansion dynamics. If cosmic expansion reflects an active physical process with internal structure, rather than simply a passive background effect, then certain particle properties may reflect stable patterns formed within that structure.

In this picture, inertial mass could arise when a localised quantum state becomes stabilised within the surrounding expansion flow, resisting changes in state because it remains dynamically coupled to the underlying expansion pattern. Other interactions may similarly reflect different stable modes or phase relationships within the same expansion driven process.

Under such a framework, electromagnetic, weak, and strong interactions could represent different manifestations of a common underlying dynamical structure expressed in different ways at different energy scales. The existence of three particle generations likewise hints at higher-order stability modes or harmonic structures within the same deeper mechanism.

Similarly, it's conceivable that quantum entanglement represents the manifestation of phase-locked harmonics established between particles, providing a persistent link that appears as non-local state information until the harmonic structure is disturbed. Within the EDR framework, this frames entanglement not as a violation of locality, but as a signature of a deeper connectivity inherent in the spatial expansion process itself, appearing in quantum interactions as the non-local correlation of state information.

9.4 Baryon Asymmetry

EDR also raises the possibility that the universe's monotonic expansion may have contributed to the emergence of baryon asymmetry in the early universe [15]. Within quantum field theory, matter and antimatter arise as excitations of underlying quantum fields. If the expansion-driven temporal structure proposed by EDR subtly influences these field dynamics under extreme early-universe conditions, it is possible that tiny symmetry-breaking effects could emerge between matter and antimatter evolution.

In such a scenario, small differences in the stability, decay behaviour, or interaction rates of matter and antimatter states during baryogenesis may accumulate over time as virtual particle pairs continually form and decay within the rapidly evolving early universe, ultimately leaving a residual excess of matter. EDR therefore raises the possibility that cosmological expansion itself may contribute to the conditions required for baryon asymmetry, without necessarily invoking entirely separate symmetry-breaking mechanisms.

9.5 Summary

None of the ideas discussed in this section are required for the core validity of EDR. They are presented only as possible avenues for future exploration arising from the framework's central coupling between expansion and time. Whether any of these speculative extensions prove physically meaningful will depend entirely on future mathematical development and observational consistency.

10 Glossary of Terms

Baryogenesis: The hypothesised early-universe process through which a small imbalance between matter and antimatter emerged, ultimately leaving the observable universe dominated by matter.

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

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.

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

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.

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.

11 References

[1] Einstein, A. (1916). *The Foundation of the General Theory of Relativity.* Annalen der Physik, 49, 769–822.

[2] Hubble, E. (1929). *A Relation Between Distance and Radial Velocity Among Extra-Galactic Nebulae.* Proceedings of the National Academy of Sciences, 15(3), 168–173.

[3] Planck Collaboration. (2020). *Planck 2018 Results. VI. Cosmological Parameters.* Astronomy & Astrophysics, 641, A6.

[4] Dyson, F. W., Eddington, A. S., & Davidson, C. (1920). *A Determination of the Deflection of Light by the Sun's Gravitational Field, from Observations Made at the Total Eclipse of May 29, 1919.* Philosophical Transactions of the Royal Society A, 220, 291–333.

[5] Pound, R. V., & Rebka, G. A. (1960). *Apparent Weight of Photons.* Physical Review Letters, 4(7), 337–341.

[6] Shapiro, I. I. (1964). *Fourth Test of General Relativity.* Physical Review Letters, 13(26), 789–791.

[7] Will, C. M. (2014). *The Confrontation Between General Relativity and Experiment.* Living Reviews in Relativity, 17(1), 4.

[8] Bertotti, B., Iess, L., & Tortora, P. (2003). *A Test of General Relativity Using Radio Links with the Cassini Spacecraft.* Nature, 425, 374–376.

[9] Williams, J. G., Turyshev, S. G., & Boggs, D. H. (2004). *Progress in Lunar Laser Ranging Tests of Relativistic Gravity.* Physical Review Letters, 93, 261101.

[10] Krasinsky, G. A., & Brumberg, V. A. (2004). *Secular Increase of the Astronomical Unit from Analysis of the Major Planet Motions, and its Interpretation.* Celestial Mechanics and Dynamical Astronomy, 90, 267–288.

[11] Williams, J. G., & Boggs, D. H. (2009). *Lunar Tidal Acceleration and the Lunar Eccentricity Anomaly.* Proceedings of the 16th International Workshop on Laser Ranging.

[12] Tully, R. B., Pomarède, D., Graziani, R., Courtois, H. M., Hoffman, Y., & Dupuy, A. (2019). *Cosmicflows-3.* Astrophysical Journal, 880, 24.

[13] Anderson, J. D., Campbell, J. K., Ekelund, J. E., Ellis, J., & Jordan, J. F. (2008). *Anomalous Orbital-Energy Changes Observed During Spacecraft Flybys of Earth.* Physical Review Letters, 100, 091102.

[14] Iorio, L. (2011). *On the Effects of a Hubble-Scale Acceleration on the Astronomical Unit and the Lunar Orbital Eccentricity.* Monthly Notices of the Royal Astronomical Society, 415, 1266–1275.

[15] Sakharov, A. D. (1967). *Violation of CP Invariance, C Asymmetry, and Baryon Asymmetry of the Universe.* Soviet Physics Uspekhi, 34, 392–393.

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.

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

Latest Version DOI: https://doi.org/10.5281/zenodo.20111434
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