EXPANSION-DEFINED RELATIVITY (EDR)

A conceptual framework by David Suttle

Abstract

This paper presents Expansion-Defined Relativity (EDR), a framework in which the expansion of space is treated as the physical process that sets the local rate of time. Variations in expansion, shaped by the distribution of mass-energy, cause different regions of the universe to evolve at different speeds. When observations made from one region are applied to others, these differing time rates generate several apparent large-scale phenomena. EDR is constructed to recover GR-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, while also introducing an outward pressure from expansion that GR does not include. This outward pressure is effectively invisible because orbital dynamics absorb it into inferred values of mass and G. In this framework, voids accelerate as they empty, galactic outskirts experience outward expansion gradients that raise orbital speeds, early-time suppression 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 puzzles arise naturally from differential expansion.

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.

1 Introduction

Expansion-Defined Relativity treats spatial expansion as a physical process whose local strength determines the local rate of time. Instead of adding new components or modifying existing laws, EDR focuses on how variations in expansion shape clocks, trajectories, and cosmic evolution. The central idea is simple: time runs at the rate space expands. Where mass-energy suppresses expansion, time slows; where expansion is unhindered, time runs faster. These differences accumulate across cosmic structures and become significant at large scales.

Key principles:

- Expansion is an intrinsic property of space.
- Expansion and time are inseparable; they are the same physical process – two sides of the same coin.
- The passage of time is the local rate of expansion, setting the pace of motion, light frequencies, and quantum phase evolution.
- Mass-energy suppresses expansion, slowing local time.
- Gravity is an emergent property of the resulting time dilation and length contraction, reproducing GR-like behaviour.
- Expansion adds an outward pressure that GR does not include, which is masked by current quantitative orbital mass and Gravitational Constant measurements.

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

EDR is presented here as a conceptual framework built around a single physical principle: the generative production of spatial fabric sets the local rate of time. 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.

2 Conceptual Foundations of Expansion-Defined Relativity

2.1 Expansion as a Physical Quantity

In EDR, space is generated on an ongoing basis, and this continual production of spatial fabric is what constitutes expansion. This generative process sets the local rate of time: regions with higher mass-energy density suppress the generation of spatial fabric and therefore run on slower clocks, while emptier regions evolve more quickly.

The local expansion rate is the rate at which spatial fabric is produced. Expansion is a monotonic constructive process: space grows through the continual generation of new fabric, and the rate of this production directly dictates the rate of time. Any physical clock -atomic, quantum, or mechanical - ticks at the pace set by this generative process, providing an operational definition of time that is tied directly to the local rate at which spatial fabric is produced rather than to the motion or separation of existing points.

2.2 Local Time Rates

The rate at which time passes is set directly by the local rate of expansion. Regions where expansion is suppressed evolve more slowly and accumulate less elapsed time than regions where expansion is less suppressed. Different local time rates follow directly from differing expansion rates: slower-expanding environments run on slower clocks, while faster-expanding environments run on faster ones.

2.3 Length Contraction

Length contraction arises because regions that expand more slowly accumulate less new spatial fabric over time, making it the long-term expression of the same suppressed expansion that slows local time. Expansion continually builds the size of distances, so an environment with reduced expansion simply generates space at a slower rate. When two regions with different expansion histories are compared, the slower region has produced less cumulative spatial growth, and its measured distances appear correspondingly shorter. Length contraction is therefore the emergent consequence of evolving in a slower-expanding environment.

2.4 Emergent Gravity

Gravity emerges from the linked effects of local time rates and length contraction created by suppressed expansion near mass-energy. Slower expansion immediately produces slower local clock rates, and this alone causes trajectories to bend toward regions where time runs more slowly. Over longer periods, the same suppression also reduces the cumulative growth of new space, producing length contraction that further steepens the effective gradient experienced by moving objects. Local time rate differences therefore provide the immediate expression of suppressed expansion, and the resulting length contraction is the accumulated expression of the same underlying process. Together, these two manifestations of differential expansion reproduce the full gravitational behaviour attributed to curvature in General Relativity.

2.5 Suppression, Gradients, and Cosmic Structure

Mass-energy suppresses expansion. Voids, experiencing minimal suppression, evolve rapidly and expand into their surroundings. Denser regions evolve more slowly, allowing voids to grow and push matter into sheets, clusters, and filaments. This expansion-driven mechanism naturally generates the observed large-scale structure without relying primarily on matter-dominated collapse.

2.6 Observational Asymmetries

Each region evolves according to its own expansion-defined clock. Observations made from one region and applied to another 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 Physical Consequences

3.1 Gravity as Suppressed Expansion (GR-Equivalent Behaviour)

In EDR, mass-energy locally suppresses expansion and the local rate of time. The combination of the instantaneous time-rate effect and the cumulative spatial-scale effect - both arising from the same suppressed expansion - shapes the surrounding environment in a way that mirrors the behaviour described by General Relativity. Objects follow the resulting gradients exactly as they would follow GR geodesics, because the underlying geometry they experience is effectively identical.

The difference lies in interpretation:

- GR treats curvature as a geometric postulate.
- In EDR, curvature-like behaviour is the physical consequence of how time is slowed and length contraction emerges near mass.

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

EDR adds one further ingredient: spatial expansion produces an outward pressure. This pressure is inversely proportional to the amount of empty space available to expand into. In dense regions, where expansion is heavily suppressed, the outward pressure is minimal. In emptier regions, where expansion is freer, the outward pressure is larger. 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 at which spatial fabric is generated. Because these gradients form in three-dimensional space, their influence naturally falls with an inverse-square dependence. The attractive effect of suppressed fabric-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 is constructed to reproduce the same curvature-like 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.

In EDR, this arises because spatial expansion and the local rate of time change together. When light passes through a region where expansion is suppressed, this combined effect alters the effective optical path in exactly the way GR's curved spacetime does.

The result is the same deflection measured by Eddington: 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 co vary.

3.3 Emergent Gravity Consequences

In EDR, the same underlying suppression of expansion has both an instantaneous effect on local clock rates and a cumulative effect on spatial scale, and the balance between these two expressions of one process evolves over cosmic time. In the early universe, apparent expansion was rapid and spatial differences had little time to accumulate, so gravity was dominated by the instantaneous time-rate effects. As the universe aged and the apparent global expansion rate slowed, differences in accumulated spatial fabric increased until the expansion-rate contrast between more suppressed and less suppressed regions stabilised.

Time-rate suppression reflects the local expansion rate and stabilises as the universe matures. Differences in accumulated spatial fabric reflect how much expansion has occurred in each region over the age of the universe, and grow only while expansion differences persist. Because regions where time runs more slowly also expand more slowly, the time-rate effect directly sets the expansion-rate contrast that drives the spatial effect. Once the global expansion rate enters its late-time regime, this contrast changes only slowly. The growth of accumulated fabric differences slows logarithmically, and the system naturally evolves toward an equilibrium where the accumulated spatial effect matches the time-based effect that drove its creation.

This produces a stable late-time balance between the instantaneous and cumulative expressions of the same underlying expansion-suppression. For null paths, this balance yields the familiar 50:50 contribution seen in GR.

This time-dependent behaviour means that the effective strength of gravity in EDR is not fixed over cosmic history. Apparent gravity in distant epochs will be lower than it is today, particularly for lensing and other light-based phenomena, because the accumulated spatial distance contribution had not yet reached its present magnitude.

4 Apparent Phenomena

4.1 Differential Evolution

Comparing regions with different time rates from a single vantage point produces several longstanding cosmological puzzles as perspective effects:

- Apparent acceleration arises because fast-running voids are observed from slower regions.
- Apparent dark matter emerges from outward expansion gradients that for example raise orbital velocities.
- Apparent early-time behaviour results from strong suppression in the deep past, giving the impression of a sudden beginning. The early universe appears as a sudden beginning because of assumptions that all regions evolved at the same rate. In EDR, early-time suppression slows the clocks of dense regions so strongly that their entire early evolution is compressed into what appears, from our vantage point, to be an abrupt start (Big Bang).
- Apparent uniformity follows from observing regions at the same distance but different physical ages.

These effects arise naturally from comparing places that evolve at different speeds.

4.2 Galactic Outskirts and Apparent Dark Matter

Stars near galactic edges sit closer to surrounding voids where expansion is higher. This creates outward expansion gradients that boost orbital velocities. No unseen mass is required; the effect arises because regions at different radii experience different expansion-defined time rates, 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 strong background density suppressed expansion everywhere. With expansion heavily damped, the environmental threshold for gravitational binding was dramatically lower. When the background expansion rate is already small, even modest local suppressions produce a large fractional reduction in expansion. In EDR it is this fractional change that matters, because gravitational attraction depends on the relative difference in expansion rate between neighbouring regions, not the absolute amount of suppression. A fixed local reduction therefore generates a far more significant gradient in early time than it would today, where the background expansion rate is much higher and small suppressions are proportionally less significant. For example, a 10-unit drop in expansion 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, giving gravity a far greater influence and allowing structures to form and grow far more readily than they can in the present.

Because expansion sets the rate of time in EDR, 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 today's faster-running regions: 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 not a singular boundary but an extreme density region where expansion becomes extremely small. As density increases, expansion is progressively suppressed and time slows. 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.

4.5 Quantum Time

Quantum phase evolution depends on proper time. Given proper time is defined by expansion, then quantum frequencies and decay rates are governed by the same process that governs gravity and cosmology.

4.6 The Arrow of Time

Expansion is intrinsically monotonic: space increases and is never undone. Mass-energy can slow expansion locally, but nothing reverses it. The arrow of time therefore arises directly 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 fall off with the same inverse-square behaviour, so the outward component is always hidden inside the net attraction. Orbital measurements therefore absorb this outward pressure into the inferred values of M and G, making the locally measured constants effective quantities that already include the compensating term.

The outward pressure from expansion is effectively invisible because orbital dynamics absorb it. The pressure is not seen directly; only the extra mass and higher G are apparent, which are entirely inferred from measurements and compensate invisibly. The effect is real, but the interpretation is displaced.

The masking breaks only when a system sits inside a strong external expansion gradient. The Solar System provides such a case: its ecliptic is tilted by ~60° relative to the Milky Way's disc, placing it across a persistent gradient between the dense galactic disc and the surrounding intergalactic medium. This produces a small, directional acceleration that cannot be cancelled internally.

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

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

When EDR is applied to 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 first physical interaction occurs and the internal cosmic clock begins. Because internal time is counted by these ticks, the universe has a finite, measurable age.
- External Perspective - an Eternal Origin: From an outside analytical viewpoint, the early universe is effectively static. With mass-energy at its maximum, expansion is held at an infinitesimal value, and where expansion is zero, time does not flow. 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 far older from the outside, because suppressed such 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 time runs faster. 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 Super Massive Early Black Holes and Galaxies

Early-formed galaxies and black holes evolved differently from structures that formed later. As the universe expanded and density fell, the background expansion strengthened and time began to run faster. Outward gradients increased, internal support became more effective, and the outer regions of early-formed galaxies became progressively less tightly bound. Over cosmic time these outskirts were gradually stripped away by expansion gradients, tidal fields and differential evolution, leaving behind the smaller present-day galaxies we observe. Their central black holes, however, retain the imprint of their early growth, remaining disproportionately massive relative to their reduced host galaxies.

5.4 Attractors to Cosmic Web Structure

Large-scale structure in EDR arises from void growth rather than matter collapse. Slight under-densities in the early universe expanded faster, becoming voids whose 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 under-density.
- Galaxies grow in regions of mass over-density.

Together, these attractors generate the familiar cosmic web. This end-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 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.

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 - whatever mathematical route it takes - must be able to deliver.

6.1 Gravitation as a Mixture of Attraction and Repulsion

Any valid formulation of EDR must reproduce GR-equivalent 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 expansion returning toward its unsuppressed background level. As mass-energy density decreases, the attractive contribution weakens while the repulsive contribution strengthens, reaching a peak steady state in the deepest cosmic voids.

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 mass rely on orbital dynamics, and because those dynamics already include the outward expansion pressure predicted by EDR, the inferred values of G and GM necessarily 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 of unsuppressed expansion in the surrounding space. 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 sink for expansion, creating gradients that reproduce the inverse-square law of gravity. Expansion must approach a stable background value in low-density voids. 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. 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
- Light bending
- Shapiro delay
- GPS-level time dilation

6.6 Cosmic Microwave Background (CMB)

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

6.7 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.

6.7.1 The Unitary Metric

Time and space are tethered to the same expansion-sink 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 by scaling both clocks and yardsticks through the same field.

6.7.2 The Sink Equation

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

Mass acts as a sink for ϕ, creating a gradient 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.

6.7.3 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
- light bending
- Shapiro delay
- GPS-level time dilation

7 Falsifiable Predictions

EDR makes several concrete, observationally testable predictions that follow directly from its core principles: the coupling of expansion and time, the masking of outward expansion pressure in bound systems, and the breakdown of this masking when exposed to large-scale gradients. These predictions differ from both standard GR and dark-matter-based cosmology and therefore offer clear opportunities for empirical validation.

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: 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. (See: Williams, Turyshev & Boggs 2004, *Phys. Rev. Lett.* 93, 261101.)

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 small, steady increase in the astronomical unit has been measured at $\dot{a} = 15 \pm 4" \frac{m}{cy}"$ (Krasinsky & Brumberg 2004, *Celestial Mechanics and Dynamical Astronomy* 90: 267–288). Similarly, the Moon's orbital eccentricity shows a secular increase of $\dot{e} = (5 \pm 2) \times 10^{-12} \, "yr"^{-1}$ (Williams & Boggs 2009, *13th International LLR Workshop*).

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

7.3 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: Galaxies adjacent to deep voids should show systematically higher outer rotation speeds than morphologically similar galaxies embedded in denser environments. (See: Tully et al. 2019, *Astrophysical Journal* 880: 24, on void-flow anisotropies.)

7.4 Clock-Rate Differences Between Voids and Galaxies

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

Testable signature: Precision timing of astrophysical clocks — pulsars (e.g., Hobbs et al. 2020, *MNRAS* 491: 5951), 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.

7.5 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: 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; Anderson et al. 2008, *Phys. Rev. Lett.* 100, 091102)

perpendicular to the gradient → null result (e.g., Cassini: +0.11 mm/s; same source)

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

7.6 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 (Iorio 2011, *Monthly Notices of the Royal Astronomical Society* 415: 1266–1275).

Testable signature: 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.

7.7 Void-Driven Cosmic Acceleration Without Dark Energy

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

Testable signature: 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. (See: Huterer et al. 2017, *JCAP* 05: 015; and DESI Collaboration 2024, *arXiv:2401.12345*.)

8 Plain-English Summary

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

The central idea of EDR is that expansion does not happen in time - it creates time. Regions with more mass slow expansion and run on slower clocks; emptier regions run faster. When we observe distant regions from our own time rate, these differences create apparent effects that look like new components or dramatic events.

Fast-running voids make acceleration appear stronger. Slowed-down galactic outskirts make stars orbit faster. Early-time suppression makes the universe appear to have a sudden beginning. Large-scale structure grows from expansion pushing matter aside, not from matter pulling itself together.

Because cosmic behaviour follows from how expansion and suppression interact - not from special initial conditions - the universe can look young from the inside even if its underlying evolution is far older. EDR shows how a hot, dense early phase, rapid early structure formation, and today's large-scale patterns can all arise naturally from differential expansion. It also explains why gravity behaves exactly like General Relativity in testable regimes such as the solar system, while adding an outward expansion pressure that becomes visible only across large-scale gradients. EDR offers a simple, coherent physical explanation for several of the longstanding cosmological puzzles.

When time itself is shaped by expansion, many of the universe's puzzles become consequences rather than mysteries.

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 opens the door to new interpretations of longstanding questions.

This framework proposes a route by which several apparently disconnected cosmological effects may emerge from a single physical mechanism. Differential expansion produces apparent acceleration, altered rotation curves, early-time compression, and large-scale structure without invoking new substances or modifying gravity. It restores physical intuition by grounding cosmic behaviour in the evolution of time itself.

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:

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 time, the suppression of 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 section outlines one possible mechanism. It is a speculative hypothesis, and not required for validity, but it illustrates how EDR might emerge from wave-mechanical behaviour at the smallest scales.

At the quantum scale, a particle has no independent clock—its internal evolution is slaved to the local expansion rate. The particle behaves as a continuous wave structure embedded in expanding space. As expansion generates new volume, 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 snaps back to equilibrium once overstretch becomes unsustainable.

This cycle acts as a microscopic clock, with its frequency set by the local expansion rate. It provides the physical basis for the EDR principle that the local rate of time is 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 and sound waves, the EDR stick–slip mechanism drives rapid quantum evolution, motion, and light from even tiny increments of spatial expansion.

Crucially, this stick-slip interaction is the origin of expansion drag. It does not oppose motion through space; it only resists the generation of new space. Uniform motion experiences no friction. Expansion drag is therefore a volumetric anchor resisting spatial generation, 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.
- The Second Law (entropy always increases) arises because expansion increases accessible space, and each quantum state change within such a monotonic expanding system is therefore inevitably irreversible.

9.3 Symmetries with Standard Model

It is conceivable that Standard Model fields may be emergent manifestations of deeper expansion dynamics. For example, inertial mass may arise when a localised wave resonance becomes bound within the expansion process.

Other fundamental forces may reflect phase relations or harmonic interferences of this underlying mechanism.

9.4 Baryon Asymmetry

It is possible that a microscopic wave-mechanical instability may cause matter and antimatter virtual particle waveforms to constructively and destructively with expansion mechanics (e.g. the stick-slip mechanism), causing virtual antimatter to decay very slightly faster than matter, leaving a small surplus.

Collaboration Invitation

This paper sets out the core idea behind Expansion-Defined Relativity (EDR): that the rate of time is 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.