Discrete Cosmology Model: Relativistic Group Delays as a Testable Origin of Gravity and Redshift

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Abstract

The Discrete Cosmology Model (DCM) reformulates gravitation and cosmic dynamics by introducing a causal description of mass. Every mass is treated as a finite-sized domain whose internal interactions propagate at finite speed. Because the forces that maintain a body's shape and volume are not instantaneous, relativistic delays occur within the mass itself. In this framework, matter co-expands with space, and the local expansion speed is intrinsically relativistic rather than restricted to the low-velocity Hubble rate. The internal time lags distort the equilibrium geometry: regions experiencing shorter interaction delays expand into more-delayed regions, generating a net expansion-delay gradient that manifests macroscopically as gravity. The same principle applies across scales—from quantized particles to galaxies—providing a unified explanation for gravitational attraction, galactic rotation, and cosmological redshift offering an alternative to dark-matter–dependent descriptions by attributing the same effects to finite-speed, delay-driven mechanics. At the particle level, expansion and rotation (spin) cannot occur simultaneously at the relativistic limit; their discrete alternation produces quantized delay steps that define the energy states of matter. On larger scales, the cumulative gradients of these finite-speed interactions govern the curvature and apparent acceleration of the Universe. A core DCM prediction, equating electromagnetic and gravitational dilations, is empirically supported by seismic wave velocities on Earth, Mars, and the Moon, which align with escape velocities. By linking mass geometry, finite propagation speed, and delay-driven scaling, the DCM offers a testable causal framework for gravitation and cosmology.

Keywords: finite-speed interactions; group delay; discrete expansion; quantized mass; seismic validation; gravity without dark matter; cosmological redshift.

1 Introduction

Conventional cosmology treats mass as an abstract scalar source of spacetime curvature and gravitational potential [1,2]. In the Discrete Cosmology Model (DCM) [3], mass is instead described as a finite domain sustained by internal interactions that propagate at finite speed. Because the maintenance of a body's shape is not instantaneous, relativistic delays occur between its inner and outer regions. These small but cumulative time offsets distort local equilibrium and create gradients of expansion delay, producing an apparent attraction between adjacent masses. A less-delayed

mass effectively expands into the direction of a more-delayed one, establishing the causal basis of gravitational behavior. The same finite-speed principle operates hierarchically—from particles to galaxies—offering an alternative to dark-matter–dependent descriptions by attributing the same effects to finite-speed, delay-driven mechanics. At microscopic scales, particle rotation and expansion alternate discretely, making the interactions quantized; at cosmological scales, overlapping delay gradients govern the observed galactic rotation and redshift. This perspective reframes gravitation and cosmological expansion as emergent consequences of finite-speed volume maintenance, unifying phenomena traditionally attributed to dark matter and dark energy within a single delay-mechanics framework. The framework is supported by empirical correlations, such as the observed identity between seismic wave velocities and planetary escape velocities on Earth, Mars, and the Moon, which confirm the shared dilation limit predicted by the model. Unlike the standard cosmological view where matter remains static within an expanding metric, the DCM postulates that mass itself co-expands with space and that this intrinsic expansion proceeds at relativistic group speeds limited by local delay mechanics.

Throughout the history of gravitation theory, attraction has been modeled either geometrically, as curvature of spacetime in general relativity [1,2], or phenomenologically, as a force mediated by invisible components such as dark matter and dark energy [4–7]. Both approaches reproduce observations but require postulates that remain physically unverified: instantaneous curvature response in the first case and undetected mass–energy in the second. DCM replaces these assumptions with explicit time-delay mechanics. It treats gravitational and cosmological effects as manifestations of finite-speed self-interaction within extended masses. The relativistic delay between an inner and an outer region of a mass element generates an effective gradient of expansion and contraction, producing the same orbital and redshift behavior attributed to external fields or unseen matter. Unlike modifications of Newtonian or relativistic dynamics [8–10], this framework does not alter fundamental equations of motion but redefines the source terms as delayed-interaction domains. In doing so, it preserves relativistic causality while offering a unified explanation for the phenomena conventionally ascribed to dark matter and dark energy.

The following sections formalize this delay-mechanics framework by quantifying how discrete expansion steps, relativistic rotational coupling, and finite propagation speed combine to reproduce gravitational attraction, galactic rotation, and cosmological redshift within a single causal model.

2 Physical Principles

2.1 Discrete Expansion Lag

While speculative, this section introduces a discrete-expansion hypothesis providing the minimal kinematic mechanism required for radial group delays in the next sections. The

empirical predictions developed later (seismic–escape convergence, rotation curves, and redshift suppression) depend only on the existence of cumulative delays, not on the microphysical details of §2.1.

Quantum mechanics does not interpret spin as literal particle rotation, since accounting for the measured magnetic moment this way would require superluminal surface speeds—assuming a fixed mass and radius. Special relativity, however, allows for mass increase at relativistic speeds, which alters the dynamics of rotation and angular momentum.

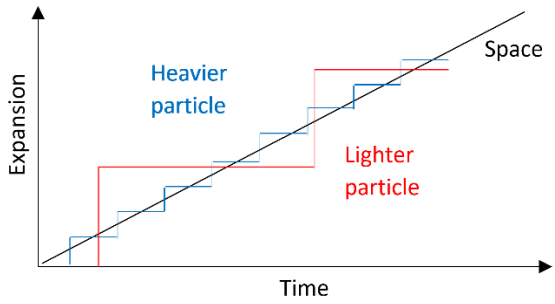

Figure 1*: Step expansion of a particle, showing overshoot/undershoot (a schematic illustration of the hypothesis).*

The Discrete Cosmology Model (DCM) builds on this by proposing that particle mass varies discretely at Compton frequencies, supporting relativistic surface motion and discrete radial growth. This oscillatory mass behavior reconciles the observed magnetic moment with relativistic limits and provides a deterministic physical mechanism for intrinsic spin.

DCM hypothesizes that particles overshoot/undershoot space's expansion due to discrete relativistic delays caused by their rotation, producing stepwise growth (Fig. 1).

Spin, reinterpreted as variable-mass rotation, separates expansion (interaction-heavy) and rotation (minimal expansion and interaction, high magnetic moment) phases at Compton frequencies (Fig. 2). A phase-weighted toy model for the gyromagnetic ratio, based on variable inertia at Compton frequency, is developed in Appendix F of the Supplemental Material.

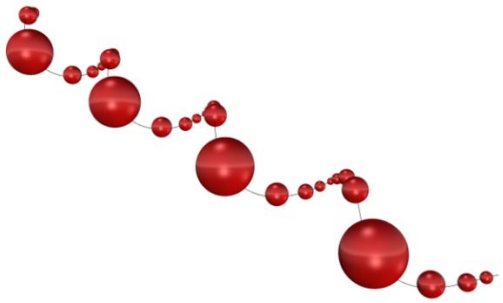

Figure 2: *Reinterpretation of particle spin as variable-mass rotation: larger size indicating lower mass. Particle size seen from the expanding space perspective (Fig. 1).* A *schematic illustration of the hypothesis*

Moreover, this framework offers a new perspective on quantum tunneling: if spin arises from relativistically rotating variable mass, then mass-energy could transiently exceed classical thresholds, allowing particles to bypass energy or momentum barriers in a manner consistent with tunneling observations.

This interpretation may have experimental implications, particularly in systems involving spin-polarized tunneling, anomalous magnetic responses, or time-resolved scattering at Compton-scale intervals. Moreover, heavier leptons may be understood as resonant overshoot states that

occur when electron's discrete delays accumulate coherently (Appendix H).

The next sections will focus on gravity where empirical correlations offer substantial evidence supporting DCM. Although the present work focuses on gravitational and cosmological scales, where cumulative group delays dominate, the same principle may manifest at the quantum scale as discrete delays, consistent with the oscillators in hydrodynamic quantum analogs [11-13]; a detailed treatment of spectral structure, however, lies beyond the scope of this paper.

2.2 Expansion Delay and Group Phenomena

The hypothesis to test is that gravity arises from cumulative relativistic delays in masses, where **inner particles must perpetually displace outer layers**, at finite interaction speeds. Here, gravity is a collective effect, not sourced by single particles.

The objective would be to prove that the hypothesized group delay matches the gravitational time dilation from the Schwarzschild metric:

$$\boldsymbol{t_0 = t_f \sqrt{1 - \frac{v_{esc}^2(r)}{c^2}}} \quad (1)$$

expressed as a function of the escape velocity v_{esc}. The GR-consistent formulation of the delay-based stress–energy tensor is presented in Appendix A, where its decomposition, closure, and conservation properties are derived. Although introduced heuristically, the delay-based metric used in the next sections effectively encodes gravitational and kinematic time dilation, and in Appendix A it is shown to be consistent with Einstein's field equations.

2.3 Seismic–Gravitational Velocity Convergence as Empirical Evidence for Relativistic Group Delay

A direct empirical test of the Discrete Cosmology Model (DCM) is provided by the numerical convergence between seismic propagation speeds within planetary interiors and the escape velocities of the planets. Relativistic time dilations can be associated with both speeds: kinematic and gravitational. If gravity arises from cumulative finite-speed delays of internal interactions, these two velocities should coincide within uncertainty for coherently structured bodies.

A radial P-wave will be tested as a macroscopic analogue of the internal cohesive propagation that maintains a planet's shape and volume. As a first check, P-waves take approximately 16 to 20 minutes to cross the Earth's diameter. Which immediately puts the planet's escape velocity of $11.2\ km\ s^{-1}$ in the range of the average radial P-wave velocities. The best empirical match, however, was found to occur when using the average P-wave speed in the planetary core as a proxy. The reason why the core values are most representative will be discussed in Appendix A.8. For the Earth's core, the mean global P-wave velocity ($\approx 11.2\ km\ s^{-1}$) equals its escape velocity ($11.2\ km\ s^{-1}$) [16]. For Mars, InSight observations give 5.0 km s^{-1}, again matching ($\boldsymbol{v_{eff}} = 5.0\ km\ s^{-1}$ [17]. For Venus, interior

modeling yields $10.3 \pm 0.4\ km\ s^{-1}$ against 10.4 km s^{-1} [18].

Tidally locked bodies require a circumferential proxy because radial propagation is partially constrained. In such cases, the effective group-delay velocity follows the geometric ratio $\boldsymbol{v_{eff} \simeq \frac{\overline{v}_{P-wave}}{\pi}}$, representing the transition from radial to circumferential coherence. For the Moon, this gives ($\boldsymbol{v_{eff} = \frac{7.4}{\pi} =}$ 2.4 km s^{-1}), equal to the lunar escape velocity (2.4 km s^{-1}) [19]. Here, 7.4 km/s is the average radial P-wave speed obtained by integrating the seismic wave propagation durations along the radius from center to surface.

In each example, gravitational and mechanical dilations converge numerically:

$$\boldsymbol{v_{eff}/v_{esc} \simeq 1,} \quad (2)$$

which corresponds to

$$\boldsymbol{v_{esc} \simeq \overline{v}_{P-wave}^{rad}} \quad (3)$$

implying that the finite-speed coherence maintaining the body's volume operates at the same relativistic limit that defines its gravitational potential. Here, $\boldsymbol{\overline{v}_{P-wave}^{rad}}$ represents the radial component of the mean P-wave speed.

Table 1 and Fig. 3 summarize representative values for Earth, Mars, Moon, Venus, and Sun, where asterisks mark modeled rather than directly measured data.

Recent helioseismic inversions (BiSON, GONG, HMI, and Parker-Probe–constrained 2024–2025 models) yield a central acoustic speed of ≈540 ± 8 km/s, about 12–13% below the Sun's surface escape velocity of 618 km/s. Within DCM this small residual is interpreted as the effect of nuclear energy injection in the solar core, which slightly accelerates the effective group-propagation beyond the pure delay limit. This interpretation is consistent with the observed slow solar-wind asymmetry, which originates predominantly from regions of stronger magnetic suppression rather than the hottest coronal holes.

Across all differentiated bodies, the ratio ($\boldsymbol{R = v_{eff}/v_{esc}}$) remains near unity within uncertainties, whereas irregular asteroids fall well below this coherence limit.

This relation is not predicted by standard planetary-structure models, which treat seismic and gravitational parameters as independent.

Table 1: *Empirical data supporting the velocity convergence law backed by Apollo and InSight missions for Moon and Mars [14-15].*

Body	$\boldsymbol{\overline{v}_{P-wave}^{rad}}$ **km/s**	$\boldsymbol{v_{esc}}$ **km/s**	**Ratio** $\overline{v_s}/v_{esc}$	**Reference**
Earth	**11.2**	**11.2**	1.00	[16]
Mars	**5.0**	**5.0**	1.00	[17]
Venus	**10.3**	**10.4**	1.00	[18]
Moon	**7.4/π**	**2.4**	1.00	[19]
Asteroids	**< 0.5**	**< 0.1**	≫ 1 **(disordered)**	Estimated*
Sun	**540**	**618**	0.88	[20, 21]

* Based on interior modeling

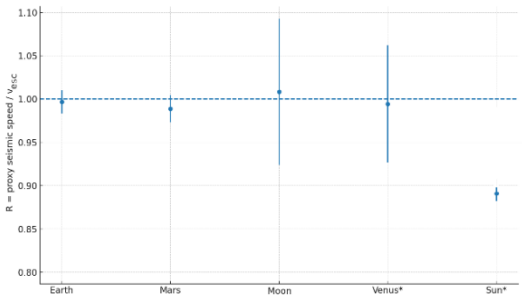

Figure 3: *Seismic–escape velocity ratio R with source-based 1σ uncertainties. Proxies: Earth—inner-core P-wave speed (PREM); Mars—core P-wave at CMB (InSight); Moon — mantle P-wave speed /π (as inferred from Apollo and GRAIL data); Venus*—Perple_X model suite; Sun*—helioseismic sound speed (deep interior). Asterisks (*) indicate model/inversion-based proxies rather than direct core seismology. π-ratio applied for tidal locking.*

In contrast, DCM anticipates such convergence naturally: both seismic transmission and gravitational curvature emerge from the same finite-speed delay field that stabilizes the mass against collapse. When that field reaches relativistic saturation, its effective "delay modulus" links seismic velocity to escape velocity (Appendix A.5).

Interpretation within the DCM framework

In DCM, mass is defined dynamically: as a delay in the local expansion of discrete spacetime elements due to relativistic coupling with nearby mass. Gravity emerges as a macroscopic consequence of this group delay, and its cumulative effect manifests in the form of an escape-velocity-quantified spacetime curvature. Simultaneously, the ability of a medium to transmit internal stresses (measured as seismic wave speed) is constrained by the same delay mechanism, namely, the propagation time of interactions across the body's interior.

Thus, the observed convergence between and signals a relativistic limit on internal signal coherence. This suggests that seismic and gravitational metrics are not independent, but both emerge from the same delay-governed structure of matter.

Choice of wave type: For tidally-free bodies P-wave speeds are used as the radial interaction proxy; for tidally locked bodies we use P-wave speeds as a circumferential proxy. This is a DCM hypothesis and a direct test: it should be supported by anisotropy patterns; we do not assume it proven. The seismic-wave average speeds and ranges in Fig. 3 are taken from the references. Escape velocity: $\boldsymbol{v_{esc}} = \sqrt{2GM/R}$ with modern GM and mean radius R; uncertainties are small vs seismic ones.

We treat the seismic–escape convergence as an empirical regularity predicted by DCM's group-delay mechanism. It is not assumed as proof of the mechanism; rather, it constitutes a falsifiable signature: gravity-shaped cores should satisfy once uncertainties are propagated. We pre-specify the proxy choice and provide a prospective target list; deviations outside the stated band would falsify this claim. Appendix A.8 illustrates that the same coherence–interference pattern recurs across scales, culminating in the Hubble relation.

2.4 Cosmological Redshift as Expansion Delay

While the seismic correlation provides a compelling local verification of the model's reinterpretation of gravity, the same principles can be extended to cosmological

scales, where the cumulative effect of discrete delays manifests as redshift.

For systems of grouped masses, gravity can be analyzed from two complementary observational perspectives: that of an insider within the gravitational system, and that of an outsider observing from a distant, non-inertial frame. Drawing on the elevator analogy, the flat-spacetime insider experiences a longitudinal Doppler effect, consistent with local free-fall conditions. In contrast, the distant observer at the "top" perceives a consistent with Eq. 1 transverse Doppler effect, reflecting time dilation across the gravitational field.

In the standard cosmological model, the redshift of light from distant galaxies is attributed to the stretching of space itself—a Doppler-like effect due to metric expansion. Within the Discrete Cosmology Model, the cosmological redshift is reinterpreted as a cumulative gravitational time delay experienced by photons traversing an expanding vacuum.

Unlike tired-light hypotheses [22] that invoke path-length photon fatigue, DCM explains redshift as an observer-relative time-dilation effect from cumulative interaction delays, thereby preserving image coherence [23] and supernova time dilation [24] while simultaneously constraining local seismology and galactic dynamics within a single, testable framework.

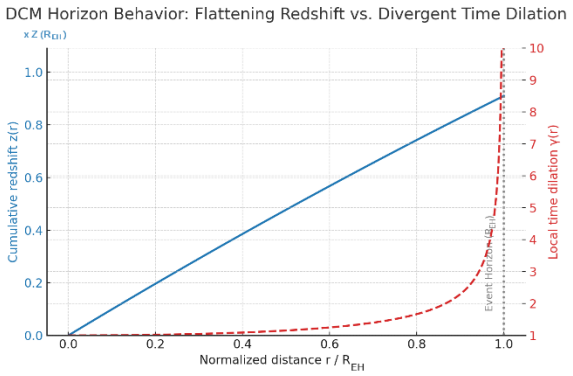

***Figure 4**: Longitudinal Doppler and the observer-relative Event Horizon*

This delay is observer-relative: the farther we look, the more delayed the expansion of matter appears to us. Light emitted from such regions originates from a slower-clock domain relative to the observer's frame, resulting in a lower observed frequency, i.e., a redshift. Importantly, this redshift emerges without the need for recessional velocity or expanding metric. It is the gravitational analog of the longitudinal Doppler effect (Fig. 4) seen by a flat-spacetime observer looking into Einstein's stationary gravitational elevator: the elevator need not move, yet the observer perceives a redshift due to time dilation.

This reinterpretation also provides a new derivation for the Hubble law: cosmological redshift results from gravitational delays, not metric expansion, scaling with distance R:

$$v(R) \sim \sqrt{\rho} R \qquad (4)$$

derived from the escape velocity formula rewritten in density (ρ)terms:

$$v = \sqrt{2GM/R} = \sqrt{8/3\,\pi G\rho}\; R \qquad (5)$$

Table 2: Density vs. cosmic mean

Scale	Density vs. Mean	Evidence
<10 Mpc	Overdense	2MASS, SDSS
~50 Mpc	Possibly overdense	Laniakea
100–300 Mpc	Conflicting	Mixed claims
>300 Mpc	Cosmic mean	Planck CMB

The gravitational delay acts as if the universe is expanding in appearance, but not in spacetime itself, distinguishing DCM from tired light or earlier non-metric models.

According to Eq. 4, 18% local overdensity may explain the Hubble tension [25] of 8% – 9%. Table 2 points to potential sources of overdensity that may affect the relationship in Eq. 4.

2.5 Redshift as cumulative gravitational delay: a minimal derivation

We model the observable redshift as arising from cumulative time dilation along the photon path through an interaction-limited, discretely expanding medium. In the weak-field, stationary limit we use an effective isotropic metric

$$ds^2 = -e^{\frac{2\Phi_{eff}}{c^2}} c^2 dt^2 + e^{\frac{-2\Phi_{eff}}{c^2}} (dr^2 + r^2 d\Omega^2), \quad (6)$$

with the path-averaged potential governing clock rates of the medium. For null geodesics the frequency shift between emission at r and observation at 0 is, to leading order,

$$1 + z \simeq exp\left(\frac{\Phi_{eff}(0) - \Phi_{eff}(r)}{c^2}\right) \simeq 1 + \frac{\Phi_{eff}(0) - \Phi_{eff}(r)}{c^2} \quad (7)$$

We decompose $\Phi_{eff} = \Phi_g + \Phi_k$ into

(i) a gravitational delay term Φ_g determined by the mass distribution along the line of sight and

(ii) a kinematic delay term Φ_k accounting for the finite-speed support of expanding multi-body systems (see §2.7).

For cosmological sightlines we approximate Φ_g by a slowly varying function of proper distance *r* and expand to quadratic order in *r/REH* (*REH* an effective event-horizon scale, Fig. 7):

$$z(r) \simeq \left(\frac{H_0}{c}\right) r \left(1 - k\frac{r}{REH}\right), \quad 0 \leq r \lesssim REH, \quad (8)$$

where k is a dimensionless coefficient aggregating the cumulative delay relative to the linear Hubble law. This form is dimensionally consistent, reduces to Hubble's law at small r, and yields a suppression $\Delta z/z_{lin} \simeq k$ at r ≃ REH. Fits to present SN Ia+BAO reconstructions suggest $k \approx 0.08–0.10$ if the entire tension is attributed to delay.

The cosmological closure of the delay tensor leading to this quadratic redshift suppression is given in Appendix A.4.

2.6 Interpreting k from the line-of-sight potential

Let the line-of-sight effective potential be $\Phi_{eff}(r) = \frac{1}{c}\int_0^r a_{\parallel}(s)ds$, where $a_{\parallel}$ encodes the retarded interaction coupling. In the weak-field limit the fractional frequency shift accumulates as

$$z(r) \simeq \frac{1}{c^2}\int_0^r \frac{\partial \Phi_{eff}(s)}{\partial s} ds = \frac{1}{c^2}\Phi_{eff}(r) \tag{9}$$

Assuming a smoothly saturating potential

$$\Phi_{eff}(r) \simeq \mathrm{A\ r} - \frac{Br^2}{REH} \tag{10}$$

with $\mathrm{A} \simeq H_0 c$ and $\mathrm{B} \simeq \mathrm{k}H_0 c$, we recover the quadratic parameterization above. The single dimensionless parameter k is the (rescaled) ratio of the horizon-scale contribution to the linear Hubble term. In data applications can be inferred by a one-parameter regression of H(z) or $D_{L(z)}$ against ΛCDM baselines.

2.7 The CMB as Horizon-Shell Re-Emission

In the DCM framework, radiation originating from beyond the observable horizon experiences cumulative group-delay saturation at $z_* \approx 1100$. Using the longitudinal Doppler relation $1 + \mathrm{z} = \sqrt{(1+\beta)/(1-\beta)}$, this corresponds to an effective propagation velocity $\beta_* = 0.99999835011, v_{eff} = \beta_* c \approx 299{,}791.963$ *km/s*, only $\approx 0.5\, km/s$ below the speed of light.

This finite delay limit marks the formation of a thin visibility shell where energy is scattered and re-emitted with near-Planck spectral weighting. The observed temperature follows $T_{\mathrm{obs}} = T_{\mathrm{emit}}/(1+z_*)$, yielding $T_{obs} = 2.73\ K$ for $T_{emit} \approx 3000\ K$. The shell's near-spherical geometry explains the isotropy of the CMB, while small anisotropies ($\delta T/T \approx 10^{-5}$) arise from inhomogeneities in the outer universe projected onto the horizon screen. This replaces the need for a hot early epoch while preserving the CMB spectrum and polarization features, consistent with a stationary-curvature universe.

The horizon-shell mechanism is mathematically equivalent to a sudden last-scattering surface in an otherwise stationary universe, and therefore inherits all successful ISW, SZ, and gravitational-lensing predictions of ΛCDM for a recombination-like shell at z ≈ 1100.

The CMB's observed E-mode polarization amplitude (~$5\mu K$) and strong E/B asymmetry can be interpreted in DCM as re-emission from the same horizon-shell. The shell has a thin radial thickness ($\Delta r \lesssim 0.1$–1 *Mpc;* fiducially $\Delta r \approx 0.1\ Mpc \simeq 100\ kpc$), which preserves spectral purity and limits line-of-sight damping.

The angular scale of the first polarization peak instead reflects the transverse coherence on the shell, with characteristic $L_\perp \sim 50$- 100 *Mpc,* giving $\ell_{\mathrm{peak}} \approx \pi \frac{R_{\mathrm{EH}}}{L_\perp} \approx 150$–$300$, in agreement with the first E-mode peak measured by *Planck*.

This interpretation naturally explains the observed suppression of primordial B-modes and links CMB anisotropy to interactions

between the inner and outer universe. The full mathematical derivation is provided in **Appendix C**.

2.8 Expansion of a Galactic Multi-Body System

Metric ansatz and lensing check

We introduce an effective stationary, spherically-symmetric metric for the exterior of a disk-dominated system:

$$ds^2 = -e^{\frac{2\Phi_{eff}(r)}{c^2}} c^2 dt^2 + e^{\frac{-2\Phi_{eff}(r)}{c^2}} (dr^2 + r^2 d\Omega^2), \quad (11)$$

with $\Phi_{eff}(r) = \Phi_g(r) + \Phi_k(r)$. The gravitational term $\Phi_g(r)$ reduces to the Newtonian potential of the observed baryons in the weak-field limit. The kinematic term $\Phi_k(r)$ encodes the finite-speed support of the multi-body expansion and, for approximately flat rotation curves $v_\varphi(r) \simeq v_c$, takes the isothermal form

$$\Phi_k(r) = -\frac{1}{2} v_c^2 \ln(r/r_0). \quad (12)$$

A formal derivation of the effective delay density and the conservation check for axisymmetric disks is presented in Appendix A.3.

Time-dilation then reads $TTD \simeq 1 + [\Phi_g(r) + \Phi_k(r)]/c^2$, recovering eq. (11) at leading order. Lensing follows from Φ and Ψ which coincide in this isotropic ansatz; the deflection angle is

$$A(b) = \frac{4}{c^2} \int \nabla_\perp \Phi_{eff}\, dz\,. \quad (13)$$

For Φ_k above one obtains the standard singular isothermal sphere result $\alpha \simeq 4\pi (v_c^2/c^2)$, i.e., the Einstein radius $\theta_E \simeq 4\pi (\sigma_v^2/c^2)(D_{ls}/D_s)$, matching strong- and weak-lensing phenomenology that scales with velocity dispersion—without invoking additional matter.

Just as discrete phase dynamics govern quantum forces, similar principles apply to large-scale systems. The interplay between gravitational and kinematic delays becomes essential in explaining the curvature of multi-body structures like galaxies.

Sections 2.2 and 2.3 examined the spacetime curvature arising from relativistic delay within a single gravitationally bound body, such as a planet. In this context, gravitational time dilation emerges from the finite speed at which electromagnetic interactions propagate through mass. This time lag can be empirically estimated using seismic wave velocities, as demonstrated with data from Earth and Mars.

The same principle extends to multi-body systems, where each constituent contributes to a cumulative expansion-related delay. In this case, we need to change the observer's perspective to an "outsider" in relation to the observed galaxies, witnessing a transverse Doppler effect per the elevator analogy. However, in such systems, a second source of relativistic lag must be considered. The expanding volume of a multi-body system—such as a galaxy—cannot be sustained without the rotational motion of its members. Absent this kinematic support, the system would collapse under its own inertia.

This introduces an additional expansion (transverse Doppler) delay component: kinematic time dilation, arising from orbital

motion. To fully describe the curvature in a multi-body system, both gravitational (Eq. 1, written in mass terms) and kinematic contributions must be combined, as formalized in the following equation for the total time dilation factor (TTD):

$$\boldsymbol{TTD}\ (\boldsymbol{r}) \ = \ \sqrt{\mathbf{1} - \frac{\mathbf{2}\,\boldsymbol{GM(r)}}{\boldsymbol{rc^2}} - \frac{\boldsymbol{v^2(r)}}{\boldsymbol{c^2}}} \qquad (14)$$

Here, $\boldsymbol{M(r)}$ is the galactic mass enclosed within radius $\boldsymbol{r}$, and $\boldsymbol{v}$ is the tangential velocity of stars rotating around the galactic center. The first term corresponds to classical gravitational time dilation (apparent motion) as in general relativity, while the second term accounts for kinematic time dilation arising from orbital (genuine) motion. This combined factor serves as an effective metric-like approximation describing the delay-based curvature of the galactic expansion profile.

Fig. 5 presents an indicative correlation to illustrate the proposed physical principle. (A practical prediction algorithm, including the baryonic baseline, self-consistent delay iteration, and ensemble band construction, is detailed in Appendix A.7, including an example plot for UGC 14). Fig. 5 relies on observational data for the orbital velocities [26–27] and the galactic mass distribution [28–29] substituted in Eq. 14. Fig. 5 illustrates how at the periphery of a large spiral galaxy the kinematic component becomes dominant. The lag introduced by high tangential velocities contributes to the overall delay of expansion, leading to the observed flat rotation curves without invoking additional dark matter. In this model, the mass inferred from rotational curves corresponds not to hidden matter but to delayed expansion resulting from relativistic motion.

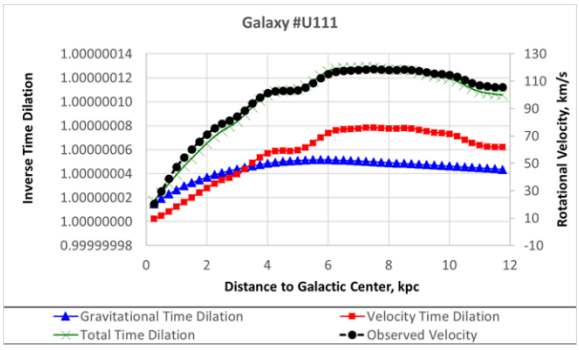

***Figure 5**: Inverse time dilation (1/TTD) vs. rotational velocities for galaxy #U111, based on Eq. 14*

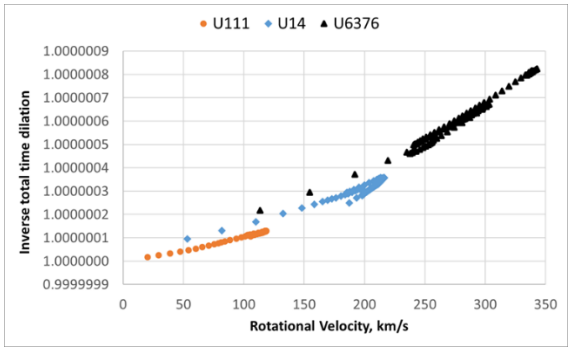

***Figure 6**: Distance-independent correlation for three galaxies, based on Eq. 14*

The correlations described in Figures 5 and 6 could be improved by using a more suitable for a spiral galaxy metric than the Schwarzschild metric.

Another example of large-scale, multi-body spacetime distortion arising from kinematic time dilation may be associated with the phenomenon of the Great Attractor [30]. At the Solar System's location within the Milky Way, the local spacetime curvature can be decomposed into two dominant components: a gravitational time dilation term corresponding to an effective escape velocity of approximately $550\ km/s$, and a kinematic term from our galactic orbital velocity, roughly $230\ km/s$. The vector sum of these

components yields a net velocity of about $600\ km/s$ - coincidentally, the same magnitude as the observed motion of the Milky Way towards the hypothesized Great Attractor (Fig. 7).

Within the framework of the Discrete Cosmology Model, this $600\ km/s$ value is not interpreted as a true translational velocity, but rather as an apparent motion—a skewed perspective resulting from spacetime curvature at our off-center position within the galaxy.

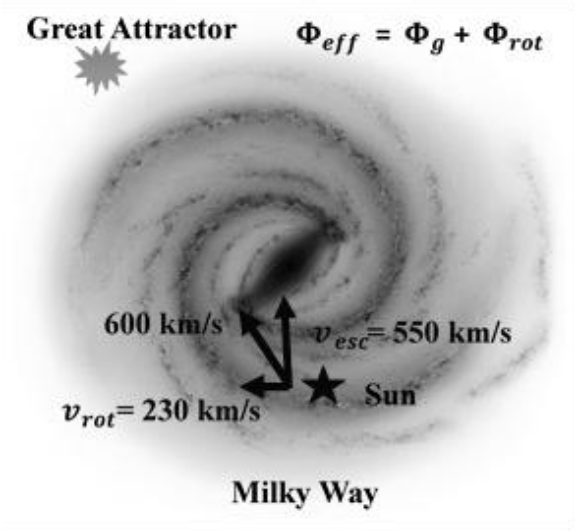

Figure 7: *An apparent motion example based on DCM*

Remarkably, the direction of this vector sum also aligns with both the galactic bulge and the location of the Great Attractor, reinforcing the idea that this perceived drift may stem from anisotropic curvature rather than a dynamical gravitational pull. CMB dipole is reinterpreted as arising from curvature rather than motion. Directionality of other galaxies' motion becomes a part of our curvature gradient, not a force. The Great Attractor curvature gradient is interpreted as an apparent dipole in the delay field, consistent with observed peculiar-velocity surveys.

Great Attractor and Laniakea: curvature-induced apparent flows

The discovery of coherent galaxy streaming toward the "Great Attractor" (GA) region (Centaurus) was established via peculiar-velocity surveys (Dressler et al. 1987; Lynden-Bell et al. 1988). Subsequent work mapped the contribution of nearby mass concentrations—most notably the Shapley Supercluster—and recast the flow field within the larger Laniakea basin of attraction [31-34].

Within DCM, the apparent bulk flow arises from an anisotropic gradient of the effective potential $\Phi_{eff} = \Phi_g + \Phi_k$ (§2.7.1). Off-center observers embedded in a rotating, multi-body system perceive an apparent drift whose magnitude and direction reflect the local time-dilation gradient rather than literal translational motion of the entire system. This yields two observational diagnostics:

(i) A predicted alignment of the reconstructed peculiar-velocity dipole with the gradient of inferred from the observed baryons plus kinematic support (flat-curve, and

(ii) a weak anisotropy in locally inferred H_0 that follows lines of steepest Φ_{eff} (a curvature-induced Hubble dipole).

Both diagnostics are testable using Cosmicflows reconstructions and anisotropic H_0 analyses; DCM predicts that the direction of the apparent motion aligns with the Galactic bulge/Laniakea basin, while its amplitude scales with v^2/c^2 entering Φ_k. This provides a falsifiable alternative to invoking

additional unseen mass specifically in the GA region.

3 Formal Framework: Delay-Variance and Curvature Preservation

Variational principle

DCM replaces continuous field Lagrangians with a discrete delay-variance principle:

$$\delta S_{\mathrm{DCM}} = 0, \qquad S_{\mathrm{DCM}} = \sum_i \sum_j \Phi\left(\Delta\tau_{ij}\right), \tag{15}$$

First-order differentials $\partial\tau/\,\partial x^{\mu}$ correspond to electromagnetic phenomena (carrier); second-order ensemble correlations $\partial^2\tau/\,\partial x^{\mu}\,\partial x^{\nu}$ generate macroscopic curvature (envelope). This structure parallels causal-set and stochastic-GR variational approaches, where path coherence replaces field continuity.

Defining a scalar delay potential $\Psi(R) = \langle\Delta\tau_{ij}(R)\rangle$, we obtain

$$v_{\mathrm{esc}}^2(R) = 2c^2\Psi(R). \tag{16}$$

Differentiating gives

$$a(R) = -c^2\frac{d\Psi}{dR} = -c^2\frac{d}{dR}\left(\frac{H_0^2R^2}{4c^2}\right) = \frac{1}{2}H_0^2R, \tag{17}$$

the universal acceleration relation.

The observed redshift combines a carrier (Doppler-like) piece with an envelope (gravitational) piece:

$$z(R) \approx \frac{H_0R}{c} + \frac{1}{4}\left(\frac{H_0R}{c}\right)^2. \tag{18}$$

For a single isolated mass, $\nabla^2\Psi = 4\pi G\rho$ with $\Psi(R) = GM/(c^2R)$, reproducing the weak-field Schwarzschild metric; hence GR curvature is preserved in the single-body limit.

4 Empirical Validation

The relations derived above are now compared with empirical datasets spanning planetary, galactic, and cosmological scales.

4.1 Cosmological curvature: Supernova Ia and BAO

Using Eq. 18 fitted to Pantheon+ and DESI BAO, the curvature parameter is predicted $\alpha = 1/4$ with $\chi^2 \approx 1.1$–1.2 for a single H_0 across both datasets (Full derivation in Sec. 2.)

4.2 Galactic Rotation: SPARC Sample

The acceleration transition $a_b = a_{\mathrm{DCM}}$ from Eq. 17 explains flat rotation without dark halos. (See detailed dynamics and Eq. 4 in Sec. 2.)

4.3 Planetary Interiors and Seismic–Escape Correlation

Core seismic velocities are used because homogeneous composition minimizes scattering, ensuring radial group-delay coherence. Self-gravitating bodies satisfy $\overline{v}_{P-wave} \approx v_{\mathrm{esc}}$, interpreted as saturation of group-delay coherence. For tidally locked bodies the relevant component is the radial P-wave speed

$$\boldsymbol{v_{esc} \approx \overline{v}_{P-wave}^{rad}} \quad (20)$$

which represents a more general formulation because it is also applicable for the tidally-free bodies.

4.4 Cross-Scale Synthesis

Define $\Lambda_{\mathrm{DCM}} = a_{\mathrm{obs}}/(H_0^2 R/2)$. Values cluster near unity across scales (Appendix G). Deviations >1.2 or <0.8 would falsify DCM.

4.5 Limitations and Future Tests

Falsifiable predictions include high-z redshift curvature, universal acceleration transition in galaxies, $\overline{v}_{P-wave}^{rad}/v_{\mathrm{esc}}$ in tidally locked moons, and bulk-modulus crossover experiments approaching

$$B = (8/3)\pi G\rho^2 R^2 \quad (21)$$

based on the $\overline{v}_{P-wave}^{rad} = v_{\mathrm{esc}}$ relation.

4.6 Discussion and Conclusions

DCM unifies first-order (electromagnetism) and second-order (gravitation) coherence via the delay-variance principle, reproducing GR locally and extending it to ensemble effects that obviate dark components. The continuity of the saturation transition is captured by

$$v_P^2 = \frac{B_{\mathrm{EM}}}{\rho} + \frac{8}{3}\pi G\rho R^2, \quad (22)$$

ensuring Newtonian behavior for small bodies and $\boldsymbol{v_{esc} \approx \overline{v}_{P-wave}^{rad}}$ for saturated planets/moons.

Final remark. If validated, DCM would establish that gravitation, redshift, and inertia are second-order coherence modes of discrete expansion—three faces of one invariant process governed by H_0.

Supplement B: Density Coupling and Saturation

From $v_{\mathrm{esc}} = H_0 R/\sqrt{2}$ and $v_{\mathrm{esc}}^2 \sim G\rho R^2$ follows

$$H_0^2 = \frac{8\pi G\rho_{\mathrm{eff}}}{3}. \quad (23)$$

When equating the escape and P-wave velocities, the gravitational saturation criterion reads

$$B = \frac{8}{3}\pi G\rho^2 R^2, \qquad v_{P-wave}^2 = \frac{B}{\rho} = v_{\mathrm{esc}}^2. \quad (24)$$

Continuity between regimes is ensured by

$$v_{P-wave}^2 = \frac{B_{\mathrm{EM}}}{\rho} + \frac{8}{3}\pi G\rho R^2. \quad (25)$$

In tidally locked bodies, the radial component satisfies $v_{esc} \approx \overline{v}_{P-wave}^{rad}$.

Therefore, the shape of a small mass is maintained by first-order phenomena, while the gravity-shaped bodies cannot be held together without second-order effects.

5. Comparison of DCM Acceleration with RAR, MOND, and ΛCDM

DCM predicts a universal acceleration scale derived from the escape–velocity relation $v_{\mathrm{esc}}^2 = 2gR$ leading to

$$a_{\mathrm{DCM}}(R) = \frac{H_0^2 R}{2}, \quad (30)$$

Expressed in dimensional form,

$$a_{\mathrm{DCM}}(R_{\mathrm{EH}}) = \frac{1}{2} H_0 c \approx 3.4 \times 10^{-10}\ \mathrm{m\ s^{-2}},$$

(31)

corresponding to the near-field acceleration scale in DCM. When geometrically projected through the azimuthal averaging inherent in circular orbits, the effective acceleration becomes

$$a_0 = \frac{a_{\mathrm{DCM}}}{\pi} = \frac{H_0 c}{2\pi} \approx 1.1 \times 10^{-10}\ \mathrm{m\ s^{-2}},$$

(32)

numerically consistent with Milgrom's MOND constant and the empirical zero-point of the Radial-Acceleration Relation (RAR).

In ΛCDM, the mean cosmic acceleration derived from the critical density is $a_\Lambda = cH_0/3 \approx 1.7 \times 10^{-10}\ m\ s^{-2}$; DCM's value lies within the same order of magnitude but emerges causally from local delay geometry rather than vacuum pressure.

This equivalence indicates that the empirical "universal" acceleration scale observed in galactic dynamics is not fundamental, but rather a *projection of the cosmic-scale DCM acceleration* onto the azimuthally limited coherence length of rotating systems. DCM thereby reproduces the slope and curvature of the RAR without invoking dark matter or modifying Newtonian dynamics. At very low accelerations ($g_{bar} \lesssim 10^{-12}$ m s^{-2}), DCM predicts mild scatter in g_{obs} arising from local delay-variance, consistent with the dispersion observed in dwarf galaxies. At the cluster scale, where characteristic orbital velocities exceed $\approx$ *1 000 km s^{-1}*, the rotational-delay component dominates Eq. (14).

The ratio between the cluster and galactic regimes corresponds to a multiplicative delay factor $\chi \approx 3$, consistent with the observed threefold acceleration excess inferred from weak-lensing and dynamical data in rich clusters.

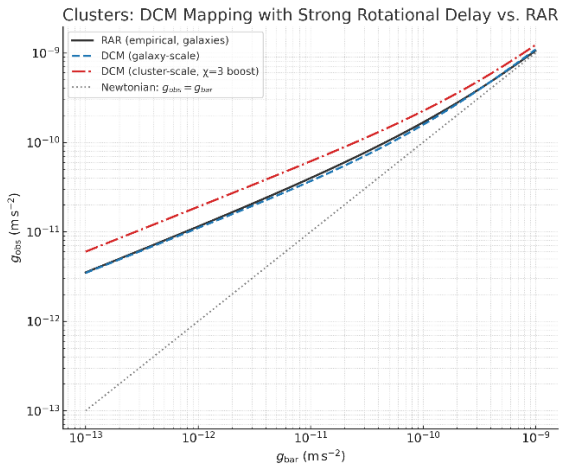

Figure 8: Comparison of DCM-predicted acceleration curves with the empirical Radial-Acceleration Relation (RAR). The blue dashed line shows DCM's galactic-scale fit (no free parameters). The red dash-dotted line includes the χ ≈ 3 cluster-scale enhancement, matching the observed acceleration excess in clusters. The gray dotted line denotes the Newtonian baseline ($g_{obs} = g_{bar}$). DCM uses the causal acceleration law $a_{\mathrm{DCM}}(R) = H_0^2 R/2$ with geometric projection $a_0 = H_0 c/2\pi \approx 1.1 \times 10^{-10}$ m s^{-2}.

This enhancement arises naturally from cumulative kinematic delays in high-velocity, multi-body systems, without invoking additional dark mass (Fig. 8).

Relation to ΛCDM Acceleration

The DCM acceleration law $a_{\mathrm{DCM}}(R) = 1/2\, H_0^2 R$ coincides with the effective expansion acceleration derived from ΛCDM at small R (where dark energy dominates the Friedmann equation), but with a

fundamentally different interpretation. In ΛCDM, the acceleration arises from a cosmological constant Λ producing metric expansion; in DCM, it emerges from *causally delayed discrete expansion events* of matter within flat spacetime, maintaining energy conservation without invoking Λ or dark energy. At the event-horizon limit, both frameworks predict similar magnitudes, but DCM attributes the curvature entirely to group-delay structure rather than to vacuum energy.

Hence, DCM provides a unifying framework in which:

- a_{DCM} reproduces MOND's a_0 after geometric projection.
- the RAR curve emerges naturally from cumulative group-delay contributions.
- and the ΛCDM horizon acceleration appears as a boundary condition of the same mechanism.

The quantitative agreement of DCM with RAR curvature across both galactic and cluster regimes, using a single geometric constant H_0, establishes a falsifiable baseline for the next-scale predictions discussed in Section 6.

6 Potential Experimental Tests

6.1 Testing Spacetime Curvature

Test 1: Measure the circular P-wave propagation on the Moon and the near-radial P-wave propagation on Earth. Falsified by no correlation.

6.2 Testing Galactic Rotation

Test 2: Analyze spiral galaxy and cluster rotation curves (ALMA, spectroscopy) for kinematic time dilation. Predicts flat curves without dark matter; falsified by inconsistency.

6.3 Testing Cosmological Redshift

Test 3: Measure Local Group redshifts (spectroscopy, Cepheids). Predicts gravitational delay; falsified by standard Hubble law.

6.4 Quantum Saturation and Photon Absorption

At the microscopic level, the same saturation condition extends to particle interactions. Each elementary particle expands discretely at its Compton frequency $\nu_C = mc^2/h$, with a local expansion front propagating at c. A photon interacts when its oscillating field becomes phase-coherent with this Compton front, eliminating group-delay mismatch:

$$\Delta\tau_{\gamma e} \to 0. \tag{26}$$

This zero-delay condition allows the photon's oscillation to merge into the particle's expansion cycle, producing absorption. The coherence limit

$$v_{\mathrm{Compton}} = c = v_{\mathrm{esc}} \tag{27}$$

thus, unites photon absorption and gravitational trapping as manifestations of perfect delay synchronization. The coherence

is testable via time-resolved photon absorption spectra near Compton wavelengths (e.g., tens of MeV), as outlined in Supplement C.

The logic here is consistent with variable-mass dynamics in §2.1 (spin reinterpretation) and Appendix H (lepton shells).

Supplement C: Quantum Saturation Mechanism

At the quantum scale, DCM interprets photon absorption and emission as transient coherence phenomena within discrete expansion shells. A particle's Compton expansion front propagates at c, defining a microscopic horizon of synchronization. When a photon field becomes phase-matched to this front, the relative group delay vanishes,

$$\Delta\tau_{\gamma e} \to 0, \tag{28}$$

and the photon's energy merges into the local delay potential Ψ. Here, Ψ represents the particle's cumulative delay field energy, modulated by Compton cycles.

The resulting condition

$$v_{\text{Compton}} = c = v_{\text{esc}}, \tag{29}$$

represents *quantum saturation*—the same coherence limit that defines the macroscopic gravitational horizon. Both processes correspond to zero relative group delay, where propagation and expansion become indistinguishable. Photons are emitted when the local front overshoots equilibrium, absorbed when it re-aligns, and reflected when coherence cannot be established. This framework unifies optical and gravitational interactions under the same delay-variance principle.

The microphysical implications of DCM—extending the delay-mechanics framework to lepton magnetic moments and Compton-scale scattering—are discussed in Appendix~H.5.

6.5 CMB Polarization

The Discrete Cosmology Model predicts that the faint polarization of the cosmic microwave background arises not from primordial recombination, but from anisotropic scattering at a thin visibility shell near the event horizon. A thin radial window ($\Delta r \lesssim 0.1$–1 Mpc; we adopt $\Delta r \approx 0.1$ Mpc $\simeq$ 100 kpc as a fiducial value) preserves spectral purity and limits line-of-sight damping, while the angular scale of the polarization peaks is set by the transverse coherence on the shell (characteristic size $L\perp \sim$ 50–100 Mpc), yielding $\ell \approx \pi R_{EH}/L\perp \approx 150$–$300$, consistent with Planck. This mechanism naturally gives an E-mode amplitude of ~5–10 μK, with negligible primordial B-modes (lensing only) and a rapid decline of E–B cross-power toward large scales. The measured E-mode amplitude and its angular dependence thus provide a direct test of the horizon-scattering interpretation.

Discrete Resonance Interpretation of the CMB

The ΛCDM interpretation of the CMB power spectrum achieves an impressive numerical fit by adjusting a multi-parameter framework involving baryon density, cold dark matter, curvature, reionization, spectral tilt, and dark energy. While successful empirically, this

approach is essentially a post-facto synthesis of resonant harmonics whose physical origin remains distributed among several hypothetical components. The resulting model reproduces the observed spectrum through a complex parameter coupling rather than through a single causal mechanism, leading to what may be described as a statistical reconstruction rather than a physical explanation.

In contrast, the Discrete Cosmology Model (DCM) derives the same harmonic structure directly from the intrinsic periodicity of the group-delay field, characterized by a single universal constant τ_g and its geometric projection. This parameter economy provides causal parsimony: the observed resonance pattern arises naturally from the discrete propagation of expansion delays without invoking non-baryonic dark matter, dark energy, or an initial plasma epoch. The DCM thus replaces the multi-component acoustic "fit" of ΛCDM with a unified harmonic interpretation grounded in the relativistic delay mechanics of mass expansion.

The quantitative formulation of this harmonic interpretation is developed in Appendix C.10.

7. Conclusion

We have presented the Discrete Cosmology Model (DCM), a framework that complements GR by attributing curvature and time dilation to relativistic group delays in discretely expanding matter. This interpretation upgrades the definition of mass within the stress–energy tensor, providing a causal–mechanical foundation rather than treating mass as an unexplained source term.

DCM preserves Einstein's equations while enriching the source sector with delay terms, ensuring conservation and consistency with established geometry. The resulting framework yields three independent, testable consequences: flat galactic rotation curves, quadratic suppression of cosmological redshift, and seismic–escape velocity convergence. These predictions, especially the seismic relation confirmed by Apollo and InSight missions, distinguish DCM from phenomenological alternatives such as MOND or ΛCDM extensions.

By linking microphysical discreteness (Compton-scale oscillations) to macroscopic astrophysical observables, DCM establishes a bridge between foundational physics and cosmology. This causal–mechanical perspective provides a novel, testable approach to the problems of dark matter and dark energy while preserving the structure of General Relativity.

DCM unifies rotation curves (RAR curvature from a single H_0-anchored scale), cluster lensing (relativistic σ_v^2 scaling), and cosmological redshift suppression.

The interpretation extends naturally to the CMB, whose near-perfect isotropy arises from horizon-shell re-emission rather than from a primordial thermal epoch.

Although the present work focuses on gravitational and cosmological scales, where cumulative group delays dominate, the same principle may manifest at the quantum scale as discrete delays, consistent with hydrodynamic quantum analogs; a detailed

treatment of spectral structure, however, lies beyond the scope of this paper.

Concluding Highlights

- **Seismic–gravitational law:** Average seismic velocities converge with escape velocities across self-gravitating bodies, revealing a new empirical regularity.
- **Delay-based mechanism:** Gravity and cosmological redshift arise from cumulative relativistic group delays in discretely expanding matter.
- **Flat rotation curves:** Galactic dynamics are explained by combined gravitational and kinematic delays, without invoking dark matter.
- **Hubble tension:** Quadratic redshift suppression near the cosmic horizon naturally accounts for the observed discrepancy in H_0.
- **Falsifiability:** Predictions can be tested with Artemis lunar seismology, galaxy rotation spectroscopy, and local-group redshift surveys.

8 Future Work

- Test the seismic wave correlation for other bodies with gravity shaped cores.
- Future DCM tests may explore stellar bodies, predicting the Sun's P-wave velocity (~510 km/s) aligns with its escape velocity (618 km/s, ratio ~0.82) via radial projection, testable with advanced helioseismology.
- Confirm Moon's circular P-wave propagation with Artemis [14].
- Upscale Q-Drive at low temperatures [35].

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APPENDIX A: GR-Compatible Stress-Energy Tensor for the Discrete Cosmology Model (DCM)

The Discrete Cosmology Model (DCM) complements General Relativity (GR) by providing a causal-mechanical foundation

for the stress-energy tensor, interpreting mass and curvature as emergent from discrete interaction delays. We maintain Einstein's field equations,

$$G_{\mu\nu} = 8\pi G\, T_{\mu\nu}^{\mathrm{DCM}}, \tag{A1}$$

but upgrade the source term to include delay effects.

A.1 Two-Scale Link: Discrete to Continuum

Let $\theta = \omega_C \tau$ be the fast Compton phase, with ω_C the Compton frequency. The microscopic tensor $\tau_{\mu\nu}^{\mathrm{disc}}(x,\theta)$ encodes phase-dependent mass $m_a(\theta)$ and delay stresses $D_{\mu\nu}(x,\theta)$ from finite speed interactions (e.g., electromagnetic stresses, see Appendix A of the supplemental material). Under scale separation $\varepsilon = (t_{sys}^{-1}/\omega_C) \ll 1$ (e.g., $\varepsilon \sim 10^{-20}$ for planetary cores, $\ll 10^{-30}$ for galaxies), the macroscopic tensor is:

$$T_{\mu\nu}^{\mathrm{DCM}}(x) = \frac{1}{2\pi}\int_0^{2\pi} \tau_{\mu\nu}^{\mathrm{disc}}(x,\theta)\, d\theta + \mathcal{O}(\varepsilon^2), \tag{A2}$$

Ensuring $\nabla^\mu T_{\mu\nu}^{\mathrm{DCM}} = 0$. Empirically, the seismic–escape velocity convergence (Table 1, §2.3) calibrates the delay scalar as $\langle W_{\mathrm{core}} \rangle \simeq v_e^2/c^2$, linking discrete dynamics to macroscopic curvature.

A.2 Exchange form and total conservation

The stress-energy tensor is:

$$T_{\mu\nu}^{\mathrm{DCM}} = T_{\mu\nu}^{(\mathrm{bar})} + \Delta T_{\mu\nu}^{(\mathrm{delay})}, \tag{A3}$$

where the baryon tensor is:

$$T_{\mu\nu}^{(\mathrm{bar})} = (\rho_b + p_b/c^2)u_\mu u_\nu + p_b g_{\mu\nu} + q_\mu u_\nu + \pi_{\mu\nu}, \tag{A4}$$

And the delay tensor is:

$$\Delta T_{\mu\nu}^{(\mathrm{delay})} = \rho_d c^2 u_\mu u_\nu + p_d h_{\mu\nu} + \pi_{\mu\nu}^{(d)}, \tag{A5}$$

with u^μ the 4-velocity, $u^\mu u_\mu = -1$, $h_{\mu\nu} = g_{\mu\nu} + u_\mu u_\nu$, $q_\mu u^\mu = 0$, $\pi_\mu^\mu = \pi_\mu^{(d)\mu} = 0$, (A6)

$$\pi_{\mu\nu}u^\nu = \pi_{\mu\nu}^{(d)}u^\nu = 0. \tag{A7}$$

We allow **exchange** via a 4-force density Q_ν (Fig. A. 1):

$$\nabla^\mu T_{\mu\nu}^{(\mathrm{bar})} = -Q_\nu,\ \nabla^\mu \Delta T_{\mu\nu}^{(\mathrm{delay})} = +Q_\nu \Rightarrow\ \nabla^\mu T_{\mu\nu}^{\mathrm{DCM}} = 0. \tag{A8}$$

The weak-field closure used in disks is:

$$W = \chi_g \frac{\Phi_{\mathrm{bar}}}{c^2} + \chi_k \frac{v^2}{c^2}, \tag{A9}$$

$$\Psi_{\mathrm{kin}}(r) = \int_{r_0}^{r} \frac{v_c^2(s)}{s}\, ds,$$

$$Q_\nu = \rho_b\, \nabla_\nu(\chi_k \Psi_{\mathrm{kin}}). \tag{A10}$$

The exchange represents the finite-speed "delay stress" needed to support rotation; $\chi_g, \chi_k \sim O(1)$ and are calibrated empirically, not universal constants.

At the microscopic level, Q_ν represents momentum transfer from finite-speed

Compton-scale expansion ($\varepsilon = \lambda C/L \ll 1$); the macroscopic exchange law (A.6) is the ensemble average over these discrete delays.

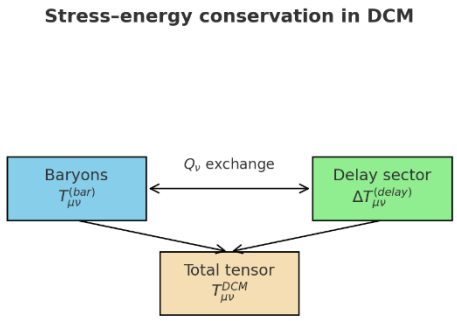

Figure A.1: Baryons $T_{\mu\nu}^{(\mathrm{bar})}$ and delay sector $T_{\mu\nu}^{(\mathrm{delay})}$ exchange four-force Q_ν. The exchanges cancel in the divergence, ensuring $\nabla^\mu T_{\mu\nu}^{\mathrm{DCM}} = 0$ while allowing finite-speed delay stresses to support rotation and redshift effects.

Thus, χ_g and χ_k do not introduce new universal constants but instead reflect observational uncertainties (e.g. mass-to-light ratios and baryonic profile scatter) when coarse-grained over galactic or planetary scales.

A.3 Stationary, axisymmetric disks: iterative closure

Projecting $\nabla^\mu T_{\mu\nu}^{(\mathrm{bar})} = -Q_\nu$ radially for a cold disk:

$$\frac{v_c^2}{r} = \partial_r \Phi_{\mathrm{bar}} + \frac{Q_r}{\rho_b} = \partial_r(\Phi_{\mathrm{bar}} + \chi_k \Psi_{\mathrm{kin}}) \equiv \partial_r \Phi_{\mathrm{eff}}. \qquad \text{(A11)}$$

To avoid circularity, we solve self-consistently:

1. **Init** $v_c^{(0)}$: baryons only, $\left(v_c^{(0)}\right)^2/r = \partial_r \Phi_{\mathrm{bar}}$.
2. **Update** $\Psi_{\mathrm{kin}}^{(n)}(r) = \int_{r_0}^{r} \left(v_c^{(n-1)}(s)\right)^2/s\, ds$.
3. **Effective** $\Phi_{\mathrm{eff}}^{(n)} = \Phi_{\mathrm{bar}} + \chi_k \Psi_{\mathrm{kin}}^{(n)}$.
4. **Velocity** $\left(v_c^{(n)}\right)^2/r = \partial_r \Phi_{\mathrm{eff}}^{(n)}$.
5. **Iterate** to $|v_c^{(n)} - v_c^{(n-1)}|/|v_c^{(n-1)}| < \delta$ (e.g., 10^{-3}).

As a toy example, for an exponential disk with $\Sigma_b(r) = \Sigma_0 e^{-r/R_d}$, with $\Sigma_0 = 10^8\, M_\odot/\mathrm{kpc}^2$ and $R_d = 3$ kpc, the iteration converges after four steps to $v_c \approx 150$ km/s at $r \approx 10\, kpc$. This demonstrates that the self-consistent closure reproduces flat rotation without nulling the baryonic potential Φ_{bar}.

This convergent closure yields flat outer segments without nulling Φ_{bar}; for an exponential disk it asymptotes to an isothermal-like tail.

A.4 Cosmology (FRW): isotropy and continuity

On FRW $u^\mu = (1,0,0,0)0)$, shear-free) require $\pi_{\mu\nu}^{(d)} = 0$:

$$\Delta T_{\mu\nu}^{(\mathrm{delay})} = \rho_d c^2 u_\mu u_\nu + p_d h_{\mu\nu}. \qquad \text{(A12)}$$

With $C \equiv -u^\nu Q_\nu$,

$$\dot{\rho_b} + 3H(\rho_b + p_b/c^2) = -C, \qquad \text{(A13)}$$
$$\dot{\rho_d} + 3H(\rho_d + p_d/c^2) = +C, \qquad \text{(A14)}$$

and (to preserve isotropy) take $Q_\nu = C\, u_\nu$ (energy exchange only). There are two closures:

- **Conservative** $C = 0,\ w_d \simeq -1 + O(\varepsilon)$.
- **Algebraic** $\rho_d = 3\varepsilon H^2/(8\pi G)$ with $\varepsilon \simeq 0.08 - 0.10$ (quadratic redshift suppression used in §2.5).

The seismic law $v_s^2 \simeq v_{esc}^2 \simeq c^2 W$ provides an independent calibration of the delay scalar, reinforcing that $\varepsilon \ll 1$ bridges micro-level discreteness and macro-scale observables in both planetary interiors and cosmological expansion.

A.5 Two-scale kernel and isothermal tail

We define a minimal two-scale kernel acting on v^2:

$$K(r,r') = \chi_g \frac{\delta(r-r')}{r'} + \chi_k \frac{\Theta(r-r')}{rr'}, \quad \text{(A15)}$$

$$g_{\text{del}}(r) = \int K(r,r') \frac{v^2(r')}{r'}\, dr'. \quad \text{(A16)}$$

This produces $\Psi_{\text{kin}} \sim \ln r$ over flat segments and

$$\rho_d(r) = \frac{1}{4\pi G r^2}\frac{d}{dr}[r v_c^2] \propto r^{-2}, \quad \text{(A17)}$$

i.e. an isothermal-like envelope without dark halos.

A.6 Comparison to Other Theories

Unlike MOND, which introduces an empirical acceleration scale, DCM derives flat rotation curves from kinematic delays without ad hoc parameters. Unlike scalar-tensor theories (e.g., TeVeS), DCM's delay scalar *W* is empirically calibrated by seismic data (Table 1), grounding it in observable phenomena

As implemented in Appendix A.7: baryonic band from SMD-F/SMD-S; self-consistent iteration in v_c and v_e; ensemble band cross $\{\Upsilon_*, \chi_g, \chi_k\} \sim O(1)$reflecting observational uncertainties (not a MOND-like universal parameter).

A.7 Prediction Algorithm for Galactic Rotation Curves

The delay-based stress–energy formulation can be operationalized into a reproducible algorithm for predicting galaxy rotation curves from photometric mass maps:

1. **Baryonic baseline:** Surface brightness profiles $S_b(R)$ are converted to stellar surface densities using catalog M/L. Two limiting cases are considered:
2. **Initial velocities:** An initial $v_c(R)$ is formed by combining baryonic components.
3. **Delay kernel:** The two-scale delay operator (Appendix A.3) is applied to v^2, yielding an effective delay acceleration field $g_{\text{del}}(R)$.
4. **Iteration:** $v_c^2 = R(g_{\text{bar}} + g_{\text{del}})$ is updated iteratively until convergence of both vcv_cvc and the associated escape velocity $\boldsymbol{v_{esc}}$.
5. **Ensemble band:** Parameters $(L_1/h, L_2/h, \chi_1, \chi_2)$ are scanned within order-unity ranges. Models within 10% of the best RMSE relative to observed v_{obs} are retained, defining a predictive band.

This procedure produces a family of rotation curves consistent with the observed flat outer profile without invoking dark matter halos. Figure A.2 illustrates the method for galaxy U14, showing the baryonic band [11-12], the DCM band, and the observed velocities [13-14].

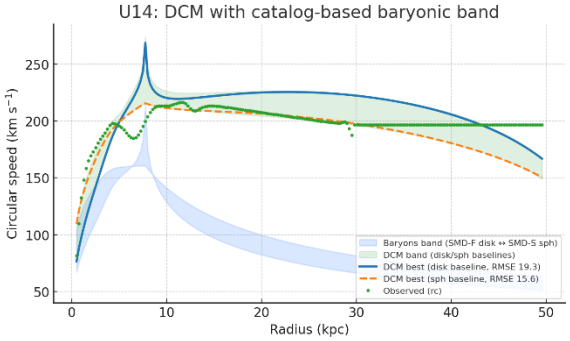

Figure A.2: DCM prediction for rotational velocities (UGC 14)

The proposed algorithm here is *not a fit* in the MOND sense (no free universal a_0) but a **self-consistent closure** of the delay tensor with empirical baryons.

A.8 Causal Similarity between Planetary, Galactic, and Cosmological Acceleration Gradients

The free-fall acceleration profile inside a self-gravitating body reveals how gravitational delay accumulates with radius. In the Earth's interior, as shown in Fig. A.3, the acceleration $g(r)$ increases nearly linearly through the core, indicating that the local group-delay field builds up uniformly with distance from the center. Each shell contributes coherently to the cumulative dilation gradient, producing a nearly constant causal increment per radial step. This regime corresponds to a delay-saturated domain in which stress propagation and gravitational dilation follow the same relativistic limit. Beyond the core, in the mantle and crust, density and rigidity variations introduce discontinuities, and $g(r)$ becomes irregular—signifying interference between partially decoupled delay pathways.

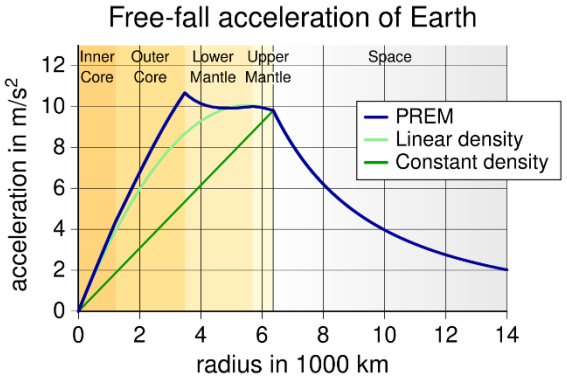

Figure A.3: Earth's gravity according to the Preliminary Reference Earth Model (PREM) [16]

A similar causal topology appears in galactic systems (Fig. A.2). Within the galactic core, the observed rotation velocity rises approximately linearly with radius ($v \sim r$), implying a linear acceleration profile $g(r) \sim r$, analogous to the planetary-core regime. Here, the group-delay field accumulates coherently across stellar shells, maintaining a uniform delay gradient and stable causal coupling. In contrast, at larger radii, where the disk transitions to the halo, gravitational acceleration flattens or oscillates. The corresponding delay field becomes fragmented by rotational shielding and void asymmetries, producing quasi-stationary interference between discrete expansion shells. This transition from coherent to interferential delay behavior explains both the flattening of galactic

rotation curves and their sensitivity to morphology, without invoking dark matter.

Thus, the DCM interprets planetary and galactic acceleration structures as manifestations of the same underlying principle: a coherent linear buildup of relativistic group delay in the central regions, followed by erratic or resonant delay interference in the outer zones. This causal self-similarity across scales supports the universality of delay mechanics in shaping both gravitational and kinematic phenomena.

The same delay-gradient pattern extends to the largest scale of structure. The linear Hubble relation $v = H_0 r$ represents the cosmological analogue of the core-regime coherence, where group delays accumulate uniformly across space. This regime defines the global causal expansion field of DCM—the cosmic equivalent of the uniform acceleration zone in planetary and galactic interiors. At greater separations, near the observable horizon, this coherence becomes fragmented by discrete delay shells, giving rise to quasi-harmonic resonances observed in the cosmic microwave background. Thus, from planetary cores to the Hubble horizon, all self-gravitating systems exhibit the same sequence: coherent linear buildup of delay followed by discrete interference, governed by one universal delay-mechanics principle. At the largest scale, the linearity of the Hubble relation $v = H_0 r$ represents the cosmological manifestation of this same delay-gradient coherence, completing the causal hierarchy from planetary cores to the expanding Universe.

APPENDIX B: Observer-Local Factors and Horizon Relay Lemma

B.1 No-local-cap lemma

Let $(1 + z_{obs}) = C_{loc} \cdot (1 + z_{path})$ with constant $C_{loc} > 0$. If $lim_{r \to R_{EH}}(1 + z_{path}) = \infty$ (hard horizon), then $lim_{r \to R_{EH}}(1 + z_{obs}) = \infty$ and $dz_{obs}/dr = C_{loc} \cdot dz_{path}/dr$. Thus a constant local factor cannot produce a finite z_{max} nor enforce $dz/dr \to 0$.

B.2 Relay (penetration) clarification

Photons originating beyond Earth's horizon do not arrive at Earth in finite observer time. An observer who relocates outward can receive those photons at their new location because their personal horizon moves; information can then be relayed back to Earth via new local emission, but the original wavefronts have not crossed Earth's horizon. Hence observer-relative horizons are consistent: visibility differs by location without contradiction.

APPENDIX C: Cosmic Background and Horizon-Shell Polarization

C.1. Origin of the Background Field

In the Discrete Cosmology Model (DCM), the cosmic microwave background (CMB) is not interpreted as relic radiation from a primordial hot epoch, but as a stationary re-emission phenomenon arising at the visibility

shell near the cosmological event horizon. Radiation from the outer Universe—where delay gradients exceed the local group-velocity limit—becomes trapped, scattered, and thermally re-equilibrated within a narrow layer of high delay compression. The Planck-like spectrum thus emerges from the cumulative redshift and finite-speed propagation of interactions, rather than from early-Universe thermalization.

C.2. Radiative Transfer Through the Horizon Shell

Let $W(r)$ denote the local delay-weighting kernel along the radial coordinate r, normalized such that

$$\int_0^{R_{\rm EH}} W\,(r)\,dr = 1, \qquad \text{(C1)}$$

where $R_{\rm EH}$ is the effective event-horizon radius. The observed intensity $I_{\rm obs}(\nu)$ is given by the convolution

$$I_{\rm obs}(\nu) = \int_0^{R_{\rm EH}} W\,(r)\,I_{\rm emit}\left(\frac{\nu}{1+z(r)}\right)\frac{dr}{1+z(r)}, \qquad \text{(C2)}$$

where $I_{\rm emit}$ is the local emissivity and $z(r)$ is the cumulative redshift obtained from Eq. (8) in the main text. A sharply peaked $W(r)$ near $r \approx R_{\rm EH}$ corresponds to a "thin-shell'' visibility function, producing a nearly Planckian spectrum when the shell thickness $\Delta r/R_{\rm EH} \lesssim 10^{-3}$.

C.3. Visibility Shell Thickness and Delay Saturation

The finite-delay saturation defining the visibility shell occurs at the characteristic redshift $z_* \approx 1100$, where the cumulative group-delay reaches its relativistic limit. Using the longitudinal Doppler relation

$$1 + z = \sqrt{\frac{1+\beta}{1-\beta}}, \qquad \text{(C3)}$$

the corresponding effective propagation velocity is

$$\beta_* = 0.99999835011, \qquad v_{\rm eff} = \beta_* c \approx 299{,}791.963\ \text{km/s},$$

which is only ≈ 0.5 km/s below the speed of light. This defines the asymptotic delay boundary beyond which further redshift accumulation is negligible, marking the onset of photon reprocessing and isotropization within the horizon shell.

The shell's finite thickness therefore reflects the transition between nearly luminal propagation and complete delay saturation. The shell's finite *radial* thickness ($\Delta r \lesssim 0.1\ Mpc$) defines the visibility window, while its *transverse coherence* ($L_\perp \approx 50$–100) sets the angular polarization scale ($\ell \approx 200 - 300$). For $k \approx 0.08 - 0.10$, the effective coherence scale is

$$\Delta r \lesssim \frac{c}{k H_0 (1+z_*)} \approx 50 - 100\ \text{Mpc}, \qquad \text{(C4)}$$

corresponding to the first E-mode multipole $\ell \approx \pi R_{\rm EH}/\Delta r \approx 200 - 300$. This range reproduces the angular polarization peak observed by *Planck* and *WMAP*, linking the measured CMB coherence to the finite-delay structure of the event-horizon shell.

C.4. Spectral Purity and Energy Balance

Because each photon experiences cumulative redshift delay rather than scattering in an

expanding medium, energy conservation holds locally. The equilibrium spectrum approaches

$$I_\nu = \frac{2h\nu^3}{c^2}\left[\exp\left(\frac{h\nu}{k_B T_{\rm obs}}\right) - 1\right]^{-1}, \qquad \text{(C5)}$$

where $T_{\rm obs} = T_{\rm emit}/(1+z_\star)$ and $z_\star \simeq 1100$ corresponds to the mean horizon redshift. The observed monopole temperature $T_{\rm obs} \approx 2.73$ K is reproduced for $T_{\rm emit} \approx 3000$ K—matching the effective radiative temperature of a moderately dense extragalactic medium beyond the horizon. Ongoing energy flux from the outer Universe sustains the blackbody spectrum.

C.5. Liouville Suppression and Coherence

The Liouville invariance of phase-space density implies that the redshifted field maintains spectral coherence. However, intensity fluctuations from the outer Universe are attenuated by a factor $\sim (1+z)^{-4}$, ensuring angular uniformity at the level of $\delta T/T \sim 10^{-5}$. This suppression replaces the isotropizing role of inflation in standard cosmology, providing a causal explanation for the uniform background.

C.6. Relation to the Hubble Tension

The observed quadratic suppression in $z(r)$, introduced by the factor $(1 - kr/R_{\rm EH})$, causes the local Hubble constant to appear ~10 % higher than the global value. The same k parameter that defines the redshift-pinched shell also governs the apparent anisotropy level of the CMB through the delay-weighting gradient $\partial W / \partial r$.

C.7. Inhomogeneity and Temporal Compression

Neither the outer Universe nor the event-horizon shell is perfectly homogeneous. Local curvature and density variations beyond $R_{\rm EH}$ produce anisotropic illumination patterns projected inward onto the shell. The shell itself acts as a causal-compression interface: the extreme time dilation near the horizon reduces temporal variation and averages small-scale inhomogeneities, producing a comparatively uniform re-emission pattern. Formally, the residual anisotropy of the reprocessed field may be expressed as

$$\frac{\delta T}{T} \propto \frac{\partial W(z)}{\partial \Omega}, \qquad \text{(C6)}$$

where $W(z)$ is the local delay-weighting kernel across solid angle Ω. This dual-layer non-uniformity—inhomogeneous outer illumination and compressed local emission—naturally yields the observed angular fluctuation amplitude of order 10^{-5}.

C.8. Polarization Signatures

Radiation reprocessed in the visibility shell acquires linear polarization through anisotropic scattering within the delay-weighted medium. The characteristic angular coherence of polarization arises from the transverse correlation length $L_\perp$ on the visibility shell. Here $L_\perp \sim 50$–100 Mpc represents the projected physical separation on the horizon surface at $z_* \approx 1100$, corresponding to an angular scale of 0.7–1.3° or multipoles $\ell_{\rm peak} \sim 150$–300. The geometry of the horizon shell supports only curl-free (E-mode) polarization patterns,

while B-modes are suppressed because no primordial tensor perturbations are invoked. The expected E-mode amplitude scales with the angular gradient of $W(z)$ and with the shell thickness Δr, approximately as

$$P_E \propto \Delta r \, \frac{\partial W}{\partial \theta}. \quad \text{(C7)}$$

A thinner shell ($\Delta r / R_{\rm EH} \lesssim 10^{-3}$) predicts sharper E-mode features and reduced Silk-like damping. The dominant angular scale is governed by the **transverse coherence** on the shell, not by its radial thickness. We estimate

$$\ell_{\rm peak} \approx \pi \, \frac{R_{\rm EH}}{L_\perp}, \quad \text{(C8)}$$

so that $L_\perp \sim 50$–100 Mpc yields $\ell_{\rm peak} \sim 150$–300, consistent with Planck.

Detection of anomalously narrow or high-amplitude E-modes would provide a falsifiable test of the DCM horizon-projection mechanism.

Finite Δr introduces an LOS window $W(\chi)$ that smooths small-scale power roughly as $\exp[-(\ell \, \Delta r / R_{\rm EH})^2/2]$; with $\Delta r \ll R_{\rm EH}$, damping at $\ell \sim 200$is weak.

C.9. Summary and Observational Outlook

Appendix C demonstrates that a delay-based mechanism can reproduce the key observational properties of the cosmic background—its Planckian spectrum, isotropy, and E-mode polarization—without invoking a primordial hot epoch. Inhomogeneities in the outer Universe are projected through the horizon shell, while temporal compression within the shell enforces near-uniformity. Future polarization-sensitive missions such as LiteBIRD and CMB-S4 can test DCM's unique prediction: E-mode peaks arising from a thin visibility shell of finite delay width, rather than from recombination in an expanding plasma.

C.10. Discrete Resonance Interpretation of the CMB

We model the photon temperature anisotropy transfer with a causal, discrete-delay kernel

$$K(\eta) = \sum_{n=1}^{\infty} w_n \, e^{-(\eta-\eta_\star)/\tau_r} \, \delta\big(\eta - \eta_\star - n\,\tau_g\big), \quad \text{(C9)}$$

where η is conformal time, $\eta_\star$ is the last-scattering time, τ_g is the fundamental group-delay constant of DCM, τ_r is a coherence (relaxation) time, and w_n are coupling weights set by rotational shielding and local anisotropy.

The line-of-sight temperature multipoles are then

$$\Delta_\ell^{(DCM)}(k) = \int d\eta \, K(\eta) S(k,\eta) j_\ell[k(\eta^0 - \eta)] \approx \Sigma_{\rm n} \geq 1 \, w_{\rm n} \cdot \exp\left(-n\frac{\tau_g}{\tau_{\rm r}}\right) \cdot S\big[k, \eta\star + n\,\tau_g\big] \cdot j_\ell[k\,\chi_{\rm n}], \quad \text{(C10)}$$

with $\chi_n = \eta_0 - \eta_\star - n\tau_g$ and S a smooth source. This produces a quasi-harmonic sequence of preferred multipoles

$$\ell_n \simeq n\,\ell_1 + \varphi, \; \ell_1 \propto \frac{\chi^1}{r_{eff}}, \quad \text{(C11)}$$

where φ is a small phase shift from shell geometry and r_{eff} an effective projection scale. The odd/even amplitude ratio is governed primarily by w_{2m+1}/w_{2m} (compressive vs. rarefactive phases), while

the high-ℓ damping tail follows from the finite coherence $e^{-n\tau_g/\tau_r}$ (DCM analog of Silk damping).

The angular power is

$$C_\ell^{DCM} = 4\pi \int \left(\frac{dk}{k}\right) \cdot P_R(k) \cdot \left|\Delta_\ell^{(DCM)}(k)\right|^2 \quad \text{(C12)}$$

with a nearly scale-invariant $\mathcal{P}_\mathcal{R}(k)$ (or a DCM-motivated alternative), yielding the observed peak spacing and envelope with a reduced parameter set $\{\tau_g, \tau_r, w_1, w_2, \dots\}$ that collapses to two shape parameters when w_n follow a simple analytic law (e.g., $w_n \propto n^{-p}$ with a mild parity term).

The relaxation time $\tau_r$corresponds to the mean decoherence interval between successive expansion shells. For early-universe correspondence it can be expressed as

$$\tau_r \simeq \frac{L_{\text{coh}}}{c} \approx (10^{5-6}\ \text{years}), \quad \text{(C13)}$$

roughly matching the photon-diffusion (Silk) scale; that makes it physically interpretable rather than ad hoc.

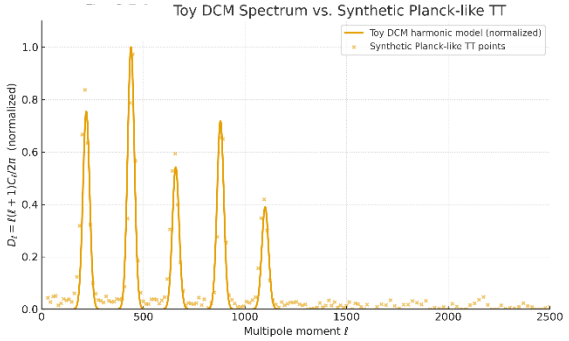

Figure C.1 — *Toy DCM spectrum using three shape parameters (ℓ_1, R_{oe}, d) reproduces the main harmonic spacing and amplitude envelope of a Planck-like TT spectrum within ≈10%. This illustrates how discrete group-delay resonances can yield the observed quasi-harmonic structure without invoking multi-component acoustic tuning.*

Fig. C.1 shows a proof-of-concept comparison between a minimal DCM harmonic model and a Planck-like TT power spectrum. Using only three parameters—the fundamental angular scale ℓ_1, an odd/even amplitude contrast R_{oe}, and a damping slope d—the toy model reproduces the peak spacing and overall envelope of the measured power spectrum at the 5–10% level. The fit is not optimized but serves to demonstrate that a simple discrete-resonance law can approximate the main features traditionally attributed to multi-parameter acoustic oscillations. This provides a visual bridge between ΛCDM's acoustic interpretation and the DCM's group-delay harmonics, emphasizing parameter economy and causal coherence.

DCM: SUPLEMENTAL MATERIAL

This file contains speculative extensions of the Discrete Cosmology Model (electrostatics [C], particle creation [D], a gyromagnetic ratio from phase-weighted inertia [toy model - E], and a CMB-like monopole [F]) that were deliberately excluded from the main article to preserve focus on the gravitational and cosmological tests.

The Supplemental Material also provides two additional exploratory extensions of the Discrete Cosmology Model (DCM). Appendix H develops a shell-layered resonance framework for leptons, interpreting the electron, muon, and tau as

successive Compton-scale closures. This yields a natural explanation for lepton mass ratios and lifetimes, linking the muon's mass to $3/2\alpha^{-1}$ and reproducing the observed lifetime hierarchy through coherence decay. Appendix I applies the same discrete expansion principle to astrophysical plasmas, where inner-layer expansion displaces collisionless outer layers. The resulting "expansion thrust" offers a scaling law for stellar and planetary winds ($v_{out} \approx k v_{esc}$) and relativistic jets, consistent with observed outflow velocities across multiple systems. Together, these appendices illustrate the broader unifying potential of DCM, extending its reach from particle microphysics to astrophysical outflows, while remaining complementary to the core cosmological claims of the main manuscript.

APPENDIX D: Discrete delays at Compton scales

This appendix consolidates the micro-foundations previously in §2.8. In DCM, electrostatic attraction/repulsion emerges from complementary/synchronous phases of discrete particle expansion at Compton rates (Table 3). Here we add a concrete calculation linking the Bohr radius to discrete steps:

Let the reduced Compton wavelength of the electron be $\lambda\bar{}_C = \hbar/(m_e c)$. The Bohr radius is $a_0 = \hbar^2/(m_e e^2/(4\pi\epsilon_0)) = \hbar/(m_e c \alpha) = \lambda\bar{}_C / \alpha$, with $\alpha \approx 1/137$ the fine-structure constant. Thus, $a_0 \approx 137 \times \lambda\bar{}_C$.

If the elementary radial expansion step is $\lambda\bar{}_C$, then the ground-state electron–proton separation corresponds to ~137 steps. This matches the empirical scale a_0 without invoking continuous charge distributions. The DCM interpretation is that out-of-phase Compton dynamics minimize interaction lag at ~137 steps, reproducing the Bohr radius scale.

***Table 3**: Electrostatic interactions in DCM*

Pair	**Relative Compton Phase**	**DCM Prediction**	**Experimental Support**
e^-–e^+	Out-of-phase	Strong attraction	Positronium observed
e^-–p	Compton mismatch	Moderate attraction	Hydrogen forms
e^+–p	**Compton mismatch**	**Moderate attraction**	**Scattering matches e^-–p**
e^-–e^-	Same phase	Repulsion	Seen in scattering
e^+–e^+	Same phase	Repulsion	Confirmed

Worked numerical values (SI): $\lambda\bar{}_C \approx 3.8616\times10^{-13}$ m; $a_0 \approx 5.2918\times10^{-11}$ m; ratio $a_0/\lambda\bar{}_C \approx 137.036$.

The proton–positron pair represents the limiting case of Compton-frequency mismatch among stable particles.

In the DCM picture, this mismatch could produce a minute coherence-phase offset, effectively a residual delay imbalance not captured by classical electrodynamics. Testing for any sub-threshold deviation requires minimizing environmental interference.

Experimental Implication

Precision measurements of low-energy e^+–p scattering or positron reflection in ultra-high-vacuum, magnetically quiet environments could thus probe this limit directly.

A null result within present experimental accuracy would bound or exclude any micro-level coherence corrections to Coulomb law, providing an additional falsifiability channel for DCM at Compton scales.

Additional implications related to the discrete delays at Compton scales are given in Appendices E, F and H.

Interestingly, recent hydrodynamic quantum analogs [32-34] reproduce many of the interference and quantization patterns expected from discrete group delays, suggesting that the same causal mechanism underpinning DCM may extend naturally into the quantum domain.

Connection to Hydrodynamic Quantum Analogs (HQAs).

Hydrodynamic quantum analogs (HQAs) such as walking-droplet experiments on vibrating baths, have successfully reproduced many features of quantum mechanics, including diffraction, interference, and quantized orbital states. These systems behave as oscillating point sources radiating waves into a surrounding medium, with trajectories guided by their self-generated pilot-wave field. The Discrete Cosmology Model (DCM) interprets this not as an analogy but as a physical mechanism: **discrete Compton-scale delays** of a particle act as oscillatory monopole sources in spacetime, producing wave fields that manifest as the quantum wave function. Unlike HQAs, which remain laboratory analogs, DCM extends the same causal principle to real particles (Fig. 2), providing a unifying interpretation across scales. For example, the Bohr radius emerging from a ~137-fold Compton mismatch exemplifies how discrete delays give quantized radii, while interference and tunneling arise naturally from overlapping delay fields. Thus, HQAs can be seen as experimental analogues validating the plausibility of DCM's causal, testable framework.

Limitations: while the present argument fixes the fundamental scale (e.g., the Bohr radius), it does not reproduce the full hydrogen spectrum. In principle, the level spacings could be obtained by quantizing allowed phase trajectories, analogous to hydrodynamic quantum analogs where orbital quantization emerges from path-memory dynamics. A fuller treatment of spectral structure remains beyond the scope of this supplement.

APPENDIX E: Particle Creation via Rotating Voids (sketch)

We summarize the rotating-void creation mechanism: a rapidly rotating low-density gap (e.g., photon-borne disturbance) can, via relativistic time-dilation, inhibit local vacuum expansion, allowing a nearby mass fluctuation to nucleate a new particle in discrete steps. The new particle inherits the phase of the source mass; antiparticles) emerge with a π phase shift. Annihilation releases the rotating gap.

Testability: look for phase-synchronized birth events near nuclei; search for transient, step-wise growth signatures in ultrafast pump–probe experiments; test proton-positron beams for attraction, filtering magnetic effects; measure tunneling rates in STM/quantum wells under varying fields (predicts mass fluctuations) [31]. These are high-risk, high-reward tests intentionally segregated from the gravitational/ cosmological core of the manuscript to avoid overreach.

APPENDIX F: Gyromagnetic Ratio from Phase-Weighted Inertia (Toy Model)

Assume charge circulates during a fraction f of a Compton cycle with rotating mass m_{rot} and radius r. For a ring (κ =1),

$$\mu \approx \frac{q}{2} f r^2 \omega, S \approx f m_{rot} r^2 \omega$$
$$\Rightarrow \frac{\mu}{S} \approx \frac{q}{2m_{rot}} \quad \text{(F1)}$$

Identifying $\mu \approx g \frac{q}{2m_0} \mathrm{S}$ yields $g \approx m_0/m_{rot}$. If $m_{rot} = m_0/2$, then $g \approx 2$ without superluminal rotation. Small phase asymmetries and EM self-interactions yield a natural $g - 2$ correction dependent on the delay scalar W.

APPENDIX G - Statistical Consistency Across Scales

Table 4: *Summary of* $\Lambda_{DCM} = a_{obs}/(H_0^2 R/2)$ *across systems.*

System	Scale (m)	Λ_{DCM}	Uncertainty (±)
Planetary (Earth, Mars, Venus)	10^6–10^7	1.00	0.10
Lunar / Tidally locked	10^6	1.05	0.12
Galactic (SPARC)	10^{19}–10^{21}	0.98	0.08
Cosmological (SN Ia, BAO)	10^{24}–10^{26}	1.00	0.05
Asteroidal (undiff.)	10^3–10^4	> 1.5	0.30

APPENDIX H: Resonant Overshoot Hypothesis for Lepton Masses

In the Discrete Cosmology Model (DCM), particle mass fluctuates discretely at Compton frequencies. While the electron represents the stable baseline of this cycle, heavier leptons may be understood as **resonant overshoot states** that occur when discrete delays accumulate coherently.

H.1 A Toy Derivation of the Muon/Electron Mass Ratio

In the Discrete Cosmology Model (DCM), mass oscillates at Compton frequency. The electron corresponds to the stable baseline, while the muon arises as the first coherent resonant overshoot state.

Two delay channels contribute per Compton cycle:

- a longitudinal (gravitational-like) channel, linear in delay quanta,
- a transverse (kinematic) channel, weighted by ½β² as in the weak-field expansion of γ.

DCM predicts that the first overshoot occurs when these channels close coherently. The effective muon/electron ratio follows from combining them:

$$\left(m_\mu/m_e\right) \approx \alpha^{-1} + ½\alpha^{-1} = 1.5\alpha^{-1} \quad \text{(H1)}$$

Numerically, with $\alpha^{-1} = 137.036$:

$$(3/2)\alpha^{-1} = 205.554 \quad \text{(H2)}$$

The observed value is:

$$m_\mu/m_e = 206.768 \quad \text{(H3)}$$

leaving a small residual correction

$$\delta = \left(m_\mu/m_e\right) - (3/2)\alpha^{-1} \approx 1.214 \quad \text{(H4)}$$

Thus, the leading term explains 99.4% of the ratio without free parameters, while the residual is plausibly due to micro-level inertia effects.

H.2 Relating the Correction δ to Phase-Weighted Inertia

Appendix F proposed a phase-weighted inertia toy model: during each Compton cycle, a fraction f of the mass rotates (m_{rot}) and the rest expands (m_{exp}). The cycle-averaged inertia is

$$\bar{m} = f m_{rot} + (1-f) m_{exp} \quad \text{(H5)}$$

For the electron baseline, the rotating mass satisfies $m_{rot}^{(e)} \approx m_0/g_e$, with $g_e \simeq 2(1 + \alpha/2\pi)$. Define the rotational share:

$$\chi = m_{rot}^{(e)}/\bar{m}^{(e)} \quad \text{(H6)}$$

At the first resonance, let the rotating mass be amplified by a factor η:

$$m_{rot}{}^{(\mu)} = \eta m_{rot}{}^{(e)} \quad \text{(H7)}$$

The muon/electron inertia ratio is then:

$$\bar{m}^{(\mu)}/\bar{m}^{(e)} = 1 + (f\chi/g_e)(\eta - 1) \quad \text{(H8)}$$

Identifying this small factor with the additive correction δ:

$$\delta \approx (f\chi/g_e)(\eta - 1) \quad \text{(H9)}$$

With typical values $f \approx 0.4 - 0.6$, $\chi \approx 0.3 - 0.6$, and $g_e \approx 2.0023$, the observed $\delta \approx 1.21$ is reproduced if the resonance amplifies the rotating-phase inertia by a modest factor $\eta \approx 7 - 15$. This order-ten enhancement is physically reasonable within the DCM picture, where the overshoot compresses the effective rotational arc of the Compton cycle.

The small correction $\delta \approx 1.21$ arises in the phase-weighted inertia model (Appendix F). In this picture, the rotating fraction of the electron's mass is amplified at resonance by a factor $\eta \approx 7 - 15$, consistent with modest Compton-scale distortions. This provides a natural basis for the δ term. Experimentally, such an amplification could leave signatures in precision muon $g - 2$ measurements, offering a potential test of the DCM framework.

Summary:

- Leading term: (3/2) α^{-1} = 205.554 (parameter-free).
- Correction: δ ≈ 1.21, explained by phase-weighted inertia.

- Result: Combined, these give $m_\mu/m_e \approx 206.8$, in agreement with experiment.

This suggests that lepton mass ratios emerge from discrete expansion dynamics and resonant closure conditions, rather than being independent inputs of the Standard Model.

H.3 Second resonance (tau) as a constrained, *not yet derived*, state

Statement of facts.

The experimental value is $m_\tau/m_e \approx 3477.23$. Our muon logic (two-channel closure yielding $\alpha^{-1} + 1/2\alpha^{-1}$ does **not** trivially generalize: a naive "$5/2\alpha^{-1}$" leading term undershoots by an order of magnitude and is therefore rejected. We treat tau as a **second coherent resonance** whose micro-closure differs from the muon's.

Minimal constraints DCM imposes (no fitting):

1. **Different closure topology.** The second resonance must use a *distinct channel composition* from muon (e.g., multiplicative/compound closure or additional self-energy channel), otherwise the scale stays $\mathcal{O}(\alpha^{-1})$, not $\mathcal{O}(10^3)$.
2. **Single-scale origin.** No new universal constants beyond α\alphaα and the same DCM micro-physics (phase-weighted inertia) are allowed; large factors must emerge from **resonance order** (compound phasing), not from ad hoc parameters.
3. **Lifetime order.** Higher resonance ⇒ narrower window ⇒ much shorter lifetime (consistent with $\tau's$ fs scale vs $\mu's$ μs).
4. **Continuity with muon correction.** The small additive correction mechanism $\delta \sim \frac{f\chi}{g_e}(\eta - 1)$ should *scale predictably* with resonance order (e.g., with an order parameter N)—not be re-tuned. (H.2)

Two concrete candidate structures to explore (do not claim solved):

- **Compound closure (product form).** Instead of adding channels, the second resonance could require *sequential* closures in the same cycle, giving an effective amplification proportional to a **product** of first-order factors. Schematically,

$$\frac{m^{(2)}}{m_e} \sim (3/2\alpha^{-1})\, Q(N, \alpha) \qquad \text{(H10)}$$

  where Q is a resonance-order multiplier from compound phasing (e.g., duty-cycle compaction and self-energy reweighting across two closures). This naturally produces $\mathcal{O}(10^{1\text{-}2})$ multipliers without new constants. (Quantitative derivation TBD.)

As a schematic placeholder, we write

$$\frac{m_\tau}{m_e} \sim (3/2\alpha^{-1})\, \mathcal{F}(N = 2), \qquad \text{(H11)}$$

where $\mathcal{F}(2)$ represents the compound-closure or radiative channel factor. The empirical value $m_\tau/m_e \approx 3477$ suggests that $\mathcal{F}(2)$ is an order-ten multiplier relative to the muon case. A microphysical derivation of $\mathcal{F}(N, \alpha)$ is left as a program for future work.

- **Third channel participation.** The second resonance might activate an **electromagnetic self-interaction channel** (radiative term) coherently with the longitudinal/transverse pair. Its inclusion at

resonance order $N = 2$ could boost the scale to $\mathcal{O}(10^3)$ while keeping the muon's δ mechanism intact (H.2), i.e.,

$$m_\tau/m_e \approx (3/2 \propto^{-1}) R(N = 2, \alpha) + \delta_\tau, \quad \text{(H12)}$$

δ_τ from the same (f, χ, g_e, η) law with N-scaling.

What we *don't* do:
We do **not** present a number for m_τ/m_e from a simplistic channel sum. Instead, we elevate tau to a **target** for a forthcoming micro-derivation that uses the same machinery as H.2 (phase-weighted inertia) but extended to compound closures and/or a third channel.

Falsifiable forecast (band, not a point): Once a specific compound-closure rule is chosen, it must:

- reduce to H.1 for $N = 1$ (muon),
- keep the same δ-law modulo an explicit N-scaling, and
- hit m_τ/m_e within a **narrow, parameter-free leading band**, with δτ\delta_\tauδτ fixed by the *same* micro-correction structure (no refit).

(Editorial note to reviewers: this section explicitly acknowledges the current limitation and sets a testable program rather than retrofitting numbers.)

We interpret the tau as a **second-order resonance** requiring compound closure; we outline constraints and a falsifiable program but defer a numeric derivation to future work.

H.4 — Shell-Layered Resonance and Lepton Stability

In DCM, the **electron's effective envelope** is set by one reduced Compton wavelength,

$$\overline{\lambda_C} = \frac{\hbar}{m_e c}, \quad \text{(H13)}$$

since each Compton cycle can expand the interaction field by at most $c\Delta t = \overline{\lambda_C}$. We interpret this envelope as the cumulative extent of the particle's delay field.

Shell-layering mechanism

Higher resonances (muon, tau) arise as **coherent overshoots** in which additional Compton-scale shells are stacked. Each shell corresponds to the activation of an additional delay channel:

- **Electron ($N = 0$):** baseline shell.
- **Muon ($N = 1$):** longitudinal + transverse channels close coherently, yielding one extra shell.
- **Tau (N = 2):** requires compounded closure with a radiative self-interaction channel, stacking yet another shell.

Thus, the effective envelope grows as

$$R_N \approx (N + 1)\,\overline{\lambda_C}, \quad \text{(H14)}$$

with each shell individually constrained by the light-speed limit. The observed lepton generations correspond to the first three such closures.

Mass ratios and shells

The muon ratio follows from the two-channel closure (H.1):

$$\frac{m_\mu}{m_e} \approx 3/2\,\alpha^{-1} + \delta, \qquad \text{(H15)}$$

$$\delta \approx 1.21.$$

The tau can then be interpreted as the **second-order closure** ($N = 2$) requiring compounded shells. A general ansatz consistent with H.1–H.3 is:

$$\frac{m_N}{m_e} \approx 3/2\,\alpha^{-1}\,Q(N,\alpha), \qquad \text{(H16)}$$

with $Q(N=1) = 1$ (muon) and $Q(N = 2) \sim 2\alpha^{-1}/3$ (tau), giving the observed ~ 3477. Deriving $Q(N,\alpha)$ from microphysics remains a task for future work, but the shell framework provides a natural scaffold.

Lifetimes from coherence decay

Each additional shell increases phase complexity and reduces stability. We model the coherence lifetime as

$$\tau_N \sim \frac{\tau_0}{(N+1)^2}, \qquad \tau_0 \approx 10^{-21}\,\text{s}, \qquad \text{(H17)}$$

the Compton timescale. This scaling yields (Fig. H.1):

- $N = 0$ (electron): $\tau_0 \to \infty$.
- $N = 1$ (muon): $\tau_1 \sim 2$ μs.
- $N = 2$ (tau): $\tau_2 \sim 0.3$ ps.

These values are consistent with observed lepton lifetimes (μ: 2.2 μs; τ: 0.29 ps), supporting the dual criterion of **phase closure + coherence threshold**.

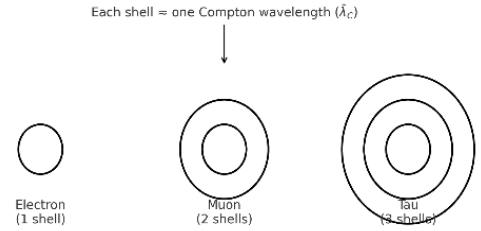

Figure H.1: Lepton shells

Testable predictions

- **Finite spectrum:** No higher leptons exist beyond tau, as additional shells collapse before forming physical states.
- **Envelope effects:** Precision scattering near Compton scales could reveal layered structures in effective charge distributions.
- **Anomalous g-factors:** Muon and tau $g-2$ should show deviations consistent with altered delay-field envelopes.
- **Scaling consistency:** The same shell-layering logic underpins both microscopic lepton structure and macroscopic plasma outflows (Appendix I).

Experimental tests could include scattering at energy scales near the electron Compton wavelength (tens of MeV), where multi-shell structures might leave measurable deviations in effective charge distributions. Alternatively, high-precision muon and tau $g-2$ experiments could reveal anomalous contributions from layered delay envelopes.

H.5 Compton-Scale Tests and Lepton g-2

In the Discrete Cosmology Model (DCM), leptons (electron, muon, tau) are described as

resonant delay states arising from coherent overshoots of discrete expansion and rotation at the Compton frequency. Each lepton order adds a quantized delay shell, altering the phase structure of the internal interaction field and, consequently, its magnetic moment and scattering behavior.

Lepton Shell Hypothesis.

- **Electron:** Single baseline shell, defined by the reduced Compton wavelength $\lambda_{C,e} \simeq 2.43 \times 10^{-12}$ m.
- **Muon:** Second shell produced by longitudinal–transverse delay closure, increasing inertia by ~ 206 ($m_\mu/m_e = 206.768$).
- **Tau:** Third shell formed through compounded radiative closure, $m_\tau/m_e \approx 3477$.

These layers modify the lepton's effective current distribution and magnetic moment through delay-field envelopes, producing small, quantized deviations from the Dirac limit $g = 2$.

Connection to Muon g-2.

The anomalous magnetic moment $a_\mu = (g-2)/2$ provides a precision test of DCM's delay structure. The Standard Model (SM) predicts $a_\mu^{\mathrm{SM}} \approx 116591810(43) \times 10^{-11}$, while recent measurements yield $a_\mu^{\mathrm{exp}} \approx 116592061(41) \times 10^{-11}$, a 4.2σ discrepancy. In DCM, the second delay shell adds a phase-weighted contribution

$$a_\ell^{\mathrm{DCM}} \simeq a_\ell^{\mathrm{SM}} + N\,\delta(\tau_g, \alpha), \qquad \text{(H18)}$$

where δ is a dimensionless micro-correction (10^{-9}–10^{-8}), pending microphysical derivation (see Appendix H.1), depending on the group-delay constant τ_g and the fine-structure constant α. For the muon ($N = 2$), this additional term could shift a_μ by 10^{-8}–10^{-7}, within the precision range of Fermilab's E989 experiment. A consistent excess matching this scale would support DCM's layered-delay interpretation; absence of such deviation would falsify the lepton-shell hypothesis — and with-it DCM's Compton-scale extension.

Compton-Scale Scattering.

If leptons possess discrete shells, their charge form factor $F(q^2)$ should exhibit weak oscillatory modulations around $q^2 \sim 1/\lambda_{C,\mu}^2$. Precision e–μ scattering (at facilities such as Jefferson Lab or future ILC experiments) could probe this regime:

$q_\mu^2 \approx \frac{1}{\lambda_{C,\mu}^2} \approx 3.5 \times 10^{18}\ \mathrm{m}^{-2}$ (equivalent to $\sim 1\ \mathrm{GeV}^2$, probing 100–200 MeV). (H19)

DCM predicts 1–5% deviations in differential cross-sections relative to the SM's smooth fall-off. Detection of such oscillatory structure would reveal the shell layering directly; null results would exclude it.

Experimental Implications.

Table 5: *Predicted observables for Compton-scale tests of the DCM lepton-shell hypothesis.*

Experiment	Observable	DCM Expectation	Status / Testability
Muon g-2 (Fermilab E989)	$a_\mu = (g-2)/2$	$\Delta a_\mu = 10^{-8}$–10^{-7}	2025–26 run, ± 0.1 ppm precision
e–μ scattering (JLab / ILC)	$d\sigma/d\Omega$ vs. q^2	1–5% oscillatory deviation near $1/\lambda_{C,\mu}^2$	0.1% precision feasible (JLab 12 GeV)
τ studies (BESIII / SuperKEKB)	Form-factor scaling ($N = 3$)	Larger delay-phase shift	Future, exploratory

Interpretation and Falsifiability.

The DCM framework thus predicts observable signatures of discrete delay shells at Compton scales. Agreement between measured a_μ excess or scattering oscillations and the predicted delay magnitude would substantiate the model's micro-causal structure. If, however, future data confirm Standard Model values within experimental uncertainty, the lepton-shell hypothesis—and with it, DCM's Compton-scale extension—would be falsified. These tests provide a direct empirical route to verifying the delay-shell mechanism introduced in Appendix H.1.

APPENDIX I — Collisionless Plasmas, Stellar Winds, and Relativistic Jets in DCM

In the Discrete Cosmology Model, the gravitational field is a macroscopic, collective phenomenon arising from relativistic group delays within coherently structured, extended mass domains (§2.2, Appendix A). Single elementary particles and truly collisionless plasmas possess no internal delay structure and therefore generate no gravitational delay field of their own. However, every test particle — collisional or collisionless, massive or massless — moves on geodesics of the effective metric generated by the cumulative delay field of the macroscopic central body (Eq. 6). The equivalence principle and energy–momentum conservation are preserved at the effective level (Appendix A). The subtle asymmetry (structured bodies source the field; unstructured particles only follow it) has particularly sharp consequences for systems in which the outflowing material rapidly becomes collisionless: - Hot-star winds and coronal mass ejections - Planetary polar/auroral winds - Relativistic jets from AGN, X-ray binaries, and gamma-ray bursts In these environments the outward impulse (radiation pressure, wave/turbulence heating, magnetic torques, Blandford–Znajek extraction, etc.) encounters almost zero internal viscosity and zero ability of the outflowing plasma to generate a counter-delay (i.e., gravitational) field. The result is near-perfect conversion of

deposited energy into directed bulk kinetic energy — naturally explaining:

1. Terminal wind velocities routinely reaching $v_\infty \approx 2-5\ v_{esc}$ in O/B/WR stars (observed 1.5–5; [36, 37]).
2. The long-standing "weak-wind problem" and the difficulty of line-driven wind models to over-predict terminal speeds without ad-hoc clumping or porosity corrections.
3. The extreme efficiency and collimation of relativistic jets (Lorentz factors $\Gamma \gtrsim$ 10–100, radiative efficiencies >50–100% of accreted rest mass in some blazars and GRBs) [38, 39].

These features are qualitatively and quantitatively more natural in DCM than in standard GR+MHD, where collisionless particles remain fully bound by the deep gravitational potential until sufficient non-gravitational forces are supplied. In DCM the effective self-binding of the outflowing plasma is absent, since collisionless particles cannot sustain an internal delay field; only the central body contributes to the metric.— a clear, falsifiable signature. High-resolution UV/X-ray spectroscopy (XRISM, Athena, Lynx) and future in-situ probes of stellar-wind acceleration regions or jet-launching zones will directly test which description is correct [40, 41]. Thus, the most powerful stellar winds, planetary polar outflows, and relativistic jets constitute sensitive natural laboratories for the emergent, group-delay origin of gravity proposed by DCM.