Nothing Is All You Need

Departure Calculus, Zero Infinity, and the Enclosure of Singularities

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Abstract

Modern cosmology and quantum mechanics contain persistent boundary tensions: the Hubble tension, the vacuum energy catastrophe, singularities in gravitational collapse and early-universe extrapolation, and the unresolved measurement boundary in quantum mechanics. These tensions do not diminish the achievements of the researchers and instruments that revealed them. They mark the edge at which successful models begin asking for a larger enclosure. This paper is designed as a nested causal enclosure of the field it addresses. It attempts to project causality into that field by nesting itself parallel to the enclosure within which the largest open problems are already nested. From that position, it projects the boundary and initial conditions needed to communicate and embody a diversity of lawful solutions. The title's "Nothing" refers to the Zero Infinity 0_∞: the countably infinite balanced reference state from which departure becomes measurable. In this construction 0_∞ is as fundamental as the Final Frontier ff, because the reference state is what enables the boundary condition to operate without becoming a terminal singularity. Spacetime and quantum state evolution are modeled as departures from 0_∞ inside an Isotropic Vector Matrix (IVM), with local contracted and expanded states mediated through jitterbug transitions. The resulting formalism replaces the invariant cosmological constant with a scale-and-depth dependent curvature term, interprets the Hubble tension as a difference between enclosure scales, structurally removes the source of the vacuum energy divergence through paired-state cancellation and quantized compactification, and bounds wave-function spread through an enclosure-filtered Schrödinger equation. The result is not the dismissal of prior models, but a proposed causal enclosure of the problem-field in which singularities had been allowed to appear.

1 Introduction

The standard cosmological model, ΛCDM, has produced extraordinary agreement with observations of the cosmic microwave background, primordial nucleosynthesis, and large-scale structure [24, 21, 7]. General Relativity remains the most successful theory of gravitation [10, 18, 5]. Quantum mechanics and quantum field theory remain unmatched in predictive precision [28, 6, 23].

Yet the most successful models also expose the boundary at which their inherited assumptions become incomplete. The Hubble tension persists between local distance-ladder measurements and early-universe ΛCDM inference [25, 24]. The vacuum energy problem remains a mismatch of roughly 120 orders of magnitude between naive quantum-field estimates and observed cosmic acceleration [32, 4]. Gravitational singularities arise when smooth spacetime is extrapolated beyond the enclosure in which the equations remain physically meaningful [13, 22]. Quantum mechanics continues to require an interpretive boundary between wave-function evolution and measurement outcome [31, 3].

The claim of this paper is direct: these are not separate crises requiring separate rescues. They are shared signs that an otherwise successful model has crossed the scale at which its boundary conditions were stated. The problem is not that the fields were studied incorrectly. The problem is that smooth, continuous, and unbounded descriptions were asked to carry phenomena whose lawful form is nested, scale-dependent, and recursively enclosed.

The conversation this claim enters is not abstract. An observational cosmologist may hear it as a warning not to overfit one epoch of the sky to another; a particle physicist may hear it as a challenge to decades of dark-sector searches; a relativist may ask whether enclosure preserves the local triumphs of the Einstein equations; a quantum theorist may ask whether a bounded wave function is still a wave function; an instrument team may ask whether the model makes testable demands on JWST, Euclid, Rubin, Roman, LIGO, or future CMB surveys; a funding agency may ask what becomes of programs built around missing particles or singular initial conditions; and a student entering the field may wonder whether the ground has moved under the textbooks. The answer offered here is deliberately conservative in one sense and radical in another. It does not ask these communities to discard what they measured, built, or proved. It asks whether the measurements, instruments, and proofs have already carried physics to the boundary where the next lawful description must include the enclosure that made those successes possible.

The paper developed here is not the enclosure of the field itself. It is a nested causal enclosure of the field it addresses. It retains the successes of General Relativity, Friedmann dynamics, ΛCDM, quantum mechanics, and the observational programs that made their limits visible, but places the open problems beside one another inside a larger boundary architecture derived from the Three Laws of Nested Causality developed in *Causality and Attraction: A Continuum of Steady States* [15, 16, 17]. If this enclosure is correct, then whole research programs, including searches for missing mass, dark-sector structure, and early-universe closure terms, are not wasted efforts. They are the empirical path by which the edge of the unenclosed model was found. From this parallel position, the paper projects candidate boundaries and initial conditions back into the field so multiple solution paths can be communicated, compared, and tested. Under that projection, singularity-related divergences no longer appear as physical endpoints. They become artifacts of applying unenclosed equations beyond their lawful boundary.

2 The Three Laws and the Enclosure Requirement

The model rests on three laws.

Law of Nested Causal Enclosure. Every steady-state dynamic equilibrium is enclosed by one or more larger equilibria that project boundary and initial conditions inward. This does not deny bottom-up causality. It encloses it. Local interactions remain real, but they persist only inside larger causal structures.

Law of Nested Exchange. When matter, energy, or information transfers between adjacent nested equilibria, entropic dissipation in one enclosure is matched by negentropic reincorporation in an adjacent or enclosing equilibrium. In ordinary observational accounting, where the dissipating and accumulating sides are measured as separated events across time, this is expressed as an approximate time-shifted balance,

$$\Delta S_i(t) + \Delta S_j(t + \tau_{ij}) \approx 0. \tag{1}$$

The approximation is important at the level of measurement because the paired terms are often observed at different locations, resolutions, and times.

At the scale-transition boundary, however, the exchange returns to exact form. When heat dissipation from the lower enclosure cannot be decoupled from heat accumulation in the adjacent or enclosing scale, the two are not separate transactions. They are one jitterbug transition viewed from opposite sides. In that case,

$$\Delta S_i + \Delta S_j = 0, \tag{2}$$

with total vector integrity preserved across the scale escalation. This is the form relevant to singularity avoidance: the apparent entropic loss that would otherwise collapse into a singular endpoint is exactly reincorporated as the heat accumulation and geometric pressure required to move the system into the next lawful scale.

Law of Nested Infinities. Nesting continues without terminal scale in both directions, but the continuum is bounded by the Final Frontier ff, the single deterministic boundary condition appearing at every scale. Volume I identifies the IVM as the local geometric visibility of this boundary structure [15, 12].

Together these laws require that no physical, cosmological, or quantum model be treated as boundaryless. The missing boundary is the source of the singularity-related problems addressed below.

3 First Principles of the Enclosure Framework

The equations introduced below are not derived from the standard assumption of an unbounded background continuum. They are proposed from a different set of first principles. The purpose of the framework is to enclose the standard assumptions, recover their verified limits, and identify the boundary conditions under which their extrapolations fail. A request to derive the enclosure framework from the unbounded assumptions it is designed to enclose would therefore reverse the order of explanation. The proper test is whether the following principles generate coherent closure rules, recover known physics inside stable domains, and fail in identifiable ways when the closure rules are wrong.

Reference before object. No physical object, field, or state is defined without a reference condition. The Zero Infinity 0_∞ is the balanced, countably infinite reference state from which measurable departure becomes possible.

Boundary before extrapolation. No equation may be extended beyond the enclosure in which its boundary conditions remain lawful. The Final Frontier ff supplies the deterministic halt condition for recursive modeling.

Departure before substance. Matter, radiation, curvature, and quantum state are treated as departures from 0_∞, not as self-standing residents of an unbounded container.

Enclosure before isolation. Every phenomenon is held between a macro-enclosing condition and a micro-enclosed condition. Isolated states are approximations inside an active enclosure.

Exchange before loss. At a lawful scale-transition boundary, apparent entropic loss in one enclosure is reincorporated as heat accumulation, geometric pressure, or structural transition in an adjacent enclosure.

Recovery before replacement. A proposed enclosure theory must recover General Relativity, Friedmann dynamics, and ordinary quantum evolution inside their verified domains before claiming to extend them.

Falsifiability before completion. The framework is incomplete unless its closure rules can fail. The forms proposed here are minimal closure rules, not final dogma.

These principles explain the status of the curvature ansatz and enclosure operator. They are not claimed to follow uniquely from the unbounded continuum assumptions used in standard General Relativity or quantum theory. They are proposed as minimal mathematical expressions of the enclosure principles above. Their validity must be judged by internal consistency, recovery of known limits, and empirical performance.

4 Departure Calculus

The structural unit of the framework is the ternary enclosure function:

$$\Psi_n = [\Psi_{n+1} \mid \sigma_n \mid \Psi_{n-1}], \tag{3}$$

where Ψ_{n+1} is the macro-enclosing function, Ψ_{n-1} is the micro-enclosed function, and

$$\sigma_n \in \{-1, +1\} \tag{4}$$

is the local departure state: contracted (-1) or expanded $(+1)$.

The recursion is explicit. Expanding either side of (3) yields a further ternary relation:

$$\Psi_n = [[\Psi_{n+2} \mid \sigma_{n+1} \mid \Psi_n] \mid \sigma_n \mid [\Psi_n \mid \sigma_{n-1} \mid \Psi_{n-2}]] \,. \tag{5}$$

The point of the notation is not symbolic ornament. It prevents the model from treating any state as isolated. A phenomenon is always an enclosed departure containing further enclosed departures.

Symbol	Meaning in the present paper
Ψ_n	active state or phenomenon at enclosure tier n
Ψ_{n+1}	macro-enclosing condition that projects boundary data inward
Ψ_{n-1}	micro-enclosed condition carried inside the active state
σ_n	local departure sign: contracted (-1) or expanded $(+1)$
0_∞	balanced scalable reference state from which departure is measured
ff	Final Frontier halt condition bounding the recursion
d	accumulated departure depth relative to 0_∞

A one-step physical reading is therefore: a measured system is not merely Ψ_n, but Ψ_n as held between the larger context that bounds it and the smaller context it carries. The observed sign σ_n is the local departure that becomes visible at that tier.

5 The Zero Infinity

The Zero Infinity 0_∞ is the scalable reference condition from which physical states depart. It is not empty space, not a chosen coordinate origin, and not a physical rest state. It is the countably infinite balanced reference condition generated by opposing contracted and expanded tendencies around the Vector Equilibrium:

$$\Psi_{0\infty} = [\mathrm{ff} \mid -1 \mid \mathrm{ff}]\, \Psi_{\mathrm{VE}}\, [\mathrm{ff} \mid +1 \mid \mathrm{ff}] = 0_\infty. \tag{6}$$

The central Ψ_{VE} is the local vector-equilibrium phase. The flanking states represent the contracted and expanded potential states, each bounded by the Final Frontier. Physical matter, radiation, and momentum are not static residents of the zero phase. They are scale-dependent departures from it.

This is why the title is literal inside the model. "Nothing" is not absence, void, or rhetorical negation. It is the lawful reference state that makes physical difference possible. Without 0_∞, ff would be only an outer stop: a boundary that halts extrapolation but does not explain what is being bounded. Without ff, 0_∞ would be an unbounded neutrality that could not halt regress. The two conditions are therefore reciprocal. 0_∞ supplies the balanced reference from which departure is measured; ff supplies the boundary that prevents that reference from becoming an infinite regress.

This is the first singularity resolution. If zero is treated as a point-like absence, the equations are allowed to collapse into it. If zero is treated as 0_∞, a bounded, countably infinite reference condition, then approach to zero is a transition boundary, not a physical residence.

$$\mathrm{ff} \,\Big|\, -1 \,\Big|\, \Psi_{\mathrm{VE}} \,\Big|\, +1 \,\Big|\, \mathrm{ff}$$

Contracted and expanded departures are paired around the Vector Equilibrium. The Zero Infinity is the balanced reference condition made possible by this bounded pairing; the Final Frontier supplies the halt condition on both sides of the transition.

Figure 1: Schematic relation between 0_∞, ff, and the Vector Equilibrium.

6 Modified Gravitational Field Equations

The classical Einstein Field Equations with cosmological constant are

$$R_{\mu\nu} - \frac{1}{2} R g_{\mu\nu} + \Lambda g_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}. \tag{7}$$

This framework replaces the invariant cosmological term with a scale-and-depth dependent curvature term:

$$R_{\mu\nu} - \frac{1}{2} R g_{\mu\nu} + \mathcal{K}(L,d) g_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}. \tag{8}$$

The enclosure curvature is

$$\mathcal{K}(L,d) = \frac{L^2}{\zeta \tanh(d)}. \tag{9}$$

Here L is the characteristic length scale of the causal enclosure and d is dimensionless departure depth from 0_∞. The coefficient ζ is not fixed to a numerical constant. It is the dimensional normalization and structural coupling required for $\mathcal{K}$ to carry curvature units. Since $[\mathcal{K}] = L^{-2}$, equation (9) requires $[\zeta] = L^4$ when L is dimensional.

Equation (9) is the minimal curvature closure rule derived from the first principles above. The derivation is not a derivation from an unbounded background action. It is a closure derivation: the mathematical form is constrained by the requirements that follow once reference, boundary, departure, and recovery are treated as prior to unbounded extrapolation.

First, by reference before object and departure before substance, the curvature correction cannot be a universal constant independent of state. It must depend on departure from 0_∞, so it must contain d. Second, by enclosure before isolation, the correction cannot be independent of the scale at which the departure is enclosed. It must contain a characteristic enclosure length L. Third, because $\mathcal{K}$ appears in the field equations in the position normally occupied by Λ, it must carry curvature dimension:

$$[\mathcal{K}] = L^{-2}. \tag{10}$$

The simplest separable form satisfying these three requirements is

$$\mathcal{K}(L, d) = A(L)\, B(d), \tag{11}$$

with $A(L)$ carrying curvature units and $B(d)$ carrying the transition behavior. Since L appears as the active enclosure scale and the normalization coefficient ζ carries the structural coupling of that scale, the minimal scale factor is

$$A(L) = \frac{L^2}{\zeta}, \qquad [\zeta] = L^4. \tag{12}$$

The transition factor follows from boundary before extrapolation and recovery before replacement. It must diverge as $d \to 0$, because physical residence at the zero phase is forbidden; it must approach a finite tier value away from the transition, because known physics must be recovered inside stable enclosures; and it must vary smoothly in ordinary observational regimes. The minimal odd, smooth, saturating transition function with linear near-zero behavior is $\tanh(d)$. The closure factor is therefore

$$B(d) = \frac{1}{\tanh(d)}. \tag{13}$$

Combining (12) and (13) gives (9). This does not prove uniqueness. It shows that (9) is the simplest separable curvature rule generated by the first principles of the enclosure framework.

The specific functional choice is falsified, even if the broader enclosure program survives, if measured transition behavior is discontinuous, exponential, power-law with a different near-zero exponent, or otherwise incompatible with the $\tanh(d)$ saturation and $1/d$ near-boundary barrier.

The hyperbolic tangent is the simplest smooth function used here that has the required transition behavior:

$$\tanh(d) \sim d \quad (|d| \ll 1), \qquad \tanh(d) \to \pm 1 \quad (|d| \gg 1). \tag{14}$$

Near the Zero Infinity transition it gives the singularity-avoidance barrier

$$\mathcal{K}(L, d) \sim \frac{L^2}{\zeta d}, \qquad d \to 0, \tag{15}$$

while away from the transition it becomes an approximately constant tier curvature,

$$\mathcal{K}(L, d) \to \mathcal{K}_n = \frac{L_n^2}{\zeta_n}, \qquad |d_n| \gg 1. \tag{16}$$

Other smooth transition functions could be tested against the same constraints. The present choice is therefore falsifiable as a minimal closure rule: if observations require a different approach to the zero boundary or a different saturation law across tiers, $\tanh(d)$ should be replaced while the enclosure constraints remain.

Departure depth is modeled as the normalized nesting sum

$$d = \sum_{n=1}^{N_{\rm ff}} \frac{\sigma_n}{n}, \tag{17}$$

where $N_{\rm ff}$ marks the effective depth of the local computation before the Final Frontier halts further regress.

The weighted sum in (17) is likewise a first closure rule. The factor $1/n$ encodes diminishing local influence from deeper nested tiers without deleting them. It is the harmonic trace of the enclosure history rather than a claim that every physical system literally samples each tier with identical weight. In later data-facing applications the weights may be generalized to

$$d = \sum_{n=1}^{N_{\rm ff}} w_n \sigma_n, \qquad \sum_{n=1}^{N_{\rm ff}} |w_n| < \infty, \tag{18}$$

with $w_n = 1/n$ serving as the simplest transparent case. The harmonic choice is natural for a first information-theoretic closure because each deeper tier contributes less distinguishable boundary information to the active scale while still remaining part of the causal history. Uniform weights would make all depths equally visible at the active tier; exponential weights would erase deep nesting too aggressively. Harmonic weighting is the minimal slowly converging trace between those extremes.

As $d \to 0$,

$$\lim_{d\to 0} \mathcal{K}(L,d) = \infty. \tag{19}$$

This is not a defect. It is the geometric barrier that prevents physical residence at the zero phase. In an unenclosed model this behavior appears as a singularity. In the enclosed model it is a deterministic rebound condition.

$$\mathcal{K}(L,d) \sim L^2/(\zeta d) \text{ as } d \to 0 \quad \longrightarrow \quad \mathcal{K}(L,d) \to L_n^2/\zeta_n \text{ on a stable tier}$$

The curvature term is nonperturbative at the Zero Infinity transition and approximately constant away from the transition. The singularity is replaced by a rebound or tier-change boundary.

Figure 2: Qualitative behavior of $\mathcal{K}(L,d)$ near and away from the Zero Infinity boundary.

7 Recovery of Known Limits

The enclosure terms must recover known physics when a system is far from a scale-transition boundary. On a stable tier n, take $L = L_n$, $d = d_n$, and $\nabla_\alpha \mathcal{K}(L_n, d_n) \approx 0$ across the local observational region. Then $\mathcal{K}$ behaves as an effective cosmological term,

$$\Lambda_{\text{eff},n} = \mathcal{K}(L_n, d_n), \tag{20}$$

and equation (8) reduces locally to the Einstein equations with a tier-specific constant. Standard General Relativity is recovered in the small-region limit where $\Lambda_{\mathrm{eff},n}$ is negligible compared with local stress-energy curvature, or in cosmological fits where $\Lambda_{\mathrm{eff},n}$ is approximately constant over the domain being modeled.

The same logic applies to Friedmann dynamics. If the observational data belong to one stable enclosure tier, then $H(L,d)$ is well approximated by a single fitted value H_n. The usual ΛCDM fit is therefore not rejected; it is recovered as the one-tier approximation. The Hubble tension appears when observations from two distinct tiers are forced into one scalar:

$$\Delta H_0 = H(L_{\mathrm{local}}, d_{\mathrm{local}}) - H(L_{\mathrm{CMB}}, d_{\mathrm{CMB}}). \tag{21}$$

A first two-tier test is to infer (L,d) proxies from redshift range, structure maturity, lensing correction, and distance-ladder anchoring, then ask whether the residuals compress under $H(L,d)$ more strongly than under a single H_0.

Quantum mechanics is recovered when the enclosure operator is approximately identity:

$$\widehat{E}_{0\infty} \approx 1. \tag{22}$$

In that regime equation (40) reduces to the ordinary time-dependent Schrödinger equation. Compactification appears only as $\widehat{E}_{0\infty} \to 0$, where the state approaches a boundary of lawful spread. Thus the proposal does not replace ordinary quantum evolution in its verified domain; it adds a transition condition at the enclosure limit.

8 Scale-Dependent Friedmann Dynamics and the Hubble Tension

For a homogeneous and isotropic approximation inside a given enclosure, the second Friedmann equation is modified by the enclosure curvature [11]:

$$\frac{\ddot{a}}{a} = -\frac{4\pi G}{3}\left(\rho + \frac{3p}{c^2}\right) + \frac{c^2}{3}\mathcal{K}(L,d). \tag{23}$$

Equivalently, using (9),

$$\frac{\ddot{a}}{a} = -\frac{4\pi G}{3}\left(\rho + \frac{3p}{c^2}\right) + \frac{c^2}{3}\frac{L^2}{\zeta\,\tanh(d)}. \tag{24}$$

The Hubble parameter is therefore not fundamentally a single global scalar. It is a scale-tier dependent observable:

$$H = H(L,d). \tag{25}$$

The Hubble tension is resolved by structural placement. CMB-inferred values measure the macro-enclosure, where fluctuations are smoothed across the largest observable background. Local distance-ladder values measure a nearer nested enclosure, where local departure depth and scale-transition effects remain active [25, 24]. The two values do not need to be forced into one universal number before the enclosure scale has been identified.

This is not measurement error disguised as theory. It is the correction of a category error: measurements from different enclosure scales were being required to report a single unenclosed value.

A minimal two-tier fit can be written as

$$H_{\mathrm{obs}}(z,\mathcal{D}) = W_{\mathrm{CMB}}(z,\mathcal{D})H_{\mathrm{CMB}} + W_{\mathrm{int}}(z,\mathcal{D})H_{\mathrm{int}}, \qquad W_{\mathrm{CMB}} + W_{\mathrm{int}} = 1, \tag{26}$$

where $\mathcal{D}$ denotes enclosure proxies such as distance-ladder anchoring, redshift range, lensing environment, structure maturity, and local density contrast. The observed values $H_{\rm CMB} \simeq 67.4$ km s^{-1} Mpc^{-1} and $H_{\rm int} \simeq 73$ km s^{-1} Mpc^{-1} provide the present calibration targets [24, 25]. The prediction is not merely that the two values differ, but that intermediate datasets should move continuously or stepwise between them as their enclosure weights change.

A concrete first-pass proxy is

$$W_{\rm int}(z,\mathcal{D}) = \left[1+\exp\left(-\alpha(z-z_*)-\beta\delta_{\rm local}-\gamma\kappa_{\rm lens}-\eta M_*(z)\right)\right]^{-1}, \qquad W_{\rm CMB} = 1 - W_{\rm int}. \quad (27)$$

Here z_* is a fitted transition redshift, $\delta_{\rm local}$ is local density contrast, $\kappa_{\rm lens}$ is lensing convergence or an equivalent environmental correction, and $M_*(z)$ is a normalized structure-maturity proxy derived from stellar mass density, luminosity function, or chemical development. The model is falsified in this first form if adding these enclosure proxies does not reduce Hubble residuals relative to a single-H_0 fit or to a standard early-dark-energy parametrization with comparable degrees of freedom.

8.1 JWST Prediction: Interior High-Redshift Expansion Should Not Collapse to the CMB Value

The enclosure interpretation makes a stronger observational prediction than simply restating the Hubble tension. If $H = H(L,d)$, then JWST observations should not merely confirm that the local distance ladder is free of major crowding bias. They should reveal that high-redshift interior structure carries an expansion normalization and structure-growth history that remains elevated relative to a strict Planck-ΛCDM macro-enclosure extrapolation.

In practical terms, JWST should increasingly show three signatures:

1. **Local ladder confirmation.** JWST Cepheid and supernova-host observations should preserve the local high-H_0 distance ladder rather than erase it through improved resolution. This is already the direction of the JWST Cepheid evidence, which rejects unrecognized HST crowding as the source of the tension [26].

2. **High-redshift maturity.** JWST should continue finding luminous, massive, chemically developed, or otherwise unexpectedly mature galaxies at $z \gtrsim 10$, because local structure formation inside the interior enclosure is not governed solely by the smoothed macro-enclosure expansion inferred from the CMB. Early JWST high-redshift galaxy abundance already places pressure on unmodified ΛCDM growth histories [20, 14].

3. **Intermediate/elevated inferred expansion.** When JWST high-redshift galaxy luminosity functions, stellar-mass densities, and spectroscopic distances are folded into expansion-history fits, the preferred effective expansion normalization should move upward from the Planck macro-enclosure value and toward the local/interior value. Existing analyses of JWST luminous high-redshift galaxies in early-dark-energy contexts already show this tendency, with JWST-favored fits supporting high effective H_0 values near the local ladder scale [19]. A later JWST+DESI analysis likewise raises the fitted expansion scale relative to Planck-ΛCDM [9].

Thus the framework predicts a redshift- and enclosure-dependent ladder of inferred expansion, not a binary dispute between "early" and "late" universe measurements. Existing JWST shots can be examined for this purpose, but not as images alone. The relevant data are the NIRCam photometry, NIRSpec redshifts, MIRI line constraints, inferred stellar masses, luminosity functions, angular sizes, and lensing-corrected distances. The prediction is that, as these datasets mature, they will sort more coherently under $H(L,d)$ than under a single global H_0.

9 Vacuum Energy and Structural Cancellation

The vacuum energy catastrophe arises when zero-point contributions are summed as though they were independent excitations in an unenclosed background [32, 4]. The Zero Infinity changes the reference condition. Contracted and expanded potential states are not free-standing additions to a vacuum container. They are paired tendencies native to the 0_∞ matrix.

In this projected enclosure,

$$\langle \text{ff} \mid -1 \mid \text{ff} \rangle + \langle \text{ff} \mid +1 \mid \text{ff} \rangle \approx 0_\infty. \tag{28}$$

The immense theoretical vacuum term does not gravitate as a global pressure because its symmetric components are structurally pre-canceled across the enclosed reference. What appears in $T_{\mu\nu}$ is the uncanceled directional remainder of a specific enclosure layer.

The compactification step is what prevents this cancellation from remaining merely verbal. In the unenclosed calculation, the vacuum density is estimated by adding independent zero-point modes,

$$\rho_{\text{vac}}^{\text{free}} = \frac{1}{V} \sum_{\mathbf{k}} \frac{1}{2} \hbar \omega_{\mathbf{k}}, \tag{29}$$

as though every mode were a free resident of a single background container. The divergence follows from the assumption that the modes are additive before they are enclosed.

In the nested enclosure, each apparent zero-point mode belongs to a contracted–expanded pair across 0_∞. The relevant object is not a free mode $E_{\mathbf{k}}$, but an enclosed pair

$$\mathscr{Z}_{\mathbf{k},n} = \left[E^-_{\mathbf{k},n} \mid 0_{\infty,n} \mid E^+_{\mathbf{k},n} \right], \tag{30}$$

where n marks the enclosure tier. A mode contributes gravitationally only through the directional remainder left after the paired tendencies are filtered by the local enclosure:

$$\delta \rho_{\text{vac}}(L, d) = \frac{1}{V_L} \sum_{\mathbf{k},n} \widehat{E}_{0\infty}(L, d, n) \left[\frac{1}{2} \hbar \omega^+_{\mathbf{k},n} - \frac{1}{2} \hbar \omega^-_{\mathbf{k},n} \right]. \tag{31}$$

The catastrophic term is therefore not a large number that must be tuned away. It is a sum over modes that were counted before the enclosure had determined whether they were independent residents of the scale at all.

A minimal scaling calculation shows the intended suppression. The usual cutoff estimate for a free quantum field has the form

$$\rho_{\text{vac}}^{\text{free}} \sim \rho_{\text{P}} = \frac{c^7}{\hbar G^2}, \tag{32}$$

when modes are counted up to the Planck scale. The observed dark-energy density is instead of order

$$\rho_\Lambda \sim \frac{3 H_0^2 c^2}{8 \pi G}. \tag{33}$$

Writing the Hubble enclosure length as $L_H = c/H_0$ and the Planck length as $L_P = (\hbar G/c^3)^{1/2}$, their ratio is

$$\frac{\rho_\Lambda}{\rho_{\text{P}}} \sim \frac{3}{8\pi} \left(\frac{L_P}{L_H} \right)^2. \tag{34}$$

This is the familiar 10^{-122}-scale suppression. In the present model that factor is not introduced as a fine tuning of Λ. It is the signature of compactification from volume-resident modes to boundary-residual modes across the largest active enclosure. The toy residual is

$$\delta\rho_{\mathrm{vac}}(L_H) = \rho_{\mathrm{P}}\,\chi_{\mathrm{ff}}\left(\frac{L_P}{L_H}\right)^2, \tag{35}$$

where χ_{ff} is an order-unity enclosure efficiency that absorbs the precise geometry of the active Final Frontier boundary. The important point is not the numerical value of χ_{ff}, which must be fitted or derived from the full enclosure geometry, but the scaling: the residual is boundary-suppressed rather than volume-summed.

Quantized compactification occurs at the saturation boundary of this accounting. As the local departure approaches the Zero Infinity transition,

$$\left|E^{+}_{\mathbf{k},n} - E^{-}_{\mathbf{k},n}\right| \to 0_{\infty,n}, \qquad \widehat{E}_{0\infty}(L,d,n) \to 0, \tag{36}$$

the paired mode no longer propagates as a free contribution to ρ_{vac}. It is compactified into the adjacent enclosure tier,

$$\mathcal{Z}_{\mathbf{k},n} \longrightarrow \mathcal{Z}_{\mathbf{k},n+1}, \tag{37}$$

preserving vector integrity while changing the scale at which the term can appear. This is why the vacuum problem and the measurement problem share the same mathematical boundary. In both cases an unenclosed continuum permits indefinite spread; in both cases the enclosure operator converts that spread into a quantized transition when the boundary is reached.

This is the second singularity-related resolution. The vacuum catastrophe is not solved by tuning the cosmological constant. It is structurally removed at its source by correcting the zero condition and by recognizing that saturated zero-point departures compactify into adjacent scale structure rather than accumulating as a freely gravitating global pressure. The calculation above is only a toy model, but it gives the right suppression scale and turns the next question into a concrete one: derive or measure χ_{ff} and the enclosure geometry that fixes it.

10 The Quantum Boundary

The standard time-dependent Schrödinger equation is

$$i\hbar\frac{\partial}{\partial t}\Psi(x,t) = \widehat{H}\Psi(x,t). \tag{38}$$

In an unenclosed interpretation, the wave function is allowed to spread over an abstract continuum until measurement imposes a boundary [31, 3].

The enclosed state is

$$\Psi_{\mathrm{Total}} = [\Psi_{\mathrm{enclosed}} \mid \Psi_{\mathrm{departure}}(t) \mid \Psi_{\mathrm{enclosing}}]. \tag{39}$$

Time evolution is governed by an enclosure-filtered Schrödinger equation:

$$i\hbar\frac{\partial}{\partial t}\Psi_{\mathrm{departure}}(t) = \widehat{E}_{0\infty}\left[\widehat{H}\Psi_{\mathrm{departure}}(t)\right]. \tag{40}$$

The enclosure operator is

$$\widehat{E}_{0\infty} = 1 - \tanh\left(\frac{\langle\Psi_{\mathrm{enclosed}} \mid \widehat{V}_{\mathrm{jitterbug}} \mid \Psi_{\mathrm{enclosing}}\rangle}{\Psi_{0\infty}}\right). \tag{41}$$

The operator $\widehat{V}_{\text{jitterbug}}$ is the geometric transition operator for the local Vector Equilibrium. Operationally, it measures the coupling between the micro-enclosed and macro-enclosing states required to move a departure through the contracted–expanded transition while preserving vector integrity:

$$\widehat{V}_{\text{jitterbug}} = \lambda_J \left(\widehat{P}_+ \widehat{R}_{\text{VE}} \widehat{P}_- + \widehat{P}_- \widehat{R}_{\text{VE}} \widehat{P}_+ \right), \tag{42}$$

where $\widehat{P}_-$ and $\widehat{P}_+$ project contracted and expanded local configurations, $\widehat{R}_{\text{VE}}$ is the Vector Equilibrium reorientation map, and λ_J sets the scale-transition coupling. This is a schematic operator definition, but it makes the testable claim explicit: compactification depends on cross-coupling between contracted and expanded states, not on an externally imposed collapse event. The specific form in (41) is falsified if transition data require an operator that is not monotone in this coupling or does not approach identity inside stable enclosure.

As local departure saturates the enclosure, $\widehat{E}_{0\infty} \to 0$, spatial spreading halts, and the system undergoes quantized compactification into the adjacent scale tier. This is not stochastic collapse. It is deterministic enclosure transition. The measurement problem is resolved by recognizing that the wave function was never physically boundaryless.

In the ordinary laboratory regime, where $\widehat{E}_{0\infty} \approx 1$, the usual Born statistics are retained as the operational rule for outcomes inside a stable enclosure:

$$P(a_i) = |\langle a_i \mid \Psi \rangle|^2. \tag{43}$$

The new claim is not that ordinary probabilities are wrong. It is that the support on which those probabilities spread is not physically unbounded. Compactification supplies the transition condition for the edge of support; the Born rule remains the interior statistical rule until that boundary becomes active.

Free spread: $\Psi(t) \to$ unbounded support

Enclosed spread: $\widehat{E}_{0\infty}\Psi(t) \to$ bounded support $\to \mathcal{Z}_{\mathbf{k},n+1}$

Inside a stable enclosure $\widehat{E}_{0\infty} \approx 1$. At saturation $\widehat{E}_{0\infty} \to 0$, and the state compactifies into the adjacent scale tier.

Figure 3: Schematic enclosure-filtered wave-function evolution and quantized compactification.

11 Unified Causal Bounding Conditions

The analytic form becomes computable through a single bounding structure:

$$B = [B_{\text{outer}} \mid B_{\text{periphery}} \mid B_{\text{inner}}]. \tag{44}$$

- B_{outer}: the Final Frontier, the macro-closure and halt condition.
- $B_{\text{periphery}}$: the local metric boundary of the active enclosure.
- B_{inner}: the quantized Zero Infinity transition boundary.

This is the computational form of enclosure. A system that cannot halt cannot compute. A model without a boundary cannot distinguish prediction from unbounded extrapolation. The Final Frontier supplies the halt condition missing from singular cosmology and unbounded quantum spread.

12 Predictions and Verification

The framework produces concrete verification pathways.

Scale-dependent redshift quantization. If light crosses nested enclosure boundaries, redshift data should contain nonlinear or stepped residual signatures corresponding to changes in metric friction across scale tiers.

Bounded probability envelopes. High-precision quantum optics and double-slit experiments should show sharper-than-standard suppression at the geometric perimeters of local enclosure closure.

Scale-sorted Hubble inference. Hubble measurements should become more coherent when sorted by enclosure scale rather than forced into one global scalar.

Singularity avoidance. Models incorporating $\mathcal{K}(L, d)$ should replace divergent zero-phase residence with deterministic rebound or scale transition.

13 Relation to Existing Approaches

Departure Calculus overlaps with several active research programs but differs in mechanism. Early dark energy models address the Hubble tension by adding or activating an energy component before recombination. In the present paper, the tension is instead treated as evidence that H_0 is being inferred across more than one enclosure tier. The empirical overlap is useful: JWST and DESI analyses that prefer elevated effective expansion scales can be read as tests of whether the extra component is a new substance, a new epoch, or a misidentified enclosure boundary.

Modified-gravity approaches such as $f(R)$ theories change the gravitational action or the relation between curvature and stress-energy [29]. The enclosure proposal is different because it modifies the status of the boundary and reference state before modifying a sector equation. In the stable-tier limit it returns to ordinary GR with an effective local curvature term; near 0_∞ it becomes nonperturbative because the zero condition itself changes.

Loop quantum cosmology, asymptotic-safety programs, and regular-black-hole models also seek to avoid singular endpoints [1, 27, 2]. Their mechanisms usually operate through quantized geometry, renormalization behavior, or modified interior metrics. The present mechanism is a nested transition rule: singularity avoidance occurs because approach to zero becomes compactification into an adjacent enclosure tier rather than residence at an infinite-density endpoint.

Holographic and emergent-gravity approaches are closest in spirit because they already treat boundary information as physically active [8, 30]. Departure Calculus differs by pairing the outer halt condition ff with the inner reference state 0_∞. The boundary is not enough by itself. The reference state is equally fundamental because it determines what counts as departure, residual, cancellation, and compactification.

14 Falsifiability

The proposal can fail in several concrete ways.

Vacuum scaling. If improved cosmological inference shows that the observed vacuum-like density cannot be represented as a boundary-suppressed residual of the form

$$\delta\rho_{\mathrm{vac}}(L) \propto \rho_{\mathrm{P}} \left(\frac{L_P}{L}\right)^2 \tag{45}$$

for any physically meaningful enclosure scale L, then the compactification account of the vacuum problem is wrong or incomplete.

Hubble sorting. If JWST, Roman, Rubin, DESI, and future CMB data reduce the Hubble tension to a single global H_0 without scale-tier residuals, then $H(L, d)$ is unnecessary. Conversely, if residuals persist but do not sort by redshift range, structure maturity, distance-ladder anchoring, lensing environment, or other enclosure proxies, then the present enclosure variables are poorly chosen.

Quantum boundary. If high-precision matter-wave, interferometric, or optomechanical experiments continue to extend coherent spread without any detectable enclosure-dependent suppression, then the proposed operator $\widehat{E}_{0\infty}$ is either too weak to matter physically or incorrectly formulated.

Singularity modeling. If collapse or early-universe models incorporating $\mathcal{K}(L, d)$ cannot produce deterministic rebound, tier transition, or finite curvature invariants under any reasonable ζ_n and d_n, then the proposed curvature ansatz fails its central purpose.

15 Conclusion

The Hubble tension, the vacuum energy catastrophe, gravitational singularities, and quantum measurement paradoxes are not indictments of modern physics. They are messages from the boundary of the model. This paper responds by forming a nested causal enclosure around the problem-field and projecting Departure Calculus, Zero Infinity, and the Final Frontier back into it as boundary and initial conditions. In that projected enclosure, the singularity-related problems are addressed at the level where they arose: the boundary condition.

This paper does not ask the standard models to collapse. It nests them inside a proposed causal architecture where their local successes remain visible. General Relativity remains valid inside the enclosure where its assumptions hold. Quantum mechanics remains valid inside the enclosure where its state evolution is bounded. ΛCDM remains a powerful interior cosmological model. What changes is the range over which unbounded extrapolation is treated as physically meaningful.

If future evidence closes some searches that have carried major institutional investment, that closure should be understood with care. It would not mean that the work was foolish. It would mean that the work succeeded in revealing that the missing term was not simply an object inside the old enclosure, but a boundary condition of the enclosure itself.

The singularities were never physical destinations. They were places where the map had not yet been enclosed.

A Finite-Enclosure Vacuum Mode Counting

This appendix gives a deliberately simple counting model for the vacuum scaling in Section 8. Consider a finite enclosure of characteristic length L with Planck-scale cutoff L_P. A free volume count treats every cell as an independent contributor:

$$N_{\text{vol}} \sim \left(\frac{L}{L_P}\right)^3. \tag{46}$$

If each cell carries a Planck-scale zero-point contribution, the result is the familiar Planck-density estimate. This is the unenclosed count: modes are added before their contracted and expanded partners have been paired across 0_∞.

In the projected enclosure, the first operation is not summation but pairing:

$$N_{\text{pair}} = N_+ + N_-, \qquad N_+ - N_- = N_{\text{res}}. \tag{47}$$

The symmetric component $N_+ + N_-$ belongs to the balanced reference state and does not appear as a freely gravitating global pressure. The physically visible term is the residual mismatch N_{res} left at the active boundary after compactification.

For the minimal boundary-residual model, the active residual count scales like area rather than volume:

$$N_{\text{res}} \sim \chi_{\text{ff}} \left(\frac{L}{L_P}\right)^2, \tag{48}$$

where χ_{ff} is the enclosure efficiency introduced in (35). The residual energy density is then suppressed relative to the free Planck-density estimate by the ratio of residual boundary count to free volume count, together with the compactification of the active boundary across the enclosure length:

$$\frac{\delta\rho_{\text{vac}}(L)}{\rho_{\text{P}}} \sim \chi_{\text{ff}} \left(\frac{L_P}{L}\right)^2. \tag{49}$$

For $L = L_H$, this gives the observed order of magnitude in (34). The model is intentionally minimal. Its purpose is to show how the counting changes when the zero condition is enclosed: the vacuum term is no longer a volume sum over independent modes, but a boundary residual after paired cancellation and compactification.

The status of χ_{ff} is therefore precise. In the present paper it is a phenomenological order-unity coefficient. In the full theory it should be calculable from the IVM boundary geometry, the effective number of active jitterbug transition channels, and the coupling λ_J in (42). If those geometric inputs force χ_{ff} far from order unity, or if the residual scales with volume instead of boundary area, the proposed vacuum compactification mechanism fails.

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