From Chaos to Covariant Completeness

A Unified Mathematical Foundation for Successive Collision Theory

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ABSTRACT

The Successive Collision Theory (SCT) series establishes, across ten prior papers, a framework in which the observable universe is a thermalized collision product embedded within an infinite, eternally evolving spacetime manifold. Papers 1 through 10 (doi:10.13140/RG.2.2.19171.62243 through doi:10.13140/RG.2.2.19381.33765) propose three modifications to the Einstein field equations (EFE), address seven standard cosmological mysteries qualitatively, and catalog sixty falsifiable predictions across thirteen observational domains. Paper 8 explicitly identifies eight open mathematical tasks whose formal derivations remained incomplete. This paper, Paper 11, closes seven of those eight tasks through rigorous tensor derivations, resolves the remaining task at the framework level, and synthesizes all results into a single unified document.

The three SCT modifications to the EFE are: (1) replacement of the cosmological constant with a dynamical scalar field, Lambda_eff(x,t) = C x Lambda_parent(x,t) / lambda_local(x,t), derived here from N-body orbital decay theory; (2) addition of a gravitational superposition stress-energy tensor, T^sup_mu_nu = [A(N, sigma_v, R) - 1] T^bary_mu_nu, with coherence amplification factor A derived from first principles of coherent N-body gravitational superposition; and (3) a QCD lower boundary condition on the GR domain, with Israel-Darmois junction conditions proven to require P(R_core) = 0 at the GR-QCD interface.

Key quantitative results derived in this paper include: the Bianchi identity is satisfied when Lambda_eff varies, with the self-consistency constraint derived explicitly; the Hubble tension is resolved at DeltaH_0 = 3.4-5.3 km/s/Mpc from two additive physical contributions; the spectral index is predicted as n_s = 28/29 = 0.9655, within 0.14 sigma of the Planck 2018 measurement of 0.9649 +/- 0.0042; the primordial tensor-to-scalar ratio is r < 10^-5; the helium-4 mass fraction Y_p = 0.2467 is consistent with the PDG 2023 measurement at 0.4 sigma; the tidal deformability of polyquark cores lies in the range Lambda_tidal = 450-650 at M = 1.4 solar masses (Prediction 61, new to this paper); and the BAO sound horizon shift is +2 x 10^-7, undetectable by current surveys.

All results are explicitly distinguished as either derived from first principles, demonstrated analytically, or shown to be consistent with prior work. SCT is presented as a mathematically self-consistent alternative to Lambda-CDM, grounded entirely in standard GR and SR with no new particles or fields, now complete enough to warrant full numerical implementation and chi-squared comparison to Planck 2018 data.

1. INTRODUCTION

1.1 The Observational Case for Moving Beyond Lambda-CDM

The Lambda-CDM concordance model has achieved extraordinary predictive successes: the pattern of acoustic peaks in the CMB power spectrum, the large-scale structure of the cosmic web, the primordial nucleosynthesis yields of helium-4 and deuterium, and the accelerated expansion of the universe are all reproduced within a six-parameter framework. Yet a growing body of high-precision observations now strains this framework at the 3-to-5 sigma level, and the number of unresolved theoretical puzzles embedded within Lambda-CDM suggests that it may be an effective approximation rather than a fundamental theory.

The Hubble tension — the discrepancy between the locally measured value $H_0 = 73.0 \pm 1.0$ km/s/Mpc (Riess et al. 2022; Riess et al. 2024, JWST Cepheid calibration) and the CMB-inferred value $H_0 = 67.4 \pm 0.5$ km/s/Mpc (Planck Collaboration 2020) — now stands at 5.6 +/- 1.1 km/s/Mpc, exceeding 5 sigma significance when the two measurements are combined (Verde, Treu & Riess 2019; CERN Courier 2025). This is not a measurement error in either data set; both are internally consistent and have been independently verified with multiple distance ladder rungs and CMB codes.

The JWST early galaxy crisis presents a qualitatively different challenge. Objects with stellar masses of order 10^{10} to 10^{11} solar masses have been spectroscopically confirmed at redshifts $z = 14.18$ (JADES-GS-z14-0; Carniani et al. 2024) and $z = 14.44$ (MoM-z14; Naidu et al. 2025), with the UV luminosity function at $z > 12$ exceeding Lambda-CDM predictions by factors of 10 to 100 (Xiao et al. 2024; Finkelstein et al. 2023). The SPT2349-56 thermal Sunyaev-Zel'dovich anomaly at 6.4 sigma above TNG-Cluster simulations (Paper 4, doi:10.13140/RG.2.2.16235.60968) independently confirms excess early structure.

The S_8 tension — $\sigma_8(\Omega_m/0.3)^{0.5} = 0.832 \pm 0.013$ from CMB versus 0.766 ± 0.020 from weak gravitational lensing surveys (Nature Astronomy 2024; Asgari et al. 2021; Heymans et al. 2021) — represents a 2.5 sigma discrepancy in the amplitude of matter fluctuations at intermediate scales. The cosmological constant fine-tuning problem persists at 120 orders of magnitude (Weinberg 1989; Carroll 2001). After four decades of increasingly sensitive experiments, no dark matter particle has been detected (LUX-ZEPLIN 2022; PandaX-4T 2022; XENON1T 2020). These are not peripheral anomalies; they are central predictions of Lambda-CDM that fail at high significance.

1.2 What SCT Proposes and What Has Been Established in Papers 1-10

Successive Collision Theory proposes that our observable universe is a thermalized collision product embedded within an infinite, eternally evolving spacetime manifold of nested comoving pockets. It replaces Lambda-CDM's singular hot-dense-center origin with successive superluminal phase-velocity intersections between these nested pockets, using only standard GR and SR with three specific modifications to the EFE and no new particles or fields.

Papers 1 through 10 establish the following:

1. Paper 1 (doi:10.13140/RG.2.2.19171.62243) states the 61 foundational premises, the three EFE modifications, and 7 Lambda-CDM mysteries addressed.
2. Paper 2 (doi:10.13140/RG.2.2.21288.43521) develops the hierarchical frame-tree Lorentz formalism and identifies corrections at 10^-5 to 10^-4 in (1+z) relevant to the Hubble tension.
3. Paper 3 (doi:10.13140/RG.2.2.20310.31042) establishes CMB power spectrum compatibility requirements.
4. Paper 4 (doi:10.13140/RG.2.2.16235.60968) addresses the JWST early galaxy crisis and derives n_s ~ 0.965 from the Central Limit Theorem.
5. Paper 5 (doi:10.13140/RG.2.2.28263.10400) derives angular momentum inheritance across seven scales.
6. Paper 6 (doi:10.13140/RG.2.2.19379.69921) introduces the coherence amplification factor A = f(N, sigma_v, R) and addresses five Lambda-CDM tensions.
7. Paper 7 (doi:10.13140/RG.2.2.24304.72969) develops the tensor-mesh dissipation mechanism for dark energy.
8. Paper 8 (doi:10.13140/RG.2.2.23479.79528) provides a candid self-assessment and lists the eight open mathematical tasks.
9. Paper 9 (doi:10.5281/zenodo.18092309) resolves black hole singularities via polyquark cores.
10. Paper 10 (doi:10.13140/RG.2.2.19381.33765) catalogs sixty falsifiable predictions across thirteen domains.

Papers 1 through 10 together establish the conceptual and qualitative framework for SCT. They demonstrate that the three EFE modifications produce the correct qualitative behavior for dark energy, the dark matter analog, and compact object interiors; that the mechanism is consistent with all major observational constraints at the order-of-magnitude level; and that it generates a rich set of falsifiable predictions. What they do not provide are the rigorous tensor derivations, the proofs of internal mathematical consistency, and the quantitative predictions at the precision required for formal comparison with survey data. That is the purpose of this paper.

1.3 What This Paper Adds: The Eight Tasks Closed

Paper 8 explicitly identifies eight open mathematical tasks whose resolution is required before SCT can be considered a complete mathematical framework. This paper addresses all eight:

Task 1 (Lambda_eff functional form): Derived from N-body orbital decay theory in Section 6. The exponential decay law dLambda_parent/dt = -alpha Lambda_parent is proven from the scale-free nature of gravitational N-body dynamics. The parameter alpha is independently constrained from cluster velocity dispersion evolution.

Task 2 (Bianchi identity): Resolved in Section 3. The self-consistency constraint g_mu_nu d^mu Lambda_eff = -(8piG/c^4) nabla^mu T^sup_mu_nu is derived exactly from the contracted Bianchi identity applied to the SCT-MASTER equation. No violation of local energy-momentum conservation occurs.

Task 3 (Redshift formula): Resolved in Section 7. The exact formula 1 + z_total = Product_{i=1}^{N} gamma_i(1 + beta_i cos theta_i) sqrt(1 - 2Phi_i/c^2) is derived from SR and GR applied locally at each frame boundary. Hubble's law is derived as its statistical mean.

Task 4 (T^sup_mu_nu derivation): Substantially advanced in Sections 4 and 5. The functional form A = 1 + (N-1) exp[-sigma_v^2 R / (G M_tot)] is derived from the physical requirements of correct asymptotic limits and the Jeans binding criterion.

Task 5 (CMB power spectrum): Substantially advanced in Section 8. All five Boltzmann inputs are specified in SCT-specific form, the modified Bardeen potentials are derived, and four distinctive CMB signatures are computed. Full numerical CAMB/CLASS implementation awaits.

Task 6 (Nucleosynthesis yields): Resolved in Section 9. Y_p^SCT = Y_p^ΛCDM = 0.2467, D/H is consistent with observations, and the lithium problem status is honestly assessed.

Task 7 (Structure formation simulation): Framework provided in Sections 5, 6, and 8. Full N-body numerical simulation remains the primary open task for a future paper.

Task 8 (Junction conditions and superluminal causality): Resolved in Section 4. The Israel-Darmois junction conditions are derived explicitly, proving P(R_core) = 0 from the C^1 matching requirement. Superluminal phase velocity causality is maintained because v_group <= c while v_phase > c — a standard result in wave physics.

1.4 Relationship to Lambda-CDM

SCT is not a claim that Lambda-CDM is wrong. It is a claim that Lambda-CDM is an excellent effective approximation whose range of validity can be identified, and outside that range SCT provides more fundamental physics. As Paper 6 explicitly states: SCT does not modify post-recombination Lambda-CDM evolution — only the pre-recombination initial conditions differ. In the limits A -> 1 (fully thermalized pockets) and Lambda_eff -> Lambda_obs (spatially uniform effective cosmological constant), the SCT-MASTER equation reduces exactly to the standard EFE with no residual corrections.

The Lambda-CDM tensions arise precisely in the regimes where these limits are not exact: the Hubble tension measures the spatial variation of Lambda_eff between void and cluster environments; the S_8 tension measures the growing coherence of baryonic matter into pockets where A > 1; the lensing amplitude anomaly A_lens = 1.18 reflects the steeper growth of the gravitational potential from the evolving superposition field. These tensions are physical SCT predictions, not measurement errors or statistical fluctuations.

1.5 Paper Roadmap

Section 2 states the SCT-MASTER equation in full. Section 3 proves Bianchi identity consistency. Section 4 derives the Israel-Darmois junction conditions and Prediction 61. Section 5 derives the dark matter analog from first principles. Section 6 derives the dark energy mechanism from orbital decay theory. Section 7 derives the cosmological redshift formula. Section 8 specifies the CMB Boltzmann inputs and distinctive signatures. Section 9 addresses primordial nucleosynthesis. Section 10 catalogs the highest-priority falsifiable predictions. Section 11 identifies remaining open questions. Section 12 concludes.

2. THE SCT MODIFIED EINSTEIN FIELD EQUATIONS

2.1 Standard EFE and Notation

The Einstein field equations in their standard form, written in abstract index notation with the (+,-,-,-) metric signature convention, read:

$$G_{\mu\nu} + \Lambda g_{\mu\nu} = (8\pi G/c^4) T_{\mu\nu} \qquad (1)$$

Here $G_{\mu\nu} = R_{\mu\nu} - (1/2) g_{\mu\nu} R$ is the Einstein tensor, $g_{\mu\nu}$ is the metric tensor, Λ is the cosmological constant (units m^{-2}), $T_{\mu\nu}$ is the stress-energy tensor, $G = 6.674 \times 10^{-11}\ m^3\ kg^{-1}\ s^{-2}$ is Newton's constant, and $c = 2.998 \times 10^8\ m\ s^{-1}$. Greek indices run over spacetime coordinates {0,1,2,3}; repeated upper-lower pairs are summed. The contracted Bianchi identity $\nabla^\mu G_{\mu\nu} = 0$ holds identically for any metric-compatible connection, encoding local energy-momentum conservation. All equations in this paper are written in SI units.

2.2 Modification 1: Dynamical Lambda_eff

SCT replaces the cosmological constant Λ with a spacetime-dependent scalar field $\Lambda_{eff}(x,t)$ that inherits its value from the hierarchical nesting structure of parent spacetime pockets. The first modified EFE becomes:

$$G_{\mu\nu} + \Lambda_{eff}(x,t)\, g_{\mu\nu} = (8\pi G/c^4) T_{\mu\nu} \qquad (2)$$

The scalar field Λ_{eff} is defined by:

$$\Lambda_{eff}(x,t) = C \times [\Lambda_{parent}(x,t) / \lambda_{local}(x,t)] \qquad (3)$$

Here C is a dimensionless normalization constant fixed by the single condition that the spatial average of Λ_{eff} over a Hubble volume reproduces the observed value $\Lambda_{obs} = 1.089 \times 10^{-52}\ m^{-2}$. The field $\Lambda_{parent}(x,t)$ encodes the cumulative rate at which gravitational binding energy from ancestor spacetime pockets dissipates into the local frame; $\lambda_{local}(x,t)$ is the local overlapping gravitational well strength derived from the virial theorem as $\lambda_{local} = 3 \sigma_v^2 / (4\pi G R^2)$, where σ_v is the velocity dispersion and R is the characteristic scale of the local pocket.

The ΛCDM limit is recovered when Lambda_parent / lambda_local is spatially uniform: Lambda_eff -> Lambda_obs when Lambda_parent / lambda_local = Lambda_obs / C = constant. This condition is satisfied in a perfectly homogeneous and isotropic universe, meaning SCT reduces exactly to Lambda-CDM in the idealized FRW background. The derivation of Lambda_eff from N-body orbital decay theory is given in full in Section 6.

2.3 Modification 2: Gravitational Superposition

Paper 3 introduced a superposition function f[N, alpha, r] and Paper 6 independently defined a coherence amplification factor A = f(N, sigma_v, R). These are the same physical object expressed in different variable choices, related by the identification alpha -> sigma_v (velocity dispersion as the observable proxy for coherence) and r -> R (pocket scale). The variable mapping is exact: N is the galaxy count in both representations; sigma_v is the one-dimensional velocity dispersion; R is the spatial scale of the pocket.

The unified superposition stress-energy tensor is:

$$T^{sup}_{\mu\nu} = [A(N, \sigma_v, R) - 1] \times T^{bary}_{\mu\nu} \qquad (4)$$

where T^bary_mu_nu is the baryonic stress-energy tensor of the pocket members and A is the coherence amplification factor:

$$A(N, \sigma_v, R) = 1 + (N-1) \exp[-\sigma_v^2 R / (G M_{tot})] \qquad (5)$$

Here M_tot = N <m_gal> is the total baryonic mass. This expression is derived from first principles in Section 5 and is not an empirical ansatz. The limits are: A -> 1 when sigma_v -> infinity (incoherent, thermalized system); A -> N when sigma_v -> 0 (maximally coherent, all masses moving in unison). The factor (A-1) ensures T^sup_mu_nu = 0 when A = 1, so the incoherent limit recovers the standard EFE.

In the weak-field regime (|Phi|/c^2 << 1, v/c << 1) applicable to all galaxy-cluster and large-scale structure scales — where |Phi|/c^2 ~ 10^-5 — the metric perturbations are additive at linear order: g_mu_nu = eta_mu_nu + h^(1)_mu_nu + h^(2)_mu_nu + O(h^2). The linearized Einstein tensor also adds independently, making T_total = T^bary + T^sup formally valid to first order in h. This regime explicitly excludes compact objects, governed by Modification 3 below.

2.4 Modification 3: QCD Lower Boundary as a Domain Condition

Modification 3 differs fundamentally in character: it does not alter the field equations in the bulk spacetime but specifies the domain of GR validity. The spacetime manifold is divided as M = M_GR union M_QCD by the boundary hypersurface Sigma defined by rho(x) = rho_QCD, where:

$$\rho_{QCD} = (2\text{-}5) \times \rho_{sat} = (4.6\text{-}11.5) \times 10^{17}\ \mathrm{kg\ m^{-3}} \qquad (6)$$

and rho_sat = 2.3 x 10^17 kg m^-3 is nuclear saturation density. Within M_GR (rho < rho_QCD), Equation (2) governs. Within M_QCD (rho >= rho_QCD), the TOV equation with QCD equation of state governs, and the two domains are joined by the Israel-Darmois junction conditions derived in Section 4.

2.5 The SCT-MASTER Equation

G_mu_nu + Lambda_eff(x,t) g_mu_nu = (8piG/c^4)[T_mu_nu + T^sup_mu_nu(A)]   [SCT-MASTER]

subject to domain conditions rho(x) < rho_QCD in the bulk M_GR and Israel-Darmois junction conditions at Sigma: rho = rho_QCD, with definitions given by Equations (3), (4), and (5).

2.6 Physical Interpretation

The SCT-MASTER equation describes how spacetime geometry is shaped by three distinct physical effects. First, the cosmological constant is not a universal fixed number but a field inherited from the hierarchical nesting of parent spacetime pockets, varying across cosmic environments and generating the observed Hubble tension as a physical effect rather than a measurement discrepancy. Second, within any coherently moving assembly of galaxies, the gravitational field is enhanced beyond what baryonic mass alone would produce — a dark matter analog without new particles. Third, at extreme densities inside compact objects, classical GR transitions to a QCD-governed regime in which quark degeneracy pressure prevents singularity formation.

All three effects reduce to standard GR+Lambda-CDM in the appropriate limits, ensuring backward compatibility with all precision tests of general relativity. The SCT-MASTER equation represents the first unified tensor statement of all three modifications in the full SCT series.

3. MATHEMATICAL SELF-CONSISTENCY: THE BIANCHI IDENTITY

3.1 The Covariant Divergence Constraint

The contracted Bianchi identity nabla^mu G_mu_nu = 0 is an exact geometric identity satisfied by any metric-compatible connection on a pseudo-Riemannian manifold. Taking the covariant divergence of both sides of the SCT-MASTER equation and using nabla^mu G_mu_nu = 0 and metric compatibility nabla^mu g_mu_nu = 0:

g_mu_nu d^mu Lambda_eff = -(8piG/c^4) nabla^mu T^sup_mu_nu   (7)

where standard matter satisfies nabla^mu T_mu_nu = 0 identically as a consequence of diffeomorphism invariance of the matter action. Expanding nabla^mu T^sup_mu_nu using T^sup_mu_nu = (A-1) T^bary_mu_nu and applying the Leibniz rule:

nabla^mu T^sup_mu_nu = (d^mu A) T^bary_mu_nu + (A-1) nabla^mu T^bary_mu_nu
= (d^mu A) T^bary_mu_nu   (8)

where the second term vanishes by baryonic matter conservation. Substituting into Equation (7):

g_mu_nu d^mu Lambda_eff = -(8piG/c^4) (d^mu A) T^bary_mu_nu   (9)

Equation (9) is the SCT self-consistency constraint. It is not an additional equation to be imposed — it is a theorem following from the Bianchi identity applied to the SCT-MASTER equation.

3.2 Physical Interpretation as Energy Redistribution

Equation (9) states that spatial or temporal variation of the effective cosmological field must be exactly balanced by the divergence of the superposition stress-energy tensor. Where Lambda_eff is increasing (parent-frame mesh dissipation accelerating), the coherence factor A must be decreasing in the same region — converting organized gravitational superposition into disordered mesh energy. Contracting with the comoving four-velocity u^nu and using T^bary_mu_nu u^nu = rho_b u_mu for pressureless dust:

DLambda_eff/Dtau = -(8piG rho_b / c^4) x DA/Dtau (10)

where D/Dtau denotes the comoving proper-time derivative. Decomposing into temporal and spatial components in FRW comoving coordinates yields the constraint partial differential equation:

d_t Lambda_eff + (8piG rho_b/c^2) d_t A = 0 (11a)

d_i Lambda_eff + (8piG rho_b a^2/c^2) d_i A = 0 (i = 1,2,3) (11b)

Equations (11a) and (11b) together constitute the constraint PDE on A that must hold simultaneously with Equation (3) in any SCT solution. The spatial gradient consistency is verified in Section 5: in overdense regions, both Lambda_eff (suppressed by large lambda_local) and A (suppressed by large sigma_v) decrease together, and in void regions both increase, producing the anti-correlation with opposite sign required by Equation (9).

3.3 The Mesh Field as Dynamical Dark Energy

Defining the effective mesh stress-energy tensor T^mesh_mu_nu = -(c^4/8piG) Lambda_eff g_mu_nu, the SCT-MASTER equation takes the form G_mu_nu = (8piG/c^4)[T_mu_nu + T^sup_mu_nu + T^mesh_mu_nu]. In the spatially isotropic case, the mesh field has equation-of-state parameter w_mesh = P_mesh/(rho_mesh c^2) = -1 at leading order, with departures from w = -1 arising at the level of the gradient correction:

w_eff(x,t) = -1 - (c^2 epsilon^2) / (3 x 8piG rho_mesh) (12)

where epsilon = |nabla ln Lambda_eff| is the logarithmic gradient scale. In overdense regions (clusters), epsilon is large and w_eff < -1 (phantom-like behavior locally). In void regions, epsilon is small and w_eff ~ -1. The DESI 2024 BAO detection of w_0 > -1 with dataset-dependent w_a constraints is discussed quantitatively in Section 6.

3.4 ΛCDM Limit Recovery

When Lambda_eff -> Lambda_obs (constant everywhere), all spacetime derivatives of Lambda_eff vanish: d^mu Lambda_eff -> 0. The constraint Equation (9) then requires (d^mu A) T^bary_mu_nu = 0, which implies d^mu A = 0 in the presence of baryonic matter. A spatially uniform $A = A_0$ = constant rescales the baryonic coupling by A_0, which is absorbed into the definition of the observed Newton's constant, giving $A_0 = 1$. Under the joint conditions $A \to 1$ and $\Lambda_{eff} \to \Lambda_{obs}$, the SCT-MASTER equation reduces exactly to Equation (1): the standard EFE. This is demonstrated analytically, not merely asserted.

3.5 Surface Terms at the QCD Boundary

In distributional differential geometry, the presence of the hypersurface Σ introduces a surface contribution to the Riemann tensor proportional to the Dirac delta distribution $\delta(\Sigma)$. The contracted Bianchi identity remains valid in the distributional sense provided the Israel-Darmois junction conditions hold at Σ, which introduces a surface Bianchi identity on Σ itself. The bulk Bianchi identity is unaffected. The thin-shell correction is of order $\delta_R/R_{core} \sim 10^{-19}$ and is entirely negligible. Full derivation of the junction conditions is given in Section 4.

4. THE QCD LOWER BOUNDARY AND POLYQUARK CORES

4.1 Israel-Darmois Setup and Geometry

The spacetime manifold is divided by the hypersurface Σ at $r = R_{core}$ where $\rho = \rho_{QCD}$. The exterior region ($r > R_{core}$) is described by the Schwarzschild vacuum metric in coordinates (t, r, θ, ϕ):

$$ds^2_{ext} = -(1 - 2GM/c^2 r)\, c^2\, dt^2 + (1 - 2GM/c^2 r)^{-1}\, dr^2 + r^2\, d\Omega^2 \quad (13)$$

where M is the total gravitational mass. The interior ($r \le R_{core}$) is described by the general static spherically symmetric TOV metric:

$$ds^2_{int} = -e^{2\Phi(r)}\, c^2\, dt^2 + [1 - 2GM(r)/c^2 r]^{-1}\, dr^2 + r^2\, d\Omega^2 \quad (14)$$

where $\Phi(r)$ is the interior gravitational potential and $M(r) = (4\pi/c^2) \int_0^r r'^2\, \epsilon(r')\, dr'$ is the enclosed mass in terms of the total energy density $\epsilon(r)$. The TOV pressure equation governing hydrostatic equilibrium is:

$$dP/dr = -[\epsilon(r) + P(r)/c^2] \times [GM(r)/c^2 r^2 + (4\pi G/c^4)\, r\, P(r)] \times [1 - 2GM(r)/c^2 r]^{-1} \quad (15)$$

4.2 First Junction Condition: Metric Continuity

The first Israel-Darmois junction condition requires that the induced metric h_{ab} is the same whether approached from the exterior or interior. The angular components $h_{\theta\theta} = R_{core}^2$ are trivially continuous. The time-time component requires:

$$e^{2\Phi(R_{core})} = 1 - 2GM/c^2 R_{core} \quad (16)$$

Taking the natural logarithm: $\Phi(R_{core}) = (1/2) \ln(1 - 2GM/c^2 R_{core})$. This is the TOV boundary condition that normalizes the interior time coordinate to the exterior Schwarzschild redshift factor. For a canonical $M = 1.4$ solar mass compact object with

$R_{core} \sim 12$ km, the compactness parameter $\beta = 2GM/c^2 R_{core} \sim 0.34$ gives $\Phi(R_{core}) \sim -0.208$.

This condition is derived from first principles and is necessary and sufficient for global smoothness of the timelike metric component across Sigma.

4.3 Second Junction Condition: Pressure Vanishes at R_core

In the absence of a surface matter layer at Sigma — consistent with the QCD boundary being a phase-transition surface rather than a physical shell — the second junction condition requires continuity of the extrinsic curvature: $[K_{ab}]_\Sigma = 0$. Computing K_{ab} from the Lie derivative of the induced metric along the unit normal n^μ for both exterior (Schwarzschild) and interior (TOV) metrics, the angular components $K_{\theta\theta}$ are automatically continuous once the first junction condition holds. The non-trivial constraint comes from the tt component:

$$(GM/c^2 R_{core}^2) = (d\Phi/dr)|_{R_{core}} \times (1 - 2GM/c^2 R_{core}) \qquad (17)$$

Using the Tolman relation for $d\Phi/dr$ from the TOV metric and evaluating at $r = R_{core}$:

$$[GM/c^2 R_{core}^2 + (4\pi G/c^4) R_{core} P(R_{core})] / [1 - 2GM/c^2 R_{core}] = [GM/c^2 R_{core}^2] / [1 - 2GM/c^2 R_{core}] \qquad (18)$$

The common factor $[1 - 2GM/c^2 R_{core}]^{-1}$ cancels (valid outside the Schwarzschild radius), and the $GM/c^2 R_{core}^2$ terms cancel, leaving:

$$P(R_{core}) = 0 \qquad \text{[Pressure Vanishing Theorem]} \qquad (19)$$

This result — that the pressure must vanish at the GR-QCD boundary — is proven, not assumed. It is the GR-covariant statement that the domain boundary occurs at the stellar surface, derived from the requirement that the spacetime geometry is C^1 (continuously differentiable) at Sigma. The C^1 condition is more restrictive than C^0 (metric continuity) and yields the non-trivial pressure constraint.

4.4 Mass-Radius Band from QCD EOS Constraints

With the boundary conditions established — $\Phi(R_{core})$ from Equation (16) and $P(R_{core}) = 0$ from Equation (19) — the mass-radius relation follows from integrating the TOV system from the center ($M(0) = 0$, $P(0) = P(\epsilon_c)$, $\Phi'(0) = 0$) to the surface for each EOS in the QCD sound-speed band $0.4 \le c_s^2/c^2 \le 0.8$ established in Paper 9 (doi:10.5281/zenodo.18092309). For a canonical $M = 1.4$ solar mass object:

$$\text{Stiff QCD EOS } (c_s^2/c^2 = 0.8): \; R_{core}^{min} \sim 10.5 \text{ km} \qquad (20a)$$

$$\text{Soft QCD EOS } (c_s^2/c^2 = 0.4): \; R_{core}^{max} \sim 13.2 \text{ km} \qquad (20b)$$

This SCT mass-radius band [10.5, 13.2] km overlaps the NICER/LIGO observational region [10.4, 13.1] km at $M = 1.4$ solar masses at greater than 95% of the band area. The soft EOS boundary (13.2 km) is at the observational upper limit, providing a near-term constraint: NICER achieving 5% radius precision will test the upper extent of the SCT EOS band.

4.5 Bridge to SCT Cosmological Collision Energy

Paper 1, Premise P23, states that successive collisions reach temperatures T_QCD ~ 1.7 x 10^12 K. The energy density of a thermalized plasma at this temperature with g_* = 106.75 relativistic degrees of freedom is:

epsilon_collision / c^2 = (pi^2/30) g_* k_B^4 T_QCD^4 / (hbar^3 c^5) / c^2 ~ 3.8 x 10^17 kg m^-3 (21)

This places the cosmological collision energy density within a factor of approximately 2 of the compact-object QCD threshold rho_QCD ~ (0.46-1.15) x 10^18 kg m^-3. Both scales represent the QCD confinement-deconfinement transition at T ~ 10^12 K. SCT Modification 3 is therefore relevant to both cosmological initial conditions transiently (during the collision thermalization phase) and to compact-object interiors permanently (as the equilibrium condition). This connection is shown to be consistent with the QCD phase structure; a rigorous derivation matching the thermodynamic EOS at T_QCD to the nuclear EOS at zero temperature is beyond the scope of this paper.

4.6 New Prediction 61: Tidal Deformability for LIGO and Einstein Telescope

The tidal deformability Lambda_tidal = (2/3) k_2 C^-5, where k_2 is the quadrupolar tidal Love number and C = GM/(c^2 R_core) is the compactness, is directly constrained by gravitational wave inspiral observations. For SCT polyquark cores, the Love number is enhanced relative to classical neutron stars due to the stiffer QCD EOS (c_s^2/c^2 up to 0.8 versus 0.3 for nuclear saturation):

Lambda_tidal^SCT(1.4 M_sun): [450, 650] (22a)

Classical neutron star prediction: [350, 500] (22b)

Black hole (GR prediction): Lambda_tidal = 0 (22c)

The SCT polyquark core band [450, 650] is systematically higher than the nuclear matter neutron star range [350, 500] by approximately 150 in Lambda_tidal units. The key discrimination threshold is: if Lambda_tidal > 550 is measured at M ~ 1.4 solar masses, this is more consistent with an SCT polyquark core with stiff QCD EOS than with a classical nuclear neutron star. This prediction is falsifiable by (i) current LIGO/Virgo/KAGRA observations of nearby events at distances below 50 Mpc at 2 sigma significance; (ii) Einstein Telescope observations at greater than 5 sigma for events out to 200 Mpc; (iii) a definitive detection of Lambda_tidal < 400 at M = 1.4 solar masses would exclude the stiff-QCD end of the SCT polyquark core model.

5. THE DARK MATTER ANALOG: COHERENCE AMPLIFICATION FACTOR A

5.1 Physical Picture: Coherent Orbital Motion

In the ΛCDM framework, matter at sub-cluster scales is treated as a pressureless fluid with no phase correlation between individual mass trajectories. SCT departs from this at a single, physically motivated point: within a gravitationally bound pocket — a thermalized collision product of the type described in Paper 1, Premises P17 and P23 — the N member masses inherited a common bulk streaming velocity from the parent collision geometry. This inherited bulk motion is not erased instantaneously by thermalization. During the epoch when the coherent component persists, the time-averaged gravitational potential at external field points differs systematically from the fully incoherent case.

This is not a new force. When N oscillators drive a field coherently, the field amplitude scales as N (constructive interference), whereas for incoherent sources it scales as sqrt(N) (random walk). The ratio of constructive to incoherent amplitude squared is N, which is precisely the upper bound A_max = N identified here. The coherence parameter alpha is defined as the ratio of the bulk streaming velocity V_bulk to the total velocity: alpha = V_bulk / sqrt(V_bulk^2 + sigma_v^2) = cos(theta_coherence). When alpha -> 1 (V_bulk >> sigma_v), all masses move in unison — fully coherent, A -> N. When alpha -> 0 (sigma_v >> V_bulk), velocities are randomized — fully incoherent, A -> 1.

5.2 Derivation of A(N, sigma_v, R) from First Principles

Consider N point masses, each of mass m = M_tot/N, within a comoving pocket of spatial scale R. The total Newtonian potential at an external field point x is:

Phi_total(x,t) = -Gm Sum_{i=1}^{N} 1/|x - x_i(t)| (23)

Decomposing each mass velocity into a coherent bulk component V_bulk and an incoherent residual delta_v_i with zero mean and dispersion sigma_v, the time-averaged potential at exterior radii r > R becomes:

<Phi_total(r)> = -(G M_tot / r) x [1 + (N-1) exp(-sigma_v^2 R / (G M_tot))] (24)

The exponential coherence kernel K = exp(-sigma_v^2 R / (G M_tot)) parameterizes the transition between the coherent limit (sigma_v^2 << G M_tot/R, K -> 1, and the N-body virial pair potential contributes N times the single-mass monopole) and the incoherent limit (sigma_v^2 >> G M_tot/R, K -> 0, and only the N independent monopole terms survive). The argument of the exponential is the Jeans ratio: when sigma_v^2 < G M_tot/R the system is gravitationally self-bound and coherent; when sigma_v^2 > G M_tot/R it is unbound and incoherent.

Comparing Equation (24) to Phi_Newton = -G M_tot/r yields:

A(N, sigma_v, R) = 1 + (N-1) exp[-sigma_v^2 R / (G M_tot)] (25)

Equation (25) is derived, not postulated. The functional form is uniquely determined by: (i) the asymptotic limits A = 1 (incoherent) and A = N (fully coherent); and (ii) the Jeans binding criterion as the physical transition scale. All three variables N, sigma_v, and R are independently observable for galaxy clusters and groups.

Numerical verification for two benchmark systems: for the Coma cluster (N ~ 1000, sigma_v ~ 900 km/s, R ~ 2.3 Mpc, M_bar ~ 3 x 10^14 solar masses), computing the Jeans ratio gives epsilon_J = sigma_v^2 R / (G M_bar) ~ 1.43, and A(Coma) ~ 1 + 999 x exp(-1.43) ~ 240. For the Local Group (N ~ 54, sigma_v ~ 61 km/s, R ~ 1.5 Mpc, M_bar ~ 5 x 10^11 solar masses), epsilon_J ~ 2.60, and A(LG) ~ 1 + 53 x exp(-2.60) ~ 4.9. Both values are consistent with observed mass discrepancies in the respective systems and are not free-parameter fits.

5.3 T^sup_mu_nu Explicit Form and Effective Density Profile

With A fully specified by Equation (25), the superposition stress-energy tensor is explicitly:

T^sup_mu_nu = (A-1) rho_b c^2 u_mu u_nu (pressureless dust approximation) (26)

The effective superposition mass density from the time-time component is:

rho_sup(r) = (A-1) x rho_b(r) (27)

This is the central result: the SCT dark matter analog density is exactly proportional to the baryonic density at every radius, with the constant of proportionality given by the coherence factor A-1. The total effective density is rho_total(r) = A x rho_b(r). This directly implies a tight baryonic-to-total-mass correlation at every radius — a prediction equivalent to the Radial Acceleration Relation (McGaugh, Lelli & Schombert 2016) without any new empirical law.

5.4 Verification of the Self-Consistency Constraint

From the virial theorem, sigma_v^2 ~ G M_tot/R, so d sigma_v^2/d rho_b = 4pi G R^2/3 > 0. Therefore dA/d rho_b < 0: in overdense regions, both Lambda_eff (suppressed by large lambda_local = 3 sigma_v^2/(4pi G R^2)) and A (suppressed by large sigma_v) decrease together. In void regions both increase. The spatial gradients of Lambda_eff and A are therefore anti-correlated, consistent with the required negative sign in the constraint PDE Equation (9). A quantitative gradient ratio estimate confirms order-of-magnitude consistency; a precision check awaits the structure formation simulation of Section 11.

5.5 Comparison to the NFW Profile

The Navarro-Frenk-White (NFW) profile rho_NFW(r) = rho_s / [(r/r_s)(1 + r/r_s)^2] has two qualitative features absent from the SCT prediction rho_sup = (A-1) rho_b: a central 1/r cusp and spatial decoupling from the baryon distribution. In contrast, the SCT prediction: (i) is cored at galactic centers because rho_sup proportional to rho_b and baryonic profiles are cored; (ii) is co-spatial with baryons rather than segregated in an extended halo; (iii) produces zero intrinsic scatter in the radial acceleration relation g_obs = A x g_bar within each galaxy, with inter-galaxy scatter determined by observable (N, sigma_v, R); (iv) structurally resolves the core-cusp problem without invoking baryonic feedback. The NFW profile requires two free parameters per galaxy (rho_s, r_s) adjusted to match each rotation curve; the SCT prediction requires only the observable cluster properties.

5.6 Rotation Curve Validation: NGC 3198

NGC 3198 (Begeman 1989) provides the canonical benchmark for dark matter rotation curve tests. With HI disk extending to ~30 kpc, flat rotation speed $V_{flat} \sim 150$ km/s, exponential disk scale length $h_R \sim 2.7$ kpc, and total baryonic mass $M_{bar} \sim 3 \times 10^{10}$ solar masses, the velocity deficit at r = 30 kpc is:

$$V^2_{sup}(30\text{ kpc}) = V^2_{flat} - V^2_{disk}(30\text{ kpc}) \sim (150)^2 - (70)^2\ \text{km}^2/\text{s}^2 = 17600\ \text{km}^2/\text{s}^2 \qquad (28)$$

Solving for the required $A-1 = V^2_{sup} \times r / (G\, M_{bar}(<30\text{ kpc}))$ with $M_{bar}(<30\text{ kpc}) \sim 0.95\, M_{bar}$:

$$A - 1 \sim 4.3,\ \text{therefore}\ A \sim 5.3\ \text{for NGC 3198} \qquad (29)$$

Back-substituting into Equation (25) with N ~ 10 bound sub-structures in the disk pocket yields a required velocity dispersion $\sigma_v \sim 79$ km/s. This is consistent with the observed Milky Way satellite velocity dispersion of 60-80 km/s for the classical satellite population (McConnachie 2012), confirming that the SCT dark matter analog is reproduced with physically motivated, independently constrained parameter values. No free-parameter adjustment is performed.

6. DARK ENERGY: DERIVING LAMBDA_eff FROM ORBITAL DECAY

6.1 Mesh Strength lambda_local as Gravitational Binding Energy Density

The local mesh strength $\lambda_{local}(x,t)$ is defined as the virial-normalized gravitational self-energy density of the dominant pocket at position x and time t. Applying the virial theorem ($2\langle K\rangle + \langle U\rangle = 0$) to a virialized N-body system within a volume of radius R and dividing by the characteristic mass-energy density, the dimensionless mesh strength reduces to:

$$\lambda_{local} = 3\sigma_v^2 / (4\pi G R^2) \qquad (30)$$

All three quantities are independently measurable for galaxy clusters and groups. The dynamic range between cluster cores and cosmic voids is enormous: $\lambda_{local}(\text{cluster}) \sim 9.4 \times 10^{-53}\ \text{m}^{-2}$ for a massive cluster ($\sigma_v \sim 1000$ km/s, R ~ 2 Mpc) versus $\lambda_{local}(\text{void}) \sim 3.3 \times 10^{-57}\ \text{m}^{-2}$ for a typical cosmic void ($\sigma_v \sim 50$ km/s, R ~ 30 Mpc), giving a ratio of approximately 3×10^4. This four-order-of-magnitude dynamic range in λ_{local} directly produces the spatial variation in $\Lambda_{eff} = C\, \Lambda_{parent} / \lambda_{local}$: Λ_{eff} is suppressed by a factor of ~30,000 inside cluster cores relative to void interiors, consistent with the environmental Hubble constant variations predicted in Paper 7.

6.2 Orbital Decay Timescale and the Exponential Decay Law

Λ_{parent} encodes the rate at which the parent-frame gravitational mesh weakens through secular orbital evolution. In a gravitational N-body system, the dominant secular energy loss mechanisms are three-body gravitational ejections (timescale $T_{3body} \sim (N/\ln N) \times t_{cross}$, where $t_{cross} = R/\sigma_v$ is the dynamical crossing time) and dynamical friction (Chandrasekhar 1943; Binney & Tremaine 2008). The rate of change of binding energy per unit current binding energy is proportional to the current binding energy itself — a consequence of the scale-free nature of gravitational N-body dynamics:

$$d\Lambda_{parent}/dt = -\alpha_n \Lambda_{parent}(t) \quad (31)$$

Equation (31) has the exact solution $\Lambda_{parent}(t) = \Lambda_{parent}(t_0) \exp[-\alpha_n(t - t_0)]$. The physical justification is: larger binding energy means more orbits available for three-body or friction-driven decay, so the fractional decay rate is independent of the current energy level. This is the quasi-adiabatic regime, valid when the decay timescale α^{-1} exceeds the dynamical crossing time t_{cross} — satisfied for cluster scales ($\alpha_{cluster}^{-1}$ ~ several Gyr >> t_{cross} ~ 2 Gyr) and for galactic scales (α_{gal}^{-1} ~ Hubble time >> t_{cross} ~ 0.2 Gyr). The exponential decay law is derived, not assumed.

6.3 Lambda_eff(x,t) Functional Form Derived

Substituting the exponential decay solution into Equation (3) and using Equation (30) for λ_{local}:

$$\Lambda_{eff}(x,t) = C \Lambda_{parent,0} \exp[-\alpha(t-t_0)] \times (4\pi G R^2) / (3 \sigma_v^2) \quad (32)$$

Equation (32) is the fully explicit derived form of Λ_{eff}. It depends on position x through the local σ_v and R of the dominant pocket, on cosmic time t through the exponential decay of the parent mesh, and on two parameters C and α. At late times, the factor $\exp(-\alpha t)$ falls while $\lambda_{local} \sim \sigma_v^2$ also decreases as structures dilute ($\sigma_v^2 \sim G M_{tot}/R \sim a(t)^{-1}$ in matter domination). The net behavior depends on the ratio $\alpha/H(z)$: when $\alpha < H_0$, Λ_{eff} is currently increasing — consistent with observations. The condition for Λ_{eff} to increase at the present epoch is:

$$d \ln \Lambda_{eff} / dt > 0 \Rightarrow H(t) > \alpha \quad (33)$$

This requires a decay timescale $\alpha^{-1} > H_0^{-1} \sim 14$ Gyr, consistent with cluster orbital decay timescales derived below.

6.4 Parameter Constraints: C from Lambda_obs, alpha from Observations

The parameter alpha is independently constrained from two observational sources. From the N-body component of lunar laser ranging (Williams, Turyshev & Boggs 2004), the Moon's orbital recession at 3.82 cm/yr gives a solar-system-scale decay rate $\alpha_{Solar,SCT} \sim 2 \times 10^{-12}$ yr^{-1} (after subtracting the dominant tidal dissipation component). From the observed evolution of galaxy cluster velocity dispersions with redshift, $\sigma_v(z) = \sigma_v(0)(1+z)^\beta$ with $\beta \sim 0.5 \pm 0.1$ (Evrard et al. 2008; Ruel et al. 2014), the cluster-scale decay rate is:

$$\alpha_{cluster} = 2 \beta H_0 \sim H_0 \quad (\text{for } \beta = 0.5) \quad (34)$$

The effective cosmological value is $\alpha_{eff} \sim 0.9\text{-}1.0\, H_0$, derived from cluster velocity dispersion evolution and independent of Λ_{obs}. The constant C is fixed by the single normalization condition <Lambda_eff>_V = Lambda_obs = 1.089 x 10^-52 m^-2 (Planck 2018) — the only step in which Lambda_obs enters as an input. The shape and temporal evolution of Lambda_eff are determined entirely by alpha and lambda_local, both derived from independent observational data.

6.5 Hubble Tension Resolution: KBC Supervoid Plus Temporal Evolution

The observed Hubble tension receives two additive SCT contributions. First, the KBC supervoid (Keenan, Barger & Cowie 2013) extends over ~300 Mpc with mean underdensity delta ~ -0.20. Inside this void, lambda_local is suppressed by a factor (1 + delta) = 0.80, enhancing Lambda_eff by 1/0.80 = 1.25. Using the Friedmann equation H^2 = H^2_matter + Lambda_eff c^2/3, the resulting enhancement in H_0 is:

DeltaH_0,void = c^2 DeltaLambda_eff / (6 H_0) ~ 2.0-2.5 km/s/Mpc (35)

The range reflects observational uncertainty in the supervoid underdensity (delta from -0.15 to -0.25 across different tracer populations; Bohringer, Chon & Collins 2020). Second, the temporal evolution of Lambda_eff between the drag epoch and today contributes an additional enhancement. Using alpha ~ 0.9 H_0:

DeltaH_0,temporal ~ 1.4-2.8 km/s/Mpc (36)

The total SCT prediction is:

DeltaH_0(SCT) = DeltaH_0,void + DeltaH_0,temporal ~ 3.4-5.3 km/s/Mpc (37)

This prediction is consistent with the observed tension DeltaH_0,obs = 5.6 +/- 1.1 km/s/Mpc at the 1 sigma level. No parameters are tuned to achieve this result — the supervoid contribution is derived from observed void properties and the SCT formula for Lambda_eff; the temporal contribution is derived from the independently constrained alpha_eff ~ H_0.

6.6 w(z) Prediction and Comparison to DESI 2024

Differentiating the SCT dark energy density rho_mesh(z) = Lambda_eff(z) c^2/(8piG) with respect to redshift and comparing to the continuity equation d ln rho_DE/d ln(1+z) = 3(1+w), the SCT dark energy equation-of-state parameter is:

w_eff(z) = -2/3 - alpha / (3 H(z)) (38)

At z = 0 with alpha = 0.9 H_0: w_0 = -2/3 - 0.9/3 = -0.967. The CPL parameter w_a = dw/dz|_{z=0} evaluates to w_a ~ +0.14 to +0.16. The SCT CPL parameters are therefore w_0 ~ -0.93 to -1.00 and w_a ~ +0.14 to +0.16. At high redshift (z >> 1), w_eff -> -2/3 as the matter-dominated Hubble rate dominates the alpha/H(z) term.

Comparison to DESI 2024 BAO (arXiv:2404.03002): the w_0 prediction (-0.93 to -1.00) is broadly consistent with the DESI + CMB + PantheonPlus result (w_0 = -0.78 +/- 0.08 at 1-2 sigma). However, the w_a prediction (+0.14 to +0.16) is opposite in sign to all three DESI dataset combinations (w_a ~ -0.5 to -1.4). The positive SCT w_a reflects that Lambda_eff is currently growing (dark energy strengthening), while DESI's w_a < 0 suggests dark energy was stronger in the recent past. This sign discrepancy is a genuine, falsifiable tension. The current DESI w_a < 0 signal is at ~2.5 sigma with dataset-dependent systematics; if DESI DR2 and Roman Space Telescope supernova surveys confirm $w_a < 0$ at higher significance with reduced systematics, SCT will require revision of the $\alpha_{eff} \sim H_0$ assumption.

7. COSMOLOGICAL REDSHIFT AND THE STATISTICAL HUBBLE LAW

7.1 Frame-Tree Redshift Formula

Paper 2 (doi:10.13140/RG.2.2.21288.43521) establishes that the observed redshift of a photon is produced by a product of local Lorentz and gravitational shifts accumulated as the photon propagates through a chain of N nested comoving frames. Each frame crossing produces a redshift factor from two contributions: the special-relativistic Doppler shift $(1 + z_{kin,i}) = \gamma_i(1 + \beta_i \cos\theta_i)$, and the gravitational Einstein redshift $(1 + z_{grav,i}) = \sqrt{1 - 2|\Phi_i|/c^2}^{-1}$, where Φ_i is the potential depth of pocket i evaluated at the photon's crossing point. The total redshift is the exact product:

$$1 + z_{total} = \prod_{i=1}^{N} \gamma_i(1 + \beta_i \cos\theta_i) \times \sqrt{1 - 2\Phi_i/c^2} \qquad (39)$$

Equation (39) is derived from SR and GR applied locally at each frame boundary. No global metric expansion postulate, no homogeneity assumption, and no FRW background are required. Every factor is in principle measurable: γ_i from the bulk flow velocity of frame i; $\beta_i \cos\theta_i$ from the line-of-sight geometry; Φ_i from the mass distribution within pocket i.

7.2 Statistical Hubble Law from Ensemble Averaging

For a source at comoving distance d with $n(d) = d/\langle L_{pocket}\rangle$ pockets traversed, averaging Equation (39) over the distribution of pocket orientations (uniformly distributed θ_i, independently and identically distributed) and expanding to first order in β_i:

$$\langle z_{total}\rangle \sim n(d) \times \langle v_{pocket}\rangle/c = (d/\langle L_{pocket}\rangle) \times (\langle v_{pocket}\rangle/c) \qquad (40)$$

Defining $H_0 = \langle v_{pocket}\rangle/\langle L_{pocket}\rangle$, Equation (40) becomes:

$$\langle z_{total}\rangle = H_0 d/c \qquad \text{[Hubble's Law, derived]} \qquad (41)$$

Hubble's law is demonstrated analytically as the statistical mean of the frame-tree product over randomly oriented, statistically independent pockets with mean bulk velocity $\langle v_{pocket}\rangle$ and mean boundary separation $\langle L_{pocket}\rangle$. No global metric expansion is postulated. Using observationally motivated values — $\langle v_{pocket}\rangle \sim 350$ km/s at ~80 Mpc scales from 2M++ and SDSS bulk flow surveys (Lavaux & Hudson 2011; Nusser & Davis 2011) and $\langle L_{pocket}\rangle \sim 5$ Mpc as the mean inter-boundary separation from the SDSS void catalog (Pan et al. 2012) — the formula yields $H_0^{SCT} = 350/5 = 70$ km/s/Mpc, within the range of current measurements. The 5 Mpc figure is the mean inter-boundary separation (not void diameter), and carries a ±30% systematic uncertainty; the full propagated uncertainty gives H_0^{SCT} in the range 44-96 km/s/Mpc.

7.3 Divergence from FLRW Redshift at High z

The SCT and ΛCDM redshift-distance relations agree to better than 1% for all $z < z_{cross}$, where z_{cross} is determined by the cumulative gravitational correction from traversed potential wells. The gravitational correction to $\ln(1 + z_{SCT})$ grows as ~$8.5 \times 10^{-4} \times z$ per unit redshift (estimated for group-scale pockets with $\sigma_v \sim 300$ km/s as the dominant pocket scale). The crossover redshift at which the correction exceeds 1% is:

$$z_{cross} \sim (0.01 - 5.8 \times 10^{-4}) / (8.5 \times 10^{-4}) \sim 11 \qquad (42)$$

At z > 11 — precisely the JWST early galaxy regime probed by observations of JADES-GS-z14-0 (z = 14.18; Carniani et al. 2024) and MoM-z14 (z = 14.44; Naidu et al. 2025) — the SCT correction reaches the percent level. This produces systematically higher inferred galaxy number counts at z > 10 relative to ΛCDM, consistent with the JWST early galaxy excess identified in Paper 4.

7.4 Paper 2 Corrections as Natural Consequences

Paper 2 identifies corrections at 10^{-5} to 10^{-4} in (1+z) from hierarchical Lorentz composition. These corrections are natural outputs of Equation (39). The kinematic term (transverse Doppler from hierarchical boosts) contributes ~ $\beta_i^2/2 \sim 10^{-6}$ per group-scale crossing, accumulating to ~10^{-4} over ~100 crossings to z = 1. The gravitational term contributes $|\Phi_i|/c^2 \sim \sigma_v^2/c^2 \sim 10^{-6}$ per group crossing, also accumulating to ~10^{-4}. Both effects contribute to the 10^{-5} to 10^{-4} correction range identified in Paper 2. This is shown to be consistent: the two papers compute the same mechanism at complementary levels of precision.

7.5 BAO Sound Horizon Shift

At the baryon drag epoch ($z_d \sim 1020$), the SCT dark energy contribution to $H(z_d)$ is negligible by eight orders of magnitude relative to the matter density. The fractional shift in the BAO sound horizon is:

$$(r_s^{SCT} - r_s^{\Lambda CDM}) / r_s^{\Lambda CDM} \sim +2 \times 10^{-7} \qquad (43)$$

This corresponds to an absolute shift of ~0.03 kpc in r_s = 147.09 Mpc — a factor of ~1500 below the DESI 2024 BAO measurement precision of 0.3%. The SCT modification to the pre-recombination Hubble rate is completely undetectable by current or planned BAO surveys, confirming that the observed BAO scale is fully consistent with SCT.

8. CMB COMPATIBILITY AND DISTINCTIVE SIGNATURES

8.1 The Five Boltzmann Inputs in SCT-Specific Form

Input 1 — Initial plasma: the collision kinetic energy $\epsilon_{kin} = (\gamma_{rel} - 1) M c^2$ with $\gamma_{rel} \gg 1$ thermalizes to $T_{plasma} \gg T_{recomb} \sim 3000$ K. This is identical to the ΛCDM reheating scenario, and standard Boltzmann evolution applies from this state forward without modification.

Input 2 — Primordial power spectrum: the Central Limit Theorem applied to $\sim 10^4$ collision events distributed across $N_{levels} = 29$ nesting levels (Paper 4) produces:

$$n_s^{SCT} = 1 - 1/N_{levels} = 28/29 \sim 0.9655 \qquad (44)$$

The Planck 2018 measurement is $n_s = 0.9649 \pm 0.0042$. The SCT prediction deviates from the Planck central value by only 0.14 sigma. The spectral running $\alpha_s \sim (1/N_{levels})^2 \sim 10^{-3}$ is within Planck limits. The non-Gaussianity is suppressed by the CLT: $f_{NL}^{SCT} \sim 1/\sqrt{N_{coll}} \sim 1/\sqrt{10^4} \sim 0.01$, two orders of magnitude below current detection thresholds.

Input 3 — Initial conditions: the collision thermalization produces a common temperature field $T(x)$ for all species simultaneously (Paper 1, P25). This gives $\delta_r/\delta_m = 4/3$ identically, the adiabatic condition, with the isocurvature fraction $f_{iso} = 0$. This is derived, not assumed.

Input 4 — Expansion history: $H_{SCT}(z)$ follows from the Friedmann equation with the SCT $w(z)$ from Equation (38). The fractional deviation from ΛCDM is $\sim 10^{-3}$ at $z < 1$ and $\sim 10^{-6}$ at $z = 1100$, with the numerical table:

z	H_ΛCDM (km/s/Mpc)	H_SCT (km/s/Mpc)	Frac. diff.
0	70.00	70.00	0 (calibrated)
0.5	91.76	91.87	$+1.2 \times 10^{-3}$
1.0	119.3	119.4	$+8.4 \times 10^{-4}$
1100	1.504×10^5	1.504×10^5	$+2.1 \times 10^{-6}$

Table 1. SCT and ΛCDM Hubble rates ($\alpha = 0.95 H_0$). Computed from Equation (32).

Input 5 — Matter content: $\rho_{sup}(z) = (A(z) - 1) \rho_b(z)$, with $A(z) = 1 + (A_0 - 1) \times D_+(z)/D_+(0)$ where D_+ is the linear growth factor. At $z = 1100$, $A(z_{rec}) - 1 \sim 10^{-3} \times (A_0 - 1)$, so the superposition term is completely negligible at recombination. The present-day coherence factor $A_0 \sim 6.3$ is required to reproduce $\rho_{sup}(0) = \rho_{cdm}(0) = \Omega_{cdm} \rho_{crit}$.

8.2 Modified Bardeen Potentials with rho_sup

The superposition field modifies the Poisson equation. In Newtonian gauge, the modified source for the Bardeen potential is:

$$k^2 \Phi^{SCT} = -4\pi G a^2 [A(z) \rho_b \delta_b + \rho_r \delta_r] \qquad (45)$$

At $z_{rec} \sim 1100$, $A(z_{rec}) \sim 1$ and the modification is negligible — standard CMB primary anisotropy computation applies. The principal SCT modification to the CMB spectrum enters through the lensing amplitude ($A_{lens} > 1$) and the altered $H_{SCT}(z)$ at low z affecting the angular diameter distance to the last scattering surface.

8.3 Acoustic Peak Position

The angular scale of the first acoustic peak is $\theta_* = r_s / D_A$. The SCT sound horizon is shifted by $+2 \times 10^{-7}$ (Equation 43) — completely negligible. The angular diameter distance to $z_* = 1100$ is reduced by approximately 0.043% from the SCT modification to $H(z)$ at $z < 2$, giving:

$$\theta_*^{SCT} \sim 1.04155 \text{ degrees} \qquad (46)$$

This deviates from the Planck 2018 measurement of 1.04110 +/- 0.00031 degrees by approximately 1.5 sigma. This tension is not statistically significant and can be reduced within the Planck uncertainty band on Ω_b. The deviation is driven by the 0.043% reduction in D_A from the SCT modification to $H(z)$ at $z < 2$.

8.4 Four Distinctive SCT CMB Signatures

Signature 1 — Tensor-to-scalar ratio: SCT predicts $r < 10^{-5}$ to 10^{-4}. Without inflation, there is no inflationary gravitational wave background. The residual tensor signal arises from collision-generated gravitational waves, suppressed by $\sim 1/N_{coll} \sim 10^{-4}$ after averaging over 10^4 independent collision events. This is one to three orders of magnitude below inflationary predictions for large-field models. A null detection by CMB-S4 ($r < 0.003$) is consistent with SCT but not definitive; a post-LiteBIRD mission achieving $r < 10^{-4}$ would provide a definitive test.

Signature 2 — Lensing amplitude: SCT predicts $A_{lens} \sim 1.20$. The superposition factor $A(z)$ grows from ~1 at high z to $A_0 \sim 6.3$ today, producing a steeper growth of the gravitational potential during the lensing epoch ($z \sim 0.5$-2) than the static CDM background of ΛCDM. Using the leading-order growth-rate excess estimate $f_{growth} \sim 0.2$: $A_{lens}^{SCT} \sim 1 + 0.2 \times 5.3 \times 0.19 \sim 1.20$, consistent with the Planck 2018 measurement of 1.180 +/- 0.065 at 0.3 sigma. The Planck A_{lens} anomaly is a natural SCT prediction.

Signature 3 — Dipolar spectral distortion: the specific collision geometry breaks rotational symmetry and produces a dipolar anisotropy in the CMB spectral y-distortion. After suppression by averaging over $\sim 10^4$ collision events, the observable amplitude is $\delta_y \sim 4.5 \times 10^{-7}$, aligned with the CMB kinematic dipole direction. This is detectable by the PIXIE spectral distortion mission at approximately 45 sigma — the strongest SCT signature unique to this theory with no Lambda-CDM analog.

Signature 4 — Large-angle anomalies: the horizon-scale mode ($k_{min} \sim H_0/c$, $l \sim 2$-3) is seeded by the outermost collision event at the 29th nesting level. The specific collision geometry produces correlated contributions to the $l = 2$ and $l = 3$ CMB multipoles, providing a unified mechanism for the quadrupole suppression ($C_2^{obs} \sim 0.25\, C_2^{\Lambda CDM}$) and the hemispherical power asymmetry ($A_{hem} \sim 1.07$). In ΛCDM, each anomaly requires an independent statistical fluctuation of probability ~1-5%, making their simultaneous occurrence unlikely at the $\sim 10^{-6}$ level. In SCT, a single physical event produces correlated anomalies across all relevant scales — a distinctive signature whose full quantitative prediction requires the structure formation simulation of Section 11.

8.5 Planck 2018 Anomalies Explained by SCT

Anomaly	SCT Mechanism	Consistency Level
Hubble tension (5.6 +/- 1.1 km/s/Mpc)	KBC supervoid + temporal Lambda_eff evolution (Sec. 6.5)	DeltaH_0 = 3.4-5.3 km/s/Mpc; consistent at 1 sigma
A_lens = 1.180 +/- 0.065 (2.8 sigma)	Steeper potential growth from evolving A(z) during lensing epoch (Sec. 8.4)	A_lens^SCT ~ 1.20; consistent at 0.3 sigma
Quadrupole suppression (C_2 ~ 0.25 C_2^ΛCDM)	Phase cancellation at l=2 from outermost collision geometry (29th nesting level)	Qualitatively consistent; quantitative prediction in Sec. 11
Hemispherical asymmetry A_hem ~ 1.07 (3.3 sigma)	Bulk motion asymmetry from dominant large-scale collision event	Base amplitude ~1% from bulk velocity; full 7% requires nesting levels 27-29
CMB cold spot (Cruz et al. 2005)	SCT pocket boundary coinciding with Eridanus supervoid; enhanced ISW from suppressed Lambda_eff inside void	Marginal; ISW amplitude requires void-enhanced Lambda_eff factor ~1.25
S_8 tension (2.5 sigma)	Anisotropic lensing from coherent rho_sup reduces effective sigma_8 inferred from weak lensing (Paper 6)	DeltaS_8 ~ 0.04-0.08 estimated; consistent at ~1 sigma

Table 2. SCT explanations for Planck 2018 anomalies. Quantitative entries reference equations in this paper.

A key observation is that the six anomalies listed in Table 2 are not statistically independent in SCT — they all trace to the same physical cause: the geometry of the 29th-level collision event. Their simultaneous occurrence is therefore not unlikely in SCT; it is expected. The correlated nature of these anomalies is itself a distinctive SCT prediction: they should be statistically correlated with each other and with observable properties of the largest cosmic structures.

8.6 Implementation Recipe for Modified CAMB/CLASS

All five inputs needed for numerical implementation in modified CAMB or CLASS are now fully specified. The required changes are: (1) replace the cosmological constant with the CPL parametrization w_0 = -0.967, w_a = +0.14 for alpha = 0.95 H_0; (2) modify the Poisson equation to include k^2 Phi^SCT with the A(z) factor as in Equation (45), active only for z < 10 (structure formation regime); (3) input the modified primordial power spectrum with n_s = 28/29 = 0.9655 and the CAMB-standard amplitude A_s calibrated to the observed CMB TT spectrum at l ~ 200; (4) set f_iso = 0 (pure adiabatic initial conditions); (5) set r = 10^-5 (negligible tensor power). No other modifications to the standard CAMB/CLASS code are required. The dominant numerical effect on C_l is expected to arise from the altered D_A (affecting peak positions at the ~1.5 sigma level) and the A_lens enhancement.

9. PRIMORDIAL NUCLEOSYNTHESIS

9.1 BBN Inputs in SCT

Standard BBN depends on three inputs evaluated at T ~ 1 MeV: the baryon-to-photon ratio eta = n_b/n_gamma ~ 6 x 10^-10; the expansion rate H(T); and the neutron lifetime tau_n = 879.4 +/- 0.6 s (PDG 2023). In SCT, the neutron lifetime is unchanged (a QCD/electroweak quantity unaffected by the spacetime pocket structure). The baryon-to-photon ratio eta_SCT is inherited from the baryon-to-entropy ratio of the colliding pockets — it is a conserved quantity along the pocket collision hierarchy, not independently generated.

At T = 1 MeV, the SCT contribution of Lambda_eff to the Hubble rate is suppressed by a factor of ~10^-39 relative to the radiation density. The superposition field contributes Deltag_* ~ 10^-18 — 18 orders of magnitude below observational sensitivity. Therefore H_SCT(T=1 MeV) = H_ΛCDM(T=1 MeV) to within 1 part in 10^39, and all standard BBN nuclear network calculations apply without modification. This is a critical self-consistency result confirming that SCT's modifications are confined to late-time cosmology (z < a few) and do not disturb the precision BBN predictions.

9.2 Helium-4 Mass Fraction Y_p

With H_SCT = H_ΛCDM at the weak freeze-out epoch, the neutron freeze-out temperature T_freeze = 0.74 MeV and the n/p ratio at freeze-out are identical to the ΛCDM values. After accounting for neutron decay between freeze-out and nucleosynthesis onset (t_nucl ~ 200 s, tau_n = 879.4 s):

(n/p)_nucl = (n/p)_freeze x exp(-t_nucl/tau_n) ~ (1/5.7) x 0.795 ~ 1/7.17 (47)

Y_p^SCT = 2(n/p)_nucl / [1 + (n/p)_nucl] ~ 2/8.17 ~ 0.2448 (48)

The full nuclear network gives Y_p^SCT = Y_p^ΛCDM = 0.2467 (Pitrou et al. 2018), since the BBN expansion history and nuclear physics are identical. This is consistent with the PDG 2023 measurement of Y_p = 0.2453 +/- 0.0034 at 0.4 sigma.

9.3 Deuterium Abundance D/H

The deuterium abundance tracks eta via the power-law scaling D/H ~ 2.527 x 10^-5 x (eta/6.1 x 10^-10)^-1.6. When eta_SCT = eta_obs = 6.1 x 10^-10, D/H^SCT = 2.527 x 10^-5 exactly. The Cooke, Pettini & Steidel (2018) measurement of D/H = (2.527 +/- 0.030) x 10^-5 from high-redshift quasar absorption systems constrains eta_SCT to within +/- 0.74% of 6.1 x 10^-10 — a precision requirement on the conservation of the baryon-to-entropy ratio across the collision hierarchy.

9.4 The Cosmological Lithium Problem: Honest Assessment

The ΛCDM prediction Li-7/H = 4.72 x 10^-10 (Pitrou et al. 2018) exceeds the Spite Plateau observation of 1.6 x 10^-10 (Spite & Spite 1982; Sbordone et al. 2010) by a factor of approximately 3 (~4-5 sigma). Two SCT mechanisms for resolving this discrepancy were investigated. Mechanism 1 — spatial inhomogeneity in eta from collision geometry — does not help: because Li-7/H ~ eta^+2.0, averaging over a distribution of eta values increases rather than decreases the mean Li-7 yield. Mechanism 2 — enhanced H(T = 30 keV) from Lambda_eff — does not help: at T = 30 keV, the ratio rho_Lambda/rho_rad ~ 10^-31, making Lambda_eff negligible by 30 orders of magnitude at the Li-7 formation epoch.

SCT therefore does not resolve the cosmological lithium problem. Li-7/H^SCT = Li-7/H^ΛCDM = 4.72 x 10^-10, sharing the factor-of-3 discrepancy with observations equally with ΛCDM. The resolution must lie elsewhere — stellar depletion in halo star atmospheres, non-standard nuclear reaction rates, or systematic errors in stellar atmosphere modeling — and these are unaffected by SCT. This is stated explicitly and honestly.

9.5 Baryon Asymmetry: Honest Assessment

SCT provides a mechanism for transporting and partially preserving a pre-existing baryon asymmetry across successive pocket collisions: the collision thermalization suppresses baryon-antibaryon pair annihilation when collision kinetic energy per particle exceeds m_p c^2, preserving a net baryon excess in the thermalized product. However, SCT does not independently generate eta > 0 from a symmetric initial state. The collision mechanism conserves baryon number — purely gravitational effects cannot satisfy the Sakharov conditions (baryon number violation, C and CP violation, departure from thermal equilibrium) required to create matter-antimatter asymmetry from zero.

The claim in Paper 1 that SCT resolves the baryogenesis problem is overstated and is corrected here. SCT explains how our pocket inherited its asymmetry from parent pockets through baryon-number-conserving collisions, but not why eta > 0 exists throughout the eternal manifold. The ultimate origin of the baryon asymmetry remains an open problem in SCT, as in ΛCDM. This honest assessment is a necessary part of the mathematical self-consistency record.

9.6 Comparison Table: ΛCDM, SCT, and Observations

Observable	ΛCDM Prediction	SCT Prediction	Observed (2023)
Y_p	0.2467 +/- 0.0006	0.2467 (identical)	0.2453 +/- 0.0034 (PDG 2023); consistent at 0.4 sigma
D/H	2.527 x 10^-5	2.527 x 10^-5 (identical, eta_SCT = eta_obs)	(2.527 +/- 0.030) x 10^-5 (Cooke et al. 2018); exact match
Li-7/H	4.72 x 10^-10	4.72 x 10^-10 (identical; problem unresolved)	1.6 x 10^-10 (Sbordone et al. 2010); factor ~3 discrepancy shared equally with ΛCDM
H(T=1 MeV)	1.13 s^-1	1.13 s^-1 (deviation < 10^-39)	~1.13 +/- 0.01 s^-1 (inferred from N_eff < 3.3)

Table 3. SCT versus ΛCDM BBN predictions. All SCT predictions are derived; Li-7 gap is stated honestly.

10. FALSIFIABLE PREDICTIONS

10.1 Status of the Paper 10 Predictions

Paper 10 (doi:10.13140/RG.2.2.19381.33765) catalogs sixty falsifiable predictions across thirteen observational domains. Those predictions were made before publication of DESI 2024 BAO results, before JWST confirmation of z > 14 galaxies, and before the

Riess et al. 2024 JWST Cepheid Hubble constant measurement. Several predictions have since moved from 'untested' to 'consistent with current data' or 'in tension with current data.'

Predictions now consistent with current data: (i) Hubble tension persists as a physical environmental effect (consistent with continued 5+ sigma significance after JWST Cepheid calibration); (ii) early galaxy excess above ΛCDM predictions at z > 10 (confirmed by JWST at z = 14.18 and 14.44); (iii) w_0 > -1 (consistent with the direction of DESI 2024 combined results); (iv) n_s ~ 0.965 from CLT (within 0.14 sigma of Planck). In tension with current data: the w_a > 0 prediction (opposite sign to DESI 2024 preferred values at 2.5 sigma, with dataset-dependent systematics).

10.2 Prediction 61 (New): Tidal Deformability

Derived from the Israel-Darmois junction conditions in Section 4: binary neutron star mergers in the remnant mass range 1.2-2.0 solar masses will exhibit combined tidal deformability Lambda_tidal in the range [450, 650] at M = 1.4 solar masses, systematically higher than the canonical neutron star prediction [350, 500] by approximately 150 in Lambda_tidal units. The discrimination threshold is Lambda_tidal > 550 favoring SCT polyquark core. Testable by current LIGO/Virgo/KAGRA for events within 50 Mpc (2 sigma) and by Einstein Telescope for events within 200 Mpc (>5 sigma).

10.3 Fifteen Highest-Priority Predictions Testable Within Five Years

#	Prediction	Observable	Test / Survey	Timescale	Falsification Criterion
61	Lambda_tidal = 450-650 at M=1.4 Msun	GW inspiral waveform phase	LIGO O4/O5; Einstein Telescope	Now; 2030s	Lambda_tidal < 400 at M=1.4 Msun excludes stiff-QCD end
P10-1	r < 10^-5 (no inflation)	B-mode CMB polarization	LiteBIRD (2032)	~2033	r > 0.002 detection would challenge SCT
P10-6	DeltaH_0 = 3.4-5.3 km/s/Mpc from void+temporal	H_0 void vs. cluster sightlines, ~9% difference	DESI DR5; Euclid; Rubin	2026-2028	No H_0 environmental variation at claimed level
P10-10	n_s = 28/29 = 0.9655	CMB TT/TE/EE power spectra	CMB-S4; Simons Observatory	2028-2031	n_s < 0.955 at >3 sigma from SCT would conflict
P10-14	f_NL < 0.05 (CLT suppression)	CMB bispectrum; galaxy bias	Euclid; SKA	2026-2030	f_NL > 1 local at >3 sigma inconsistent with SCT
P10-20	RAR scatter correlates with N_sat and sigma_v	Rotation curves + satellite counts	DESI + Rubin joint catalog	2026-2028	RAR scatter independent of satellite kinematics
P10-22	w_a > 0 (growing dark energy)	BAO + SNIa joint w(z)	DESI DR2-5; Roman SN survey	2025-2029	w_a < -0.3 confirmed at >3 sigma with stable systematics
P10-31	delta_y ~ 4.5 x 10^-7 dipolar y-distortion	CMB spectral distortion dipole	PIXIE (proposed)	2030s	No dipolar y-distortion at claimed level

P10-35	A_lens ~ 1.20	CMB lensing convergence power	CMB-S4; SPT-3G; ACT	2025-2029	A_lens < 1.05 at 3 sigma would challenge SCT
P10-38	Angular momentum alignment across 7 scales	Galaxy spin-filament-BCG alignment	Euclid; SKA; Rubin	2026-2030	No alignment beyond 2 sigma at any scale
P10-41	R_core in [10.5, 13.2] km at M=1.4 Msun	NS radius from X-ray timing	NICER extended mission	2025-2027	R > 13.2 km at 5 sigma would exclude soft-QCD EOS
P10-44	BAO scale unshifted (delta r_s/r_s < 10^-5)	Sound horizon from CMB+LSS	DESI DR5; Euclid	2028-2029	Measured r_s shift > 0.1% from ΛCDM value
P10-48	JWST galaxy excess persists at z > 12	UV LF at z = 12-16	JWST Cycle 3-4 surveys	2025-2027	LF drops below ΛCDM predictions at z > 13
P10-52	Kinematic SZ bulk flow coherent on >100 Mpc	pairwise kSZ amplitude vs. scale	CMB-S4; Simons Obs. + DESI	2027-2031	kSZ bulk flow coherence length < 30 Mpc at 3 sigma
P10-57	~9% H(z) difference: voids vs. overdensities	Differential Hubble flow by environment	Rubin + DESI joint catalog	2026-2030	No environmental H(z) variation at >3 sigma

Table 4. Fifteen highest-priority SCT falsifiable predictions testable within approximately five years. All prediction numbers reference Paper 10 (doi:10.13140/RG.2.2.19381.33765) except Prediction 61 which is new to this paper.

11. OPEN QUESTIONS AND PATH FORWARD

This paper closes seven of the eight open mathematical tasks from Paper 8. Task 7 — the structure formation simulation — is the primary remaining task at the numerical level. The analytic framework for the simulation has been fully specified across Sections 5, 6, and 8: the governing equation is the modified Poisson equation (45) with the A(z) factor replacing CDM, the expansion history is H_SCT(z) from Table 1, and the initial conditions are adiabatic with n_s = 28/29. A modified N-body code or linear Boltzmann code (CAMB/CLASS) implementing these inputs is the immediate next step before SCT can achieve a full chi-squared comparison with Planck 2018 data.

The self-consistency of the SCT framework is now established at the analytic level. The Bianchi identity is satisfied, the ΛCDM limit is recovered exactly, the junction conditions are proven, the spectral index is derived from first principles, the dark energy form is derived from orbital decay theory, the dark matter analog is derived from N-body gravitational superposition, and Hubble's law is derived from the frame-tree product. What remains is the numerical validation.

Several sub-tasks within the structure formation simulation framework will also produce quantitative predictions for specific observables currently estimated only at the order-of-magnitude level: the exact prediction for the hemispherical power asymmetry amplitude (currently estimated at ~1-7%); the precise growth factor D_+(z) in the SCT framework (needed for $A(z)$ evolution); the angular power spectrum C_l from a modified CAMB run with the inputs of Section 8; and the precision prediction for the w_a parameter given a fully specified $\alpha_{eff}(z)$ function rather than the constant $\alpha = 0.9 H_0$ approximation used throughout this paper.

The honest assessment of what this paper provides and what remains: derived, not assumed — the exponential decay law for Λ_{parent}; the functional form $A(N, \sigma_v, R)$; the pressure vanishing theorem $P(R_{core}) = 0$; the statistical origin of Hubble's law; the adiabatic condition from simultaneous thermalization; the BBN consistency of SCT with standard nuclear physics. Demonstrated analytically — the Bianchi identity consistency; the ΛCDM limit recovery; the Hubble tension quantification; the w_0 prediction; the $n_s = 28/29$ derivation. Shown to be consistent with — the Planck CMB acoustic peak position (1.5 sigma); the NICER/LIGO mass-radius band; the Planck A_{lens} anomaly; the D/H and Y_p measurements. Not yet achieved — a chi-squared fit to the full Planck 2018 C_l spectrum; a full N-body structure formation simulation; an independent derivation of the baryon asymmetry.

12. CONCLUSION

Successive Collision Theory proposes that our observable universe is a thermalized collision product embedded within an infinite, eternally evolving spacetime manifold of nested comoving pockets. Papers 1 through 10 established the conceptual framework, identified the three EFE modifications, addressed seven Lambda-CDM mysteries qualitatively, and cataloged sixty falsifiable predictions. Paper 8 identified eight open mathematical tasks whose formal derivations remained incomplete.

This paper, Paper 11, has closed seven of those eight tasks through rigorous derivations in standard GR and SR. The three EFE modifications are now stated in unified tensor form in the SCT-MASTER equation for the first time. The Bianchi identity is proven to be satisfied when Λ_{eff} varies, with the explicit constraint PDE derived. The Israel-Darmois junction conditions are proven, yielding the pressure vanishing theorem $P(R_{core}) = 0$ and the new Prediction 61 for tidal deformability. The coherence amplification factor A is derived from N-body gravitational superposition. The dark energy field Λ_{eff} is derived from orbital decay theory with both parameters independently constrained. Hubble's law is derived as the statistical mean of the frame-tree redshift product. The CMB Boltzmann inputs are fully specified. Primordial nucleosynthesis is shown to be unchanged from ΛCDM, with honest statements about what SCT does and does not explain.

Key quantitative results: the Hubble tension is resolved at $\Delta H_0 = 3.4\text{-}5.3$ km/s/Mpc from two independent physical contributions; the spectral index $n_s = 28/29 = 0.9655$ is within 0.14 sigma of Planck 2018; the tensor-to-scalar ratio $r < 10^{-5}$ is far below inflationary predictions; the helium-4 mass fraction $Y_p = 0.2467$ is consistent with PDG 2023 at 0.4 sigma; the lensing amplitude $A_{lens} \sim 1.20$ is consistent with the Planck anomaly at 0.3 sigma; the BAO sound horizon shift is $+2 \times 10^{-7}$, undetectable by current surveys.

SCT is now a mathematically self-consistent alternative to Lambda-CDM, grounded entirely in standard GR and SR with no new particles or fields, with all major qualitative mechanisms analytically derived and internally consistent. It is not yet a proven replacement for Lambda-CDM; it is a research program now complete enough to warrant full numerical implementation — a modified CAMB/CLASS run and a chi-squared comparison to Planck 2018 data — and formal journal scrutiny. The prediction of a dipolar CMB spectral distortion at delta_y ~ 4.5 x 10^-7, detectable by the PIXIE mission at ~45 sigma, and the tidal deformability prediction Lambda_tidal = 450-650 at M = 1.4 solar masses, testable by the Einstein Telescope, provide decisive observational opportunities to confirm or refute the central mechanism of SCT within this decade.

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