

From Chaos To Confirming Falsifiability

Compiled Predictions, Falsification Criteria, and Evidence

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Abstract

Section 1: SCT Predictions and Falsification Criteria

Total predictions: 60, spanning 13 domains (numbered 1 through 60).

Domain 1: Tensor-to-Scalar Ratio (r)

1. The primordial tensor-to-scalar ratio r is approximately zero — SCT requires no inflationary gravitational wave background.

Source: Paper 1 §13.4 (doi:10.13140/RG.2.2.20310.31042); Paper 3 Table 3 (doi:10.13140/RG.2.2.20310.31042); Paper 4 §3.5 & §4.3 (doi:10.13140/RG.2.2.20310.31042)

Detail: SCT replaces the inflationary phase entirely; the horizon and flatness problems are resolved by collision thermalization of the entire overlap volume simultaneously (Premises P23–P25, doi:10.13140/RG.2.2.20310.31042). Without inflation there is no inflationary gravitational wave background. Tensor perturbations generated by the collision cascade are suppressed because the stress-energy tensor of each thermalized collision remnant is dominated by its isotropic components — the anisotropic stress per event is of order $(\sigma_{\nu}/c)^2 \times$ isotropic pressure. For a thermalized remnant, $\sigma_{\nu}/c \ll 1$. After incoherent summation over $N_{\text{coll}} \sim 10^4$ independent events (Equation 23, doi:10.13140/RG.2.2.20310.31042), the total tensor-to-scalar ratio is $r = r_{\text{single}} / N_{\text{coll}}^{1/2} < 10^{-5}$ for all physically plausible parameter combinations — far below any inflationary prediction. Current upper limit: $r < 0.06$ from Planck 2018 + BICEP/Keck, consistent with SCT. CMB-S4 is projected to reach $\sigma(r) \sim 0.002\text{--}0.005$ in the early 2030s, providing a decisive test.

Current Status: Consistent with current upper limits ($r < 0.06$). Not yet falsified.

Falsification Criterion: A confirmed detection of $r > 0.01$ at $\geq 3\sigma$ significance from CMB B-mode polarization (CMB-S4, LiteBIRD, Simons Observatory) would directly falsify the SCT perturbation-generation mechanism. No combination of collision parameters within the physically allowed range produces r above 10^{-5} .

Domain 2: BAO, Power Spectrum, and Sound Horizon

2. The BAO sound horizon r_s is slightly shifted upward relative to Λ CDM — reflecting the baryon-only pre-recombination photon-baryon fluid (no CDM particle present).

Source: Paper 1 §13.2 (doi:10.13140/RG.2.2.20310.31042); Paper 3 Table 3 (doi:10.13140/RG.2.2.20310.31042)

Detail: In Λ CDM the pre-recombination photon-baryon fluid includes cold dark matter, which reduces the sound speed. In SCT there is no CDM particle; the dark-matter-like gravitational effect is provided entirely by the constructive superposition mechanism (Premises P45–P48, doi:10.13140/RG.2.2.20310.31042), which acts only after structure formation begins. The pre-recombination baryon-only fluid has higher sound speed $c_s^2 = 1/[3(1+R)]$ because $R = 3\rho_b/(4\rho_\gamma)$ is

smaller without CDM. The sound horizon $r_s = \int c_s dz/H(z)$ from z_* to ∞ is therefore slightly larger than in Λ CDM. The exact magnitude requires implementation in a modified CAMB or CLASS Boltzmann solver (identified as essential future work in Paper 3).

Current Status: Not yet measured at sufficient precision to distinguish. DESI full survey (2026–2030) and Euclid will provide the decisive test.

Falsification Criterion: BAO peak position matching the Λ CDM CDM+baryon value exactly with no upward shift detectable at DESI/Euclid sub-percent precision.

3. The matter power spectrum shows excess power at $k < \sim 0.01 \text{ Mpc}^{-1}$ from the largest collision stages — a signature with no Λ CDM analog.

Source: Paper 1 §13.2, §10.2 (doi:10.13140/RG.2.2.20310.31042)

Detail: The first and largest collision stage deposited density perturbations at the scale of the colliding pockets — characteristic scales of several gigaparsecs (Premise P50, doi:10.13140/RG.2.2.20310.31042). In Fourier space this manifests as enhanced power at $k < 0.01 \text{ Mpc}^{-1}$. Standard inflationary perturbation spectra do not produce excess power at these scales. SCT predicts an upward deviation from Λ CDM at the lowest accessible k-modes, contributing to the observed CMB quadrupole suppression and large-angle anomalies. Detected at the level of the Big Ring ($\sim 1.3 \text{ Gly}$, Lopez et al. 2024) and Giant Arc ($\sim 3.3 \text{ Gly}$) whose scales correspond to $k \sim 5 \times 10^{-4}$ to $5 \times 10^{-3} \text{ Mpc}^{-1}$.

Current Status: CMB quadrupole suppression and gigaparsec structures observed. Quantitative power spectrum excess not yet systematically measured.

Falsification Criterion: Wide-field surveys (DESI, Euclid, Roman) finding no power excess at $k < 0.01 \text{ Mpc}^{-1}$ beyond cosmic variance expectations.

4. SCT expansion history $H_{\text{SCT}}(z)$ departs from Λ CDM at the sub-percent level for $z < 2$ due to variable $\Lambda_{\text{eff}}(z)$; jointly measurable via Euclid and DESI BAO+RSD analysis.

Source: Paper 1 §13.3 (doi:10.13140/RG.2.2.20310.31042); Paper 7 §3–§4 (doi:10.13140/RG.2.2.24304.72969)

Detail: The dynamical cosmological ratio $\Lambda_{\text{eff}}(x,t) = \kappa \times [U_{\text{local}}/U_{\text{parent}}]$ (Premise P17, doi:10.13140/RG.2.2.20310.31042) evolves temporally as the tensor mesh weakens across the hierarchy. Because Λ_{eff} grows with time as mesh dissipation accelerates ($dM_n/dt = -\alpha_n M_n(t)$, doi:10.13140/RG.2.2.24304.72969 Equation 8–9), the effective expansion history $H_{\text{SCT}}(z)$ differs from the Λ CDM value by a sub-percent correction that grows toward the present. The deviation is: $[H_{\text{SCT}}(z) - H_{\Lambda\text{CDM}}(z)]/H_{\Lambda\text{CDM}}(z) \sim O(\alpha_n/H_0) \times f(z)$ where $f(z)$ encodes the redshift evolution of the mesh. For $z < 2$ where the deviation is largest, this is measurable via the joint BAO+RSD (redshift-space distortions) analysis from Euclid and DESI, which can jointly constrain $H(z)$ and the growth rate $f\sigma_8(z)$ to sub-percent precision.

Current Status: Not yet measured. The deviation is at the edge of current precision; Euclid DR1 and DESI DR2 will begin to probe it.

Falsification Criterion: Euclid+DESI BAO+RSD joint analysis finding $H(z)$ for $z < 2$ indistinguishable from the Λ CDM prediction at the 0.1% level.

5. BAO standard-ruler scale shows systematic environment-dependent shifts at the ~ 0.1 – 0.3% level — void-environment BAO tracers yield a slightly different inferred D_A than cluster-environment tracers at the same redshift.

Source: Paper 7 §8.3 Pred 2 (doi:10.13140/RG.2.2.24304.72969)

Detail: In the Λ/λ framework, $\Lambda_{\text{eff}} = C \times \Lambda_{\text{parent}} / \lambda_{\text{local}}$ is larger in voids (low λ) and smaller in overdense regions (high λ). BAO features sit in mildly overdense filament-and-wall structures with intermediate λ . When BAO measurements are separated by environment — void-dominated versus filament-dominated lines of sight — the inferred angular diameter distance D_A should show a systematic offset of $\sim 0.1\text{--}0.3\%$ (Section 8.3, doi:10.13140/RG.2.2.24304.72969). This is accessible to DESI environment-tagged BAO analyses that classify BAO tracers by their large-scale density environment. The Λ CDM prediction is no such offset after peculiar velocity corrections.

Current Status: Qualitative prediction; DESI environment-tagged BAO analysis not yet published at required precision.

Falsification Criterion: DESI BAO void vs. cluster environment split finding inferred D_A consistent to better than 0.05% at the same redshift — ruling out the predicted 0.1–0.3% shift.

Domain 3: Dark Energy, Hubble Tension, and Expansion

6. The Hubble tension — $H_0 = 73.0$ km/s/Mpc (local distance ladder) vs. $H_0 = 67.4$ km/s/Mpc (CMB/BAO) — is predicted as a natural consequence of local Λ_{eff} variability from two compounding contributions: the KBC supervoid ($\sim 2\text{--}3$ km/s/Mpc) plus temporal evolution of Λ_{eff} between $z = 1100$ and $z = 0$ ($\sim 2\text{--}3$ km/s/Mpc).

Source: Paper 1 §13.3, P18–P19 (doi:10.13140/RG.2.2.20310.31042); Paper 7 §6.1 (doi:10.13140/RG.2.2.24304.72969)

Detail: SCT's Premise P18 (long-term Λ_{eff} trajectory) and Premise P19 (short-term local variability) together produce the Hubble tension without new physics. P18: mesh dissipation operates simultaneously at every hierarchy level; the exponential growth of Λ_{eff} means the early-universe Λ_{eff} (at $z \sim 1100$) was smaller than today's — producing a lower inferred H_0 from CMB analyses. P19: the KBC supervoid extending ~ 300 Mpc around the Local Group locally suppresses $U_{\text{local}}/U_{\text{parent}}$, raising Λ_{eff} by $\sim 2\text{--}3$ km/s/Mpc. Combined total: $\sim 4\text{--}6$ km/s/Mpc enhancement locally above the global mean, consistent with the observed 5.6 km/s/Mpc discrepancy. A required amplitude of $\sim 9\%$ variation in Λ_{eff} between local and global environments is a testable number (Section 6.1, doi:10.13140/RG.2.2.24304.72969).

Current Status: Consistent with observed $H_0 = 73.0$ vs. 67.4 discrepancy. The $\sim 9\%$ Λ_{eff} variation amplitude is a quantitative prediction.

Falsification Criterion: The Hubble tension being resolved by a mechanism that requires zero environmental Λ variation — such as early dark energy acting uniformly across all environments — while simultaneously ruling out a $\sim 9\%$ local Λ_{eff} enhancement.

7. $w(z)$ evolves with two distinct modes from two distinct SCT premises: P18 predicts a long-term exponential increase in Λ_{eff} driving $w(z)$ toward more negative values over Gyr timescales; P19 predicts short-term local variability producing scatter in w measurements between surveys sampling different environments.

Source: Paper 1 §13.3, P18–P19 (doi:10.13140/RG.2.2.20310.31042); Paper 7 §6.3 (doi:10.13140/RG.2.2.24304.72969)

Detail: These are two separate, distinguishable SCT predictions about $w(z)$ behavior that must both be tested independently. P18 (long-term global): the exponential weakening of the hierarchy's gravitational mesh $dM_n/dt = -\alpha_n M_n$ gives $\Lambda_{\text{eff}}(t) \propto \exp(+\alpha t)$, producing a slowly evolving effective w that departs from -1 over Gyr timescales — detectable as a coherent redshift trend in Euclid/LSST dark energy surveys. P19 (short-term local): local over- and underdensities produce $\sim 1\%$

variations in Λ_{eff} on 100–300 Mpc scales, creating apparent scatter in w values between different survey fields. A strictly constant $w = -1$ at all redshifts and all environments would falsify both premises simultaneously. The 2024 DESI BAO results (arXiv:2404.03002) preferring $w_0 > -1$ and $w_a < 0$ are consistent with the P18 long-term trend.

Current Status: DESI 2024 preliminary $w_0 > -1$, $w_a < 0$ consistent with P18 direction. P19 environmental scatter not yet measured at required precision.

Falsification Criterion: Precision measurement of $w(z) = -1.000 \pm 0.005$ confirmed constant across all redshifts and all survey environments at high significance; OR demonstration that inter-survey w scatter is consistent with noise, not environmental Λ_{eff} variation.

8. Large spectroscopic surveys with environment classification will detect a systematic ~9% difference in inferred $H(z)$ between void-dominated and overdensity-dominated sightlines.

Source: Paper 7 §8.3 Pred 1 (doi:10.13140/RG.2.2.24304.72969)

Detail: The Λ/λ mechanism predicts that the effective expansion rate is modulated by the ratio $\Lambda_{\text{parent}}/\lambda_{\text{local}}$. Lines of sight through voids (low λ) yield a larger effective Hubble parameter; lines through filaments and clusters (high λ) yield a smaller effective Hubble parameter. The magnitude — ~9% — is fixed by the Hubble tension amplitude itself (Section 6.1, doi:10.13140/RG.2.2.24304.72969), making it a predicted value rather than a free parameter. DESI provides spectroscopic redshifts and large-scale structure reconstructions that can classify sightlines by environment; Euclid and Rubin/LSST will extend this to higher redshift. The prediction is that void-calibrated $H(z)$ should exceed filament-calibrated $H(z)$ by approximately 9% at $z < 0.5$, declining toward negligible values at $z \sim 1.5$ following the growth of structure in reverse.

Current Status: Not yet measured. DESI DR2 will begin to probe this differential.

Falsification Criterion: Environment-tagged $H(z)$ measurements in DESI finding no systematic difference between void-dominated and overdensity-dominated sightlines at the >2% level after all peculiar velocity corrections.

9. The DESI-observed $w(z)$ evolving signal ($w_0 > -1$, $w_a < 0$) is a geometric artifact of fitting an inhomogeneous $\Lambda_{\text{eff}}(x,t)$ into a homogeneous parameterization — and its amplitude will correlate with the void fraction of the survey volume.

Source: Paper 7 §6.3 (doi:10.13140/RG.2.2.24304.72969)

Detail: SCT predicts that when surveys with different void fractions are fit to a single homogeneous $w_0 w_a$ parameterization, the apparent w_0 and w_a values will depend on the fraction of survey volume in void environments. Surveys dominated by voids (high effective Λ_{eff} sightlines) will infer stronger apparent dark energy evolution than surveys dominated by filaments and clusters. This is a directly testable prediction: DESI, Euclid, and Roman can partition their Type Ia SN and BAO samples by environment and test whether the inferred w_0 and w_a shift coherently with void fraction. If $w(z)$ evolution is intrinsic (a real dark field), it should be independent of the survey's environmental weighting. If it is a Λ/λ artifact, the correlation with void fraction should be detected at $>2\sigma$ in the combined DESI+Euclid dataset.

Current Status: DESI 2024 preliminary $w_0 > -1$ consistent with SCT direction. The void-fraction correlation test has not yet been performed.

Falsification Criterion: DESI/Euclid finding w_0 and w_a values independent of survey void fraction at $>3\sigma$ significance — ruling out the environmental-artifact explanation.

10. The expansion rate inside virialized galaxy clusters — measured via proper separations of cluster member galaxies over cosmological time — shows zero cosmological expansion contribution. Any claimed expansion signal inside virialized structures falsifies the high- λ suppression mechanism.

Source: Paper 7 §5.1 (doi:10.13140/RG.2.2.24304.72969)

Detail: In the Λ/λ framework, strongly bound regions are characterized by large λ , giving $\Lambda_{\text{eff}} = C \times \Lambda_{\text{parent}} / \lambda_{\text{local}} \ll \Lambda_{\text{parent}}$ (Equation 11, doi:10.13140/RG.2.2.24304.72969). The inherited stretch from parent frames is absorbed by the local mesh. Galaxy clusters, galaxies, and stellar systems do not expand with the Hubble flow — an observational fact already established (Cooperstock et al.; Carrera & Giulini). SCT provides the physical mechanism for this non-expansion: high- λ bound interiors suppress Λ_{eff} to effectively zero, consistent with Birkhoff's theorem in the GR limit. This is not merely a consistency requirement — it is a falsifiable boundary: any precision measurement finding a non-zero cosmological expansion signal inside a virialized cluster (e.g., via proper motion monitoring of cluster members over decades) at the level predicted by Λ CDM's global Λ would directly falsify the high- λ suppression mechanism.

Current Status: Absence of expansion inside virialized structures is already an established observational fact; SCT's mechanistic account is not yet independently tested.

Falsification Criterion: Precision astrometric monitoring finding cosmological-rate expansion of proper separations between member galaxies inside a virialized cluster — a non-zero signal at the $\sim H_0 \times d$ level — would falsify the λ -suppression mechanism.

11. $\Lambda_{\text{eff}}(z) \rightarrow 0$ at high redshift ($z \gg 1$): the dark energy contribution to the Friedmann equation diminishes faster than a cosmological constant in the matter-dominated era, yielding a distinctive $H(z)$ signature measurable by future 21-cm surveys.

Source: Paper 7 §4.2, §3.4 (doi:10.13140/RG.2.2.24304.72969)

Detail: In the hierarchical mesh-dissipation framework, $\Lambda_{\text{eff}}(z) = C \times \Lambda_{\text{parent}}(z) / \lambda_{\text{local}}(z)$. At high redshift, two effects combine to suppress Λ_{eff} : (1) Λ_{parent} was smaller in the past because the cascade of mesh dissipation had not yet accumulated to its present value — the exponential growth $M_n(t) = M_n(t_0) \exp[-\alpha_n(t - t_0)]$ means $\Lambda_{\text{eff}} \propto 1/M_n \propto \exp(+\alpha_n t)$ was much smaller at early times; (2) λ_{local} was larger at high redshift when matter was more uniformly dense. Both effects push $\Lambda_{\text{eff}} \rightarrow 0$ for $z \gg 1$. This produces a distinctive $H(z)$ signature in the matter-dominated era: $H(z)$ approaches the pure matter-dominated value $H(z) \approx H_0 \sqrt{(\Omega_m(1+z)^3)}$ more closely than in Λ CDM, with a transition to dark-energy-dominated behavior at lower redshift than Λ CDM predicts. Future 21-cm surveys (SKA, HERA) mapping the intergalactic medium at $z = 2-10$ will probe $H(z)$ in this regime.

Current Status: Qualitative prediction; 21-cm cosmology surveys not yet at required sensitivity. SKA Phase 1 will begin to probe this regime.

Falsification Criterion: 21-cm surveys finding $H(z)$ at $z = 3-5$ consistent with Λ CDM's constant- Λ model, with no evidence of faster Λ_{eff} suppression at high z .

12. Local bulk-flow anisotropies correlate with the Λ_{eff} field: galaxies in void directions show higher bulk-flow velocities than galaxies in cluster directions, exceeding Λ CDM peculiar-velocity predictions; the bulk-flow direction aligns with the Λ_{eff} gradient.

Source: Paper 7 §8.3 Pred (doi:10.13140/RG.2.2.24304.72969); Paper 1 §11.2 (doi:10.13140/RG.2.2.20310.31042)

Detail: In the Λ/λ picture, voids have larger Λ_{eff} and therefore experience stronger effective acceleration. The Λ_{eff} gradient — pointing from high- λ cluster regions toward low- λ void regions — exerts a net push on matter, generating bulk flows that exceed what Λ CDM's gravitational peculiar-velocity theory predicts from the observed density field alone. The observed 600 km/s bulk flow of the Local Group toward the Shapley Concentration (Carrick et al. 2015) is consistent with SCT because the Dipole Repeller void (Hoffman et al. 2017, Nature Astronomy) sits on the opposite side, pushing material away via enhanced Λ_{eff} . SCT predicts that the bulk-flow residual — what is left over after subtracting the Λ CDM gravitational prediction from observed peculiar velocities — should be correlated with the local Λ_{eff} map, pointing preferentially toward void regions. This is testable with 6dFGS, DESI peculiar velocity surveys, and cross-correlation of the velocity field with cosmic web reconstructions.

Current Status: Qualitative consistency with observed Dipole Repeller and 600 km/s bulk flow. Quantitative Λ_{eff} map cross-correlation not yet performed.

Falsification Criterion: DESI peculiar velocity survey finding bulk-flow residuals uncorrelated with environmental density (void vs. cluster direction) at $>3\sigma$ — consistent with Λ CDM gravitational-only peculiar velocities.

13. The S_8 tension diminishes with increasing redshift: $\Delta S_8 \equiv S_8^{\text{CMB}} - S_8^{\text{low-z}}$ decreases from ~ 0.05 at $z \sim 0.3$ to $\lesssim 0.01$ at $z \sim 1.5$, following $A(z) \propto (1+z)^{-\gamma}$ with $\gamma \approx 0.5-1.0$ — in direct conflict with massive neutrino or early dark energy resolutions which predict the tension to persist at high redshift.

Source: Paper 6 §5.4 Pred 5.4 (doi:10.13140/RG.2.2.19379.69921)

Detail: The gravitational superposition amplification factor $A(N, \sigma_v, R) = 1 + (N-1) \exp(-\sigma_v^2/v_{\text{cross}}^2)$ builds up as structures form and comoving coherence develops. At high redshift, structures are less developed, N is smaller, and coherent comoving populations are fewer, so $A \rightarrow 1$ and CMB and lensing measurements of σ_8 should agree. At low redshift when cluster-scale comoving structures are fully assembled, $A \sim 1.10-1.20$, raising the inferred σ_8 from gravitational observables above the true underlying value probed by the CMB. This creates an apparent tension that grows toward lower redshift. Euclid's photometric weak lensing at $z \sim 0.3-1.5$ will trace $\Delta S_8(z)$ directly.

Current Status: ACT DR6 CMB lensing (Madhavacheril et al. 2024, ApJ 962:113) hints at S_8 closer to Planck at high z . Not yet definitive.

Falsification Criterion: S_8 tension persisting at equal magnitude at $z \sim 1.5$ as at $z \sim 0.3$, measured by multiple independent high- z weak-lensing surveys — this favors neutrino or early dark energy solutions and strongly disfavors the superposition mechanism.

14. CMB gravitational lensing convergence power spectrum at $z \sim 2-4$ yields S_8 closer to Planck CMB primary value (~ 0.83) than to low-redshift weak-lensing value (~ 0.77).

Source: Paper 6 §5.4 Pred 5.5 (doi:10.13140/RG.2.2.19379.69921)

Detail: CMB lensing probes the matter distribution at redshifts $z \sim 1-4$, intermediate between the CMB epoch ($z \sim 1100$) and today. At $z \sim 2$, large-scale structures are still assembling, and the superposition amplification A is significantly smaller than today. An observer measuring σ_8 through CMB lensing convergence should find a value intermediate between ~ 0.83 (CMB primary) and ~ 0.77 (low- z lensing), but closer to 0.83 because $z \sim 2$ has smaller A . ACT DR6 already hints at this trend. Simons Observatory and CMB-S4 lensing cross-correlations will test this prediction quantitatively.

Current Status: ACT DR6 hints consistent with this trend. Not yet at definitive precision.

Falsification Criterion: CMB lensing S_8 at $z \sim 2-4$ matching the low-redshift weak-lensing value ~ 0.77 , indicating the S_8 tension is already fully present at high z .

15. Spatial anisotropy in Λ_{eff} is correlated with the parent-frame bulk motion direction (Premise P54): supernova surveys measuring H_0 in different sky directions should detect a coherent dipole-like Λ_{eff} variation aligned with the ~ 600 km/s bulk flow direction.

Isotropic Λ_{eff} at the same precision would falsify Premise P54.

Source: Paper 1 §11.2, P54 (doi:10.13140/RG.2.2.20310.31042); Paper 7 §6.1 (doi:10.13140/RG.2.2.24304.72969)

Detail: Premise P54 of SCT states that our pocket has a residual bulk velocity within its parent frame set by the collision geometry. This bulk motion modulates Λ_{eff} directionally: in the direction of bulk motion, the pocket is moving into its parent mesh, slightly compressing λ_{local} and lowering Λ_{eff} ; in the opposite direction, λ_{local} is reduced and Λ_{eff} is higher. The result is a dipole-like modulation of the expansion rate aligned with the observed ~ 600 km/s bulk flow direction ($l \sim 282^\circ$, $b \sim 6^\circ$ toward the Shapley Concentration). Supernova surveys with all-sky coverage (Pantheon+, LSST SNe) can test for a coherent H_0 dipole at the $\sim 0.5\%$ level on top of the monopole. The amplitude is set by $v_{\text{bulk}}/c \sim 0.002$, producing $\Delta H_0/H_0 \sim 0.2\%$ — at the edge of current Pantheon+ precision and accessible to LSST's full SN sample.

Current Status: Pantheon+ shows marginal hints of H_0 directional variation; significance below 3σ . LSST full SN sample will provide definitive test.

Falsification Criterion: All-sky LSST supernova survey finding H_0 isotropic at 0.1% precision in all sky directions after dust and peculiar velocity corrections — ruling out the dipole-like Λ_{eff} variation at $>3\sigma$.

Domain 4: CMB-Specific Signatures

16. Tensor-to-scalar ratio $r < 10^{-5}$ (see Domain 1 for full treatment).

Source: Paper 1 §13.4 (doi:10.13140/RG.2.2.20310.31042); Paper 4 §3.5 (doi:10.13140/RG.2.2.20310.31042)

Detail: Cross-reference Domain 1, Prediction 1. The $r < 10^{-5}$ value follows from incoherent summation over $N_{\text{coll}} \sim 10^4$ collision events, each contributing anisotropic stress of order $(\sigma_v/c)^2$ per event.

Current Status: Consistent with $r < 0.06$ (Planck/BICEP/Keck). Not yet falsified.

Falsification Criterion: Detection of $r > 0.01$ at $\geq 3\sigma$ from CMB B-mode polarization.

17. Non-Gaussianity $f_{\text{NL}}^{\{\text{local}\}} \sim 1/\sqrt{N_{\text{coll}}}$ (small but detectable). Critically, a detection of $f_{\text{NL}} > 5$ constrains the number of independent collision events to $N_{\text{coll}} < 25$, providing a direct count of the cascade stages.

Source: Paper 3 §IV.5 (doi:10.13140/RG.2.2.20310.31042); Paper 4 §3.5 (doi:10.13140/RG.2.2.20310.31042)

Detail: By the Central Limit Theorem applied to $N_{\text{coll}} \gg 1$ independent collision events (after cascade termination, more than 10^{11} thermalization timescales before acoustic evolution), the perturbation field is nearly Gaussian with corrections of order $1/\sqrt{N_{\text{coll}}}$. For $N_{\text{coll}} \sim 10^4$, $|f_{\text{NL}}| \sim 10^{-2}$. The key quantitative inversion: since $f_{\text{NL}} \sim 1/\sqrt{N_{\text{coll}}}$, a measurement $f_{\text{NL}} > 5$ directly implies $\sqrt{N_{\text{coll}}} < 1/5$, so $N_{\text{coll}} < 25$. This provides an upper bound on the total number of independent collision events in the cascade — a uniquely SCT prediction about the cascade's internal structure.

For comparison: slow-roll inflation predicts $f_{\text{NL}} \sim 0.01$; ekpyrotic models predict large f_{NL} . SCT occupies an intermediate regime. Current Planck constraint: $f_{\text{NL}} = -0.9 \pm 5.1$ — consistent. Future CMB-S4 and 21-cm surveys may reach $\sigma(f_{\text{NL}}) \sim 1$, directly probing this regime.

Current Status: Consistent with Planck 2018 $f_{\text{NL}} = -0.9 \pm 5.1$. The $N_{\text{coll}} < 25$ inversion threshold not yet testable at current precision.

Falsification Criterion: Detection of $|f_{\text{NL}}| > 5$ at $>3\sigma$ significance would constrain $N_{\text{coll}} < 25$, deeply conflicting with the $\sim 10^4$ events required to produce $n_s = 0.965$ via the CLT. Alternatively, f_{NL} confirmed to be exactly zero at the 10^{-2} level would conflict with the finite cascade prediction.

18. $A_{\text{lens}} > 1$ naturally — constructive gravitational superposition from the parent-frame mesh provides additional lensing power beyond the local matter distribution; specifically $A_{\text{lens}} \approx 1.18$, matching the existing Planck anomaly. This is a confirmed, predicted observation.

Source: Paper 3 Table 3 (doi:10.13140/RG.2.2.20310.31042); Paper 6 §5.2 (doi:10.13140/RG.2.2.19379.69921)

Detail: In Λ CDM the lensing amplitude A_{lens} should equal exactly 1.0; any deviation is unexplained. In SCT the effective gravitational potential at any point includes both Φ_{local} (local matter) and Φ_{mesh} (coherent mesh contribution from parent frames, Premise P46, doi:10.13140/RG.2.2.20310.31042). The mesh contribution provides additional lensing convergence, naturally producing $A_{\text{lens}} > 1$. The enhancement factor $f[N, \alpha, r]$ approaches 5–10 at cluster outskirts and 1 in inner regions. Averaged over the CMB lensing kernel, a few-percent to $\sim 20\%$ enhancement is expected, consistent with Planck 2018's $A_{\text{lens}} = 1.18 \pm 0.065$. The boundary condition $S(z_0) \sim \Omega_{\text{CDM}}/\Omega_b - 1 \sim 4.4$ (Paper 3 §VII.3) gives the normalization of the superposition contribution at $z = 0$, implying $A_{\text{lens}} \sim 1 + O(S(z_*)) \sim 1.18$ when integrated over the lensing kernel.

Current Status: CONFIRMED: Planck 2018 $A_{\text{lens}} = 1.18 \pm 0.065$ at $>2\sigma$ directly matches the SCT prediction. Λ CDM has no physical explanation for $A_{\text{lens}} \neq 1$.

Falsification Criterion: Future CMB lensing measurements (CMB-S4, Simons Observatory) converging to $A_{\text{lens}} = 1.000 \pm 0.005$, ruling out any coherent mesh lensing contribution.

19. Running spectral index $\alpha_s \approx -\beta^2 \approx -0.001$ (with $\beta \approx 0.035$ being the fractional scale reduction per cascade generation). A measurement of $|\alpha_s| > 0.01$ would falsify the collision-scale distribution model.

Source: Paper 3 Table 3 (doi:10.13140/RG.2.2.20310.31042); Paper 4 §3.5 (doi:10.13140/RG.2.2.20310.31042)

Detail: The collision-scale distribution $dN/dL = N_0 L^{-1} [1 + \beta \ln(L/L_0)]^{-1}$ gives $n_s = 1 - \beta$ with $\beta = 0.035$. The running $\alpha_s = dn_s/d \ln k$ is then $\alpha_s \approx -\beta^2 \approx -0.001$ from the logarithmic curvature of the distribution. This is a small but in-principle detectable value. Current Planck constraint: $\alpha_s = -0.0045 \pm 0.0067$, consistent. Future CMB-S4 and 21-cm measurements will probe α_s at the 10^{-3} level. A measurement outside the range $-0.005 < \alpha_s < 0$ at $>3\sigma$ would challenge the collision-scale distribution model.

Current Status: Consistent with Planck 2018 $\alpha_s = -0.0045 \pm 0.0067$. Not yet constrained at the predicted 10^{-3} level.

Falsification Criterion: Detection of α_s clearly positive at $>3\sigma$, or $|\alpha_s| > 0.01$ confirmed at high significance.

20. Hemispherical CMB power asymmetry (~7%), quadrupole-octupole alignment, odd-parity preference, and the CMB Cold Spot all share the same preferred axis — the collision axis — as a falsifiable mutual alignment cross-check. Future CMB polarization maps will show a correlated polarization anomaly co-located with the Cold Spot.

Source: Paper 3 §X.1 (doi:10.13140/RG.2.2.20310.31042)

Detail: In Λ CDM these four anomalies are independent statistical fluctuations. In SCT the collision geometry defines a single preferred spatial axis J, and each anomaly is a different physical expression of that same axis. The hemispherical asymmetry arises from the asymmetric collision density distribution; the quadrupole-octupole alignment from the preferred collision direction; the odd-parity preference from the angular momentum grazing geometry breaking even/odd symmetry; the Cold Spot from a geometrically distinct sub-collision boundary region producing a localized temperature decrement. Critically, the Cold Spot has an additional distinct SCT prediction: the sub-collision that produced it also left a specific polarization pattern at the same angular location. Future Simons Observatory and CMB-S4 polarization maps, with their sensitivity to E-mode and B-mode polarization at the 1-arcminute scale, will test whether the Cold Spot region shows the predicted correlated polarization anomaly that is specifically absent in the Λ CDM stochastic picture.

Current Status: All four anomalies observed in Planck data. Shared-axis cross-check partially supported. Cold Spot polarization prediction not yet tested at required sensitivity.

Falsification Criterion: High-sensitivity CMB polarization maps finding no correlated polarization anomaly at the Cold Spot location; OR dedicated analysis showing the four anomaly axes are mutually inconsistent at 3σ .

21. Directional CMB parameter variations (already detected at $\sim 3\sigma$ by Migkas et al. 2021) will persist and sharpen with increased sky coverage and sensitivity. SCT specifically predicts a dipolar modulation pattern aligned with the primary collision axis — the same axis as the hemispherical power asymmetry and quadrupole-octupole alignment.

Source: Paper 3 §X.1 (doi:10.13140/RG.2.2.20310.31042)

Detail: Migkas et al. (2021, A&A 649:A148) detected directional variations in cosmological parameters inferred from galaxy cluster X-ray data at $\sim 3\sigma$ significance. SCT explains these as the result of the dipolar modulation of $\Lambda_{\text{eff}}(x,t)$ across the sky — regions in the direction of the collision axis experience systematically different effective expansion histories than regions perpendicular to it. This produces a coherent dipole-like pattern in: (1) inferred H_0 values across sky sectors; (2) cluster X-ray temperature-luminosity relation normalization; (3) matter power spectrum amplitude measured in different sky directions. All three should be aligned with the collision axis. The predicted amplitude is $\sim 1\text{--}3\%$ variation across opposite hemispheres. Euclid's all-sky cluster catalog combined with Planck CMB data will provide a definitive test.

Current Status: Migkas et al. (2021) $\sim 3\sigma$ detection consistent with SCT directional modulation. Not yet confirmed at $>5\sigma$ or with full-sky data.

Falsification Criterion: Euclid all-sky cluster survey finding cosmological parameters isotropic to $<0.5\%$ across all sky sectors at $>3\sigma$ — ruling out the collision-axis dipolar modulation.

22. Isocurvature fraction $\beta_{\text{iso}} \approx 0$ — complete thermalization from a single thermal bath suppresses isocurvature modes to $\beta_{\text{iso}} < 10^{-9}$. Detection of $\beta_{\text{iso}} > 0.05$ would falsify the complete-thermalization premise.

Source: Paper 3 §V.2 (doi:10.13140/RG.2.2.20310.31042); Paper 4 §5.1 (doi:10.13140/RG.2.2.20310.31042)

Detail: Complete shock thermalization acts simultaneously on all species at a common temperature $T_{\text{coll}}(x) = \bar{T}_{\text{coll}}[1 + \delta_T(x)]$, giving $\delta n_i/n_i = 3\delta_T$ for all relativistic species — identical for all species, hence adiabatic (Theorem 4, doi:10.13140/RG.2.2.20310.31042). Isocurvature modes are suppressed by the ratio $(t_{\text{therm}}/t_{\text{weak}})^2 \sim 10^{-9}$ because thermalization acts on timescales far shorter than the weak interaction rate. This is nine orders of magnitude below the Planck 2018 upper bound $\beta_{\text{iso}} < 0.038$ at 95% CL. Consistent with all current observational constraints.

Current Status: Consistent with Planck 2018 $\beta_{\text{iso}} < 0.038$. Predicted value $\beta_{\text{iso}} \sim 10^{-9}$ far below current and near-future sensitivity.

Falsification Criterion: Detection of isocurvature modes $\beta_{\text{iso}} > 0.05$ at high significance — would conflict with the complete-thermalization premise.

Domain 5: Angular Momentum and Rotation Coherence

23. Co-rotating satellite planes appear around all adequately sampled host galaxies. The joint Λ CDM probability of the already-observed 6 independent systems is $\sim 2 \times 10^{-14}$. All future adequately sampled systems will show co-rotation at $\geq 99.5\%$ significance.

Source: Paper 5 §2 (doi:10.13140/RG.2.2.28263.10400); Paper 6 §3 (doi:10.13140/RG.2.2.19379.69921); Paper 1 §13.1 (doi:10.13140/RG.2.2.20310.31042)

Detail: Co-rotating satellite planes confirmed: Milky Way VPOS (7–9 of 11, Λ CDM prob $\leq 0.1\%$), M31 Great Plane (15 of ~ 27 , 99.998% significance, Λ CDM prob $< 0.04\%$, Ibata et al. 2013), Centaurus A (14–21 of 16–28, Λ CDM prob $< 0.5\%$, Müller et al. 2018, 2021), NGC 4490/4485, NGC 2750 (Pawlowski, Ibata & Bullock 2017), and NGC 5713/5719 (12 of 14, Jerjen et al. 2025 — caught in the act of formation during an ongoing merger). 100% detection rate in every adequately sampled system. The joint probability $(0.005)^6 \approx 2 \times 10^{-14}$ makes stochastic Λ CDM assembly effectively impossible. SCT mechanism: all hosts and companions condensed from the same rotating collision debris field inheriting $J = \mu(b \times v_{\text{rel}})$, co-planarity and co-rotation entangled from the outset as two expressions of the same initial condition. The rms plane thickness $h_{\text{plane}} \approx r_{\perp} \times \sqrt{(k_B T_{\text{frag}}/m_p)/v_{\text{orb}}} \sim 5\text{--}75$ kpc brackets observed values (VPOS $\sim 20\text{--}30$ kpc, M31 plane ~ 13 kpc, CenA plane ~ 150 kpc at $3\times$ larger physical scale).

Current Status: CONFIRMED across six independent systems. Sawala et al. (2022) transient-alignment argument does not extend to M31 and CenA where kinematic co-rotation is directly observed.

Falsification Criterion: A systematic survey of ≥ 20 adequately sampled host galaxies finding co-rotation frequencies comparable to the Λ CDM prediction ($\sim 0.5\%$), rather than the observed $\sim 100\%$.

24. Satellite plane thickness scales with host mass as $h_{\text{plane}} \propto M_{\text{host}}^{-1/3}$; satellite plane normals of neighboring galaxies (separation < 5 Mpc) are more correlated than Λ CDM predicts; orbital poles are statistically perpendicular to the nearest cosmic filament at $> 2\sigma$ in ≥ 50 systems; thinner planes have systematically higher co-rotation fractions.

Source: Paper 6 §3.3 Preds 3.1–3.4 (doi:10.13140/RG.2.2.19379.69921)

Detail: Four distinct scaling predictions: (a) $h_{\text{plane}} \propto M_{\text{host}}^{-1/3}$: since $v_{\text{orb}} \propto M_{\text{host}}^{1/3}$ from virial scaling, and $h_{\text{plane}} \approx r_{\perp} \times \sqrt{(k_B T_{\text{frag}}/m_p)/v_{\text{orb}}}$ (Equation 17, doi:10.13140/RG.2.2.19379.69921), the plane thickness scales inversely with host mass to the $1/3$ power. Testable with SAGA and ELVES satellite kinematic surveys. (b) Neighboring hosts ($d < 5$ Mpc): sibling hosts condensed from the same collision debris share the global J-vector, producing

correlated plane normals at separations within the same debris field. Testable with LSST deep-field satellite censuses. (c) Orbital pole \perp filament: the collision axis simultaneously produced the filament and set the host's satellite plane. Marginal supporting evidence already exists (Pawlowski & Kroupa 2013; Libeskind et al. 2015). Testable with DESI + 4MOST filament reconstructions + ≥ 50 systems. (d) Thinner planes have higher co-rotation fractions: larger-b collisions produce more precise J imprinting (thinner plane) and higher co-rotation simultaneously — a unique Λ CDM-free correlation.

Current Status: (c) has marginal existing supporting evidence. (a), (b), (d) untested at required sample sizes.

Falsification Criterion: LSST satellite census finding: no h - M scaling; no plane normal correlation below 5 Mpc; no orbital pole-filament perpendicularity at $>2\sigma$; no h vs. f_{co} correlation.

25. Galaxy cluster major-axis orientation alignment persists to 200–300 Mpc and strengthens monotonically with redshift ($d\langle\cos\theta_{\text{align}}\rangle/dz > 0$). Specifically, ellipticity evolution follows $e \approx 0.33 + 0.05z$ from $z = 0$ to $z > 1.5$ — the opposite of what Λ CDM tidal-torque buildup predicts.

Source: Paper 6 §4.3 Preds 4.1–4.3 (doi:10.13140/RG.2.2.19379.69921); Paper 5 §3 (doi:10.13140/RG.2.2.28263.10400)

Detail: West et al. (2025) report cluster major-axis correlation to 200–300 comoving Mpc. The Λ CDM prediction is alignment coherence only to ~ 15 – $30 h^{-1}$ Mpc, with signal growing with time (tidal accumulation). SCT predicts the opposite redshift trend: alignment was established at formation epoch as an initial condition and is progressively degraded by secondary mergers, so $d\langle\cos\theta_{\text{align}}\rangle/dz > 0$ monotonically. Hopkins, Bahcall & Bode (2005, ApJ 618:1) provide the observational quantification: mean cluster ellipticity increases from $\langle\epsilon\rangle \approx 0.30$ at $z = 0$ to $\langle\epsilon\rangle \approx 0.50$ at $z = 3$. SCT parameterizes this as $e \approx 0.33 + 0.05z$ — a linear fit to this trend that can be tested observationally. The precession timescale for inter-cluster tidal forces at 250 Mpc separation is $\sim 10^{14}$ yr (Equation 19, doi:10.13140/RG.2.2.19379.69921), confirming that the alignment is cosmologically frozen from the formation epoch. The BCG-cluster alignment fully in place at $z > 1.3$ (West et al. 2017) directly confirms that this is a formation-epoch boundary condition, not a gradual assembly.

Current Status: West et al. (2025) alignment to 200–300 Mpc confirmed. BCG alignment at $z > 1.3$ CONFIRMED by West et al. (2017). Ellipticity evolution trend from Hopkins et al. (2005) consistent with $e \approx 0.33 + 0.05z$.

Falsification Criterion: CMB-S4 cluster catalogs at $z > 1.5$ showing alignment amplitude decreasing with redshift, or ellipticity evolution inconsistent with $e \approx 0.33 + 0.05z$ at $>3\sigma$.

26. BCG-cluster shape alignment is established at better than one-in-a-million significance and is fully in place at $z > 2$ — proving it was set at formation as an initial condition, not assembled by tidal torques over time.

Source: Paper 5 §3.2 (doi:10.13140/RG.2.2.28263.10400); Paper 6 §4 (doi:10.13140/RG.2.2.19379.69921)

Detail: Smith et al. (2023) report alignment significance of one-in-a-million when BCG position angles are compared simultaneously with cluster member distribution and nearest large-scale structure filament orientation. Multi-wavelength confirmation: Hashimoto et al. (2008) paired Chandra X-ray cluster morphologies with Subaru optical BCG position angles and found consistent alignment. The temporal constraint is decisive: West et al. (2017) confirmed BCG alignments at $z > 1.3$ as strong as at low redshift — when the universe was only 4.3 Gyr old. Tidal reorientation timescales from dynamical friction are several Gyr; at $z > 1.3$, insufficient time has elapsed for

gradual tidal mechanisms to have assembled the full alignment. JWST cluster imaging programs at $z > 2$ will further push this constraint, testing whether the alignment is fully established when the universe was < 3 Gyr old.

Current Status: CONFIRMED at $z > 1.3$. JWST $z > 2$ cluster sample needed for next test.

Falsification Criterion: JWST cluster imaging at $z > 2$ finding BCG-cluster alignment absent or significantly weaker than at $z = 0$, consistent with gradual tidal assembly rather than formation-epoch imprinting.

27. Cluster spin velocity scales as ~ 360 km/s at $10^{14} M_{\odot}$ rising to ~ 693 km/s at $10^{15} M_{\odot}$; spin axes \perp filament and parallel to BCG spin axis; signal strongest in dynamically young clusters (opposite of tidal torque theory). The $J \propto M \times v_{\text{rel}}$ scaling must hold at all observed redshifts.

Source: Paper 5 §3.3 (doi:10.13140/RG.2.2.28263.10400); Paper 6 §4 (doi:10.13140/RG.2.2.19379.69921)

Detail: Tang et al. (2025) confirm the $>100\sigma$ aggregate spin signal in $\sim 1,300$ – $2,200$ spectroscopically confirmed clusters from SDSS/BOSS. Rotation velocities: ~ 360 km/s at $10^{14} M_{\odot}$, ~ 693 km/s at $10^{15} M_{\odot}$. The mass scaling $J \propto M^{5/3}$ (equivalently, $j = J/M \propto M^{2/3}$) is observed across seven decades of scale (Paper 1 §7.2, doi:10.13140/RG.2.2.20310.31042). In SCT this scaling follows directly from $J = \mu(b \times v_{\text{rel}})$ where $\mu \propto M$ for comparable-mass collisions and v_{rel} scales with the collision energy. The forward SCT prediction is that this $J \propto M \times v_{\text{rel}}$ scaling must hold at all observed redshifts — not just $z \approx 0$ as currently confirmed. Cluster spin surveys at $z = 0.5$ – 1.5 (accessible with Euclid spectroscopic cluster catalogs) will test whether the mass–rotation scaling evolves with redshift (Λ CDM expectation: yes, due to tidal torque growth) or remains approximately constant (SCT expectation: scaling reflects formation-epoch J , not late-time accumulation).

Current Status: CONFIRMED at $z \approx 0$ by Tang et al. (2025). Dynamically young cluster preference (opposite of TTT) confirmed by Manolopoulou & Plionis (2017). Redshift evolution of scaling not yet measured.

Falsification Criterion: Cluster spin surveys at $z = 0.5$ – 1.5 finding $J \propto M \times v_{\text{rel}}$ scaling absent or strongly redshift-dependent — consistent with gradual tidal torque accumulation.

28. Individual cosmic filaments carry coherent bulk angular momentum (~ 110 km/s); member galaxy spin axes exceed IllustrisTNG predictions in alignment amplitude. Next filament samples will confirm this scaling.

Source: Paper 5 §5.9 (doi:10.13140/RG.2.2.28263.10400)

Detail: Tudorache et al. (2025): first direct detection of coherent bulk angular momentum in an individual cosmic filament using MeerKAT 21-cm HI spectroscopy. A chain of 14 HI-selected galaxies spanning ~ 1.7 Mpc shows solid-body-like rotation at ~ 110 km/s. Galaxy spin axes within this filament are aligned with the filament spine at an amplitude exceeding IllustrisTNG predictions beyond parameter uncertainty. Wang et al. (2021): statistical vortical velocity excess around stacked SDSS filaments confirmed. SCT interpretation: filaments are structural relics of large-scale superluminal collisions, carrying $J = \mu(b \times v_{\text{rel}})$ as bulk angular momentum inherited by every cluster and galaxy condensing within. The prediction is that all physically real filaments — not just those caught in HI surveys — carry coherent bulk angular momentum at ~ 100 km/s scale, and that systematic MeerKAT and SKA surveys of ≥ 50 filaments will confirm this scaling with dispersion set by the distribution of collision impact parameters.

Current Status: CONFIRMED by Tudorache et al. (2025) and Wang et al. (2021). Next-sample confirmation is the pending test.

Falsification Criterion: Systematic MeerKAT/SKA survey of ≥ 50 filaments finding bulk rotation velocities consistent with IllustrisTNG predictions (i.e., amplitude within simulation uncertainty) and spin-axis alignment no stronger than simulations predict.

29. Hierarchical alignment strength in filaments: spin coherence is strongest in the main strand of a well-defined filament, weaker and differently oriented in secondary branches ('tentacles'), and most disordered at branch points where two collision-defined J-vectors compete.

Source: Paper 5 §5.7, §7 Pred 2 (doi:10.13140/RG.2.2.28263.10400)

Detail: In SCT a cosmic filament is the structural relic of a large-scale collision; its sub-filaments are relics of smaller secondary collisions occurring within the main debris field. Each secondary collision imprints its own J-vector, generically misaligned with the dominant J-vector of the parent strand. The galaxy spin coherence direction in a secondary branch should diverge from the main-strand coherence direction. At branch points where secondary and primary J-vectors compete, the angular momentum field shows a rapid transition — an 'eddy' in the angular momentum flow — producing elevated scatter in galaxy spin orientations. Predictions: (1) spin coherence decreases from main strand to secondary branches to branch points; (2) coherence axis changes discontinuously at branch points; (3) galaxies nearest branch points show widest spin-axis dispersion. Testable with MeerKAT deep HI surveys over ~ 10 – 50 Mpc filament volumes.

Current Status: Theoretical prediction; no systematic observational test yet published.

Falsification Criterion: MeerKAT/SKA survey finding no gradient in spin coherence strength or axis direction across main strand, secondary branches, and branch points of a well-resolved filament system.

30. Filament length-to-width aspect ratio correlates with parent collision velocity and mass ratio: higher v_{rel} produces more elongated filaments ($L_{\text{strand}} \propto v_{\text{rel}} \times \tau_{\text{therm}}$); more equal mass ratios produce wider, more symmetric debris. Head-on collisions produce strand-like filaments; grazing collisions produce rotating sheets. This geometry–kinematics duality is testable with Euclid morphology catalogs.

Source: Paper 5 §5.1, §7 Pred 3 (doi:10.13140/RG.2.2.28263.10400); Paper 6 §2.1 (doi:10.13140/RG.2.2.19379.69921)

Detail: From SCT collision geometry (Paper 6 §2.1, doi:10.13140/RG.2.2.19379.69921): Case (b) head-on collision ($b \approx 0$): $J_{\text{debris}} \rightarrow 0$, nearly all kinetic energy converts to thermal energy producing elongated strand-like structures along the collision axis \hat{z} , with characteristic dimensions $L_{\text{strand}} \propto v_{\text{rel}} \times \tau_{\text{therm}}$ and $W_{\text{strand}} \propto \min(R_A, R_B)$, where τ_{therm} is the thermalization timescale. For highly unequal mass ratios ($M_1 \gg M_2$), the lighter pocket is disrupted, producing asymmetric structures along the heavier pocket's motion direction. Case (a) grazing collision ($b \gg 0$): most kinetic energy is retained as angular momentum; the result is a rotating sheet or wall rather than a thin strand. This geometry–kinematics duality means that within a given filament system, the most elongated filaments should contain the most dispersion-dominated (non-rotating) galaxy populations, while the widest sheets should contain the most co-rotating populations. This is testable via Euclid morphology catalogs combined with 3D velocity field reconstructions from DESI and 4MOST.

Current Status: Theoretical prediction accessible with Euclid + DESI spectroscopic samples. Not yet tested systematically.

Falsification Criterion: DESI/4MOST spectroscopic analysis finding no correlation between filament aspect ratio and galaxy velocity dispersion profile (rotational vs. dispersion-dominated populations) after controlling for mass and environment.

31. Radio-loud quasar jet and polarization-vector alignments persist coherent over ≥ 1 Gpc baselines in future SKA and LOFAR surveys — 20–30 \times beyond the Λ CDM tidal-torque maximum coherence length of ~ 30 –50 Mpc.

Source: *Paper 5 §4 (doi:10.13140/RG.2.2.28263.10400); Paper 1 §13.1 (doi:10.13140/RG.2.2.20310.31042)*

Detail: Hutsemékers (1998, 2001, 2005): optical quasar polarization coherence ~ 1 Gpc; probability of random occurrence $< 0.1\%$. Blinov et al. (2020) and Mandarakas et al. (2021): VLBI 3D jet alignment at 400–900 Mpc at $>99.5\%$ significance. Pelgrims & Hutsemékers (2016): radio polarization at 8.4 GHz perpendicular to LQG major axes at $>99\%$ for groups with >20 members. In SCT these alignments represent the largest-scale manifestation of $J = \mu(b \times v_{\text{rel}})$ inheritance: the J-vector of the most energetically dominant formative collision in our observable region sets the preferred spin-axis orientation for all structures condensing within the debris, including supermassive black holes whose spin axes are traced by jets and polarization. SKA will map radio jet morphologies for millions of AGN across the sky, enabling the most precise large-scale alignment test. LOFAR low-frequency surveys provide an independent, population-independent test using steep-spectrum sources.

Current Status: CONFIRMED by Hutsemékers effect (optical, ~ 1 Gpc) and VLBI jets (400–900 Mpc). Both exceed TTT coherence length by 20–30 \times .

Falsification Criterion: New large-sample SKA or LOFAR surveys showing alignment coherence scale is limited to < 100 Mpc after correcting for previously unrecognized systematics; or VLBI jet alignment significance dropping below 3σ with improved calibration.

32. The CMB dipole direction is approximately perpendicular to the large-scale angular momentum coherence axis — a geometric cross-check prediction testable with currently available data.

Source: *Paper 1 §11.2 (doi:10.13140/RG.2.2.20310.31042); Paper 5 §7 Pred 5 (doi:10.13140/RG.2.2.28263.10400)*

Detail: In SCT the CMB dipole reflects our pocket's residual bulk velocity within its parent frame: $v_{\text{frame}} \approx v_{\text{rel}}(\text{final}) \times (b/R_{\text{min}})$ where b is the collision impact parameter. The bulk velocity vector is parallel to b . Since $J = \mu(b \times v_{\text{rel}})$ is perpendicular to b by definition, the frame velocity (and hence the CMB dipole direction) should be approximately perpendicular to J . The large-scale J-axis is observationally identified with: the quasar polarization preferred axis (Hutsemékers), the CMB multipole anomaly 'Axis of Evil', and the bulk flow direction. The CMB dipole is precisely measured at $(l, b) \approx (264^\circ, 48^\circ)$. A dedicated analysis comparing this direction with the quasar polarization axis direction from the Hutsemékers surveys — both already measured — would constitute an immediate, cost-free test of this cross-check prediction. The expected relationship is perpendicularity (within angular measurement uncertainties), not alignment.

Current Status: All directional measurements exist; cross-check analysis not yet published as a dedicated study.

Falsification Criterion: Dedicated analysis finding the CMB dipole direction aligned with (not perpendicular to) the large-scale AM coherence axis at $>3\sigma$.

Domain 6: Dark Matter (Particle Non-Detection and Superposition)

33. No dark matter particle will be detected in any laboratory experiment or astrophysical observation. The effective gravitational constant $G_{\text{eff}}(z) = G[1 + S(z)]$ grows with cosmic time as clustering increases — the apparent 'dark matter' contribution is entirely from constructive gravitational superposition of comoving baryonic matter, and must grow alongside large-scale structure.

Source: Paper 3 §VII.2 (doi:10.13140/RG.2.2.20310.31042); Paper 6 §2.2, §5.2 (doi:10.13140/RG.2.2.19379.69921); Paper 1 §13.5 (doi:10.13140/RG.2.2.20310.31042)

Detail: The constructive superposition function $f[N, \alpha, r]$ in the modified EFE (Equation 17, doi:10.13140/RG.2.2.20310.31042) produces an effective gravitational constant $G_{\text{eff}}(z) = G[1 + S(z)]$ where $S(z)$ is the superposition enhancement factor with boundary conditions $S(z_*) \sim 10^{-5}$ at recombination (no structure yet; $S \rightarrow 0$ as $z \rightarrow \infty$) and $S(z_0) \sim \Omega_{\text{CDM}}/\Omega_{\text{b}} - 1 \sim 4.4$ at $z = 0$ (reproducing observed total matter density, Paper 3 §VII.3, doi:10.13140/RG.2.2.20310.31042). This means G_{eff} grows from G at $z \gg 1$ to $G \times 5.4$ at $z = 0$, tracking the growth of large-scale structure. The explicit $G_{\text{eff}}(z) = G[1 + S(z)]$ formulation is measurable via: (1) precision CMB lensing surveys at multiple redshifts — higher effective lensing power at low z than high z beyond Λ CDM; (2) growth-rate surveys measuring $f\sigma_8(z)$ — the effective growth of structure should track $S(z)$; (3) weak lensing mass calibrations at different redshifts — clusters at $z = 0.3$ should show higher $M_{\text{WL}}/M_{\text{true}}$ than clusters at $z = 1.0$ by a factor of $[1 + S(0.3)]/[1 + S(1.0)]$.

Current Status: $S(z_0) \sim 4.4$ boundary condition set by observations. $S(z)$ growth with structure consistent with observed increase in dark-matter-like phenomena at low redshift. No DM particle detected in four decades of searching.

Falsification Criterion: A robust, confirmed detection of a dark matter particle — WIMP, axion, sterile neutrino — in a laboratory direct-detection, collider, or astrophysical indirect-detection experiment. OR: redshift surveys finding $M_{\text{WL}}/M_{\text{true}}$ independent of redshift (flat $G_{\text{eff}}(z)$), ruling out $S(z)$ growth with structure.

34. Substructure compactness scaling: $A \propto \sigma_v/v_{\text{cross}}$ — denser, slower-dispersion subhalos show stronger lensing excess. The GGSL rate scales as $N \times C(\sigma_v, R)$, with the explicit formula $(A_{\text{sub}} - 1)/(A_{\text{cluster}} - 1) = (N_{\text{sub}}/N_{\text{cluster}})(R_{\text{cluster}}/R_{\text{sub}})^2 \times \exp[(\sigma_{v,\text{cluster}}^2 - \sigma_{v,\text{sub}}^2)/v_{\text{cross}}^2]$.

Source: Paper 6 §6.2, §6.3 (doi:10.13140/RG.2.2.19379.69921)

Detail: From Equations 9–10 and 27–28 of doi:10.13140/RG.2.2.19379.69921: the coherence function $C(\sigma_v, R) = \exp(-\sigma_v^2/v_{\text{cross}}^2)$ where $v_{\text{cross}} = R/t_{\text{obs}}$. The coherence is maximal ($C \rightarrow 1$) when $\sigma_v \ll v_{\text{cross}}$, i.e., for compact, slow-moving groups. This means the lensing enhancement is largest precisely for the most compact, lowest-velocity-dispersion substructures — the ones that Λ CDM's CDM concentration alone cannot explain. The ratio $(A_{\text{sub}} - 1)/(A_{\text{cluster}} - 1) \approx 23$ for typical parameters ($N_{\text{sub}} \sim 20$, $\sigma_{v,\text{sub}} \sim 300$ km/s, $R_{\text{sub}} \sim 200$ kpc vs. $N_{\text{cluster}} \sim 300$, $\sigma_{v,\text{cluster}} \sim 1000$ km/s, $R_{\text{cluster}} \sim 1500$ kpc), giving $A_{\text{sub}} \approx 3.8$, $A_{\text{sub}}^2 \approx 14$ — consistent with the Meneghetti et al. (2020, Science) factor of ~ 10 – 16 excess. The critical falsification test (Prediction 6.5, doi:10.13140/RG.2.2.19379.69921): increasing CDM concentration in simulations alone cannot resolve the GGSL excess at all radii and for all substructure masses, because the SCT mechanism operates through external superposition rather than internal subhalo properties.

Current Status: Consistent with Meneghetti et al. (2020) factor ~ 10 excess and Ragagnin et al. (2022) conservative lower bound ~ 2 – 4 . Specific σ_v -dependent scaling test untested.

Falsification Criterion: Increasing CDM concentration uniformly in Λ CDM simulations fully resolving the GGSL excess at all radii and masses — demonstrating that the excess is an artifact of CDM concentration, not external superposition.

35. Gravitational superposition yields S_8 tension that is mass-dependent: strongest at intermediate cluster masses $M \sim 10^{14} - 10^{14.5} M_\odot$ where $A(M)$ peaks; hydrostatic mass bias b increases monotonically with cluster richness λ ; $M_{WL}/M_{hyd} \propto A(\lambda)$.

Source: Paper 6 §5.4 Preds 5.1–5.3 (doi:10.13140/RG.2.2.19379.69921)

Detail: $A(N, \sigma_v, R) = 1 + (N-1) \exp(-\sigma_v^2/v_{cross}^2)$. At very low masses (groups), N is small and $A \approx 1$; at very high masses, σ_v is large and the coherence factor is suppressed, also giving $A \approx 1$. Maximum A occurs at intermediate masses $M \sim 10^{14} - 10^{14.5} M_\odot$ where N is large enough and σ_v/v_{cross} is moderate. This produces a mass-dependent S_8 tension (Prediction 5.1). The hydrostatic mass bias $b = 1 - M_{hyd}/M_{WL}$ should scale as $b(\lambda) \propto \lambda^\beta$ with $\beta \approx 0.3-0.5$ for richness λ (Prediction 5.3). SDSS redMaPPer, DES, and Euclid richness-binned mass calibrations can test $M_{WL}/M_{hyd} \propto A(\lambda)$ directly (Prediction 5.3). The S_8 tension is predicted to weaken at $z > 1.5$ as $A(z) \rightarrow 1$ (Prediction 5.4), in direct conflict with massive neutrino resolutions.

Current Status: Qualitative richness trend reported but not quantified. Mass-dependent S_8 tension consistent with existing cluster data trends.

Falsification Criterion: Richness-binned mass calibrations showing b independent of richness at $>3\sigma$; S_8 tension independent of cluster mass; $A(\lambda)$ showing no monotonic richness scaling.

Domain 7: Early Structure Formation and JWST

36. Confirmed galaxies with $M_* > 10^8 M_\odot$ continue to appear at $z > 14$ following a power-law (not exponential) decline in comoving number density — contradicting the Λ CDM exponential suppression at $z > 12$.

Source: Paper 4 §4.1 Pred 1 (doi:10.13140/RG.2.2.20310.31042)

Detail: The Λ CDM stellar mass ceiling at $z = 14$: $M_*^{*ceil} \sim 3 \times 10^7 M_\odot$ from the halo mass function exponential cutoff $\times f_b = 0.156 \times \epsilon_*^{*max} \sim 0.20$. JADES-GS-z14-0 at $z = 14.18$ has dynamical mass $\sim 10^8 M_\odot$ and $O > 0.1 Z_\odot$ (Carniani et al. 2024), exceeding the ceiling by factor ~ 30 when metallicity-implied progenitor populations are included. MoM-z14 at $z = 14.44$ requires Wolf-Rayet stellar populations needing multiple Gyr of evolution yet the universe is only 280 Myr old (Naidu et al. 2025). In SCT proto-structure masses $M_{proto} = \alpha_{th} \times f_b \times \mu \times \Omega(b, R_1, R_2)$ are set by collision dynamics, not gravitational growth rate — eliminating the assembly bottleneck. Number density follows $n_{SCT} \propto (1+z)^{-\beta_{ev}}$ with $\beta_{ev} = 0.5 \pm 0.3$ (power-law), not the Λ CDM exponential cutoff.

Current Status: CONFIRMED at $z = 14.18$ and $z = 14.44$. Power-law vs. exponential requires $z > 14$ statistical sample not yet available.

Falsification Criterion: All JWST spectroscopic programs targeting $z > 14$ finding zero galaxies with $M_* > 10^8 M_\odot$, consistent with Λ CDM exponential suppression.

37. The Roman Space Telescope High Latitude Wide Area Survey detects 550–4770 galaxies with $M_* > 10^{10} M_\odot$ at $z = 12-15$ (central prediction: 1590 total across three z -bins); Λ CDM predicts fewer than 3 detections in the same survey volume.

Source: Paper 4 §4.2 (doi:10.13140/RG.2.2.20310.31042)

Detail: SCT collision mass function (Equation 40–41, doi:10.13140/RG.2.2.20310.31042): $dn/d(\log M_{\text{proto}}) = n_0(M_{\text{proto}}/M_{\text{ref}})^{-\alpha}$ with $n_0 = (3.2 \pm 1.1) \times 10^{-5} \text{ Mpc}^{-3} \text{ dex}^{-1}$, $\alpha = 1.4 \pm 0.3$, mild redshift evolution $\beta_{\text{ev}} = 0.5 \pm 0.3$. Roman HLWAS parameters: 2000 sq.deg., 5σ depth ~ 27.5 AB mag, 70% completeness for $M_* > 10^{10} M_{\odot}$. Survey volume in three redshift bins: $z = 12\text{--}13$: $\sim 1.4 \times 10^9 \text{ Mpc}^3$ (SCT: 820 detections; ΛCDM : <1); $z = 13\text{--}14$: $\sim 1.2 \times 10^9 \text{ Mpc}^3$ (SCT: 490; ΛCDM : <1); $z = 14\text{--}15$: $\sim 1.0 \times 10^9 \text{ Mpc}^3$ (SCT: 280; ΛCDM : <1). Uncertainty range (factor ~ 3) reflects impact parameter distribution uncertainty ($\alpha = 1.1\text{--}1.7$), thermalization efficiency uncertainty ($\alpha_{\text{th}} = 0.25\text{--}0.85$), and completeness uncertainty. Roman survey operations anticipated ~ 2027 ; definitive counts by ~ 2029 .

Current Status: Not yet testable. JWST isolated detections above ΛCDM ceiling at $z = 12\text{--}15$ already exist; full statistical test requires Roman wide-field coverage.

Falsification Criterion: Fewer than 100 total detections with $M_* > 10^{10} M_{\odot}$ across all three bins in the full 2000 sq.deg. Roman survey — this threshold lies $>2.3\sigma$ below the lower edge of the SCT uncertainty band.

38. Disk fraction at $z > 10$ exceeds 10% — morphological type is set at the collision seeding epoch by impact parameter J/J_{circ} ratio and preserved by exact angular momentum conservation.

Source: Paper 4 §4.1 Pred 2 (doi:10.13140/RG.2.2.20310.31042); Paper 4 §3.3 (doi:10.13140/RG.2.2.20310.31042)

Detail: The ratio j/j_{circ} (specific angular momentum relative to circular orbit angular momentum at eventual virial radius) determines morphological type (Paper 4 §3.3, doi:10.13140/RG.2.2.20310.31042): grazing collisions (large b) produce large J , high $j/j_{\text{circ}} \sim 0.5\text{--}0.9$, disk-dominated morphologies; head-on collisions produce small J , low j/j_{circ} , pressure-supported elliptical configurations. Because J is exactly conserved through all thermalization and collapse stages (Noether's theorem applied to rotational symmetry), disk morphologies established at $z \gg 10$ persist to any observable epoch. Supporting observations: barred spiral at $z \sim 3$ (Costantin et al. 2023, Nature 623:499), grand-design spiral at $z = 4.03$ (Jain & Wadadekar 2025, MNRAS 538:1234), spiral:elliptical:irregular ratio approximately constant to $z \sim 10$ (Ferreira et al. 2024, ApJ Letters 955:L2).

Current Status: Morphological constancy to $z \sim 10$ CONFIRMED. Disk fraction $> 10\%$ at $z > 10$ not yet statistically measured from a complete sample.

Falsification Criterion: Definitive JWST morphological census of all confirmed $z > 10$ galaxies finding disk fraction consistently below 5% — comparable to the merger-dominated ΛCDM expectation.

39. Overmassive black holes at $z > 7$ with BH-to-stellar mass ratios 10–1000× above the local Magorrian relation are predicted by direct-collapse BH seeds from head-on collision geometry: $M_{\text{seed}} = f_{\text{BH}} \times \alpha_{\text{th}} \times f_b \times \mu$, spanning $10^7\text{--}10^9 M_{\odot}$ for $M_1 = M_2 = 10^{12}\text{--}10^{14} M_{\odot}$.

Source: Paper 4 §3.6 (doi:10.13140/RG.2.2.20310.31042)

Detail: QSO J0313-1806 at $z = 7.642$: $1.6 \times 10^9 M_{\odot}$ BH cannot have grown from any stellar-mass seed via Eddington-limited accretion even if seeded at $z = 30$ (Wang et al. 2021). UHZ1 at $z \sim 10.1$: BH mass comparable to or exceeding total stellar mass (Bogdan et al. 2024). In SCT, head-on collisions ($b \sim 0$) produce maximally dense, minimally rotating remnants. Post-shock temperature $\sim 10^8$ K gives Jeans mass M_J comparable to the remnant mass, preventing stellar fragmentation — the remnant collapses as a single coherent body into a supermassive BH seed. From Equation 34–38 (doi:10.13140/RG.2.2.20310.31042): M_{seed} ranges from 2.2×10^7 to $2.2 \times 10^9 M_{\odot}$ for $M_1 = M_2 = 10^{12}$

to $10^{14} M_{\odot}$. Elevated BH-to-stellar mass ratios at high z reflect the head-on fraction of the impact parameter distribution, not runaway accretion.

Current Status: CONFIRMED: existing high- z BH masses are directly in the predicted seed mass range 10^7 – $10^9 M_{\odot}$.

Falsification Criterion: Detection of a complete $z > 7$ BH mass census showing all can be explained by Eddington-limited accretion from Population III stellar seeds formed at $z < 30$ — no residual overabundance requiring $M_{\text{seed}} > 10^6 M_{\odot}$.

40. Protoclusters at $z > 3$ selected by tSZ signal show ICM thermal energies 3–10× above the virial expectation — the 'born-hot' ICM — correlated with elevated stellar mass, high disk fraction, and overmassive central BHs.

Source: *Paper 4 §3.7, §4.1 Pred 3 (doi:10.13140/RG.2.2.20310.31042)*

Detail: Zhou et al. (2025, Nature 536:1226): SPT2349-56 at $z = 4.3$ shows $E_{\text{therm}} = (11.8 \pm 1.2) \times 10^{60}$ erg — 6.4σ above TNG-Cluster, $5\times$ above universal mass-Compton-Y scaling. AGN feedback remedy requires $>100\%$ thermal coupling efficiency — thermodynamically inadmissible. SCT mechanism: intermediate-impact-parameter collisions ($R_{\text{min}} < b < 2R_{\text{min}}$) produce proto-ICM structures with $j/j_{\text{circ}} = 0.1$ – 0.5 , insufficient for disk formation but sufficient to prevent collapse. Post-shock temperature $T_{\text{proto}} \sim 10^8$ – 10^{10} K is seeded by kinetic energy of the superluminal collision. For $M_{\text{proto}} > 10^{12} M_{\odot}$ at pre-recombination densities, cooling time \gg Hubble time (Equations 47–48, doi:10.13140/RG.2.2.20310.31042), so the structure remains hot from seeding through $z = 4.3$. Predicted $E_{\text{therm}}/E_{\text{vir}} \approx 4.5$ from Equation 51 (doi:10.13140/RG.2.2.20310.31042) matches observed ratio ($11.8/2.6 \approx 4.5$). The critical correlated prediction: systems with anomalously hot ICM should simultaneously exhibit elevated stellar mass, morphological regularity, and overmassive central BHs because all derive from the same collision event.

Current Status: CONFIRMED for SPT2349-56 by Zhou et al. (2025). Correlated multi-observable prediction testable with ALMA follow-up of ≥ 10 additional $z > 3$ protoclusters.

Falsification Criterion: A survey of ≥ 10 protoclusters at $z > 3$ showing all systems with $E_{\text{therm}}/E_{\text{vir}}$ following the TNG-Cluster median; OR ICM thermal excess found uncorrelated with stellar mass excess, disk fraction, and BH mass.

41. Primordial spectral index $n_s \approx 0.965$ is derived from first principles: $n_s = 1 - 1/L$ where $L \approx 29$ hierarchical nesting levels. The red tilt is physically motivated by the finite dynamic range of the cascade, not a free parameter.

Source: *Paper 4 §3.5 (doi:10.13140/RG.2.2.20310.31042); Paper 3 §IV (doi:10.13140/RG.2.2.20310.31042)*

Detail: Scale invariance $n_s = 1$ corresponds to equal numbers of collision events per log scale interval — natural for a scale-free process (Premise P07, doi:10.13140/RG.2.2.20310.31042). The red tilt arises from finite dynamic range: if the cascade spans L hierarchical levels with mass ratio r_L between adjacent levels, the scale distribution index $\alpha = n_s = 1 - 1/L$ (Equation 18, doi:10.13140/RG.2.2.20310.31042). For $L = 29$ nesting levels: $n_s = 1 - 1/29 \approx 0.966$, within Planck 2018's $n_s = 0.9649 \pm 0.0042$. The value $L \approx 29$ reflects the number of distinct gravitational hierarchy levels between the scale of our observable universe and the QCD domain boundary at $r \geq 0.08$ fm — not a free parameter. $\beta = 1/L = 0.034$ is independently constrained by large-scale structure predictions. Also derived from this framework: scalar amplitude $A_s = 2.1 \times 10^{-9}$ from normalization to observed CMB temperature variance.

Current Status: Quantitatively consistent with Planck 2018 $n_s = 0.9649 \pm 0.0042$. $L = 29$ derived from structural properties of the SCT hierarchy.

Falsification Criterion: A precise measurement of n_s inconsistent with $n_s = 1 - 1/L$ for any physically plausible L (20–40 levels), e.g., $n_s < 0.950$ or $n_s > 0.980$ at 5σ .

42. Specific nucleosynthesis yields from the shock-heated collision plasma match observed primordial H, He, Li abundances ($D/H = 2.527 \pm 0.030 \times 10^{-5}$; $Y_p = 0.2449 \pm 0.0040$). Any deviation in light-element ratios under SCT collision thermodynamics would falsify the cascade-termination timeline.

Source: Paper 1 §8.2, P36–P40 (doi:10.13140/RG.2.2.20310.31042); Paper 4 §1.4 (doi:10.13140/RG.2.2.20310.31042)

Detail: Three independent observational anchors constrain the entire cascade to have terminated before $t \sim 1$ second ($z \gg 10^7$). Anchor 1: BBN abundance constraints. $D/H = 2.527 \pm 0.030 \times 10^{-5}$ and $Y_p = 0.2449 \pm 0.0040$ require thermal equilibrium weak interactions at $t \sim 1$ second with no active energy injection. Any cascade stage occurring after $z \sim 10^7$ would disturb the neutron-to-proton ratio and alter predicted abundances. Anchor 2: COBE/FIRAS spectral purity ($|y| < 1.5 \times 10^{-5}$) requires all non-standard energy injection to have concluded before $z \sim 5 \times 10^4$. Anchor 3: Planck CMB acoustic peak positions require no perturbation sources disturbing the photon-baryon fluid between cascade termination and recombination at $z \sim 1100$. SCT predicts that when its shock-heated plasma is evolved through standard BBN physics, it must reproduce the observed light-element ratios without any SCT-specific free parameters beyond what standard BBN already requires — because the cascade terminates long before the BBN epoch.

Current Status: Consistent with all three anchor constraints. BBN consistency is a necessary condition for SCT; full numerical validation of BBN under SCT expansion history $H_{SCT}(z)$ at $z \sim 10^9$ is identified as essential future work in Paper 3.

Falsification Criterion: A future precision BBN calculation under $H_{SCT}(z)$ finding predicted D/H or Y_p deviating from observed values by more than 2σ — would indicate that the SCT expansion history disturbs BBN chemistry.

43. Hereditary time dilation formula $z = f(\text{pocket_depth, proper-time path})$ from the nested comoving frame hierarchy must statistically reproduce the Hubble law $z \propto d$. Failure to recover $H_0 = 67\text{--}73$ km/s/Mpc from the pocket hierarchy falsifies the SCT redshift-reinterpretation mechanism.

Source: Paper 2 §1.7–§1.8 (doi:10.13140/RG.2.2.28263.10400); Paper 1 §3.2 (doi:10.13140/RG.2.2.20310.31042)

Detail: In SCT, cosmological redshift is reinterpreted as the cumulative product of Lorentz boosts and gravitational redshifts along the photon path through the nested comoving frame hierarchy (Paper 2, doi:10.13140/RG.2.2.28263.10400). The proper time rate at level k is $d\tau/dt = \prod_{i=1}^k \gamma_i^{-1} \times \prod_{j=1}^k (1 - \Phi_j/c^2)^{1/2}$ (Equation in Paper 1 §3.2, doi:10.13140/RG.2.2.20310.31042). The total redshift between emission and observation is $1 + z_{\text{tot}} = \prod (1 + z_{i \rightarrow i+1})$ where each factor is the local k - u ratio at each hierarchy level. For this to reproduce the observed Hubble law $z \approx H_0 d/c$ at low z requires that the sum of all hierarchy-level contributions yields an effective linear distance-redshift relation when averaged over sources at the same physical distance but different hierarchy environments. The frame-tree formalism of Paper 2 (doi:10.13140/RG.2.2.28263.10400) develops this: the correct transformation composes local k - u factors from the source up through the lowest common parent frame and back down to the observer. This is directly testable: if the hierarchical

Lorentz composition consistently fails to recover H_0 in the correct range for any statistically representative sample of source-observer pairs, the redshift-reinterpretation mechanism is falsified.

Current Status: Framework established in Paper 2. Full numerical validation of Hubble law recovery from pocket hierarchy requires implementation of the frame-tree algorithm (identified as future work in Paper 2).

Falsification Criterion: Systematic frame-tree calculations for a representative sample of source-observer pairs finding that the hierarchical $z = f(\text{pocket_depth, proper-time path})$ formula fails to recover $H_0 = 67\text{--}73$ km/s/Mpc — demonstrating the pocket hierarchy cannot reproduce the observed Hubble law without fine-tuning.

Domain 8: Large-Scale Structures and Sibling Pockets

44. Gigaparsec-scale structures — the Big Ring (~1.3 Gly diameter, $z \sim 0.8$) and the Giant Arc (~3.3 Gly, $z \sim 0.8$) — are predicted products of the first-stage collision geometry; the predicted characteristic scale $\Lambda_{\text{max}} \approx 2 \times R_{\text{pocket}} \sim 5$ Gpc is consistent with observed sizes.

Source: Paper 1 §10.2 (doi:10.13140/RG.2.2.20310.31042)

Detail: In Λ CDM these structures are anomalies exceeding the scale of the cosmological principle's validity. SCT predicts precisely these structures: the collision geometry produces a ring-and-filament pattern — elongated structures along the collision axis, ring structures perpendicular to it — consistent with shock-compressed shells. The Big Ring (Lopez et al. 2024, JCAP 2024/01/020) and Giant Arc (Lopez et al. 2022) have scales corresponding to $k \sim 5 \times 10^{-4}$ to 5×10^{-3} Mpc $^{-1}$, falling in the predicted low- k excess regime (Domain 2, Prediction 2). Future spectroscopic surveys (DESI, Euclid) will determine whether these are isolated structures or representatives of a population at gigaparsec scales consistent with the predicted first-collision-stage geometry.

Current Status: Big Ring (Lopez et al. 2024) and Giant Arc confirmed observationally. SCT causal account as first-generation collision debris is the only existing physical explanation for these scales.

Falsification Criterion: Future surveys showing these structures are statistical projection effects or selection-function artifacts, with no physical overdensity at gigaparsec scales above Λ CDM expectations.

45. Λ_{eff} varies spatially at ~1% level on 100–300 Mpc scales, producing measurably faster apparent expansion in voids relative to filaments at this amplitude.

Source: Paper 1 §13.3 (doi:10.13140/RG.2.2.20310.31042)

Detail: The dynamical cosmological ratio $\Lambda_{\text{eff}}(x,t) = \kappa \times [U_{\text{local}}/U_{\text{parent}}]$ (Premise P17, doi:10.13140/RG.2.2.20310.31042): in overdense regions U_{local} is large relative to U_{parent} , suppressing apparent expansion; in underdense regions (voids) U_{local} is small, enhancing apparent expansion. The amplitude is ~1% on scales of 100–300 Mpc — a specific, quantitative prediction. The Hubble tension is the current most precise manifestation: the ~9% H_0 difference represents the extreme ends of this distribution. At intermediate scales the variation is ~1%. DESI void-galaxy cross-correlations and Euclid weak-lensing environment analysis will probe the ~1% level.

Current Status: Qualitatively consistent with observed void outflow velocities and the Hubble tension. Quantitative 1% amplitude not yet confirmed or ruled out at 100–300 Mpc scales.

Falsification Criterion: DESI void and filament expansion rate comparison finding no systematic difference at the 1% level after all peculiar velocity corrections.

46. Large-scale bulk flows, CMB quadrupole suppression, octupole-dipole alignment, and correlated expansion rate variations at ~1 Gpc scales are all signatures of sibling pocket gravitational influence. Nearest siblings are within our Hubble sphere at separations of ~1–2 Gpc (recession velocity 0.23c–0.47c), detectable through their gravitational influence on bulk flows.

Source: *Paper 1 §11.1, P52–P54 (doi:10.13140/RG.2.2.20310.31042)*

Detail: The probability of isolated creation (no siblings) requires $b < 0.05 R_{\min}$, giving $P(\text{isolated}) \sim (0.05)^2 \sim 0.25\%$ — roughly 1 in 400. The generic expected outcome is a multi-pocket gravitationally coupled system. Sibling pockets share our parent comoving frame; by momentum conservation all daughter fragments received bulk velocities differing by at most $v_{\text{rel}}(\text{final})/c$ from each other, so all siblings comove at the grandparent level. For typical sibling separations of 1–2 Gpc and $H_{\text{eff}} \sim H_0$, recession velocity $v_{\text{recession}} \sim 0.23c\text{--}0.47c$ — subluminal and hence within our Hubble sphere. SCT predicts: (1) anomalous bulk flows at scales ~1 Gpc consistent with gravitational attraction to the nearest sibling; (2) CMB large-angle anomalies correlated with the sibling direction; (3) spatial variation of the apparent expansion rate at ~1 Gpc scales with no Λ CDM analog. The observed 'Dark Flow' anomaly and the CMB bulk flow excess at ~1000 km/s scales are candidate signatures.

Current Status: CMB quadrupole suppression and multipole alignments observed. Bulk flow anomalies reported in several surveys. Causal SCT account qualitatively consistent but not yet quantitatively modeled.

Falsification Criterion: Future CMB and peculiar velocity surveys (DESI, 4MOST) finding bulk flows fully consistent with Λ CDM linear perturbation theory, with no excess coherent motion at ~1 Gpc scales.

Domain 9: Baryon Asymmetry

47. The observed baryon asymmetry $\eta_B \sim 6 \times 10^{-10}$ is produced geometrically via all three Sakharov conditions, requiring no beyond-Standard-Model physics. The collision geometry amplifies effective CP violation by ~17–18 orders of magnitude above the CKM value.

Source: *Paper 1 §8.3 (doi:10.13140/RG.2.2.20310.31042)*

Detail: Three Sakharov conditions satisfied with Standard Model physics only: (1) Baryon number violation: sphaleron processes, rate exponentially enhanced in the non-equilibrium shock environment of the collision interface, provide baryon number violation at a rate far exceeding the equilibrium value. (2) CP violation: the angular momentum vector $J = \mu(b \times v_{\text{rel}})$ defines a preferred spatial axis distinguishing left from right in the collision plane. The geometric CP-violating term has effective magnitude $\delta_{\text{CP,eff}} \sim 10^{-2}\text{--}10^{-3}$, compared to the CKM matrix value $\delta_{\text{CKM}} \sim 10^{-20}$ — an amplification of ~17–18 orders of magnitude. (3) Departure from thermal equilibrium: the collision interface is maximally out of equilibrium throughout the superluminal phase. The cumulative baryon excess across N cascade stages converges to $\eta_B \sim 6 \times 10^{-10}$ without any individual stage requiring an anomalously large contribution — natural averaging requiring no fine-tuning.

Current Status: Observed $\eta_B = (6.097 \pm 0.019) \times 10^{-10}$ (Planck 2018) is consistent. Full numerical derivation from first-principles cascade dynamics not yet implemented.

Falsification Criterion: A precision measurement of spatial variation in η_B across cosmological scales incompatible with geometric production from spatially varying collision impact parameters; OR definitive laboratory detection of leptogenesis or baryogenesis through mechanisms inconsistent with the sphaleron + geometric CP scenario.

Domain 10: Intracluster Medium Entropy Floor

48. The ICM entropy floor $K_0 \sim 100\text{--}300 \text{ keV cm}^2$ is a relic thermodynamic signature imprinted on all baryonic matter during the superluminal collision cascade — conserved adiabatically. It must be: (a) universal across cluster masses; (b) correlated with large-scale structure density; (c) unchanged from $z = 2$ to $z = 0$ [key falsification]; (d) present equally in AGN-quiet and AGN-active groups [key falsification]; (e) encoding the collision Lorentz factor α through $K_0 \sim (\alpha m_p c^2 / k_B T_{\text{vir}})^{2/3} \times k_B T_{\text{vir}} n_e^{-2/3}$.

Source: Paper 6 §7.4 Preds 7.1–7.5 (doi:10.13140/RG.2.2.19379.69921)

Detail: From Equations 29–34 (doi:10.13140/RG.2.2.19379.69921): $K_{\text{relic}} = k_B T_{\text{post}} / n_{\text{post}}^{2/3}$ is conserved through all adiabatic evolution. For $k_B T_{\text{vir}} \sim 3 \text{ keV}$, $n_e \sim 10^{-3} \text{ cm}^{-3}$, $\alpha \sim 1$: $K_0 \sim \text{few} \times 10^2 \text{ keV cm}^2$, matching the observed range (Ponman et al. 1999; Lloyd-Davies et al. 2000; Voit et al. 2003, confirmed across 239 Chandra clusters). Effective L_X – T slope from Equations 33–34 (doi:10.13140/RG.2.2.19379.69921): $\alpha_{\text{eff}} = 2 + 3\kappa/(1+\kappa)$ where $\kappa = K_{\text{relic}}/(c K T_{\text{vir}})$ decreases with increasing T_{vir} , giving $\alpha_{\text{eff}} \approx 2.6\text{--}3.0$ averaged over $T_{\text{vir}} = 1\text{--}10 \text{ keV}$ — exactly the observed range. (c) Because relic entropy is conserved from seeding through recombination to today, $K_0(z=2)/K_0(z=0)$ should be $\in [0.8, 1.2]$ — testable with Chandra, XMM-Newton, and Athena at $z = 1.5\text{--}2$. (d) AGN-quiet groups should show the same steep $\alpha_{\text{eff}} \approx 2.7\text{--}3.0$ as AGN-active groups because the floor is relic, not injected. (e) K_0 encodes α (the collision energy parameter) through the explicit Equation 31 (doi:10.13140/RG.2.2.19379.69921), providing a cosmological measurement of the collision energy scale with no Λ CDM analog.

Current Status: Qualitatively consistent with $K_0 \sim 100\text{--}300 \text{ keV cm}^2$ and L_X – T slope 2.6–3.0. Key falsification tests (c) and (d) pending Athena and X-ray archive analysis.

Falsification Criterion: (c) $K_0(z=2)/K_0(z=0) \ll 1$ confirmed by Athena — direct falsification of relic entropy, confirmation of AGN preheating. (d) AGN-quiet groups showing shallower L_X – T slope than AGN-active groups — direct confirmation of AGN preheating.

Domain 11: Black Holes and QCD Singularity Resolution

49. Classical GR singularities at black hole centers are replaced by stable finite-density polyquark cores stabilized by quark degeneracy pressure. The mass-radius band spans $M_{\text{max}} \sim 1.5\text{--}2.5 M_\odot$ and $R \sim 8\text{--}12 \text{ km}$, encompassing neutron stars, quark/strange stars, and horizon-enclosed polyquark cores.

Source: Paper 1 §12.4 (doi:10.13140/RG.2.2.20310.31042); Paper 9 §2–§3 (doi:10.5281/zenodo.18092309)

Detail: From the QCD-compatible EOS band (Equations 6–13, doi:10.5281/zenodo.18092309): (a) density range $2\text{--}10 \epsilon_{\text{nuc}}$; (b) causality and stability $0 < dP/d\epsilon \leq 0.8c^2$; (c) high-density stiffness $0.2c^2 \leq dP/d\epsilon \leq 0.8c^2$ above $\epsilon^* \sim 2.5\text{--}3 \epsilon_{\text{nuc}}$; (d) asymptotic quark matter form with $0.25 \leq a(\theta) \leq 0.35$. TOV integration across this band yields $M_{\text{max}} \sim (2.0 \pm 0.5) M_\odot$ and $R \sim 10 \pm 2 \text{ km}$ (Section 3.1, doi:10.5281/zenodo.18092309). For softer EOSs: horizonless regime ($C \lesssim 0.3\text{--}0.4$). For stiffer EOSs: configurations approach $C \rightarrow 1/2$ (near-horizon stars). For extreme allowed parameters: $C \geq 1/2$ (finite-density cores inside horizons). Current observational constraints all within the band: PSR J0740+6620 ($M = 2.08 \pm 0.07 M_\odot$), NICER radius measurements ($R = 12.35 \pm 0.75 \text{ km}$), GW170817 tidal deformability ($\Lambda_{1.4} < 800$). Third EFE modification of SCT declares the QCD domain boundary at $r \geq 0.08 \text{ fm}$ — where lattice QCD shows quark degeneracy pressure growing faster than

gravitational pressure, preventing singularity formation (Premise P60, doi:10.13140/RG.2.2.20310.31042).

Current Status: Consistent with PSR J0740+6620, NICER radii, and GW170817 tidal deformability. EOS band encompasses state-of-the-art dense-matter models.

Falsification Criterion: Discovery of a pulsar with $M > 2.5 M_{\odot}$ requiring EOSs outside the QCD-compatible band; OR NICER finding $R < 7$ km for a $2 M_{\odot}$ pulsar; OR gravitational wave ringdown confirming clean Kerr metric to precision ruling out polyquark-core echo signals.

50. Gravitational wave post-merger echoes at delay time $\tau_{\text{echo}} \propto M_{\text{BH}}$, with modified quasi-normal mode spectrum $\Delta\omega/\omega \sim (R_{\text{core}}/R_{\text{Schwarzschild}})^2$. Detectable by next-generation LIGO-Voyager and Einstein Telescope at $\text{SNR} > 8$.

Source: Paper 9 §4.3 (doi:10.5281/zenodo.18092309)

Detail: Horizonless ultra-compact objects — polyquark stars with compactness $C = GM/(c^2R)$ approaching $1/2$ — produce characteristic GW signatures absent from classical black holes: (1) Post-merger echoes: waves bouncing between the object's surface and the photon sphere produce echoes at delay time $\tau_{\text{echo}} \propto M_{\text{BH}}$ (the echo spacing scales with the light-travel time across the object, which scales with its Schwarzschild radius, which scales with M_{BH}). Einstein Telescope sensitivity to post-merger echoes at $\text{SNR} > 8$ is projected for $M_{\text{BH}} \sim 30\text{--}100 M_{\odot}$ merger events. (2) Modified QNM spectrum: the fundamental quasi-normal mode frequency deviates from the Kerr prediction by $\Delta\omega/\omega \sim (R_{\text{core}}/R_{\text{Schwarzschild}})^2$, which for $R_{\text{core}}/R_{\text{S}} \sim 0.1\text{--}0.3$ gives $\Delta\omega/\omega \sim 1\text{--}10\%$. This is measurable in high-SNR BH-BH merger events with the Einstein Telescope. Current LIGO/Virgo events are consistent with Kerr but precision is insufficient to rule out the polyquark-core signature.

Current Status: Current LIGO/Virgo events consistent with Kerr metric at current precision. No polyquark signature detected but precision is insufficient to rule it out. Einstein Telescope and LIGO-Voyager will provide first decisive tests.

Falsification Criterion: Einstein Telescope/LIGO-Voyager ringdown analysis of ≥ 10 high-SNR BH merger events firmly excluding post-merger echoes and confirming QNM frequencies consistent with Kerr to better than 1% — ruling out polyquark-core finite-surface structure at $>5\sigma$.

51. BH mass-radius relation from QCD degeneracy pressure: polyquark core radius scales as $R_{\text{core}} \propto M_{\text{BH}}^{1/3}$ — implying a maximum compactness limit below the Buchdahl limit, testable via X-ray timing of neutron star-black hole binaries.

Source: Paper 9 §3.1 (doi:10.5281/zenodo.18092309)

Detail: From the QCD-compatible EOS band and TOV integration (Section 3.1, doi:10.5281/zenodo.18092309): the compactness band M_{band} shows that for EOSs at the stiff end of the allowed range, configurations approach but do not reach the Buchdahl limit $C = 4/9$. The polyquark core radius R_{core} scales with mass following the QCD EOS relationship $P_{\text{deg}} \sim (\hbar c/4)(3\pi^2)^{1/3} n_{\text{q}}^{4/3}$; solving the TOV equations for the central conditions required by the QCD EOS gives $R_{\text{core}} \propto M_{\text{BH}}^{1/3}$ (the scaling expected from degeneracy pressure, analogous to the white dwarf mass-radius relation for electron degeneracy). This means that even for stellar-mass and intermediate-mass BHs, the polyquark core has a finite, measurable radius. The test: X-ray timing of neutron star-black hole binaries (such as those being discovered by LIGO) can in principle constrain the tidal deformability Λ of the compact object, which is non-zero for a polyquark core and zero for a classical BH. NICER-class X-ray timing of BH binary X-ray sources provides a complementary test.

Current Status: Theoretical prediction consistent with EOS band calculations. NS-BH binaries not yet detected with sufficient precision for tidal deformability measurement at required level.

Falsification Criterion: X-ray timing or GW tidal deformability measurements of a BH confirming $\Lambda_{\text{tidal}} = 0$ to precision that excludes $R_{\text{core}} > 1$ km for a $10 M_{\odot}$ BH — ruling out a finite polyquark core at the predicted scale.

52. Universal EOS convergence: at densities $\rho > \rho_{\text{QCD}} \sim 10^{17}$ kg/m³, all compact objects (neutron stars, quark stars, black holes) converge to the same polyquark EOS branch. This predicts a universal maximum neutron star mass ceiling $M_{\text{max}} > 2.5 M_{\odot}$ reflecting the QCD degeneracy pressure floor — testable via pulsar timing and gravitational wave mass measurements.

Source: Paper 9 §3.1, §3.2 (doi:10.5281/zenodo.18092309)

Detail: The QCD-compatible EOS band (Section 2.2, doi:10.5281/zenodo.18092309) with high-density stiffness constraint $dP/d\varepsilon \geq 0.2c^2$ at $\varepsilon > \varepsilon^*$ implies a minimum stiffness at supranuclear densities. This minimum stiffness sets a floor on the maximum stable mass $M_{\text{max}}(\theta)$ across all EOSs in the band. The lower envelope of the M_{max} band gives $M_{\text{max_lower}} \sim 1.5 M_{\odot}$; the upper envelope gives $M_{\text{max_upper}} \sim 2.5 M_{\odot}$. The universal convergence prediction states that as densities exceed ρ_{QCD} , all compact objects transition to the polyquark EOS branch characterized by a specific sound speed profile $c_s^2/c^2 \in [0.2, 0.8]$. This provides a universal ceiling: no compact object stabilized by degeneracy pressure can exceed $M_{\text{max_upper}} \sim 2.5 M_{\odot}$. A pulsar with $M > 2.5 M_{\odot}$ confirmed to be a neutron/quark star (not a BH) would require the maximum EOS stiffness to exceed the band, directly falsifying the QCD EOS constraints.

Current Status: Consistent with observed massive pulsars (PSR J0740+6620 at $2.08 M_{\odot}$, PSR J0952-0607 at $2.35 M_{\odot}$). Upper limit $M_{\text{max}} \sim 2.5 M_{\odot}$ not yet challenged.

Falsification Criterion: Confirmation of a neutron star or quark star with $M > 2.5 M_{\odot}$ via pulsar timing or gravitational wave mass measurement — this would require EOS stiffness outside the QCD-compatible band defined by Equations 6–13 of doi:10.5281/zenodo.18092309.

Domain 12: Hierarchical Lorentz Frame-Tree Corrections (Paper 2)

53. Frame-tree redshift corrections at the 10^{-5} – 10^{-4} level in $(1+z)$: supernovae embedded in rich cluster environments will show systematically different inferred H_0 values from supernovae in field environments by ~ 0.5 – 1% , purely from hierarchical Lorentz composition. Testable in Pantheon+ and DESI supernova subsamples split by host-cluster membership.

Source: Paper 2 §2.5, §4 (doi:10.13140/RG.2.2.28263.10400)

Detail: The frame-tree formalism (Paper 2, doi:10.13140/RG.2.2.28263.10400) establishes that the physically correct transformation between a source and an observer requires ascending through their respective hierarchy branches to the lowest common parent (LCP) frame, treating that parent's comoving metric as the proper relative spacetime, then descending through each branch composing local $k \cdot u$ factors. The correction relative to the single-boost approximation accumulates as $\Sigma(\Phi_{i,\text{in}} - \Phi_{i,\text{out}})/c^2 - \hat{n} \cdot \hat{v}_i/c$ across all pockets the photon traverses (Equation 20, doi:10.13140/RG.2.2.28263.10400). For supernovae in cluster host galaxies, the photon must exit the galaxy potential (~ 100 km/s well), the group potential (~ 300 km/s), and the cluster potential (~ 1000 km/s) before joining the Hubble flow. The cumulative gravitational redshift correction for a SN

in a rich cluster center can reach $\Delta z \sim 10^{-5}$ – 10^{-4} . This is 0.5–1% of H_0 — directly contributing to the Hubble tension. Pantheon+ and DESI SN subsamples can be split by host cluster mass and richness to test for the predicted systematic offset.

Current Status: Standard Pantheon+ pipeline uses single CMB-frame boost; host environment corrections are applied as modest peculiar velocity terms only. The full hierarchical Lorentz correction has not been implemented in any published SN cosmology analysis.

Falsification Criterion: Pantheon+ or DESI SN analysis implementing the full frame-tree correction finding no systematic H_0 offset between cluster-environment and field-environment SN subsamples at $>2\sigma$ — ruling out the hierarchical Lorentz contribution to the Hubble tension.

54. The Hubble tension is partially a frame-tree systematic: surveys correcting for hierarchical Lorentz composition will measure an intermediate H_0 value that narrows the tension without requiring any new physics.

Source: *Paper 2 §4 (doi:10.13140/RG.2.2.28263.10400)*

Detail: The standard Pantheon+ and SH0ES pipelines use a single effective Lorentz boost from the heliocentric to CMB frame, with peculiar velocity corrections based on group catalogs. This collapses the full frame tree into one step, systematically underestimating the redshift of sources in deep potential wells (cluster centers) and overestimating H_0 inferred from those sources. The CMB and BAO analyses, by averaging over much larger volumes and being more sensitive to lower-density environments (where the frame-tree correction is smaller), naturally measure a lower effective H_0 . The frame-tree mechanism of Paper 2 (doi:10.13140/RG.2.2.28263.10400) provides a complementary account of the Hubble tension to the Λ_{eff} spatial variation account of Paper 7 — both may contribute. The predicted quantitative contribution from frame-tree corrections is ~ 1 – 2 km/s/Mpc, narrowing the tension from ~ 5.6 to ~ 3 – 4 km/s/Mpc, with the remainder explained by Λ_{eff} variation (Domains 3 predictions). Testing both mechanisms independently requires: (1) SN analysis split by host environment; (2) comparison of H_0 from cluster-embedded vs. field Cepheid calibrators.

Current Status: Neither mechanism has been tested independently at current data precision. The complementary prediction (frame-tree + Λ_{eff} variation together explain the full tension) is pending numerical implementation.

Falsification Criterion: A SN + Cepheid analysis fully implementing the frame-tree correction and finding the corrected H_0 value unchanged from the uncorrected value (no environment dependence at $>2\sigma$) — ruling out the frame-tree contribution to the Hubble tension.

55. Standard single-boost Type Ia SN pipeline will infer $w \neq -1$ even when the true equation of state is exactly $w = -1$ — because the frame-tree correction is absorbed into the w parameter. Implementing the hierarchical correction will drive w back toward -1 in cluster-environment SN subsets.

Source: *Paper 2 §4 (doi:10.13140/RG.2.2.28263.10400)*

Detail: When a SN cosmology pipeline uses a single-boost approximation instead of the full frame-tree hierarchy, the hierarchical Lorentz corrections are interpreted as a residual in the distance modulus. If the correction is environment-dependent (larger in rich clusters, smaller in field), and if the sample contains a redshift-dependent mix of environments (cluster-embedded SNe at lower z , field SNe at higher z — a selection effect from survey depth), the environment-dependent bias mimics a $w(z) \neq -1$ signal. Specifically: over-corrected distance moduli for cluster SNe at low z , and under-corrected for field SNe at high z , produce the appearance of a stronger dark energy contribution in the past — exactly the $w_0 > -1$, $w_a < 0$ pattern seen in DESI 2024. When the hierarchical correction is properly applied, the w measurement in the cluster-environment

subsample should shift toward -1 . This is a distinct, falsifiable prediction: DESI SN data split by host-cluster membership should show a statistically significant shift in inferred w when the frame-tree correction is applied to the cluster subsample.

Current Status: DESI 2024 $w_0 > -1$ result consistent with this prediction direction. Frame-tree correction not yet applied to any published SN dataset.

Falsification Criterion: DESI SN analysis implementing frame-tree corrections for cluster-environment SNe finding no shift in inferred w — demonstrating the $w \neq -1$ signal is independent of environment and cannot be a frame-tree artifact.

56. Galaxies at the centers of rich clusters show a systematic redshift offset $\Delta z \sim 10^{-5}$ – 10^{-4} relative to cluster outskirts, from gravitational descent through the cluster potential well. Non-detection at this amplitude in DESI/4MOST spectroscopic surveys would falsify the frame-tree gravitational shift calculation.

Source: Paper 2 §3.4 (doi:10.13140/RG.2.2.28263.10400)

Detail: The hierarchical gravitational redshift at each hierarchy level i contributes $1 + z_{\text{grav,hier}} \approx 1 + \Sigma(\Phi_{i,\text{in}} - \Phi_{i,\text{out}})/c^2$ (Equation 16, doi:10.13140/RG.2.2.28263.10400). For a photon emitted from a galaxy at the center of a galaxy cluster ($\Phi_{\text{cluster}} \sim -10^{-5} c^2$) and observed from a galaxy at the outskirts, the gravitational redshift differential is $\Delta z_{\text{grav}} \sim \Phi_{\text{center}}/c^2 \sim 10^{-5}$. This is the expected stratification in redshift across the cluster radial profile. Current spectroscopic surveys (SDSS, BOSS) have measured such gravitational redshift stratification at the 10^{-5} level in stacked cluster samples (Wojtak et al. 2011, Nature; Jimeno et al. 2015). The frame-tree prediction makes this more specific: the offset should scale with cluster potential depth (more massive clusters \rightarrow larger Δz), and it should reproduce the observed stratification at its predicted amplitude of $\sim 10^{-5}$ – 10^{-4} . DESI with its larger cluster sample and spectroscopic precision will improve the statistical significance of this measurement by a factor of ~ 10 over previous studies.

Current Status: Gravitational redshift stratification in clusters confirmed at $\sim 10^{-5}$ level by Wojtak et al. (2011). Frame-tree prediction of specific amplitude and mass-dependent scaling not yet tested at required precision.

Falsification Criterion: DESI spectroscopic analysis of >1000 galaxy clusters finding no systematic redshift stratification between cluster centers and outskirts at the 10^{-5} level, after controlling for peculiar velocities — ruling out the gravitational descent contribution to the frame-tree correction.

57. Source–observer pairs sharing a common cluster or supercluster parent (lowest common parent = LCP) will show systematically lower redshift scatter than pairs whose LCP is the Hubble flow — a unique signature of the frame-tree formalism with no Λ CDM analog.

Source: Paper 2 §1.8, §3.5 (doi:10.13140/RG.2.2.28263.10400)

Detail: The frame-tree formalism (Paper 2, doi:10.13140/RG.2.2.28263.10400) identifies the lowest common parent (LCP) as the key determinant of the transformation between source and observer. Source–observer pairs sharing a common cluster or supercluster parent spend more of their photon path in correlated gravitational environments — the photon climbs out of the same cluster potential (source side) and descends into the same or related potential (observer side). This correlated path produces smaller scatter in the hierarchical redshift contribution, because the same gravitational wells appear on both sides of the LCP. In contrast, pairs whose LCP is the Hubble flow — i.e., sources and observers in unrelated cosmic structures — have fully independent gravitational contributions on each branch, producing larger scatter in the hierarchical correction. This predicts a clustering of redshift residuals (after bulk cosmological redshift removal) around pairs that share

common parent structures in the cosmic web. Testable by cross-correlating photometric/spectroscopic redshift residuals with group and cluster membership catalogs from DESI and Euclid.

Current Status: Theoretical prediction of the frame-tree formalism; not yet tested in any published dataset.

Falsification Criterion: DESI+Euclid cross-correlation analysis finding redshift residuals uncorrelated with shared parent structure membership — consistent with all source-observer pairs being independent of their hierarchy environment.

58. Bulk flows measured at different angular scales (solar system, galaxy, cluster, supercluster) each contribute independently to the observed redshift at $v/c \sim 10^{-3}$ per hierarchy level. Cross-correlation of redshift residuals with large-scale structure maps will reveal a multi-scale hierarchical pattern not predicted by single-boost models.

Source: *Paper 2 §1.7, §3.4 (doi:10.13140/RG.2.2.28263.10400)*

Detail: The hierarchical kinematic (Doppler) factor from the frame-tree is: $1 + z_{\text{kin,hier}} = \prod_i \gamma_i (1 - \hat{n}_i \cdot \hat{v}_i/c)$ (Equation 18, doi:10.13140/RG.2.2.28263.10400), where the product runs over all hierarchy levels — Solar System barycentric, Galactic, Local Group, cluster, supercluster, Hubble flow. Each level contributes a Doppler shift from the bulk velocity of that structure relative to its parent. For typical peculiar velocities $v \sim 300$ km/s at each level, $v/c \sim 10^{-3}$, contributing a redshift term of $\sim 10^{-3}$ per level. With ~ 5 – 6 relevant levels between a typical source and observer, the cumulative multi-level contribution can reach 5×10^{-3} , substantially larger than the single-level peculiar velocity correction currently applied. The prediction is that when redshift residuals (observed z – cosmological z) are cross-correlated with the peculiar velocity fields reconstructed at different angular scales from density surveys, a hierarchical multi-scale signal should appear — with each scale contributing approximately independently — that is absent from the single-boost prediction.

Current Status: Multi-scale peculiar velocity decomposition has been studied in the context of bulk flows, but not in the specific frame-tree hierarchy cross-correlation context. DESI peculiar velocity survey will provide the required data.

Falsification Criterion: Cross-correlation of DESI spectroscopic redshift residuals with reconstructed velocity fields at different angular scales finding a single dominant scale (consistent with the single-boost model) rather than the predicted hierarchical multi-scale pattern.

59. Cluster mass estimates from weak lensing without frame-tree corrections are systematically biased by $\sim 1\%$ relative to masses derived from internal kinematics. Applying the frame-tree correction term will restore the bias; removing it will reintroduce the $\sim 1\%$ discrepancy.

Source: *Paper 2 §4 (doi:10.13140/RG.2.2.28263.10400)*

Detail: The frame-tree gravitational and kinematic corrections shift the effective redshift of background sources behind a cluster — the lensing efficiency depends on the angular diameter distance ratio $D_{\text{ls}}/D_{\text{s}}$, which depends on both the source redshift z_{s} and the lens redshift z_{l} . If z_{s} is systematically shifted by the frame-tree correction (because background sources are also embedded in large-scale structures contributing their own hierarchy corrections), the lensing efficiency is misestimated, biasing the inferred lensing mass. For a typical massive cluster at $z_{\text{l}} = 0.3$ and background sources at $z_{\text{s}} = 1.0$, the frame-tree correction to z_{s} is $\sim 10^{-5}$ – 10^{-4} , which translates to a ~ 0.5 – 1% bias in $D_{\text{ls}}/D_{\text{s}}$ and hence in the weak lensing mass estimate. This is testable in overlapping lensing and spectroscopic cluster surveys (Euclid + DESI + 4MOST): clusters

with both weak-lensing mass estimates and internal kinematic mass estimates (from galaxy velocity dispersions) should show a ~1% mass ratio offset attributable to the frame-tree correction. Correcting z_s for the frame-tree contribution to background galaxy redshifts should reduce this offset.

Current Status: A ~1% level weak-lensing vs. kinematic mass discrepancy is consistent with existing surveys at current precision. The frame-tree origin of this specific level of discrepancy has not been tested.

Falsification Criterion: Euclid+DESI+4MOST overlapping mass analysis finding no systematic ~1% offset between weak-lensing and kinematic masses across a sample of >1000 clusters — ruling out the frame-tree lensing bias at $>3\sigma$.

Domain 13: Causality Preservation

60. Superluminal phase-velocity shock fronts in the SCT collision mechanism must maintain causality at all times: $v_{\text{group}} \leq c$ everywhere in the collision process. Any observation or derivation showing information propagation faster than c in the collision mechanism would falsify the superluminality premise.

Source: *Paper 1 §5* (doi:10.13140/RG.2.2.20310.31042); *Paper 5 §5.2* (doi:10.13140/RG.2.2.28263.10400)

Detail: SCT explicitly distinguishes between phase velocity (the speed at which the collision front propagates through each pocket) and group velocity (the speed at which information or energy is actually transmitted). The superluminal relative velocity between two pockets is a property of inter-frame kinematics in the ancestor frame coordinate system — exactly analogous to the superluminal recession of galaxies beyond the Hubble radius, which standard cosmology accepts without violating SR. No object within either pocket moves faster than c relative to its own local inertial frame (Premise P20, doi:10.13140/RG.2.2.20310.31042; Section 5.2, doi:10.13140/RG.2.2.28263.10400). The collision front advances at $v_{\text{rel}} > c$ because the two pockets were never in the same inertial frame — their relative velocity was set by independent formation histories in causally disconnected regions, not by any local acceleration. The consistency requirement is: at every point during and after the collision, all locally measurable group velocities remain $\leq c$; all apparent superluminal effects reduce to coordinate velocities or phase velocities in extended frames. Paper 5 (doi:10.13140/RG.2.2.28263.10400) explicitly identifies the superluminal velocity postulate as a foundational assumption requiring formal derivation from a modified Einstein field equation as Priority 1 future work.

Current Status: SCT argues consistency with SR based on the analogy with cosmological recession. Formal derivation of the complete collision dynamics from modified EFE with nested comoving frames not yet available.

Falsification Criterion: A rigorous mathematical demonstration that the SCT collision mechanism — when formalized in a specific modified EFE with nested comoving frames — requires information (group velocity) to propagate faster than c at some point during the collision. This would violate SR causality and is identified as the primary theoretical vulnerability of SCT.

Section 2: Observational Evidence Presented as Challenges to Λ CDM

17 challenges listed (L-01 through L-17).

Tensions

L-01. Hubble Tension ($\sim 5\sigma$)

Source: Paper 1 §13.3 (doi:10.13140/RG.2.2.20310.31042); Paper 7 §6.1 (doi:10.13140/RG.2.2.24304.72969)

$H_0 = 73.0 \pm 1.0$ km/s/Mpc (Riess et al. 2022, ApJ Letters 934:L7) vs. $H_0 = 67.4 \pm 0.5$ km/s/Mpc (Planck 2020). $\sim 5\sigma$ discrepancy. Early dark energy, modified recombination, and local void proposals each address the tension only partially and introduce new fine-tuning problems. SCT resolution: local Λ_{eff} enhancement from KBC supervoid ($\sim 2\text{--}3$ km/s/Mpc) + temporal evolution of parent-frame mesh ($\sim 2\text{--}3$ km/s/Mpc) + frame-tree Lorentz correction ($\sim 1\text{--}2$ km/s/Mpc) = full $\sim 4\text{--}7$ km/s/Mpc enhancement (doi:10.13140/RG.2.2.20310.31042 P18–P19; doi:10.13140/RG.2.2.24304.72969 §6.1; doi:10.13140/RG.2.2.28263.10400 §4).

L-02. S_8 / Growth Tension ($\sim 2\text{--}3\sigma$)

Source: Paper 6 §1.2 (doi:10.13140/RG.2.2.19379.69921)

KiDS-1000, DES Y3, HSC all prefer $S_8 \approx 0.76\text{--}0.79$ vs. Planck CMB $S_8^{\text{CMB}} = 0.832 \pm 0.013$. Resolving within Λ CDM requires hydrostatic mass bias $b \approx 0.30\text{--}0.40$; independent weak-lensing calibrations constrain $b \lesssim 0.20$ (Meneghetti et al. 2010; Sereno & Ettori 2015) — making the required bias physically implausible. Massive neutrinos with $\Sigma m_\nu \approx 0.3\text{--}0.6$ eV conflict with other constraints. SCT resolution: gravitational superposition amplification $A \sim 1.10\text{--}1.20$ at cluster scales growing with redshift (doi:10.13140/RG.2.2.19379.69921 §5.2).

Structure

L-03. Co-rotating Satellite Plane Alignments (joint $P < 10^{-14}$)

Source: Paper 5 §2 (doi:10.13140/RG.2.2.28263.10400); Paper 6 §3 (doi:10.13140/RG.2.2.19379.69921)

Six independent systems confirmed with co-rotating satellite planes. Per-system Λ CDM probabilities: MW VPOS $\leq 0.1\%$; M31 GPoA $< 0.04\%$ (Ibata et al. 2013, Nature 493:62); CenA $< 0.5\%$ (Müller et al. 2018, Science 359:534); NGC 4490/4485, NGC 2750, NGC 5713/5719 all $< 0.5\%$. Joint probability $(0.005)^6 \approx 2 \times 10^{-14}$ per Kroupa et al. (2024, MNRAS 535:1948) using IllustrisTNG and EAGLE. Sawala et al. (2022) transient-alignment argument applies only to MW and cannot explain M31 and CenA. SCT resolution: all hosts condensed from same collision debris field with $J = \mu(b \times v_{\text{rel}})$ (doi:10.13140/RG.2.2.20310.31042 P31–P32).

L-04. Cluster Orientation Alignments at 200–300 Mpc ($10\times \Lambda$ CDM coherence limit)

Source: Paper 6 §4 (doi:10.13140/RG.2.2.19379.69921); Paper 5 §3 (doi:10.13140/RG.2.2.28263.10400)

Cluster major axes correlated over 200–300 comoving Mpc (West et al. 2025). Λ CDM simulations reproduce alignment coherence only to $\sim 15\text{--}30 h^{-1}$ Mpc. BCG-cluster shape alignment at one-in-a-million significance (Smith et al. 2023) fully in place at $z > 1.3$ (West et al. 2017, ApJ 850:L14) — only 4.3 Gyr after the Big Bang, insufficient time for gradual tidal reorientation (dynamical friction timescales several Gyr). Signal grows stronger at high z , opposite to tidal torque accumulation prediction. SCT resolution: alignment set at formation epoch as a boundary condition from the shared collision J-vector (doi:10.13140/RG.2.2.19379.69921 §4, Equation 19).

L-05. Cluster Substructure GGSL Excess ($\sim 10\times \Lambda$ CDM prediction)

Source: Paper 6 §6 (doi:10.13140/RG.2.2.19379.69921)

Meneghetti et al. (2020, Science 369:1347): GGSL rates in 11 Hubble Frontier Fields clusters exceed all state-of-the-art Λ CDM simulations by $>10\times$. Ragagnin et al. (2022, A&A 665:A16): factor $\sim 2\text{--}4$ excess persists in higher-resolution resimulations with full baryonic physics. Effective Einstein radii of observed substructures ($\theta_E \sim 2\text{--}5$ arcsec) greatly exceed simulations ($\theta_E \sim 0.3\text{--}1$ arcsec). No known CDM concentration enhancement resolves the excess. SCT resolution: constructive gravitational superposition of compact comoving subgroups, $A_{\text{sub}}^2 \approx 10\text{--}16$ (doi:10.13140/RG.2.2.19379.69921 §6.3, Equations 26–28).

ICM

L-06. Universal ICM Entropy Floor / Steepened $L_X\text{--}T$ Relation

Source: Paper 6 §7 (doi:10.13140/RG.2.2.19379.69921)

$L_X \propto T^{2.6\text{--}3.0}$ observed (Ponman et al. 1999, Nature 397:135; Voit et al. 2003, confirmed across 239 Chandra clusters) vs. self-similar $L_X \propto T^2$. Universal entropy floor $K_0 \gtrsim 100\text{--}300$ keV cm² requires $\sim 1\text{--}3$ keV/particle non-gravitational injection. Supernova feedback insufficient (McCarthy et al. 2008, MNRAS 386:1309). AGN+SN feedback reproduces some profiles but requires fine-tuned duty cycles and jet opening angles and cannot explain universality across the full mass range $T_{\text{vir}} \sim 0.5\text{--}15$ keV. SCT resolution: relic thermodynamic signature from collision cascade, conserved adiabatically — $K_0 = f(\alpha, T_{\text{vir}}, n_e)$ (doi:10.13140/RG.2.2.19379.69921 §7.2, Equations 29–34).

Early Universe

L-07. JWST Mass Assembly Crisis: Stellar Mass ($4\text{--}16\sigma$ above Λ CDM ceiling)

Source: Paper 4 §1–§2 (doi:10.13140/RG.2.2.20310.31042)

JADES-GS-z14-0 ($z = 14.18$): dynamical mass $\sim 10^8 M_\odot$, $O > 0.1 Z_\odot$, implying progenitor populations exceeding Λ CDM ceiling by factor ~ 30 (Carniani et al. 2024, Nature 633:318). MoM-z14 ($z = 14.44$): super-solar N/C requiring Wolf-Rayet populations needing multiple Gyr of evolution; universe is only 280 Myr old (Naidu et al. 2025, ApJ Letters 978:L14). Xiao et al. (2024, Nature 635:311): $\varepsilon_* \sim 47\text{--}52\%$, factor $3\text{--}5\times$ above maximum at any epoch. Weibel et al. (2025, ApJ 979:143): quenched $z = 7.29$ galaxies $100\text{--}1000\times$ above IllustrisTNG, EAGLE, SIMBA predictions. SCT resolution: collision-seeded proto-structures with M_{proto} from dynamics, not growth-rate bottleneck (doi:10.13140/RG.2.2.20310.31042 §3.2, Equation 2).

L-08. JWST ICM Thermal Energy Crisis at $z = 4.3$ (6.4σ above TNG-Cluster)

Source: Paper 4 §2.4 (doi:10.13140/RG.2.2.20310.31042)

Zhou et al. (2025, Nature 536:1226): SPT2349-56 at $z = 4.3$ shows 10.4σ tSZ detection, $E_{\text{therm}} = (11.8 \pm 1.2) \times 10^{60}$ erg — 6.4σ above TNG-Cluster, $5\times$ above universal mass-Compton-Y scaling, one order of magnitude above maximum from gravitational collapse of the observed $9 \times 10^{12} M_\odot$ halo. AGN-feedback remedy requires thermal coupling efficiency $120 \pm 20\%$ — violates energy conservation ($>100\%$ inadmissible). SPT2349-56 is the brightest object in a 2500 sq.deg. survey; any proposed mechanism must explain this system without parameter adjustment beyond observationally motivated ranges. SCT resolution: born-hot ICM from collision-seeded proto-ICM structures, $E_{\text{therm}}/E_{\text{vir}} \sim 4.5$ (doi:10.13140/RG.2.2.20310.31042 §3.7, Equations 46–51).

L-09. Overmassive Black Holes at $z > 7$ (BH/stellar $10\text{--}1000\times$ above local Magorrian)

Source: Paper 4 §3.6 (doi:10.13140/RG.2.2.20310.31042)

QSO J0313-1806 ($z = 7.642$): $1.6 \times 10^9 M_{\odot}$ BH — cannot have grown from any stellar-mass seed via Eddington-limited accretion even if seeded at $z = 30$ (Wang et al. 2021, ApJ Letters 907:L1). UHZ1 ($z \sim 10.1$): BH mass \geq total stellar mass of host (Bogdan et al. 2024, Nature Astronomy 8:126; Natarajan et al. 2024, ApJ Letters 960:L1). BH-to-stellar mass ratios at $z > 7$ are $10\text{--}1000\times$ above local Magorrian relation. Λ CDM has no seeding mechanism producing $10^8\text{--}10^9 M_{\odot}$ seeds at $z > 30$. SCT resolution: direct-collapse BH seeds from head-on collision geometry ($b \sim 0$), $M_{\text{seed}} = 10^7\text{--}10^9 M_{\odot}$ from Equations 33–38 (doi:10.13140/RG.2.2.20310.31042 §3.6).

L-10. Morphological Maturity at High Redshift (constant spiral:elliptical ratio to $z \sim 10$)

Source: Paper 4 §2.2 (doi:10.13140/RG.2.2.20310.31042)

Barred spiral at $z \sim 3$ structurally indistinguishable from Milky Way analog (Costantin et al. 2023, Nature 623:499). Grand-design spiral at $z = 4.03$ (Jain & Wadadekar 2025, MNRAS 538:1234). Spiral:elliptical:irregular ratio approximately constant to $z \sim 10$ (Ferreira et al. 2024, ApJ Letters 955:L2). Λ CDM predicts progressively more disturbed, irregular, merger-driven morphologies at higher redshift. Constancy of morphological mix to $z \sim 10$ directly contradicts hierarchical assembly. SCT resolution: morphological type set at seeding epoch by impact parameter J/J_{circ} ratio, preserved by exact angular momentum conservation (doi:10.13140/RG.2.2.20310.31042 §3.3).

Large Scale

L-11. Quasar Polarization / VLBI Jet Alignment at 400 Mpc–1 Gpc (20–30 \times TTT maximum)

Source: Paper 5 §4 (doi:10.13140/RG.2.2.28263.10400)

Hutsemékers (1998, 2001, 2005): optical polarization coherence ~ 1 Gpc; random probability $< 0.1\%$ under two independent tests. Signal grows with sample size (not dominated by outliers); alignment angle varies with redshift (rules out Galactic dust). Mandarakas et al. (2021): VLBI 3D jet alignment at 400–900 Mpc at $>99.5\%$ significance — three-dimensional, no projection ambiguity. Pelgrims & Hutsemékers (2016): radio polarization perpendicular to LQG major axes $>99\%$ for groups with >20 members. TTT maximum coherence $\sim 30\text{--}50$ Mpc; observed coherence exceeds by $20\text{--}30\times$. SCT resolution: J-vector imprinting on supermassive BH spin axes through filamentary accretion from rotating collision debris (doi:10.13140/RG.2.2.28263.10400 §4).

L-12. Individual Cosmic Filament Bulk Rotation (Tudorache et al. 2025)

Source: Paper 5 §5.9 (doi:10.13140/RG.2.2.28263.10400)

Tudorache et al. (2025): first direct detection of coherent bulk angular momentum in individual cosmic filament via MeerKAT 21-cm HI spectroscopy — 14 galaxies spanning ~ 1.7 Mpc, solid-body rotation at ~ 110 km/s. Galaxy spin axes aligned with filament spine exceeding IllustrisTNG predictions beyond parameter uncertainty. Wang et al. (2021): statistical vortical velocity excess around stacked SDSS filaments not reproduced at observed amplitude by IllustrisTNG. Λ CDM TTT cannot produce the observed amplitude. SCT resolution: filaments are structural relics of large-scale superluminal collisions inheriting $J = \mu(b \times v_{\text{rel}})$ as bulk angular momentum (doi:10.13140/RG.2.2.28263.10400 §5.9).

CMB

L-13. $A_{\text{lens}} = 1.18 \pm 0.065$ ($>2\sigma$ above Λ CDM expectation of 1.00)

Source: Paper 3 §X.2 (doi:10.13140/RG.2.2.20310.31042); Paper 6 §5.2 (doi:10.13140/RG.2.2.19379.69921)

Planck 2018 (A&A 641:A5, A&A 641:A6): $A_{\text{lens}} = 1.18 \pm 0.065$, meaning CMB is lensed $\sim 18\%$ more strongly than the best-fit matter distribution predicts. Λ CDM has no physical mechanism for $A_{\text{lens}} \neq 1$; it has been discussed as a modeling systematic but persists across data cuts. SCT natural explanation: coherent mesh contribution Φ_{mesh} from the parent-frame hierarchy provides additional lensing convergence not attributable to catalogued matter, producing $A_{\text{lens}} > 1$. The boundary condition $S(z_0) \sim 4.4$ (doi:10.13140/RG.2.2.20310.31042 §VII.3) gives the superposition contribution at $z = 0$, implying $A_{\text{lens}} \sim 1 + O(S(z_*)) \sim 1.18$ when integrated over the lensing kernel.

L-14. DESI 2024 Evolving Dark Energy Hints ($w_0 > -1$, $w_a < 0$)

Source: Paper 7 §6.3 (doi:10.13140/RG.2.2.24304.72969)

DESI 2024 VI (arXiv:2404.03002): DESI BAO + CMB + Type Ia SN combination in $w_0 w_a$ parameterization yields $w_0 > -1$, $w_a < 0$ at $>2\sigma$ — suggesting dark energy was stronger in the past. Inconsistent with a strictly constant Λ at $>2\sigma$. Λ CDM provides no physical mechanism for $w \neq -1$. If confirmed at higher significance by DESI DR2 + Euclid, would require either a dynamical dark-energy field, modified gravity, or a reinterpretation of Λ . SCT reinterprets this as forcing inhomogeneous $\Lambda_{\text{eff}}(x,t)$ into a homogeneous fluid parameterization — expected geometric artifact of the Λ/λ mechanism (doi:10.13140/RG.2.2.24304.72969 §6.3).

Foundations

L-15. Cosmological Constant Fine-Tuning ($\sim 10^{120}$ orders of magnitude)

Source: Paper 7 §6.5 (doi:10.13140/RG.2.2.24304.72969)

Observed $\Lambda_{\text{obs}} \sim 1.1 \times 10^{-52} \text{ m}^{-2}$ vs. QFT vacuum energy estimate $\sim 10^{74} \text{ m}^{-2}$ — a discrepancy of $\sim 10^{126}$ in m^{-2} units (or $\sim 10^{120}$ in natural units). No known symmetry principle, cancellation mechanism, or anthropic argument explains this value. Λ CDM simply takes Λ as an observational input. SCT reframes: Λ_{eff} is an emergent ratio $\Lambda_{\text{parent}}/\lambda_{\text{local}}$, not fundamental vacuum constant. Its smallness in strongly bound regions (large λ) is a dynamical consequence. The problem becomes: what governs the statistical properties of the eternal hierarchy's tensor-mesh evolution? — arguably more tractable than fine-tuning a fundamental constant (doi:10.13140/RG.2.2.24304.72969 §6.5).

L-16. Horizon Problem: CMB uniformity across causally disconnected regions

Source: Paper 1 §1 (doi:10.13140/RG.2.2.20310.31042)

CMB temperature uniform to $<10^{-5}$ across regions not in causal contact at recombination under standard expansion (angular separation $> \sim 2^\circ$). Inflation solves this by postulating an earlier phase of accelerated expansion — but the inflaton field and inflationary potential have no fundamental derivation and require significant parameter tuning. SCT non-inflationary resolution: the collision thermalized the entire overlap volume simultaneously before any internal signal could traverse the collision interface (Premise P24, doi:10.13140/RG.2.2.20310.31042). Homogeneity is not the result of post-hoc causal equilibration but of simultaneous thermalization during the superluminal intersection.

L-17. Flatness Problem: Fine-tuning to 1 part in 10^{60}

Source: Paper 1 §1 (doi:10.13140/RG.2.2.20310.31042)

Observed spatial flatness $|\Omega_k| < 0.005$ (Planck 2018) requires energy density at Planck epoch fine-tuned to critical density to 1 part in 10^{60} without inflation. SCT resolution: the virial theorem applied to the collision remnant — $2K + U = 0$ — constrains the resulting geometry to near-flatness without fine-tuning. Flat geometry emerges as a mechanical consequence of collision dynamics (a

sufficiently energetic virialized collision remnant) rather than as selection from an exponentially improbable set of initial conditions (Premise P24, doi:10.13140/RG.2.2.20310.31042).

Section 3: Priority Falsification Tests by Timeline

The table below summarizes the highest-priority upcoming tests with specific numerical thresholds distinguishing SCT from Λ CDM.

| Timeline | Test / Observable | SCT Prediction | Λ CDM Prediction | Falsifies SCT If... |
|--|---|--|--|--|
| Now — existing JWST data | $M_* > 10^8 M_\odot$ galaxy number density at $z > 14$ | Power-law decline; detections continue at $z > 14$ | Exponential cutoff; effectively zero above $z = 12$ | Zero detections at $z > 14$ in all Cycle 1–3 NIRSpec programs |
| Now — existing data | CMB dipole direction vs. large-scale AM coherence axis | Dipole approximately perpendicular to quasar polarization J-vector axis | No predicted relationship between dipole and AM axis | Dipole aligned with (not \perp to) AM axis at 3σ |
| ~2025+ (DESI DR2, existing Pantheon+) | SN H_0 split by host-cluster membership (frame-tree test) | Cluster-embedded SNe infer $H_0 \sim 0.5\text{--}1\%$ higher than field SNe; corrected H_0 moves toward intermediate value | No systematic environment dependence of H_0 after peculiar velocity correction | No measurable H_0 offset between cluster and field SN subsamples at $>2\sigma$ |
| ~2026–2028 (Euclid+DESI full survey) | Environment-tagged $H(z)$: void vs. overdense sightlines | $\sim 9\%$ systematic $H(z)$ difference between void-dominated and cluster-dominated sightlines | No such correlation after standard peculiar velocity correction | No systematic $H(z)$ environment dependence at $>2\%$ level |
| ~2027–2029 (Roman HLWAS) | Galaxy counts at $z = 12\text{--}15$, $M_* > 10^{10} M_\odot$ (2000 sq.deg.) | 1590 central (range 550–4770) across three z -bins | Fewer than 3 (Λ CDM halo mass function exponential cutoff) | Fewer than 100 total detections across all three z -bins |
| ~2027+ (Athena X-ray Observatory) | ICM entropy floor: $K_0(z=2) / K_0(z=0)$ | Ratio $\in [0.8, 1.2]$ — relic entropy conserved since collision epoch | Ratio $\ll 1$ — AGN preheating entropy floor grows with time | $K_0(z=2)/K_0(z=0) \ll 1$ confirmed at 3σ |

| Timeline | Test / Observable | SCT Prediction | Λ CDM Prediction | Falsifies SCT If... |
|--|--|--|---|---|
| Current X-ray archives + near-term | L _X -T slope in AGN-quiet vs. AGN-active groups | Same steep slope $\alpha_{\text{eff}} \approx 2.7\text{--}3.0$ in both — relic entropy, not injected | AGN-active groups show steeper slope than AGN-quiet groups | AGN-quiet groups show systematically shallower slope at 3σ |
| Early 2030s (CMB-S4 / Simons Observatory) | Tensor-to-scalar ratio r from B-mode polarization | $r < 10^{-5}$ (no inflationary GWB; collision cascade produces no coherent tensor modes) | $r \sim 0.01\text{--}0.06$ for large-field inflation; $r > 0.001$ for small-field | Detection of $r > 0.01$ at $\geq 3\sigma$ |
| Within current decade (PIXIE/PRISM class) | CMB y -distortion dipole axis alignment | Dipolar y -distortion aligned with collision J-vector (quasar polarization axis) | No dipolar CMB y -distortion of this character | y -distortion dipole axis inconsistent with AM coherence axis at 3σ |
| Ongoing (LZ, XENONnT, LHC, Fermi-LAT) | Dark matter direct / collider / indirect detection | Null results in all channels — no DM particle exists; $G_{\text{eff}}(z) = G[1+S(z)]$ grows with structure | WIMP, axion, or sterile neutrino detectable in lab | Robust confirmed detection of any CDM particle with properties consistent with the dark matter role |
| 2030s (Einstein Telescope / LIGO-Voyager) | GW post-merger echoes and modified QNM at $\tau_{\text{echo}} \propto M_{\text{BH}}$, $\Delta\omega/\omega \sim (R_{\text{core}}/R_{\text{S}})^2$ | Post-merger echoes and QNM deviation from Kerr at predicted amplitude; $\text{SNR} > 8$ | Clean Kerr metric ringdown; no echoes; $\Delta\omega/\omega = 0$ | High-SNR BH merger events showing no echoes and QNM consistent with Kerr to $<1\%$ at 5σ |

Summary Counts

SCT predictions (Section 1): 60, numbered 1 through 60, spanning 13 physical domains.

Λ CDM challenges (Section 2): 17, labeled L-01 through L-17, spanning 5 thematic areas.

Source coverage: 8 of 9 papers (Paper 8 unavailable). All Nipok references use registered DOI numbers. American English throughout.

Key DOIs: Paper 1/3/4: doi:10.13140/RG.2.2.20310.31042 · Paper 2/5:
doi:10.13140/RG.2.2.28263.10400 · Paper 6: doi:10.13140/RG.2.2.19379.69921 · Paper 7:
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