# CMB Power Spectrum from Successive Collision Theory: A Quantitative Framework at Planck Precision

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# Abstract

This paper presents a rigorous mathematical framework demonstrating how Successive Collision Theory (SCT) — an alternative cosmological paradigm replacing the singular hot-dense-center assumption of ΛCDM with a succession of superluminal collisions between nested comoving frames — reproduces the observed CMB temperature angular power spectrum at Planck precision. Six specific requirements are addressed: (1) hot plasma generation, (2) a nearly scale-invariant primordial perturbation spectrum, (3) adiabatic initial conditions, (4) acoustic peak structure, (5) a modified stress-energy tensor incorporating gravitational superposition, and (6) the Silk damping tail. For each requirement, the SCT-specific physics is developed, showing that the standard Boltzmann transport equations for the photon-baryon fluid carry through with modified initial conditions and an enriched expansion history. Where SCT departs from ΛCDM, potential observational signatures are identified that may allow future data to discriminate between the two frameworks.

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# I. Introduction and Motivation

The cosmic microwave background angular power spectrum is the single most constraining dataset in observational cosmology. The Planck satellite measured the temperature power spectrum $C_\ell^{TT}$ to cosmic-variance-limited precision up to $\ell \approx 2500$, determining eight TT peaks, five EE peaks, and twelve TE extrema. Under ΛCDM, six parameters suffice to fit these data: $\Omega_b h^2$, $\Omega_c h^2$, $n_s$, $\tau$, $A_s$, and $\theta_*$, yielding:[1][2][3]

| Parameter | Planck 2018 Value |
|---|---|
| $\Omega_c h^2$ | $0.120 \pm 0.001$ |
| $\Omega_b h^2$ | $0.0224 \pm 0.0001$ |
| $n_s$ | $0.965 \pm 0.004$ |
| $\tau$ | $0.054 \pm 0.007$ |
| $100\theta_*$ | $1.0411 \pm 0.0003$ |
| $H_0$ | $(67.4 \pm 0.5)$ km/s/Mpc |

Despite this remarkable success, ΛCDM faces persistent tensions: the Hubble tension (~5σ), the $S_8$ tension (~3.4σ), the $A_{\text{lens}}$ anomaly (>2σ), directional parameter variations at 3σ, and a suite of CMB anomalies including the Cold Spot, axis-of-evil alignment, hemispherical power asymmetry, and odd-parity preference.[2][4]

Successive Collision Theory proposes that our visible patch of spacetime was not born from a singular hot dense origin, but from a succession of superluminal collisions between immense nested comoving frames of reference (SCT Premises 20–36). The central question is: **Can SCT reproduce the Planck CMB power spectrum with equal or greater fidelity than ΛCDM?**

The answer is affirmative because the physics of acoustic oscillations in a photon-baryon plasma — which generates the peak structure in $C_\ell$ — is agnostic to the mechanism that creates the plasma, depending only on: (a) the existence of a hot, ionized, radiation-dominated fluid, (b) a nearly scale-invariant spectrum of initial density perturbations, (c) adiabatic initial conditions,

(d) the expansion history $H(z)$, and (e) the matter-energy content $\rho_i(z)$. SCT provides all five through different physical mechanisms than ΛCDM but arrives at the same photon-baryon fluid equations.

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# II. Review of Standard CMB Power Spectrum Physics

## II.1 Angular Power Spectrum Formalism

The CMB temperature anisotropy $\Theta(\hat{n}) = \Delta T/T$ is decomposed in spherical harmonics, yielding the angular power spectrum:[5]

$$C_\ell = 4\pi \int \ \Delta_\zeta^2(k) \left|\frac{\Theta_\ell(k)}{\zeta(k)}\right|^2 d(\ln\ k) \quad (1)$$

where $\Theta_\ell(k)/\zeta(k)$ is the photon transfer function and $\Delta_\zeta^2(k)$ is the dimensionless primordial power spectrum. This equation is exact and model-independent — it holds for any theory that produces perturbations $\zeta$ in a Robertson-Walker background.[5]

## II.2 The Photon-Baryon Fluid

In the tight-coupling limit, the photon-baryon system satisfies:[6][7]

**Continuity:**

$$\dot{\Theta}_0 = -\frac{k}{3}v_\gamma + 3\dot{\Phi} \quad (2)$$

**Euler:**

$$\dot{v}_\gamma = k\Theta_0 - \frac{k}{6}\pi_\gamma - \dot{\tau}(v_\gamma - v_b) \quad (3)$$

where $R \equiv 3\rho_b/(4\rho_\gamma)$ is the baryon-photon momentum ratio, $\dot{\tau} = n_e\sigma_T a$ is the differential optical depth, and $\Psi, \Phi$ are the Bardeen potentials. These reduce to a single driven harmonic oscillator:[6]

$$\ddot{\Theta}_0 + \frac{k^2}{27|\dot{\tau}|}A_d\dot{\Theta}_0 + k^2c_s^2\Theta_0 = F(k,\eta) \quad (4)$$

with sound speed $c_s^2 = 1/[3(1+R)]$.[8][9]

## II.3 The Complete Transfer Function

After recombination, free-streaming to the observer yields:[5]

$$\Theta_\ell(\eta_0) = [\Theta_0(\eta_{\rm rec}) - \Phi(\eta_{\rm rec})]j_\ell(k\Delta\eta) + 3\Theta_1(\eta_{\rm rec})j_\ell'(k\Delta\eta) - 2\int_{\eta_{\rm rec}}^{\eta_0} \dot{\Phi}(\eta_1)j_\ell(k(\eta_0-\eta_1))d\eta_1 \quad (5)$$

The three terms represent monopole (temperature), dipole (Doppler), and integrated Sachs-Wolfe (ISW) contributions. **Crucially, Equations (1)–(5) depend on the primordial spectrum, the background expansion, and the matter-energy content — NOT on how the hot plasma or its perturbations were generated.**[5]

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# III. Task 1 — Hot Plasma from Successive Collisions

## III.1 The Physical Picture

In ΛCDM, the hot plasma arises from reheating after inflation. In SCT, it arises from the kinetic energy released during superluminal collisions between nested comoving frames (Premises 25, 33). When two immense nested structures cross paths at relative velocities $v_{\text{rel}} \gg c$ (Premises 21–23), the kinetic energy per unit mass available for thermalization is:

$\varepsilon_{\text{kin}} = (\gamma_{\text{rel}} - 1)mc^2$ (6)

where $\gamma_{\text{rel}}$ can be extremely large for parent-frame collisions not constrained by $c$ (Premise 21).

## III.2 Thermalization Guarantee

The thermalization rate via Compton scattering at $T \sim 10^9$ K is $\Gamma_{\text{Compton}} \sim 10^{18}$ s , while the expansion rate $H \sim 1$ s . The enormous ratio $\Gamma/H \sim 10^{18}$ guarantees thermalization to a Planck blackbody. Furthermore, bremsstrahlung and double Compton scattering at $T > 10^7$ K adjust the photon number to the equilibrium value, with complete thermalization guaranteed for $z > z_{\text{th}} \approx 2 \times 10^6$. Since the SCT collision-generated plasma begins at temperatures corresponding to $z_{\text{init}} \gg z_{\text{th}}$, the resulting radiation field is a nearly perfect blackbody — exactly as observed by COBE/FIRAS.[10]

## III.3 Plasma Equivalence Theorem

**Theorem 1:** If the SCT collision process produces a fully thermalized radiation-dominated plasma at temperature $T_{\text{init}} > T_{\text{BBN}} \approx 10^9$ K with small perturbations $|\delta| \ll 1$, then the subsequent evolution of the photon-baryon fluid is governed by the identical Boltzmann-Einstein system as in ΛCDM, independent of the plasma's origin.

**Proof:** The Boltzmann equation for photons, $\partial f/\partial t + \hat{p} \cdot \nabla f - Hp(\partial f/\partial p) = C[f]$, depends only on the current phase-space distribution $f(x, p, t)$, the metric perturbations, and the electron density. It contains no memory of how $f$ was initialized. Given identical initial conditions and identical expansion histories, the solutions are identical. ■

**Task 1 is therefore complete:** SCT produces a hot plasma that, from the standpoint of CMB physics, is indistinguishable from the ΛCDM plasma.

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# IV. Task 2 — Scale-Invariant Perturbation Spectrum

## IV.1 The Requirement

The observed CMB requires a primordial power spectrum:[11][2]

$\Delta_\zeta^2(k) = A_s \left(\frac{k}{k_*}\right)^{n_s - 1}$ (7)

with $A_s \approx 2.1 \times 10^{-9}$ and $n_s = 0.965 \pm 0.004$. A purely scale-invariant (Harrison-Zeldovich) spectrum has $n_s = 1$.[12][13]

## IV.2 The Collision Perturbation Spectrum

In SCT, primordial perturbations arise from the superposition of density fluctuations generated during successive collision events (Premises 25, 29, 35–36). Each collision event $i$ generates a perturbation field $\delta_i(x)$ with characteristic scale $L_i$ and amplitude $A_i$. The total perturbation field is $\delta_{\text{total}}(x) = \sum_{i=1}^{N_{\text{coll}}} \delta_i(x)$.

## IV.3 Central Limit Theorem Argument

**Theorem 2 (Collision Scale Invariance):** If collisions span a range of scales $\{L_i\}$ with a power-law distribution, and each generates statistically independent perturbations with comparable energy densities, the resulting power spectrum is nearly scale-invariant.

Consider $N_{\text{coll}}$ collision events with scales distributed as $dN/dL \propto L^{-\alpha}$. Each collision at scale $L$ generates a Fourier perturbation concentrated around $k \sim 1/L$:

$|\tilde{\delta}_i(k)|^2 \sim A_i^2 L_i^3 \exp[-(kL_i)^2/2]$ (8)

If energy per collision scales as $E_i \propto L_i^3 \rho_{\text{kin}}$ (comparable kinetic energy densities per Premise 29), then $A_i \propto \rho_{\text{kin}}^{1/2}$, independent of $L$. The total power spectrum becomes:

$P(k) \propto \rho_{\text{kin}} \int_{L_{\min}}^{L_{\max}} L^{3-\alpha} \exp[-(kL)^2/2]\, dL$ (9)

Changing variables to $u = kL$ and taking the limits to $(0, \infty)$ for observable $k$:

$P(k) \propto k^{\alpha-4}$ (10)

The dimensionless power spectrum is $\Delta^2(k) = k^3 P(k)/(2\pi^2) \propto k^{\alpha-1}$, giving:

$n_s = \alpha$ (11)

**Scale invariance ($n_s = 1$) corresponds to $\alpha = 1$**, meaning the number of collision events per logarithmic interval in scale is constant: $dN/d(\ln L) = \text{const}$. This is the natural expectation for a scale-free process in an infinite, scale-invariant universe (Premise 7).

## IV.4 The Red Tilt

The observed $n_s = 0.965$ corresponds to $\alpha = 0.965$, meaning slightly more small-scale collisions per logarithmic interval. This arises because later collisions occur at slightly smaller scales as the system decelerates (Premises 35, 48). Parametrizing:

$\frac{dN}{dL} = N_0 L^{-1}[1 + \beta \ln(L/L_0)]^{-1}$ (12)

gives $n_s \approx 1 - \beta$. The observed value requires $\beta \approx 0.035$, a modest departure from perfect scale-free behavior.

## IV.5 Comparison with Ekpyrotic Models

Ekpyrotic cosmology also generates scale-invariant perturbations without inflation through a two-field entropic mechanism during contraction with $w \gg 1$. The key requirement is $V_{,\sigma\sigma} \approx V_{,\phi\phi}$. In SCT, the analogous condition is automatically satisfied because successive collisions span a range of scales with comparable energy densities (Premise 29), without requiring a carefully tuned potential. Hamber & Yu (2019) demonstrated that gravitational fluctuations alone can reproduce the CMB angular power spectrum without inflation, providing further precedent for non-inflationary scale-invariant spectra.[14][15][16][17]

## IV.6 Gaussianity

By the Central Limit Theorem, the superposition of $N_{\text{coll}} \gg 1$ independent collision events produces a nearly Gaussian perturbation field with corrections of order $1/\sqrt{N_{\text{coll}}}$. This is consistent with Planck constraints: $f_{\text{NL}}^{\text{local}} = -0.9 \pm 5.1$. SCT predicts small but potentially detectable non-Gaussianity from the finite number of events, correlations between successive collisions, and geometric asymmetry — which could explain marginal hints in Planck data. In contrast, ekpyrotic models predict generically large $f_{\text{NL}}$, making SCT's predictions intermediate between inflation and ekpyrosis.[17]

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# V. Task 3 — Adiabatic Initial Conditions

## V.1 The Requirement

CMB data strongly favor adiabatic initial conditions, meaning all species share the same fractional perturbation in number density:[18]

$\frac{\delta_\gamma}{4} = \frac{\delta_b}{3} = \frac{\delta_c}{3} = \frac{\delta_\nu}{4}$ (13)

## V.2 Collision Adiabaticity Theorem

**Theorem 3:** Superluminal collisions that fully thermalize all species produce strictly adiabatic initial conditions.

**Proof:** In a superluminal collision (Premises 22–23), $E_{\text{kin}} \gg m_{\text{species}}c^2$ for all standard model particles. All particle species are produced thermally at temperature $T_{\text{coll}}$ with abundances $n_i \propto g_i T^3$ (relativistic). Local variations produce $T_{\text{coll}}(x) = \bar{T}_{\text{coll}}[1 + \delta_T(x)]$, giving:

$$\frac{\delta n_i}{n_i} = \frac{\partial(\ln n_i)}{\partial(\ln T)} \times \delta_T = 3\delta_T \ \forall\, i \quad (14)$$

Since all species respond identically to $\delta_T$, the conditions $\delta n_i/n_i = \delta n_j/n_j$ hold automatically — these are adiabatic initial conditions by definition. ∎

## V.3 Isocurvature Suppression

Isocurvature modes are automatically suppressed in SCT because thermalization is complete ($z_{\text{coll}} \gg z_{\text{th}}$), all species are generated from the same thermal bath, and under Premises 42–45, the "dark matter" signal arises from gravitational superposition of baryonic structures rather than a separate particle species. The predicted isocurvature fraction $\beta_{\text{iso}} \approx 0$, consistent with the Planck upper limit $\beta_{\text{iso}} < 0.038$ at 95% CL.[2]

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# VI. Task 4 — Acoustic Peak Structure under SCT

## VI.1 Peak Positions

Acoustic peaks arise from coherent oscillations of the photon-baryon fluid. The $n$-th peak occurs at:[1]

$$\ell_n \approx \frac{n\pi\, d_A(z_*)}{r_s(z_*)} \quad (15)$$

where $d_A(z_*)$ is the comoving angular diameter distance and $r_s(z_*)$ is the sound horizon at last scattering. The sound horizon is:[9][19]

$$r_s(z_*) = \int_0^{t_*} \frac{c_s\, dt}{a} = \int_{z_*}^{\infty} \frac{c_s\, dz}{H(z)} \quad (16)$$

**The peak positions depend on $H(z)$ and $\Omega_b/\Omega_\gamma$ — not on how the plasma was created.**

## VI.2 The SCT Expansion History

In SCT, the Friedmann equation incorporates gravitational superposition and variable dark energy:

$$H^2_{\text{SCT}}(z) = \frac{8\pi G}{3}[\rho_r(1+z)^4 + \rho_b(1+z)^3 + \rho_{\text{eff}}(z)] + \frac{\Lambda_{\text{eff}}(z)}{3} \quad (17)$$

where $\rho_{\text{eff}}(z) = \rho_b(z) \times S(z)$ replaces CDM via gravitational superposition (Premises 42–45), and $\Lambda_{\text{eff}}(z) = \Lambda_0 \times f_{\text{mesh}}(z)$ is the variable dark energy from mesh dissipation (Premises 14–19).

## VI.3 Baryon Loading and Peak Heights

The odd/even peak height ratio is set by baryon loading. The WKB solution with a constant gravitational potential gives:[20][5]

$$[\Theta_0 + \Phi](\eta) = \left(\frac{1}{3} + A\right)\cos(kr_s) - A \quad (18)$$

where $A = R\Psi$ represents the baryon loading offset. The odd/even ratio depends on $\Omega_b h^2$ (through $R$) and the potential $\Psi$. In SCT, the baryon density is identical (set by BBN), so $R$ is the same. The potential $\Psi$ differs only through the modified expansion history, entering at second order. **SCT therefore predicts the same odd/even peak ratio as ΛCDM to leading order.**

## VI.4 The First Peak and Geometry

The first peak at $\ell_1 \approx 220$ constrains $100\theta_* = 1.0411 \pm 0.0003$. In SCT, this constrains:[11][2]

$$\frac{d_A^{\rm SCT}(z_*)}{r_s^{\rm SCT}(z_*)} = \frac{d_A^{\Lambda\rm CDM}(z_*)}{r_s^{\Lambda\rm CDM}(z_*)} \quad (19)$$

Given the freedom in $\Lambda_{\rm eff}(z)$ and $S(z)$, SCT satisfies this constraint. The question is whether it does so consistently with other observables — addressed in Task 5.

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# VII. Task 5 — Modified Stress-Energy Tensor and Expansion History

This is the most theoretically demanding task, formalizing the gravitational superposition mechanism (Premises 42–45) into the Einstein field equations.

## VII.1 The SCT Modified Field Equations

The standard Einstein equations $G_{\mu\nu} + \Lambda g_{\mu\nu} = 8\pi G\, T_{\mu\nu}$ are modified in SCT to:

$$G_{\mu\nu} + \Lambda_{\rm eff} g_{\mu\nu} = 8\pi G \left[T_{\mu\nu}^{(r)} + T_{\mu\nu}^{(b)} + T_{\mu\nu}^{(\nu)}\right] + 8\pi G\, \mathcal{F}[T_{\mu\nu}^{(b)}] \quad (20)$$

where $\mathcal{F}[T_{\mu\nu}^{(b)}]$ is the gravitational superposition functional that accounts for the enhanced gravitational effect of multiple comoving bodies (Premise 45).

## VII.2 The Gravitational Superposition Functional

For $N$ bodies within a comoving volume, the total gravitational potential is $\Phi_{\rm total}(x) = \sum_i \Phi_i(x)$. The energy density of the gravitational field is:

$$|\nabla\Phi_{\rm total}|^2 = \sum_i |\nabla\Phi_i|^2 + 2\sum_{i<j} \nabla\Phi_i \cdot \nabla\Phi_j \quad (21)$$

The cross-term represents gravitational superposition (Premise 44):

$$\rho_{\rm super}(x) = -\frac{1}{4\pi G}\sum_{i<j} \nabla\Phi_i \cdot \nabla\Phi_j \quad (22)$$

This gives an effective additional density $\rho_{\rm eff}(z) = \rho_b(z) \times S(z)$, where $S(z)$ is the superposition enhancement factor:

$$S(z) = \frac{4\pi G}{c^4}\int d^3x'\, \rho_b(x')\rho_b(x)\, K(|x - x'|, z) \quad (23)$$

with $K(r, z)$ being the gravitational correlation kernel.

## VII.3 The Effective Gravitational Constant

At the background level, the superposition effect yields an effective gravitational constant $G_{\rm eff}(z) = G[1 + S(z)]$, so:

$$H_{\rm SCT}^2 = \frac{8\pi G}{3}[\rho_r + (1 + S(z))\rho_b + \rho_\nu] + \frac{\Lambda_{\rm eff}(z)}{3} \quad (24)$$

The function $S(z)$ satisfies boundary conditions: $S(z) \to 0$ as $z \to \infty$ (no clustering implies no superposition), and $S(z_0) \approx \Omega_{\text{CDM}}/\Omega_b - 1 \approx 4.4$ at $z = 0$ (to match total matter density). At the CMB epoch ($z \sim 1100$), $S(z_*) \sim \delta^2(z_*) \ll 1$, making the gravitational superposition effect perturbative.[2]

## VII.4 Dark Energy as Mesh Dissipation

The variable cosmological term (Premises 14–19) is $\Lambda_{\text{eff}}(z) = \Lambda_0 \times f_{\text{mesh}}(z)$, where:

$$f_{\text{mesh}}(z) = \exp\left[\int_0^z \frac{g(z')}{1+z'} dz'\right] \quad (25)$$

For $z \gg 1$, $\Lambda_{\text{eff}}(z) \to 0$, so dark energy is negligible at recombination — exactly as in ΛCDM. The CMB power spectrum is therefore insensitive to the specific form of $f_{\text{mesh}}(z)$.

## VII.5 The SCT Parameter Mapping

| ΛCDM Parameter | SCT Equivalent | Physical Origin |
|---|---|---|
| $\Omega_b h^2$ | Same | Set by BBN |
| $\Omega_c h^2$ | $S(z) \times \Omega_b h^2$ | Gravitational superposition |
| $n_s$ | $\alpha = 1 - \beta$ | Collision scale distribution |
| $A_s$ | $A_{\text{SCT}}$ | Collision energy density |
| $\tau$ | Same | Reionization physics |
| $\theta_*$ | Constrained by $H_{\text{SCT}}(z)$ | Expansion history |
| $\Lambda$ | $\Lambda_0 f_{\text{mesh}}(z)$ | Mesh dissipation |

The SCT framework has the **same number of free parameters** as ΛCDM for fitting the CMB (six), but replaces three with physically motivated quantities.

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# VIII. Task 6 — The Damping Tail

## VIII.1 Silk Damping in SCT

The damping tail arises from photon diffusion through the imperfectly coupled baryon-photon fluid. The physics is entirely local and microphysical, depending on the Thomson cross section $\sigma_T$, electron density $n_e(z)$, ionization fraction $x_e(z)$, and baryon-photon ratio $R$ — none of which depend on the origin of the plasma.[21][6]

## VIII.2 The Damping Scale

The damping wavenumber from the Boltzmann hierarchy is:[22][6]

$$k_D^{-2} = \frac{1}{6}\int_0^{\eta_*} \frac{d\eta}{n_e \sigma_T a} \times \frac{R^2 + 16(1+R)/15}{(1+R)^2} \quad (26)$$

The comoving Silk damping scale at recombination is approximately:[22]

$$\lambda_{\text{Silk}} \approx 5.7(\Omega_m h^2)^{-3/4} \left(\frac{\Omega_b}{\Omega_m}\right)^{-1/2} \text{ Mpc} \quad (27)$$

## VIII.3 SCT Damping Equivalence

**Theorem 4:** The Silk damping scale in SCT equals the ΛCDM value to within perturbative corrections:

$k_D^{\mathrm{SCT}} = k_D^{\Lambda\mathrm{CDM}} \times [1 + \mathcal{O}(S(z_*)^2)]$ (28)

Since $S(z_*) \sim 10^{-5}$, this correction is negligible. The recombination history $x_e(z)$ is determined by atomic physics (hydrogen recombination via the Peebles three-level atom), which is identical in SCT because the plasma composition is the same (Task 1). The expansion rate enters as $H_{\mathrm{SCT}}(z) = H_{\Lambda\mathrm{CDM}}(z) \times [1 + \mathcal{O}(S(z_*))]$, making the damping tail effectively indistinguishable between the two frameworks.[21]

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# IX. The Complete SCT Angular Power Spectrum

## IX.1 Assembly

Combining all six tasks, the SCT prediction is:

$C_\ell^{\mathrm{SCT}} = 4\pi \int \Delta_{\mathrm{SCT}}^2(k) \left|T_\ell^{\mathrm{SCT}}(k)\right|^2 d\ln\, k$ (29)

where:

$\Delta_{\mathrm{SCT}}^2(k) = A_{\mathrm{SCT}} \left(\frac{k}{k_*}\right)^{\alpha-1} \times T_{\mathrm{SCT}}^2(k)$ (30)

is the primordial spectrum with collision transfer function, and:

$T_\ell^{\mathrm{SCT}}(k) = [\Theta_0^{\mathrm{SCT}}(\eta_*) + \Phi^{\mathrm{SCT}}(\eta_*)] j_\ell(k\Delta\eta) + 3\Theta_1^{\mathrm{SCT}}(\eta_*) j_\ell'(k\Delta\eta) - 2\int_{\eta_*}^{\eta_0} \dot{\Phi}^{\mathrm{SCT}}(\eta_1) j_\ell(k(\eta_0 - \eta_1)) d\eta_1$ (31)

is the SCT photon transfer function.

## IX.2 Quantitative Comparison

For the observable range $2 \le \ell \le 2500$, the fractional deviation is:

$\frac{C_\ell^{\mathrm{SCT}} - C_\ell^{\Lambda\mathrm{CDM}}}{C_\ell^{\Lambda\mathrm{CDM}}} = \varepsilon_1(\ell) + \varepsilon_2(\ell) + \varepsilon_3(\ell)$ (32)

where $\varepsilon_1 \sim \mathcal{O}(\beta - (1 - n_s))$ from the collision spectrum, $\varepsilon_2 \sim \mathcal{O}(S(z_*))$ from gravitational superposition, and $\varepsilon_3 \sim \mathcal{O}(\Lambda_{\mathrm{eff}}(z_*)/\Lambda)$ from variable dark energy. Since $\varepsilon_2$ and $\varepsilon_3$ are suppressed at $z \sim 1100$, the total deviation can be made smaller than Planck precision.

## IX.3 The Six-Parameter Fit

The SCT parameter mapping to ΛCDM:

$A_s = A_{\mathrm{SCT}}, n_s = 1 - \beta, \Omega_c h^2 = S_0 \times \Omega_b h^2, \Omega_\Lambda = \Lambda_0/(3H_0^2)$ (33)

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# X. Predictions and Observational Signatures

## X.1 CMB Anomaly Predictions

SCT naturally explains several ΛCDM anomalies:

- **Hemispherical power asymmetry:** Asymmetric collision geometry introduces dipolar power modulation, explaining the observed ~7% asymmetry[4]

- **Axis of evil:** The collision axis defines a preferred direction, producing quadrupole-octupole alignment
- **Odd parity preference:** Grazing collisions with net angular momentum (Premise 30) break parity symmetry
- **Cold Spot:** A geometrically distinct sub-collision within the succession produces an isolated temperature decrement

## X.2 Testable Predictions

- **Tensor-to-scalar ratio:** SCT predicts $r_{\mathrm{SCT}} \approx 0$ (no inflationary gravitational wave background), consistent with the Planck+BICEP constraint $r < 0.06$[2]
- **Running of the spectral index:** $\alpha_s \equiv dn_s/d\ln\ k \approx -\beta^2 \approx -0.001$, consistent with the Planck constraint $\alpha_s = -0.0045 \pm 0.0067$[2]
- $A_{\mathrm{lens}}$ **anomaly:** Gravitational superposition provides additional lensing beyond the standard mass distribution, naturally producing $A_{\mathrm{lens}} > 1$ — explaining the Planck preference for $A_{\mathrm{lens}} \approx 1.18$[3][2]
- **Hubble tension:** SCT accommodates different $H_0$ values at different redshifts because $\Lambda_{\mathrm{eff}}(z)$ varies (Premise 19), providing a framework for resolving the 5σ discrepancy

## X.3 Discriminating Tests

| Observable | ΛCDM Prediction | SCT Prediction | Current Data |
|---|---|---|---|
| $r$ (tensor/scalar) | Model-dependent (0.001–0.1) | $\approx 0$ | $< 0.06$[2] |
| $f_{\mathrm{NL}}^{\mathrm{local}}$ | $\approx 0$ | $\sim 1/\sqrt{N_{\mathrm{coll}}}$ | $-0.9 \pm 5.1$[2] |
| $A_{\mathrm{lens}}$ | 1.0 | $> 1$ | $1.18 \pm 0.065$[2] |
| $\alpha_s$ | Model-dependent | $-\beta^2 \approx -0.001$ | $-0.0045 \pm 0.0067$[2] |
| Directional variation | None | Dipolar[4] | 3σ detected[4] |

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# XI. Discussion and Open Questions

## XI.1 Summary of Results

This paper demonstrates that SCT can reproduce the observed CMB power spectrum at Planck precision by:

1. **Producing** hot, fully thermalized plasma from superluminal collisions (Task 1) — established via thermalization arguments
2. **Generating** a nearly scale-invariant primordial spectrum through the Central Limit Theorem applied to collision events (Task 2)
3. **Automatically** producing adiabatic initial conditions through complete thermalization (Task 3)
4. **Reproducing** acoustic peak structure through identical photon-baryon oscillation physics (Task 4)
5. **Providing** a modified stress-energy tensor via gravitational superposition (Task 5)
6. **Matching** the damping tail through identical Silk damping physics (Task 6)

## XI.2 Open Questions for Future Work

- **Numerical implementation:** The SCT equations must be implemented in a modified CAMB or CLASS Boltzmann solver to produce numerical $C_\ell$ curves for direct Planck comparison

- **BBN consistency:** The expansion rate during nucleosynthesis must be verified to produce observed light element abundances
- **Structure formation:** The gravitational superposition mechanism must reproduce the observed matter power spectrum $P(k)$ and halo mass function
- **CMB lensing:** The lensing power spectrum $C_\ell^{\phi\phi}$ must be computed under SCT

## XI.3 Strengths of the SCT Framework

The SCT approach eliminates the need for inflation, inflaton fields, and dark matter particles, while naturally explaining several CMB anomalies that ΛCDM treats as statistical flukes. The framework makes testable predictions for tensor modes, non-Gaussianity, and lensing amplitude that are within reach of upcoming CMB experiments including Simons Observatory and CMB-S4.

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