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Cosmological Microwave Background Without Expansion

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Abstract

The cosmic microwave background is often taken as definitive evidence for universal expansion. No static framework has yet reproduced its exact blackbody spectrum under known physical conditions. This study extends the companion paper *Redshift Without Expansion* by applying a frequency-independent redshift mechanism within a Liouville formulation. The kinetic redshift operator preserves a perfect Planck spectrum, maintains $\mu = 0$, and yields $T \propto K^{-1}$ with an identical temperature–redshift relation $T(z) = T_0(1+z)$ consistent with measurements from COBE and FIRAS. Photon number and energy densities evolve as $\dot{n}_\gamma = -3H_{\text{eff}}n_\gamma$ and $\dot{\rho}_\gamma = -4H_{\text{eff}}\rho_\gamma$, where $H_{\text{eff}} = \dot{K}/K$ represents an effective Hubble parameter without metric expansion. The result establishes an observational degeneracy between kinetic redshift and geometric expansion while predicting a measurable secular temperature drift $\dot{T}/T = -H_{\text{eff}} \approx -2.3 \times 10^{-18}\,\text{s}^{-1}$. The framework provides a static, falsifiable pathway for examining the cosmic microwave background without reliance on expanding-space assumptions. The redshift kernel emerges from scalar field relaxation dynamics $\ddot{\Phi} + \Gamma(\dot{\Phi} - \dot{\Phi}_\infty) = 0$, with coupling $H_{\text{eff}} = g\dot{\Phi}$ reproducing the required CMB temperature scaling to illustrative $\sim 0.1\%$ precision for the example parameter set, and predicting $H_{\text{eff}}(z = 1100) \approx 281H_0$, testable via high-redshift measurements.

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1. Introduction

The discovery of the cosmic microwave background (CMB) in 1965 by Penzias and Wilson [20] established the most direct observational link between present-day cosmic radiation and the conditions of an early, hot universe. Subsequent measurements by COBE [17,22], WMAP [2,11], and *Planck* [21] confirmed that the CMB follows a near-perfect blackbody spectrum with temperature $T_0 = 2.725 \pm 0.001\,\text{K}$ and anisotropies at the level of 10^{-5}. This spectral uniformity is widely considered decisive evidence that the universe underwent adiabatic expansion, stretching photon wavelengths while preserving thermal equilibrium at the background level. Under standard Friedmann–Lemaître–Robertson–Walker (FLRW) dynamics, the temperature evolution $T(z) = T_0(1+z)$ arises from the scale factor relation $a(t_0)/a(t) = 1+z$ [7,19,25]. The blackbody form of the CMB is therefore interpreted as a natural outcome of expansion combined with photon-number conservation after recombination. Within this framework, the Boltzmann equation with a vanishing collision term guarantees that the Planck distribution remains invariant under Liouville flow [12,15]. These results form the foundation of the modern cosmological model.

Despite this success, no static model has yet reproduced the same spectral precision without invoking metric expansion. Classical tired-light proposals [3,16,26] introduced photon–medium interactions or plasma effects to generate redshift, but they failed two critical tests. The maintenance of a perfect Planck spectrum and the absence of image blurring. Any frequency-dependent loss mechanism distorts the distribution, producing a nonzero chemical potential μ that violates the COBE/FIRAS limit $|\mu| < 9 \times 10^{-5}$ at 95% confidence [9]. As a result, static alternatives were dismissed for lack

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of spectral coherence and empirical consistency. A companion paper "Redshift Without Expansion" (DOI:10.20944/preprints202509.1258.v1) introduced a new formalism that replaces the cosmological scale factor with a redshift kernel $K(t)$ satisfying $(1+z) = K(t_0)/K(t_e)$. That work demonstrated that, by applying $K(t)$ to luminosity distance, surface brightness, and supernova time-dilation data, the observed background relations can be reproduced without spatial expansion. The framework achieved complete algebraic equivalence to ΛCDM at the background level, providing an observationally degenerate but physically distinct description of redshift; however, that analysis was limited to geometric and photometric observables. The thermal behavior of the radiation field, its preservation of a Planck spectrum, its chemical potential evolution, and its global energy balance, were not addressed. These aspects determine whether a static framework can match the CMB constraints that historically ruled out all previous tired-light models. Without a kinetic proof of spectral invariance, the equivalence established in the companion paper remains incomplete. The CMB has historically been the test that ruled out static models. The present work addresses the thermal evolution but remains limited to background-level observables; CMB anisotropies, primordial nucleosynthesis, and structure formation lie outside the current scope. This work adopts the recombination redshift $z_{\rm rec} \approx 1100$ from standard cosmology as an external boundary condition and does not compute recombination internally. If n_b is treated as constant in a static background while $n_\gamma \propto (1+z)^3$, the photon-to-baryon ratio evolves as $(1+z)^3$, and the implied recombination epoch shifts. A consistent recombination calculation requires extending the matter sector and is left for future work. The present study extends the $K(t)$ model into kinetic theory by deriving the collisionless Boltzmann (Liouville) equation for photons under a frequency-independent redshift operator. The goal is to show that a uniform redshift rate $\dot{\nu}/\nu = -\dot{K}/K \equiv -H_{\rm eff}$ preserves the Planck form exactly, maintains $\mu = 0$, and produces the same temperature–redshift law $T(z) = T_0(1+z)$. The analysis also introduces an energy-compensating field Φ required by energy conservation to ensure global conservation when photon energy decreases, addressing one of the primary objections to static interpretations.

2. Kinetic Framework

The analysis proceeds under four assumptions that are consistent with post-recombination cosmology and establish the framework for collisionless photon evolution.

A1. Null Geodesics. Photons propagate along null geodesics of a static metric. Gravitational potentials are treated as time-independent at the background level, and light paths follow $p^\mu p_\mu = 0$ [18,25].

A2. Photon Number Conservation. No photon creation or annihilation occurs after last scattering. The distribution evolves collisionlessly except for redshift effects [15,19].

A2b. Baryon Sector Clarification. The baryon number density n_b is not evolved dynamically in this background-only analysis and is treated as constant in the static metric. The photon-to-baryon ratio η is therefore inherited from standard early-universe physics rather than computed in this framework. Recombination is taken as an external boundary condition.

A3. Redshift Kernel. The redshift is determined by a continuous kernel $K(t)$ satisfying $(1+z) = K(t_0)/K(t_e)$. Frequency evolution is given by $\dot{\nu}/\nu = -\dot{K}/K \equiv -H_{\rm eff}$ [5]. The quantity $H_{\rm eff}$ represents an effective rate parameter without invoking spacetime expansion. The physical origin of $K(t)$ evolution remains to be established but can be constrained empirically through the observational predictions developed in Section 3. For the purposes of this work $K(t)$ is treated as an empirical kernel fixed by observation. No microphysical model for $K(t)$ is assumed outside Section 5.6.

A4. Collisionless Evolution. After decoupling, the photon distribution obeys the collisionless Boltzmann equation. The collision term vanishes, $C[f] = 0$, leaving the Liouville operator as the governing dynamic term [7,15].

These assumptions reproduce the same background conditions under which the standard cosmological Liouville theorem preserves a Planck spectrum [19,25]. They ensure that any deviation in outcome arises from the redshift mechanism itself, not from added sources or sinks.

2.1. Collisionless Boltzmann Equation Under Uniform Redshift

The evolution of the photon distribution function $f(x^i, p^i, t)$ in phase space is described by the general Boltzmann equation [7,19]

$$\frac{\partial f}{\partial t} + \frac{p^i}{E}\frac{\partial f}{\partial x^i} - \Gamma^i_{jk} p^j p^k \frac{\partial f}{\partial p^i} = C[f]. \tag{1}$$

After recombination, $C[f] = 0$. In a homogeneous, isotropic background, the spatial gradient term vanishes. The remaining momentum-derivative term becomes a pure kinetic redshift operator. Defining $H_{\rm eff} = \dot{K}/K$ gives

$$\frac{\partial f}{\partial t} - H_{\rm eff}\, p\, \frac{\partial f}{\partial p} = 0. \tag{2}$$

This is the collisionless Liouville equation for frequency-independent redshift [15]. The operator acts uniformly on all photon momenta, guaranteeing phase-space density conservation.

2.2. Liouville Solution and Planck Preservation

The Liouville equation admits the general solution

$$f(p,t) = f_0(pK(t)), \tag{3}$$

where f_0 is the initial distribution function at reference epoch t_0 [25].

For an initial Planck distribution,

$$f_0(p) = \frac{1}{e^{p/kT_0} - 1}, \tag{4}$$

substitution yields

$$f(p,t) = \frac{1}{e^{pK(t)/(kT_0)} - 1} = \frac{1}{e^{p/(kT(t))} - 1}, \tag{5}$$

with the temperature scaling

$$T(t) = \frac{T_0}{K(t)}. \tag{6}$$

This shows that a frequency-independent redshift preserves the Planck form exactly, producing no chemical potential distortion and maintaining $T \propto K^{-1}$ [19]. The spectral purity of the CMB therefore follows as a mathematical consequence of Liouville's theorem, not an empirical adjustment.

2.3. Conservation Laws from Stefan-Boltzmann Integrals

Having established spectral preservation, the corresponding evolution of photon number and energy densities follows from standard thermodynamic integrals. Number and energy densities are obtained by integrating $f(p,t)$ over momentum space using the Stefan-Boltzmann relations [7,25]:

$$n_\gamma = \frac{8\pi}{h^3}\int_0^\infty \frac{p^2\, dp}{e^{p/(kT)} - 1}, \qquad \rho_\gamma = \frac{8\pi}{h^3}\int_0^\infty \frac{p^3\, dp}{e^{p/(kT)} - 1}. \tag{7}$$

Because $T \propto K^{-1}$, differentiation gives

$$\dot{n}_\gamma = -3H_{\rm eff} n_\gamma, \qquad \dot{\rho}_\gamma = -4H_{\rm eff}\rho_\gamma. \tag{8}$$

Derivation of Equation (8). Start with the solution $f(p,t) = f_0(pK)$ and the temperature relation $T = T_0/K$. The Planck form satisfies

$$f(p,t) = \frac{1}{\exp(p/(kT)) - 1} = \frac{1}{\exp((pK)/(kT_0)) - 1}.$$

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Differentiate with respect to time:
$$\frac{\partial f}{\partial t} = \frac{\partial f}{\partial (pK)}\,(p\dot{K}).$$
The momentum derivative satisfies
$$p\frac{\partial f}{\partial p} = \frac{\partial f}{\partial (pK)}\,(pK).$$
Using $\dot{K} = H_{\text{eff}}K$ gives
$$\frac{\partial f}{\partial t} = H_{\text{eff}}\,pK\,\frac{\partial f}{\partial (pK)} = H_{\text{eff}}\,p\,\frac{\partial f}{\partial p}.$$
Thus the collisionless Boltzmann equation takes the form
$$\frac{\partial f}{\partial t} - H_{\text{eff}}\,p\,\frac{\partial f}{\partial p} = 0.$$

Photon Number Density. The number density is
$$n_\gamma(t) = \int f(p,t)\,d^3p.$$
Let $q = pK$. Then $p = q/K$ and $d^3p = K^{-3}d^3q$. Since $f(p,t) = f_0(q)$, I obtain
$$n_\gamma(t) = K^{-3}\int f_0(q)\,d^3q \propto K^{-3}.$$

Photon Energy Density. The energy density is
$$\rho_\gamma(t) = \int p\,f(p,t)\,d^3p.$$
With $p = q/K$ and $d^3p = K^{-3}d^3q$,
$$\rho_\gamma(t) = K^{-4}\int q\,f_0(q)\,d^3q \propto K^{-4}.$$
These relations give the scaling laws summarized in equation (8).

The results are identical in form to the Friedmann background relations [19] but originate from a static kinetic process rather than metric expansion. To preserve total energy, a compensating sink field Φ absorbs photon energy loss such that $\dot{\rho}_\Phi = +4H_{\text{eff}}\rho_\gamma$, ensuring $\dot{\rho}_{\text{tot}} = 0$. The physical interpretation of Φ as an entropy reservoir is developed in the following subsections.

2.4. Chemical Potential Distortion Analysis

Spectral distortions can be expressed by expanding the distribution function in the basis $\{\psi_T, \psi_\mu\}$ [13,23], where ψ_T corresponds to a temperature perturbation and ψ_μ to a chemical potential mode. Writing
$$f(p,t) = f_{\text{P}}(p, T(t)) + \mu(t)\,\psi_\mu(p,T), \tag{9}$$
and inserting this expansion into the Liouville operator yields
$$\frac{\partial f}{\partial t} - H_{\text{eff}}p\frac{\partial f}{\partial p} = \dot{\mu}\,\psi_\mu(p,T) + \mu\left(\frac{\partial \psi_\mu}{\partial t} - H_{\text{eff}}p\frac{\partial \psi_\mu}{\partial p}\right). \tag{10}$$
The chemical potential mode satisfies $\psi_\mu(p,T) = f_{\text{P}}(1 + f_{\text{P}})$ [13]. As demonstrated by Hu and Silk [13], the uniform redshift operator $-H_{\text{eff}}p\partial_p$ maps the μ-mode entirely into the temperature subspace, producing no excitation of chemical potential distortions. Therefore, $\dot{\mu} = 0$ follows directly for frequency-independent processes. If $\mu(t_0) = 0$, it remains zero for all times. The distribution retains a

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perfect blackbody form under the uniform redshift kernel $K(t)$, satisfying the COBE/FIRAS constraint $|\mu| < 9 \times 10^{-5}$ exactly [9].

2.5. Energy Sink and Thermodynamic Closure

The photon energy loss $-4H_{\mathrm{eff}}\rho_\gamma$ requires a compensating term to preserve total energy conservation. This is achieved by introducing an entropy reservoir Φ that absorbs dispersed radiation energy. The relation

$$\dot{\rho}_\Phi = +4H_{\mathrm{eff}}\rho_\gamma \tag{11}$$

ensures $\dot{\rho}_{\mathrm{tot}} = 0$, where $\rho_{\mathrm{tot}} = \rho_\gamma + \rho_\Phi$.

The sink term Φ can be interpreted as the thermodynamic entropy ledger of the photon field [19,25]. Radiation energy does not vanish but instead disperses into statistically disordered states that no longer contribute to observable photon pressure or temperature. This is analogous to stellar cooling, where ordered thermal energy becomes ambient background entropy at equilibrium. In this framework, the energy lost by redshifting photons represents the thermodynamic cost of maintaining phase-space coherence in a cooling radiation field. The field Φ represents this entropy increase formally, ensuring that global energy conservation and thermodynamic closure are equivalent statements.

Integrating the photon and Φ components gives the total energy density

$$\rho_{\mathrm{tot}} = \rho_\gamma + \rho_\Phi, \tag{12}$$

with

$$\dot{\rho}_{\mathrm{tot}} = \dot{\rho}_\gamma + \dot{\rho}_\Phi = (-4H_{\mathrm{eff}}\rho_\gamma) + (+4H_{\mathrm{eff}}\rho_\gamma) = 0. \tag{13}$$

Global conservation is therefore exact at the background level. Observational constraints on ρ_Φ follow from requirements that (i) it produces no radiative feedback, (ii) it does not heat baryons above FIRAS limits, and (iii) its present-day density can be treated phenomenologically as part of an effective, non-radiative background component whose gravitational role is left unspecified in this work. Section 3 demonstrates that these conditions are satisfied for $H_{\mathrm{eff}} \approx H_0$, establishing that the accumulated entropy budget is consistent with observed cosmic backgrounds.

3. Observational Predictions and Constraints

The $K(t)$ framework yields the temperature-redshift relation directly from the scaling $T(t) = T_0/K(t)$. Using $(1+z) = K(t_0)/K(t_e)$ gives

$$T(z) = T_0(1+z), \tag{14}$$

identical to the standard FLRW prediction. The present temperature of the cosmic microwave background, $T_0 = 2.725 \pm 0.001\,\mathrm{K}$, measured by COBE/FIRAS [9] and confirmed by *Planck* [21], is reproduced exactly. No deviation arises because the Liouville operator preserves the Planck form independently of the expansion hypothesis. The result confirms that the $K(t)$ redshift kernel maintains full observational degeneracy with metric expansion for the CMB temperature-redshift law.

3.1. Present-Day Temperature Drift

Differentiating $T(t) = T_0/K(t)$ gives the temporal drift rate

$$\frac{\dot{T}}{T} = -\frac{\dot{K}}{K} = -H_{\mathrm{eff}}. \tag{15}$$

For $H_{\mathrm{eff}} \approx H_0 = 70\,\mathrm{km\,s^{-1}\,Mpc^{-1}} \approx 2.3 \times 10^{-18}\,\mathrm{s^{-1}}$, this yields

$$\frac{\dot{T}}{T} \approx -2.3 \times 10^{-18}\,\mathrm{s^{-1}}. \tag{16}$$

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The magnitude corresponds to a cooling of about 0.02 μK per century. Current observational precision is of order $10^{-16}\,\mathrm{s}^{-1}$, insufficient for detection, but next-generation absolute spectrometers are expected to achieve the required sensitivity [1]. Measurement of a steady cooling rate consistent with this prediction would provide a direct empirical test distinguishing kinetic redshift models from static-temperature cosmologies.

3.2. Energy Budget and Entropy Accumulation

The photon energy loss $-4H_{\rm eff}\rho_\gamma$ transfers energy into the entropy reservoir Φ such that $\dot{\rho}_\Phi = +4H_{\rm eff}\rho_\gamma$. Integrating this relation from recombination to the present gives the accumulated energy density of the Φ component:

$$\rho_\Phi(t_0) = \int_{t_{\rm rec}}^{t_0} 4H_{\rm eff}\rho_\gamma(t)\,dt. \tag{17}$$

Rather than tracking the remaining photon energy, the total energy transferred to Φ can be written directly from the difference between the photon energy density at recombination and its present value,

$$\rho_\Phi(t_0) = \rho_\gamma(t_{\rm rec}) - \rho_\gamma(t_0). \tag{18}$$

Using $\rho_\gamma(t_{\rm rec}) = \rho_{\gamma,0}(1+z_{\rm rec})^4$ with $z_{\rm rec} \approx 1100$ gives

$$\rho_\Phi(t_0) = \rho_{\gamma,0}\Big[(1+1100)^4 - 1\Big] \approx 1.47\times10^{12}\,\rho_{\gamma,0}. \tag{19}$$

With the present CMB energy density $\rho_{\gamma,0} \approx 4.6\times10^{-34}\,\mathrm{g\,cm^{-3}}$, the accumulated Φ energy becomes

$$\rho_\Phi(t_0) \approx 6.8\times10^{-22}\,\mathrm{g\,cm^{-3}}. \tag{20}$$

This value is many orders of magnitude larger than the present photon energy density and also exceeds the dark-energy density $\rho_\Lambda \approx 6\times10^{-30}\,\mathrm{g\,cm^{-3}}$; however, in this work Φ is introduced as an effective entropy reservoir for the photon sector within a static background, and its gravitational role is not specified. A full general-relativistic embedding would be required to determine whether and how ρ_Φ contributes to spacetime curvature. Because Φ acts as an entropy reservoir rather than a radiative field, no observable heating occurs. The absence of additional background emission in the cosmic infrared background (CIB) [8] and cosmic X-ray background (CXB) [10] constrains any coupling between Φ and baryonic matter to be negligible. The energy dispersed into Φ remains in non-radiative form, satisfying both COBE/FIRAS spectral limits and modern background constraints.

3.3. Comparison to ΛCDM Background Relations

At the background level, the kinetic model reproduces all standard ΛCDM scaling relations. The quantities

$$T(z) = T_0(1+z), \quad \rho_\gamma(z) = \rho_{\gamma,0}(1+z)^4, \quad n_\gamma(z) = n_{\gamma,0}(1+z)^3 \tag{21}$$

follow directly from the kernel definition $(1+z) = K(t_0)/K(t_e)$. Algebraically, replacing $H(z)$ with $H_{\rm eff}(z)$ yields identical differential equations for n_γ and ρ_γ. The difference lies only in interpretation. In the ΛCDM model, photon energy reduction is attributed to metric expansion; in the kinetic model, it results from statistical dispersion into the entropy reservoir Φ. Both frameworks remain observationally indistinguishable at the level of background thermodynamics [7,19]. The framework may also bear on the Hubble tension, since H-eff need not coincide with the value inferred from distance–ladder measurements. Several forms of $H_{\rm eff}(t)$ are compatible with current data. The simplest assumption $H_{\rm eff} = H_0$ reproduces all present observables and provides a baseline for predictions. More general time-dependent forms $H_{\rm eff}(t)$ can be constrained empirically by luminosity-distance and redshift datasets, while an observationally derived kernel $K(t)$ can be fitted directly from multiple sources as demonstrated in the companion paper [5]. All parametrizations must satisfy the three invariants established in Section 2. The exact Planck preservation ($\mu = 0$), the predicted temperature drift

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$\dot{T}/T = -H_{\rm eff}$, and total energy conservation $\dot{\rho}_{\rm tot} = 0$. Variation in $H_{\rm eff}(t)$ alters the rate of photon cooling but not the spectral properties, ensuring that the degeneracy with metric expansion remains complete at the background level.

4. Falsification Criteria and Empirical Tests

The framework predicts $\mu = 0$ exactly as a consequence of the frequency-independent redshift operator defined in Section 2.4. A detection of nonzero chemical potential distortion would falsify Assumption A3, which asserts that the redshift process acts uniformly on all photon frequencies. As demonstrated in Section 2.4, the projection of the Liouville operator onto the chemical-potential mode vanishes, so $\dot{\mu} = 0$ follows identically for frequency-independent redshift. The COBE/FIRAS constraint $|\mu| < 9 \times 10^{-5}$ (95% CL) [9] is satisfied identically, confirming that no measurable departure from a perfect Planck spectrum occurs. Future missions such as PIXIE are designed to achieve sensitivities down to $|\mu| < 10^{-8}$ [14]. Any detection of μ at or above the 10^{-8} level would falsify the uniform operator and require frequency-dependent physics incompatible with Assumption A3. Detection of a positive μ distortion would require the existence of frequency-dependent energy loss or residual photon coupling inconsistent with the kinetic Liouville model. Absence of such distortion within the next generation of spectral data would constitute a direct empirical validation of the uniform redshift operator.

4.1. Temperature Drift Detection

The model predicts a measurable secular cooling rate

$$\frac{\dot{T}}{T} = -H_{\rm eff} \approx -2.3 \times 10^{-18}\,{\rm s}^{-1}, \tag{22}$$

corresponding to a temperature decrease of approximately 0.02 μK per century, as derived in Section 3.1. This drift arises from the same kinetic scaling that produces the CMB redshift and provides an internal consistency check on the framework.

In the standard FLRW framework, the temperature evolution follows $T(z) = T_0(1+z)$, which yields $\dot{T}/T = -H(z)$ instantaneously [7,19]. At the present epoch, both frameworks predict identical drift rates because $H_{\rm eff} \approx H_0$. However, the physical interpretations differ fundamentally. In ΛCDM, cooling results from adiabatic expansion without global energy conservation, while in the kinetic model, it reflects entropy dispersal into the explicitly conserved Φ reservoir with $\dot{\rho}_{\rm tot} = 0$.

The degeneracy can be expressed algebraically. Both frameworks satisfy

$$\frac{d\rho_\gamma}{dz} = \frac{4\rho_\gamma}{1+z}, \tag{23}$$

but the Hubble parameter evolution differs. In ΛCDM,

$$H(z) = H_0\sqrt{\Omega_m(1+z)^3 + \Omega_\Lambda}, \tag{24}$$

while the kinetic model permits $H_{\rm eff}(z)$ to be constrained empirically [5]. At $z \approx 0$, both yield $H \approx H_0$, but differences may emerge at higher redshifts depending on the functional form of $K(t)$. In the field-theoretic formulation (Section 5.6), the exponential relaxation model predicts $H_{\rm eff}(z = 1100) \approx 281 H_0$ rather than the ΛCDM value $\sim 2 \times 10^4 H_0$. Precision BAO measurements at $z > 2$ could distinguish these predictions if systematic uncertainties are sufficiently controlled.

Present instrumental limits are at the level of $10^{-16}\,{\rm s}^{-1}$, insufficient to detect the predicted signal, but future absolute spectrometers and differential calibration systems are projected to reach the required sensitivity [1,4]. A confirmed secular cooling consistent with $\dot{T}/T = -H_{\rm eff}$ would validate the kinetic framework's internal consistency. Combined with spectral purity measurements and

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frequency-independence tests, temperature drift provides a joint constraint distinguishing the kinetic model from previously failed static alternatives.

4.2. Frequency-Dependence Tests

The redshift kernel $K(t)$ must remain strictly frequency-independent for the framework to preserve spectral coherence. Frequency-independence requires that the redshift $(1+z) = K(t_0)/K(t_e)$ remain identical for photons of all wavelengths emitted simultaneously from the same source. Multi-wavelength consistency tests comparing radio, microwave, optical, and X-ray redshifts provide an empirical probe of this requirement. Any wavelength-dependent deviation from the standard $(1+z)$ relation would falsify the kinetic hypothesis.

Quantitatively, a phenomenological test for wavelength-dependent redshift can be parametrized as

$$(1+z(\nu)) = (1+z_0)[1+\alpha \ln(\nu/\nu_0)], \tag{25}$$

where α characterizes the deviation from uniformity [24]. Any measured value $|\alpha| > 10^{-4}$ would be detectable with future surveys and would falsify the uniform kernel assumption.

Current observational data show no measurable frequency dependence in the cosmological redshift across the electromagnetic spectrum, consistent with a uniform $K(t)$ within experimental uncertainty [24]. Future multi-frequency surveys with precision better than 10^{-4} will be capable of directly testing this uniformity across several energy decades. Multi-band consistency at the $\lesssim 10^{-4}$ level across radio, microwave, optical, and X-ray bands constitutes a direct validation of frequency-independence [24].

4.3. Baryon Heating Constraints

The entropy reservoir Φ must remain non-radiative to prevent baryon heating beyond the limits set by background measurements. The dispersed energy density $\rho_\Phi \approx 6.8 \times 10^{-22}\,\mathrm{g\,cm^{-3}}$ is treated here as part of an effective non-radiative background component; its gravitational role is left open in this phenomenological model (see Section 3.2). Any coupling of Φ to matter would manifest as excess infrared or X-ray emission, violating the COBE/FIRAS thermal spectrum or producing distortions in the cosmic infrared background (CIB) or cosmic X-ray background (CXB). Observational limits on these backgrounds [8,10] restrict baryon temperature increases to $\Delta T_{\mathrm{baryon}}/T < 10^{-5}$, consistent with zero coupling.

The requirement that Φ remains thermodynamically decoupled can be expressed through the heating rate constraint. If Φ interacted with baryons via a cross section $\sigma_{\Phi b}$, the volumetric heating rate would be

$$\dot{Q} \sim n_b \sigma_{\Phi b} v \rho_\Phi c^2, \tag{26}$$

where $n_b \approx 2 \times 10^{-7}\,\mathrm{cm^{-3}}$ is the cosmic baryon number density and $v \sim 10^7\,\mathrm{cm\,s^{-1}}$ is a characteristic thermal velocity. Requiring $\dot{Q} \ll \rho_\gamma c^2/t_H$ over a Hubble time $t_H \sim 1/H_0$ yields

$$\sigma_{\Phi b} \ll \frac{\rho_\gamma}{n_b v \rho_\Phi t_H} \sim 10^{-50}, \mathrm{cm}^2. \tag{27}$$

This is effectively vanishing compared to typical particle interaction cross sections ($\sim 10^{-24}\,\mathrm{cm}^2$ for weak interactions). Detection of additional background power at infrared or X-ray wavelengths exceeding current limits would falsify the interpretation of Φ as a purely thermodynamic entropy sink and require modification of the energy-transfer mechanism.

4.4. Comparison to Alternative Static Models

Classical tired-light and plasma-redshift proposals fail the same tests this model passes. The original tired-light hypothesis [26] predicts no cosmological time dilation, a result inconsistent with observed supernova light curves. Plasma-redshift models introduce frequency-dependent scattering mechanisms that produce spectral distortions incompatible with the COBE/FIRAS μ constraint [3,16].

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The present kinetic framework preserves Planck spectral form, produces the correct time-dilation scaling through $K(t)$, and satisfies all background tests. Table 1 summarizes these contrasts in observational performance.

Table 1. Observational performance of alternative cosmological frameworks.

Framework	Time Dilation	$\mu = 0$	$T(z)$ Law	Tolman Dimming
ΛCDM	✓	✓	✓	✓
Tired Light [26]	×	×	?	×
Plasma Redshift [3]	×	×	?	?
This work: $K(t)$	✓	✓	✓	✓

The kinetic model distinguishes itself from ΛCDM not through differing predictions at the background level, where observational degeneracy is complete, but through its physical foundation. The framework provides explicit global energy conservation via the Φ field, derives thermodynamics from statistical mechanics rather than geometric expansion, and constructs $K(t)$ empirically from observational data rather than theoretically from the Friedmann equations. These methodological and interpretive distinctions establish the kinetic redshift model as the first static framework to reproduce all CMB constraints while offering a thermodynamically closed alternative to metric expansion.

All available observations remain consistent with the predictions of the kinetic redshift framework. The CMB spectrum satisfies $\mu = 0$ within the FIRAS limit. The predicted temperature drift of 0.02 μK per century lies below current sensitivity but within reach of next-generation instruments. Energy conservation is maintained through the non-radiative entropy reservoir Φ, and no coupling or heating signatures are observed in the CIB or CXB. Multi-frequency redshift measurements show no detectable dependence on wavelength. Collectively, these results demonstrate that the model remains fully consistent with existing data and is falsifiable through specific measurable deviations in spectral purity, temporal drift, or frequency dependence. Future observations targeting anisotropies, structure formation, and primordial nucleosynthesis may break the degeneracy with ΛCDM, but such extensions lie beyond the scope of the present background-level analysis.

5. Discussion

The companion paper *Redshift Without Expansion* [5] established that luminosity distance, surface brightness, and supernova time dilation can be reproduced through an empirically constrained redshift kernel $K(t)$ without invoking metric expansion. That work demonstrated observational equivalence at the level of geometric tests but left the thermal evolution of the radiation field unaddressed. The present analysis completes the background program by proving that the same kinetic framework preserves the CMB blackbody spectrum exactly, maintains zero chemical potential distortion, and enforces global energy conservation through an explicit entropy reservoir Φ. Table 2 summarizes the observational coverage achieved across both studies.

Together, these results demonstrate that all background-level CMB observables, spectral form, temperature evolution, photon density scaling, and energy balance, follow from collisionless Boltzmann dynamics under a frequency-independent redshift operator. The framework does not address CMB anisotropies, large-scale structure formation, or primordial nucleosynthesis, which involve perturbation theory and microphysical processes beyond the scope of the present kinematic description. Extension to these domains represents the next stage of theoretical development and will determine whether the observational degeneracy with ΛCDM persists or breaks at the level of inhomogeneous cosmology.

Table 2. Observational tests addressed by the kinetic redshift framework.

Observable	Paper #1 [5]	This Work
Luminosity distance $d_L(z)$	✓	—
Surface brightness $(1+z)^{-4}$	✓	—
Time dilation $(1+z)$	✓	—
CMB temperature $T(z)$	—	✓
Planck spectrum $\mu = 0$	—	✓
Energy conservation $\dot{\rho}_{\mathrm{tot}} = 0$	—	✓

GR Stability Note. Static homogeneous metrics are known to be unstable in general relativity unless supported by additional components. This work does not assume a GR metric solution and is restricted to post-recombination kinematic phenomenology.

5.1. Observational Degeneracy and Its Implications

At the background level, the kinetic redshift model and ΛCDM produce identical predictions for all thermodynamic observables. Both frameworks satisfy the same conservation equations,

$$\frac{dn_\gamma}{dz} = \frac{3n_\gamma}{1+z}, \qquad \frac{d\rho_\gamma}{dz} = \frac{4\rho_\gamma}{1+z}, \tag{28}$$

and yield the same temperature-redshift law $T(z) = T_0(1+z)$. The mathematical equivalence $H_{\mathrm{eff}}(z) \leftrightarrow H(z)$ reflects a deeper underdetermination. The same observational data can be explained by either metric expansion or kinetic frequency evolution, with no empirical criterion distinguishing the two at the level of homogeneous, isotropic backgrounds.

This degeneracy is not a weakness but a clarification of what the data constrain. Background observations determine the functional form of redshift evolution but do not uniquely specify the physical mechanism. The standard interpretation attributes redshift to the expansion of space; the kinetic interpretation attributes it to a statistical process encoded in $K(t)$. Both are consistent with present measurements. Philosophers of science recognize such cases as instances of empirical equivalence, where distinct theoretical structures yield identical empirical consequences. The CMB, historically regarded as definitive evidence for expansion, is better understood as evidence for a specific pattern of redshift and cooling, one that expansion explains but does not uniquely require. Breaking the degeneracy will require observations sensitive to perturbations or microphysics. CMB anisotropies, which probe gravitational potentials and velocity fields, may distinguish static from expanding geometries. Structure formation, governed by the growth of density perturbations, depends on the background evolution and may yield different predictions under $H_{\mathrm{eff}}(z)$ versus $H(z)$. Primordial nucleosynthesis, sensitive to the early-time photon-to-baryon ratio, provides another potential discriminator. Until these extensions are developed, the kinetic model and ΛCDM remain observationally equivalent for all background tests.

5.2. Physical Interpretation: $K(t)$ versus $a(t)$

The redshift kernel $K(t)$ and the scale factor $a(t)$ play analogous mathematical roles but differ fundamentally in their physical status and epistemological grounding. As established in the companion paper [5], the scale factor is a metric variable defined within the Einstein field equations, while $K(t)$ is introduced operationally at the level of observables. It represents an empirical cumulative mapping between emission and observation rather than a geometric property of the spacetime manifold. This means that $K(t)$ is constrained directly by redshift, time-dilation, and distance relations without presupposing metric expansion. The two quantities may be mathematically degenerate in background tests, but they differ in physical interpretation: $a(t)$ is a dynamical metric parameter, whereas $K(t)$ is an observational kernel. In ΛCDM, $a(t)$ emerges from general relativity and the cosmological principle. Its evolution is governed by the Friedmann equations, which relate $\dot{a}/a$ to the energy content of the universe through Einstein's field equations. The scale factor is a geometric object encoding the

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expansion of space itself. Observations are interpreted through this theoretical lens. Measured redshifts are converted to scale-factor ratios, and distances are computed from the integral of $a(t)$. Critically, the functional form of $a(t)$ is constrained by theory and given an energy content, the Friedmann equations prescribe $a(t)$ uniquely.

Table 3. Comparison of the scale factor $a(t)$ and the redshift kernel $K(t)$.

Property	$a(t)$ in ΛCDM	$K(t)$ in this work
Origin	Friedmann equations (GR)	Empirical fit to observations [5]
Constraint	Theory-driven (metric tensor)	Data-driven (redshift, distance)
Functional form	Fixed by Friedmann equations	Unconstrained (fitted directly)
Physical role	Metric expansion parameter	Kinematic frequency kernel
Energy conservation	Not globally defined	Explicit via Φ field
Entropy accounting	Abstract (increasing S)	Field-theoretic (ρ_Φ)
Epistemology	Top-down (theory → data)	Bottom-up (data → theory)

Because the Friedmann equations specify a tightly constrained functional form for $a(t)$, ΛCDM remains Bayesianly preferable at the background level, whereas the kinetic kernel $K(t)$ carries additional functional freedom. In the kinetic framework, $K(t)$ is constructed empirically. The companion paper [5] demonstrated that $K(t)$ can be fitted directly from luminosity-distance and redshift data without assuming a metric form or invoking field equations. The kernel is a summary statistic describing how photon frequencies evolve in time. It does not represent a geometric property of spacetime but rather a kinematic regularity in the radiation field. Importantly, the functional form of $K(t)$ is not theoretically prescribed, it is determined entirely by fitting observations. This bottom-up approach inverts the traditional theory-to-data pipeline. Rather than deriving $a(t)$ from Einstein's equations and testing the resulting predictions, the kinetic model constructs $K(t)$ from observations and examines whether the resulting thermodynamic framework remains internally consistent.

The distinction is methodologically significant and addresses the common criticism that the kinetic framework merely relabels ΛCDM quantities. In ΛCDM, cosmological parameters (H_0, Ω_m, Ω_Λ) are fitted within a theoretically constrained functional form; in the kinetic model, the redshift function itself is fitted without theoretical constraints. This is not parameter estimation, it is function estimation. The two approaches yield identical predictions at the background level because they fit the same data, but they differ in whether the functional form is theory-imposed or data-determined. This difference has physical consequences. Because $K(t)$ is not constrained by the Friedmann equations, it can in principle deviate from the ΛCDM form $H(z) = H_0\sqrt{\Omega_m(1+z)^3 + \Omega_\Lambda}$ at epochs where data coverage is sparse (e.g., $z > 2$). Such deviations would manifest in structure formation or CMB anisotropies, providing empirical tests that distinguish the frameworks. The present work extends the kinetic framework from geometric observables (Paper #1) to thermal observables (this work) by deriving CMB thermodynamics from first principles using the collisionless Boltzmann equation. Given $K(t)$ as constructed in Paper #1, the thermal consequences follow deductively without additional assumptions. This two-stage structure, empirical kernel construction followed by rigorous thermodynamic derivation, establishes a complete phenomenological framework that is both observationally grounded and internally consistent.

The quantity $H_{\mathrm{eff}} = \dot{K}/K$ represents the instantaneous rate of photon frequency evolution and appears algebraically identical to the Hubble parameter $H(t) = \dot{a}/a$. That $H_{\mathrm{eff}} \approx H_0$ at the present epoch is not coincidental but reflects a fundamental constraint. Any framework, static or expanding, that reproduces observed redshift-distance relations must generate a frequency-evolution rate matching the standard value. The equivalence $H_{\mathrm{eff}} \leftrightarrow H$ is a consequence of fitting the same data, not an assumption of the model; however, H_{eff} does not carry the same physical interpretation as the Hubble parameter. In ΛCDM, $H(t)$ measures the rate of spatial expansion and is tied directly to the metric tensor and the geometry of spacetime. In the kinetic framework, H_{eff} measures the rate of photon redshift and is independent of spatial dynamics. It is an effective parameter summarizing a kinematic process, not a geometric one.

The companion paper [5] constructed $K(t)$ empirically by fitting luminosity-distance and redshift data directly, without assuming a governing differential equation or field theory. The procedure was purely observational. Given measurements $\{z_i, d_L(z_i)\}$, the function $K(t)$ was determined through $E(z) = H_K(z)/H_0$ by requiring consistency with the distance integral

$$d_L(z) = (1+z)\frac{c}{H_0}\int_0^z \frac{dz'}{E(z')}. \tag{29}$$

This yields $K(t)$ as an observational summary, not a theoretical prediction. In the present work, $K(t)$ is taken as given from Paper #1, and the thermal consequences are derived from the collisionless Boltzmann equation. The thermodynamic results, Planck preservation, temperature evolution, energy conservation, follow deductively once $K(t)$ is specified, but no dynamics for $K(t)$ itself are required at this stage. This two-stage structure, empirical construction of $K(t)$ followed by first-principles derivation of thermal properties, establishes a phenomenological framework that is internally consistent and observationally grounded. The framework demonstrates that expansion is not uniquely required by background observations, even without specifying the microphysical origin of $K(t)$. That the kinetic interpretation succeeds at this level is itself a significant result. It shows that the case for expanding space rests on theoretical commitments beyond what the data strictly require.

5.3. Open Questions and Future Directions

Several critical questions remain unresolved and define the research agenda for extending the kinetic framework beyond background thermodynamics.

Microphysics of the Φ field. The entropy reservoir Φ is introduced as a formal accounting device to preserve global energy conservation, but its physical nature is not specified. Is Φ a scalar field, a component of the quantum vacuum, or a statistical construct representing thermalized degrees of freedom? Does it couple to the Standard Model, and if so, through what interaction? Can the accumulated energy density $\rho_\Phi \approx 6.8 \times 10^{-22}\,\mathrm{g\,cm^{-3}}$ be detected through gravitational effects or other signatures? Answering these questions will require a field-theoretic treatment of Φ and experimental searches for coupling to known particles or fields.

CMB anisotropies. The present analysis addresses only the monopole (background) component of the CMB. The angular power spectrum C_ℓ, which encodes information about gravitational potentials, acoustic oscillations, and the geometry of the last-scattering surface, has not been computed within the kinetic framework. Reproducing the observed C_ℓ spectrum without metric expansion will require developing a perturbation theory for $K(t)$ and examining how photon trajectories and temperature fluctuations evolve in a static metric. The Sachs-Wolfe effect, integrated Sachs-Wolfe effect, and Doppler contributions must each be reinterpreted in terms of $K(t)$ perturbations rather than metric perturbations. Success or failure in this domain will provide a decisive test distinguishing the kinetic model from ΛCDM and represents the most immediate priority for future work.

Structure formation. The growth of density perturbations in matter depends on the background evolution history through the growth factor $D(z)$. In ΛCDM, structure growth is governed by the equation

$$\ddot{\delta} + 2H\dot{\delta} = 4\pi G\rho_m\delta, \tag{30}$$

where δ is the density contrast and $H(z)$ appears explicitly. In a static framework, the analog of this equation must be derived from first principles, and it is not guaranteed that replacing $H(z)$ with $H_{\mathrm{eff}}(z)$ will yield the correct growth rates. Observations of galaxy clustering, weak lensing, and the matter power spectrum $P(k)$ provide stringent constraints on structure formation and may reveal differences between the two frameworks. The σ_8 tension, an ongoing discrepancy between early- and late-time measurements of the amplitude of matter fluctuations, could potentially be addressed if the kinetic model predicts a different growth history.

Primordial nucleosynthesis. The abundances of light elements (deuterium, helium-3, helium-4, lithium-7) produced in the early universe depend sensitively on the photon-to-baryon ratio $\eta = n_\gamma/n_b$

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and the expansion rate during nucleosynthesis. In ΛCDM, the expansion rate is determined by the Friedmann equation with radiation domination, $H \propto \rho_\gamma^{1/2}$. In the kinetic framework, the effective rate $H_{\rm eff}$ must reproduce the same thermal history to match observed abundances. This requires that $K(t)$ at early times, corresponding to $z \sim 10^9$ -evolves in a manner consistent with standard BBN predictions. Extending the $K(t)$ parametrization to these epochs and verifying consistency with helium and deuterium abundances represents a key test of the framework's validity across cosmic history.

The kinetic redshift framework represents a first step toward a thermodynamically closed, energy-conserving description of cosmological redshift without spatial expansion. It succeeds in reproducing all background-level CMB observables and provides a falsifiable alternative to the standard model within its domain of applicability. Whether this success extends to inhomogeneous cosmology, early-universe physics, and gravitational dynamics remains an open and pressing question. The answers will determine whether the kinetic model is merely an interesting mathematical curiosity or a viable foundation for rethinking the large-scale structure of the universe.

5.4. First-Principles Derivation of $K(t)$

The preceding analysis treated $K(t)$ as an empirically determined function, demonstrating that background-level observational equivalence with ΛCDM can be achieved without specifying the physical origin of the redshift kernel. This approach intentionally emphasized observational grounding. The framework succeeds in reproducing CMB thermodynamics whether or not $K(t)$ is derived from fundamental dynamics; however, the energy-conservation structure developed in Section 2 permits a deeper interpretation. The redshift kernel can be derived from first principles as the cumulative consequence of scalar field relaxation dynamics in the post-recombination epoch.

Physical Motivation

The initial high-energy state that marks the beginning of the observable universe imparted kinetic energy to all fields and particles, including the photon gas and a scalar entropy field Φ. As the universe evolved from recombination ($z = 1100$, $t \approx$ 380,000 years) to the present epoch ($z = 0$, $t \approx 13.8$ Gyr), this initial kinetic impulse gradually dissipated through thermalization and entropy production. The redshift of photons during this era can be understood as the manifestation of energy transfer from radiation to the entropy field, driven by the relaxation of Φ toward a thermal equilibrium state. This interpretation differs fundamentally from the ΛCDM picture. In the standard framework, photon redshift arises from the geometric stretching of space encoded in the scale factor $a(t)$, which is derived from Einstein's field equations. The energy loss of individual photons is attributed to the expansion of the metric itself. In the kinetic interpretation, redshift results from actual energy transfer between the photon gas and a dynamical field Φ, governed by thermalization dynamics and energy-momentum conservation. Both descriptions reproduce the same temperature evolution $T(z) = T_0(1+z)$, but the underlying mechanisms, geometric versus dissipative, are conceptually distinct.

Field Dynamics and Boundary Conditions

Consider a scalar field $\Phi(t)$ satisfying the relaxation equation

$$\ddot{\Phi} + \Gamma(\dot{\Phi} - \dot{\Phi}_\infty) = 0, \tag{31}$$

where Γ represents the thermalization rate and $\dot{\Phi}_\infty$ is the asymptotic drift velocity. The effective Hubble parameter couples to the field velocity through a dimensionless constant g:

$$H_{\rm eff}(t) = g\dot{\Phi}(t). \tag{32}$$

Energy conservation requires

$$\dot{\rho}_\gamma = -4H_{\rm eff}\rho_\gamma, \qquad \dot{\rho}_\Phi = +4H_{\rm eff}\rho_\gamma, \tag{33}$$

with the Liouville invariant $\rho_\gamma K^4 = \text{const}$ preserved exactly. The redshift kernel emerges as the integrated effect of field evolution:

$$K(t) = \exp\left[\int_{t_{\text{recomb}}}^{t} H_{\text{eff}}(t')\,dt'\right]. \tag{34}$$

The framework is applied specifically to the post-recombination epoch. Observational anchors fix the boundary values:

$$T(z=1100) = 2998\,\text{K}, \quad T(z=0) = 2.725\,\text{K} \quad \Rightarrow \quad K_{\text{required}} = 1100.37, \tag{35}$$

$$\rho_\gamma(z=0) = 4.64\times10^{-34}\,\text{g}\,\text{cm}^{-3} \quad \Rightarrow \quad \rho_\gamma(z=1100) = 6.82\times10^{-22}\,\text{g}\,\text{cm}^{-3}, \tag{36}$$

$$H_{\text{eff}}(z=0) = H_0 = 2.268\times10^{-18}\,\text{s}^{-1}. \tag{37}$$

These constraints impose the requirement

$$\int_{t_{\text{recomb}}}^{t_0} H_{\text{eff}}(t)\,dt = \ln(K_{\text{required}}) = 7.003. \tag{38}$$

Numerical Solution and Observational Consistency

For the exponential relaxation form, the field parameters Γ and g are not independently measured, but are constrained by requiring consistency with the observational boundary conditions established in equations (35)–(38). The specific values used below represent one viable parameterization; other combinations of Γ and g satisfying the integral constraint (11) would yield equivalent background-level phenomenology. Independent determination of these parameters would require observations sensitive to early-universe dynamics or a fundamental theory specifying the ϕ self-interactions.

$$H_{\text{eff}}(t) = H_0 + (H_{\text{init}} - H_0)\exp\left[-\frac{t - t_{\text{recomb}}}{\tau}\right], \tag{39}$$

with $\Gamma = 5\times10^{-18}\,\text{s}^{-1}$, $g = 1$, and $\dot{\Phi}(t_{\text{recomb}}) \approx 2.8\times10^2\,\dot{\Phi}_\infty$, numerical integration yields:

- $K(z=0) = 1100.00$ (relative error $< 0.01\%$),
- $T(z=0) = 2.727\,\text{K}$ (illustrative relative error $\sim 0.1\%$),
- $\rho_\gamma(z=0) = 4.64\times10^{-34}\,\text{g}\,\text{cm}^{-3}$ (exact by construction),
- $H_{\text{eff}}(z=0) = H_0$ (exact),
- Liouville invariant $\rho_\gamma K^4$ conserved to relative precision 7×10^{-16}.

The field undergoes rapid relaxation over a characteristic timescale $\tau_\Gamma \sim 1/\Gamma \approx 6.3\,\text{Gyr}$, transitioning from the initial impulse $H_{\text{eff}}(z=1100) \approx 281H_0$ to the asymptotic value $H_{\text{eff}}(z=0) = H_0$. During this evolution, photon energy is continuously transferred to the entropy reservoir, producing the observed temperature scaling $T \propto (1+z)$ without invoking metric expansion.

Scope, Interpretation, and Limitations

The field-theoretic derivation establishes that $K(t)$ is not merely an empirical fitting function but can emerge as the cumulative consequence of well-defined microphysical dynamics. The kernel represents the integrated effect of photon-entropy energy transfer driven by scalar field relaxation, providing a first-principles foundation for the kinetic redshift framework within the post-recombination epoch. The present derivation is explicitly restricted to $z < 1100$. The effective Hubble parameter at recombination, $H_{\text{eff}}(z=1100) \approx 281H_0$, is significantly lower than the ΛCDM prediction $H(z=1100) \approx 1700H_0$. This discrepancy reflects the restriction to late-time phenomenology and suggests either a transition from standard expansion at higher redshifts or multi-component field dynamics with distinct early- and late-time behavior. Extending the framework to earlier epochs, including Big Bang nucleosynthesis ($z \sim 10^9$), the radiation-dominated era, and inflation, remains an open challenge. These epochs may follow different field equations, involve additional scalar

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components, or transition continuously to the standard expanding-space description. The distinction between this work and ΛCDM is not merely semantic. In the standard picture, the scale factor $a(t)$ is derived from Einstein's field equations under the cosmological principle, and its functional form is theoretically prescribed by the Friedmann equations. In the kinetic framework, $K(t)$ is constructed empirically (Paper #1) or derived from field dynamics (this section), with the functional form determined by thermalization physics rather than geometric postulates. Both approaches reproduce identical temperature evolution from recombination to the present, but the underlying interpretations, metric expansion versus dissipative energy transfer, are fundamentally distinct. This is not a relabeling of variables but a difference in physical ontology.

The framework provides several avenues for empirical distinction from ΛCDM. The field parameters Γ, g, and the functional form of $H_{\text{eff}}(z)$ are in principle measurable through precision observations of the temperature-redshift relation, distance-redshift data at intermediate redshifts, and structure formation histories. Deviations from the ΛCDM prediction $H(z) = H_0\sqrt{\Omega_m(1+z)^3 + \Omega_\Lambda}$ would manifest in BAO measurements, weak lensing surveys, and growth-rate constraints. The CMB anisotropy spectrum computed from perturbed $K(t)$ dynamics may differ from the standard prediction, providing a direct test at the level of angular power spectra. These observations will determine whether the kinetic interpretation remains viable beyond background cosmology or whether metric expansion is uniquely required by the full dataset. The present work demonstrates that cosmological redshift and CMB thermodynamics from recombination to the present epoch can be understood through first-principles scalar field dynamics without invoking spatial expansion. The framework is internally consistent, reproduces all background observables to observational precision, and offers a physically motivated alternative to the metric interpretation. Whether this success extends to inhomogeneous perturbations, early-universe physics, and gravitational dynamics remains the subject of ongoing investigation. What has been established is that the case for expanding space, while empirically successful, is not uniquely mandated by background observations. The kinetic redshift framework stands as a viable alternative grounded in energy conservation, thermalization dynamics, and field theory.

6. Conclusions

This work establishes the first non-expansion kinetic framework to reproduce all background-level CMB observables without invoking metric expansion or special relativistic kinematics.[1] The kinetic redshift model, developed through collisionless Boltzmann dynamics and energy-momentum conservation, successfully passes every classical test that historically distinguished expanding from static cosmologies:

- **Planck spectrum preservation:** The CMB blackbody form is maintained exactly under frequency-independent redshift operators, with zero chemical potential distortion ($\mu = 0$) arising as a direct consequence of Liouville's theorem.
- **Temperature evolution:** The observed scaling $T(z) = T_0(1+z)$ follows from the redshift kernel $K(t)$ without requiring geometric expansion.
- **Energy conservation:** Global energy balance is enforced explicitly through the entropy reservoir Φ, with $\dot{\rho}_{\text{tot}} = 0$ maintained to machine precision.
- **Photon number conservation:** The Liouville invariant $\rho_\gamma K^4 = \text{const}$ is preserved exactly, ensuring correct photon density scaling across cosmic epochs.

Combined with the companion paper [5], which demonstrated consistency with luminosity distance, surface brightness, and supernova time dilation, the framework achieves complete observational equivalence with ΛCDM at the background level. This establishes that the expansion of

[1] The detection of the CMB in 1965 was widely interpreted as confirmation of the hot Big Bang model [6,20]. The present work demonstrates that while the CMB confirms a hot early state and specific redshift pattern, it does not uniquely require metric expansion.

space, while providing a successful description of cosmological observations, is not uniquely required by background data.

6.1. The Role of Liouville's Theorem

The central theoretical result is that Liouville's theorem, applied to the collisionless photon distribution under a frequency-independent redshift operator, guarantees both Planck spectrum preservation and zero μ-distortion without additional assumptions. The proof proceeds in three steps:

1. The redshift operator $\mathcal{L}_K$ acts uniformly on all photon momenta: $\mathcal{L}_K f = -H_{\text{eff}} p \partial f / \partial p$.
2. Any distribution satisfying $f(p) = f_0(pK)$ is a stationary solution of the Liouville equation $\dot{f} + \mathcal{L}_K f = 0$.
3. The Planck distribution $f_P(p, T) \propto [\exp(p/T) - 1]^{-1}$ has this form with $T = T_0/K$, and projects exactly onto the $\mu = 0$ eigenmode.

This result differs in physical interpretation from ΛCDM, where Planck preservation follows from covariance under scale-factor transformations tied to metric geometry. In the kinetic framework, the same mathematical structure arises from phase-space invariance under frequency-independent redshift operators, independent of metric assumptions. The distinction is not in the transformation algebra, both frameworks employ scale-like mappings, but in the physical mechanism. Geometric stretching of space versus dissipative energy transfer to an entropy field.

6.2. Falsifiability and Empirical Tests

The framework makes three independent, falsifiable predictions that distinguish it from previous static models and provide empirical tests beyond the background observations already satisfied:

Temperature Drift

The model predicts a secular cooling rate

$$\frac{\dot{T}}{T} = -H_{\text{eff}} \approx -2.3 \times 10^{-18}\,\text{s}^{-1}, \tag{40}$$

corresponding to a temperature decrease of approximately 0.02 μK per century. This drift is identical to the ΛCDM prediction at present but arises from a fundamentally different mechanism. Photon energy transfer to the Φ field rather than adiabatic expansion. The degeneracy may break at higher redshifts if $H_{\text{eff}}(z)$ evolves differently from $H(z)$.

In the field-theoretic formulation (Section 5.6), the exponential relaxation model predicts $H_{\text{eff}}(z) = H_0 + \Delta H \exp[-(t_0 - t(z))/\tau]$ with characteristic timescale $\tau \sim 0.6$ Gyr, yielding $H_{\text{eff}}(z = 1100) \approx 281 H_0$ rather than the ΛCDM value $\sim 1700 H_0$. Precision BAO measurements at $z > 2$ could distinguish these predictions if systematic uncertainties are sufficiently controlled. Proposed missions such as the Primordial Inflation Explorer (PIXIE) [14] and next-generation CMB spectrometers targeting absolute temperature calibration at the sub-μK level over decadal timescales will test the drift prediction directly.

Spectral Purity

The framework predicts $\mu = 0$ exactly as a consequence of frequency-independent redshift. Any detection of nonzero chemical potential distortion at the sensitivity of future missions such as PIXIE ($|\mu| \sim 10^{-8}$) would falsify the uniform operator assumption and require frequency-dependent physics incompatible with the present model. Conversely, continued confirmation of $\mu = 0$ to ever-higher precision validates the fundamental symmetry underlying the kinetic framework.

Frequency Independence

The redshift kernel must act uniformly across the electromagnetic spectrum. Multi-wavelength observations comparing radio, optical, and X-ray redshifts from the same sources provide a direct

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test of this requirement. Any wavelength-dependent deviation from the standard $(1+z)$ relation parametrized by

$$(1+z(\nu)) = (1+z_0)[1+\alpha\ln(\nu/\nu_0)] \tag{41}$$

with $|\alpha| > 10^{-4}$ would be detectable with future surveys and would falsify the frequency-independence assumption. Current observations show no measurable frequency dependence, consistent with a uniform $K(t)$ within experimental uncertainty [24].

These three tests are independent and non-degenerate. Together, they provide a comprehensive empirical framework for distinguishing the kinetic model from both ΛCDM and from previous failed static alternatives such as tired light.

6.3. Observational Degeneracy and Physical Interpretation

The success of the kinetic framework in reproducing all background CMB observables establishes a fundamental underdetermination in cosmological inference. The same data, CMB temperature, photon density, spectral form, and redshift-distance relations, admit two distinct physical interpretations:

- **Geometric (ΛCDM):** Redshift arises from the expansion of space encoded in the metric tensor. Photon energy loss is attributed to the stretching of wavelengths as space itself expands. The scale factor $a(t)$ is derived from Einstein's field equations under the cosmological principle.
- **Kinetic (this work):** Redshift arises from energy transfer between photons and a dynamical entropy field Φ. Photon energy is dissipated into a non-radiative reservoir through thermalization. The kernel $K(t)$ is constructed empirically or derived from field relaxation dynamics.

Both frameworks satisfy the same conservation equations, produce identical temperature evolution, and pass all classical observational tests. The degeneracy reflects not a failure of observation but a fundamental ambiguity in the interpretation of background data. Expansion is revealed as a *sufficient* but not *necessary* explanation for cosmological redshift at the background level. This does not imply that the two frameworks are equivalent beyond background cosmology. CMB anisotropies, structure formation, and primordial nucleosynthesis may break the degeneracy by probing perturbations, gravitational dynamics, or early-universe conditions where the kinetic and geometric interpretations diverge. Recent JWST detections of unexpectedly early massive galaxies may offer an additional test, as their formation times could differ under a non-expanding redshift history. The present work establishes the starting point. At the level of homogeneous, isotropic backgrounds, expansion is not uniquely required.

The significance of this result extends beyond technical cosmology. The CMB has long been regarded as definitive evidence for both the hot Big Bang and the ongoing expansion of space. The present analysis shows that while the CMB confirms the hot early state and specific redshift pattern, it does not uniquely mandate continuing metric expansion beyond the background level. This clarification is methodologically important. It separates what the data directly constrain (the functional form of redshift evolution) from the theoretical commitments used to interpret them (metric versus kinetic mechanisms).

6.4. Scope, Limitations, and Future Directions

The present framework is explicitly restricted to background-level thermodynamics in the post-recombination epoch. Several critical extensions remain unaddressed and define the research agenda for future work.

CMB Anisotropies

The angular power spectrum C_ℓ encodes information about gravitational potentials, acoustic oscillations, and the geometry of the last-scattering surface. Computing C_ℓ within the kinetic framework requires developing a perturbation theory for $K(t)$ and reinterpreting the Sachs-Wolfe effect, integrated Sachs-Wolfe effect, and Doppler contributions in terms of field perturbations rather than metric perturbations. Success or failure in reproducing the observed C_ℓ spectrum will provide the most decisive test distinguishing the kinetic model from ΛCDM. If the kinetic framework cannot match the detailed anisotropy structure, its validity will be restricted to background-level phenomenology, still representing a significant methodological contribution by demonstrating observational degeneracy at this level.

Structure Formation

The growth of density perturbations depends on the background expansion history through the growth factor $D(z)$. Replacing $H(z)$ with $H_{\mathrm{eff}}(z)$ in the growth equations may yield different predictions for the matter power spectrum $P(k)$, galaxy clustering, and weak lensing observables. The σ_8 tension, an ongoing discrepancy between early- and late-time structure measurements, could potentially be addressed if the kinetic model predicts a different growth history. Conversely, if structure formation is inconsistent with observations, the framework fails beyond the background level.

Primordial Nucleosynthesis

Big Bang nucleosynthesis depends sensitively on the expansion rate during the first few minutes of cosmic history. Matching the observed abundances of deuterium, helium-3, helium-4, and lithium-7 requires that H_{eff} at $z \sim 10^9$ reproduces the standard BBN predictions. Extending the $K(t)$ parametrization or field dynamics to these early epochs and verifying consistency with light-element abundances represents a key test of the framework's validity across cosmic history.

Microphysics of the Entropy Field

The physical nature of the Φ field remains incompletely specified. Section 5.6 introduced a phenomenological relaxation equation governing post-recombination dynamics, but the fundamental microscopic origin, whether scalar field, vacuum component, or emergent collective phenomenon remains an open question. Is it a fundamental scalar degree of freedom, an effective description of collective phenomena, or a component of the quantum vacuum? Does it couple to the Standard Model, and if so, through what interaction? Can the accumulated energy density $\rho_\Phi \approx 6.8 \times 10^{-22}\,\mathrm{g\,cm^{-3}}$ be detected through gravitational effects or other signatures? Answering these questions will require embedding the kinetic framework within a field-theoretic action, deriving the coupling from fundamental principles, and identifying observational consequences beyond CMB thermodynamics.

Gravitational Coupling and GR Embedding

The present analysis assumes null geodesic propagation and photon number conservation but does not specify how the Φ field couples to spacetime curvature. A complete theory would require a field-theoretic action specifying the Φ self-interactions and photon coupling, from which the relaxation dynamics and redshift operator could be derived variationally. Deriving the field equations from such an action, solving the coupled Einstein-field system, and demonstrating consistency with observations would elevate the kinetic framework from phenomenological to fundamental status. Until this is achieved, the model remains an effective description valid within its observational domain but incomplete as a gravitational theory.

These limitations do not diminish the contribution of the present work. The framework has established that background-level observational equivalence with ΛCDM is achievable without metric expansion, that Liouville dynamics and energy conservation provide sufficient structure to reproduce all CMB thermodynamic properties, and that the case for expanding space rests on theoretical commitments beyond what background data strictly require. Whether the kinetic interpretation extends successfully to perturbations, early-universe physics, and gravitational dynamics will determine its ultimate viability. What has been proven is that such an extension is worth pursuing. The framework is not ruled out by existing observations and offers a conceptually distinct alternative grounded in energy conservation and field dynamics.

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6.5. Concluding Remarks

The kinetic redshift framework represents a methodological advance in cosmological model-building. By constructing $K(t)$ empirically from observations and deriving thermal properties from first-principles kinetic theory, the analysis inverts the traditional theory-to-data pipeline. Rather than imposing a metric structure and testing its predictions, the framework begins with observational invariants and examines what theoretical structures are compatible with them. This approach reveals that metric expansion, while empirically successful, is not uniquely mandated by the data. The contribution is both technical and conceptual. Technically, the work demonstrates that Liouville's theorem applied to collisionless photon dynamics under frequency-independent redshift produces exact Planck preservation and zero μ-distortion, establishing the first non-expansion model to pass all CMB background constraints. Conceptually, it clarifies the logical structure of cosmological inference. The CMB provides evidence for a specific pattern of redshift and cooling but does not uniquely specify the physical mechanism. Expansion is one explanation; kinetic energy dissipation is another. Both are consistent with current observations.

The framework succeeds in its stated goal. To establish observational degeneracy at the background level and demonstrate that non-expansion cosmologies need not fail the classical tests that historically excluded them. Whether this degeneracy persists beyond background observations into anisotropies, structure formation, and gravitational dynamics, remains an open and empirically decidable question. The present work provides the foundation for that investigation. It shows that the kinetic interpretation is viable, falsifiable, and worthy of serious consideration as an alternative to the standard expanding-space paradigm. The ultimate verdict will be determined not by theoretical preference but by observation. Future measurements of CMB anisotropies, structure growth, and precision thermodynamics will decide whether cosmological redshift is fundamentally geometric or kinetic in origin. Until then, both interpretations stand as legitimate descriptions of the cosmos, and the choice between them reflects not what the data demand but what the theoretical commitments permit.

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