Emergence of the Cosmic Microwave Background in Quarkbase Cosmology

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Abstract

The cosmic microwave background (CMB) is conventionally interpreted as relic radiation originating from an early hot phase of the universe and subsequently modified by metric expansion. In this work, we present an alternative formulation within Quarkbase Cosmology, where the physical vacuum is modeled as a continuous, frictionless medium described by a scalar pressure field Ψ, and quarkbases are identified with the cosmological neutrino population.

Starting from a single variational principle, we derive the linear dynamics of the Ψ-field, identify a unique dispersionless luminal mode, and formulate its statistical mechanics. We show that the CMB corresponds to a unique, globally stable stationary Planckian state of this luminal sector, continuously sustained by coupling to the quarkbase background. The observed blackbody spectrum, its temperature, and its isotropy follow as necessary mathematical consequences of the medium dynamics, without invoking primordial thermal equilibrium, cosmological inflation, metric expansion, or a recombination surface.

Temperature anisotropies are shown to arise as linear transport effects induced by spatial variations of the medium, rather than as imprints of primordial fluctuations at a last-scattering surface. Cosmological redshift is derived as an intrinsic temporal evolution of the vacuum medium and is shown to preserve the Planckian spectral form exactly.

The resulting framework reproduces all kinematic observational properties of the CMB while eliminating the horizon problem and prohibiting spectral distortions by construction. These results provide a self-consistent, falsifiable, and non-expanding cosmological description of the CMB grounded in a single physical ontology.

Contents

1 Foundations of the Vacuum Medium

In this framework, the cosmic microwave background is described as a stationary Planckian configuration of a luminal mode of the Ψ-field, maintained by a homogeneous bath of quarkbases. Its spectral form, temperature, isotropy, anisotropies, and relation to redshift follow as consequences of the internal dynamics of the medium.

No assumptions are introduced regarding spacetime expansion, primordial emission epochs, or geometric horizons. All quantities are defined operationally within the dynamics of the vacuum medium itself.

1.1 Physical Assumptions and Definitions

The formulation is based on the following physical assumptions:

1. The vacuum is a continuous physical medium characterized by a real scalar pressure field $\Psi(\mathbf{x}, t)$.
2. The medium is frictionless ($\mu = 0$) and isotropic in its equilibrium state.
3. The medium admits a finite correlation (screening) length λ.
4. Quarkbases are identified with neutrinos and constitute a homogeneous population weakly coupled to the Ψ-field.
5. Observable radiation corresponds to propagating solutions of the Ψ-field.

These assumptions define the complete physical content of the model at the fundamental level. No additional hypotheses concerning early-universe thermodynamics or global spacetime structure are introduced.

1.2 Variational Formulation of the Ψ-Field

The dynamics of the Ψ-field are derived from the quadratic action functional

$$\mathcal{S}[\Psi] = \int d^3x\, dt\, \frac{1}{2} \left[(\partial_t \Psi)^2 - c_\Psi^2 (\nabla \Psi)^2 - c_\Psi^2 \lambda^{-2} \Psi^2 \right].$$

Here c_Ψ denotes the characteristic propagation speed of the medium, while λ defines its finite correlation length.

This action is the most general local, quadratic, Lorentz-invariant functional compatible with isotropy, absence of dissipation, and finite-range correlations.

Variation with respect to Ψ yields the linear field equation

$$\left(\nabla^2 - \frac{1}{c_\Psi^2} \partial_t^2 - \lambda^{-2} \right) \Psi = 0.$$

This equation completely determines the linear dynamics of the vacuum medium at cosmological scales.

2 Linear Dynamics of the Ψ-Field

2.1 Luminal Mode and Dispersion Relation

Plane-wave solutions of the field equation are considered in the form

$$\Psi(\mathbf{x}, t) = A\, e^{i(\mathbf{k}\cdot\mathbf{x} - \omega t)}.$$

Insertion into the field equation yields the dispersion relation

$$\omega^2 = c_\Psi^2 \left(k^2 + \lambda^{-2}\right).$$

In the long-wavelength regime $k \ll \lambda^{-1}$, the group velocity approaches

$$v_g = \frac{d\omega}{dk} \to c_\Psi,$$

independently of frequency. This identifies a unique dispersionless luminal mode.

This mode propagates coherently and non-dissipatively and defines the invariant signal speed of the theory. It is identified operationally with electromagnetic radiation.

2.2 Mode Decomposition and Phase Space

The linearity of the field equation permits the mode expansion

$$\Psi(\mathbf{x}, t) = \sum_{\mathbf{k}} \left[a_{\mathbf{k}}\, e^{i(\mathbf{k}\cdot\mathbf{x} - \omega_k t)} + a_{\mathbf{k}}^*\, e^{-i(\mathbf{k}\cdot\mathbf{x} - \omega_k t)}\right].$$

Each wavevector $\mathbf{k}$ labels an independent harmonic degree of freedom. The phase-space measure is fixed uniquely by the dispersion relation and the isotropy of the medium, without reference to microscopic substructure.

2.2.1 Derivation of the Effective Propagation Index

The group velocity is given by

$$v_g(k) = \frac{\partial \omega}{\partial k} = \frac{c_\Psi^2 k}{\sqrt{c_\Psi^2\left(k^2 + \lambda^{-2}\right)}}.$$

An effective propagation index may therefore be defined as

$$n_\Psi(k) = \frac{c_\Psi}{v_g(k)} = \sqrt{1 + \frac{1}{k^2\lambda^2}}.$$

In the luminal regime $k\lambda \gg 1$, one has $n_\Psi \to 1$, ensuring frequency-independent propagation. Deviations occur only for modes probing the correlation scale of the medium.

3 Statistical Mechanics of the Luminal Sector

A large comoving volume of the vacuum medium populated by quarkbases with number density n_q is considered. Weak coupling between quarkbases and Ψ-modes induces incoherent mode mixing while preserving linearity and total energy.

Let $n_{\mathbf{k}}$ denote the occupation number of the luminal Ψ-modes. The entropy functional associated with independent linear bosonic modes is

$$S = k_B \sum_{\mathbf{k}} \left[(1+n_{\mathbf{k}})\ln(1+n_{\mathbf{k}}) - n_{\mathbf{k}} \ln n_{\mathbf{k}}\right].$$

The total energy of the luminal sector is given by

$$E = \sum_{\mathbf{k}} \hbar\omega_k \, n_{\mathbf{k}}.$$

Maximization of the entropy subject to fixed total energy yields the stationary distribution

$$n_{\mathbf{k}} = \frac{1}{e^{\hbar\omega_k/k_B T} - 1}.$$

This result follows solely from linearity, mode completeness, and energy conservation, without invoking quantization as a fundamental postulate.

3.1 Identification of the Cosmic Microwave Background

The spectral energy density associated with the luminal Ψ-mode is therefore

$$u(\omega) = \frac{\hbar\omega^3}{\pi^2 c_\Psi^3} \frac{1}{e^{\hbar\omega/k_B T} - 1}.$$

This stationary Planckian distribution is identified with the observed cosmic microwave background.

In this formulation, the CMB is not interpreted as radiation emitted at a specific spacetime hypersurface. Instead, it is defined as a stationary statistical state of the luminal Ψ-sector, continuously sustained by interaction with the homogeneous quarkbase background.

No assumptions concerning recombination, decoupling, or primordial equilibrium are required.

4 Temperature and Isotropy

4.1 Mathematical Status of the Temperature Parameter

The temperature parameter T appearing in the stationary distribution is not introduced as a boundary condition nor as a relic of an initial thermal state. Its role is purely constitutive.

Stationarity requires that luminal Ψ-modes remain phase-coherent over arbitrarily large propagation distances. This imposes a convergence condition on accumulated phase fluctuations.

For a superposition of modes with occupation numbers $n_{\mathbf{k}}$, the mean-square phase fluctuation accumulated over a propagation distance L scales as

$$\langle \Delta\phi^2 \rangle \sim \int_0^\infty \frac{u(\omega)}{\omega^2} \left(1 - e^{-L/\ell(\omega)}\right) d\omega,$$

where $\ell(\omega)$ denotes the effective coherence length induced by weak coupling to quarkbases.

Stationarity requires

$$\lim_{L\to\infty} \langle \Delta\phi^2 \rangle < \infty.$$

Substitution of the Planck form for $u(\omega)$ shows that convergence is achieved only within a bounded interval of admissible temperatures. Outside this interval, phase diffusion destroys the luminal character of the mode and stationary propagation ceases to exist.

Thus, the CMB temperature is constrained by the constitutive parameters (λ, n_q) of the medium. Its numerical value is empirical but neither arbitrary nor historical.

4.2 Isotropy as a Consequence of Mode Completeness

The isotropy of the cosmic microwave background follows directly from the isotropy of the Ψ-field in equilibrium.

The dispersion relation depends only on k^2, and the phase-space measure is rotationally invariant. Consequently, the stationary distribution satisfies

$$\langle n_{\mathbf{k}} \rangle = f(|\mathbf{k}|),$$

which implies

$$u(\omega, \hat{\mathbf{n}}) = u(\omega).$$

Isotropy is therefore inherent and does not require any dynamical smoothing mechanism. Any observed deviation from isotropy must arise from perturbations of the medium itself rather than from initial conditions.

5 Perturbations and Anisotropies

5.1 Linear Perturbations of the Ψ-Field

Let the effective propagation index of the medium be defined as

$$n_\Psi(\mathbf{x}, t) = \frac{c_\Psi}{v_g(\mathbf{x}, t)}.$$

Small deviations from equilibrium are written as

$$n_\Psi(\mathbf{x}, t) = 1 + \delta n(\mathbf{x}, t), \qquad |\delta n| \ll 1.$$

These perturbations may arise from spatial variations in the quarkbase density, residual inhomogeneities of the medium, or weak external excitations.

To first order in δn, the perturbed field equation induces a linear correction to the phase accumulation of propagating luminal modes, while preserving their coherence structure.

5.2 Transport Equation for Temperature Fluctuations

Consider a ray trajectory $\gamma(\hat{\mathbf{n}})$ in direction $\hat{\mathbf{n}}$. The accumulated phase shift along the trajectory induces a local modification of the effective temperature.

To first order in δn, the resulting temperature fluctuation satisfies

$$\frac{\Delta T}{T}(\hat{\mathbf{n}}) = \int_{\gamma(\hat{\mathbf{n}})} \partial_s \delta n(\mathbf{x}, t)\, ds + \delta T_{\text{loc}},$$

where ∂_s denotes differentiation along the ray path and δT_{loc} accounts for strictly local contributions.

This expression is exact at linear order. Higher-order corrections scale as $\mathcal{O}(\delta n^2)$ and are suppressed well below the observed anisotropy level $|\Delta T/T| \sim 10^{-5}$.

The anisotropy pattern is therefore interpreted as a line-integrated transport effect through a structured medium, rather than as an imprint of primordial fluctuations at a fixed emission surface.

5.3 Absence of a Distinguished Emission Surface

Because the cosmic microwave background is a stationary field configuration, there exists no mathematically privileged spacelike hypersurface from which it originates.

The effective depth of observation is controlled by the coherence length $\ell(\omega)$, which defines a finite, frequency-dependent transparency scale of the medium.

This naturally produces an apparent shell-like origin for the observed radiation without invoking a recombination epoch, decoupling surface, or last-scattering boundary.

The notion of an emission surface is therefore emergent and approximate, not fundamental.

5.4 Mathematical Structure of Anisotropies

Let $\delta n(\mathbf{x})$ be a smooth function with compact support or sufficiently rapid decay at infinity.

The line integral

$$\int_\gamma \partial_s \delta n\, ds$$

is well defined for all null rays γ. By the fundamental theorem of calculus, it reduces to boundary terms when δn is localized, ensuring that anisotropy amplitudes remain finite.

The observed magnitude

$$\left|\frac{\Delta T}{T}\right| \sim 10^{-5}$$

implies

$$|\nabla \delta n| \ll 1,$$

which validates the perturbative expansion globally.

No infrared divergence, secular growth, or instability arises within this formulation.

6 Redshift and Symmetry Properties

6.1 Redshift as Temporal Evolution of the Medium

Frequency is defined operationally as the oscillation rate of local resonators coupled to the Ψ-field.

Let $n_\Psi(t)$ denote the spatially averaged propagation index of the medium at cosmic time t. The frequency measured by an observer at time $t_{\rm obs}$ is then given by

$$\omega_{\rm obs} = \frac{\omega}{n_\Psi(t_{\rm obs})}.$$

For radiation associated with a mode characterized at an earlier time t_e, one obtains

$$1 + z = \frac{n_\Psi(t_{\rm obs})}{n_\Psi(t_e)}.$$

This relation defines the observed redshift purely in terms of the temporal evolution of the medium.

The cosmic microwave background corresponds to the reference stationary distribution evaluated at $t_{\rm obs}$. No expansion of space, stretching of wavelengths, or metric dilation is invoked at any step of the derivation.

6.2 Preservation of the Planckian Spectrum under Redshift

Let the stationary spectral distribution be expressed as

$$u(\omega) = \frac{\hbar\omega^3}{\pi^2 c_\Psi^3} \frac{1}{e^{\hbar\omega/k_B T} - 1}.$$

Under the mapping

$$\omega \mapsto \omega_{\rm obs} = \frac{\omega}{n_\Psi(t)},$$

the frequency transformation is a smooth diffeomorphism on $\mathbb{R}^+$.

Consequently, spectral ordering is preserved and the functional form of the Planck distribution remains invariant. The redshift modifies only the effective temperature scale, without distorting the spectral shape.

This establishes rigorously that a stationary Planckian distribution remains Planckian under arbitrary smooth evolution of the medium.

6.3 Compatibility with Lorentz Invariance

Although a physical medium is present, Lorentz invariance is preserved operationally.

The Ψ-field is frictionless and isotropic, and all clocks, rods, and signals couple universally to the same luminal mode. Any attempt to detect absolute motion relative to the medium is renormalized by the medium response itself.

The Lorentz group emerges as the symmetry group of the equations governing the luminal sector. No preferred inertial frame can be operationally identified.

Thus, the presence of the medium does not violate Lorentz invariance in any observable sense.

6.4 Relation to Conventional Cosmological Parameters

If one formally defines an effective scale factor

$$a(t) = n_\Psi^{-1}(t),$$

the algebraic structure of standard cosmological relations is recovered identically.

Distance–redshift relations, frequency ratios, and temperature scaling laws all retain their conventional form under this identification.

This correspondence does not imply physical equivalence. It demonstrates that the Quarkbase formulation reproduces the successful kinematic relations of standard cosmology while assigning them a distinct physical origin rooted in medium dynamics rather than metric expansion.

7 Stationarity and Stability of the Planckian State

7.1 Proof of Stationarity of the Planckian Solution

The Planck distribution derived previously is now shown to be not merely a solution, but the *unique stable stationary solution* of the luminal Ψ-sector under the stated assumptions.

Consider the time evolution of the occupation numbers $n_{\mathbf{k}}(t)$ under weak coupling to the quarkbase background. To leading order, their dynamics can be written in kinetic form as

$$\frac{dn_{\mathbf{k}}}{dt} = \mathcal{C}[n_{\mathbf{k}}],$$

where $\mathcal{C}$ is a collision-like operator encoding incoherent mode mixing induced by quarkbases.

By construction, the operator $\mathcal{C}$ satisfies:

1. Energy conservation:
$$\sum_{\mathbf{k}} \hbar\omega_k\, \mathcal{C}[n_{\mathbf{k}}] = 0.$$

2. Rotational invariance in $\mathbf{k}$-space.

3. Vanishing on entropy-maximizing distributions at fixed energy.

The entropy production rate is given by

$$\frac{dS}{dt} = k_B \sum_{\mathbf{k}} \ln\left(\frac{1+n_{\mathbf{k}}}{n_{\mathbf{k}}}\right) \mathcal{C}[n_{\mathbf{k}}].$$

Standard results from kinetic theory imply

$$\frac{dS}{dt} \geq 0,$$

with equality if and only if $n_{\mathbf{k}}$ has the Planck form.

Therefore, the Planckian distribution is a stationary point of the dynamics and an entropy maximum under the conserved energy constraint.

7.2 Uniqueness and Global Attractivity

Assume the existence of two distinct stationary distributions $n_{\mathbf{k}}^{(1)}$ and $n_{\mathbf{k}}^{(2)}$ satisfying

$$\mathcal{C}[n_{\mathbf{k}}^{(1)}] = \mathcal{C}[n_{\mathbf{k}}^{(2)}] = 0.$$

Define the entropy difference

$$\Delta S = S[n^{(1)}] - S[n^{(2)}].$$

The entropy functional

$$S[n] = k_B \sum_{\mathbf{k}} \Big[(1 + n_{\mathbf{k}}) \ln(1 + n_{\mathbf{k}}) - n_{\mathbf{k}} \ln n_{\mathbf{k}}\Big]$$

is strictly concave under linear constraints.

Hence, the entropy maximizer at fixed energy is unique. The assumption of two distinct stationary solutions leads to a contradiction.

It follows that the Planck distribution is the *unique stationary solution* of the luminal sector.

7.3 Linear Stability Against Arbitrary Perturbations

Consider an arbitrary perturbation of the form

$$n_{\mathbf{k}} \to n_{\mathbf{k}} + \delta n_{\mathbf{k}}.$$

Linearizing the kinetic equation yields

$$\frac{d}{dt}(\delta n_{\mathbf{k}}) = \sum_{\mathbf{k}'} \mathcal{L}_{\mathbf{k}\mathbf{k}'}\, \delta n_{\mathbf{k}'},$$

where $\mathcal{L}$ is the linearized collision operator.

The operator $\mathcal{L}$ is negative semi-definite, with a null space corresponding only to energy-preserving shifts.

Consequently,

$$\delta n_{\mathbf{k}}(t) \to 0 \quad \text{as} \quad t \to \infty.$$

The Planckian stationary state is therefore globally asymptotically stable.

8 Ultraviolet and Infrared Control

8.1 Ultraviolet Convergence

For $\omega \to \infty$, the spectral energy density behaves as

$$u(\omega) \sim \omega^3 e^{-\hbar\omega/k_B T}.$$

The exponential suppression ensures convergence of all integrals defining total energy, entropy, and phase variance.

No ultraviolet regularization or cutoff procedure is required.

8.2 Infrared Behaviour and Absence of Pathologies

For $\omega \to 0$, the Planck spectrum satisfies

$$u(\omega) \sim k_B T\, \omega^2.$$

The infrared behaviour is regular and does not generate divergences in energy density or phase coherence.

Moreover, the dispersion relation

$$\omega^2 = c_\Psi^2 (k^2 + \lambda^{-2})$$

implies the existence of a finite minimum frequency

$$\omega_{\min} = c_\Psi \lambda^{-1}.$$

There is no zero-frequency mode. As a result:

- No infrared catastrophe occurs.
- No secular growth of long-wavelength modes is possible.
- The ground state is well defined.

The finite screening length λ acts as a rigorous infrared regulator arising directly from the variational principle.

9 Causality and Propagation Properties

9.1 Propagator Structure and Analyticity

The linear field equation derived from the variational principle admits a well-defined Green function. In Fourier space, the propagator associated with the Ψ-field is

$$G(\omega, \mathbf{k}) = \frac{1}{\omega^2 - c_\Psi^2 \left(k^2 + \lambda^{-2}\right) + i0^+}.$$

This propagator satisfies the standard analyticity conditions required for causal evolution. In particular:

- The poles lie strictly on the real axis.
- The $i0^+$ prescription enforces retarded boundary conditions.
- The propagator is analytic in the upper half of the complex ω-plane.

Therefore, the evolution of Ψ respects microscopic causality without the introduction of auxiliary constraints.

9.2 Absence of Superluminal Signal Propagation

The group velocity associated with the dispersion relation

$$\omega^2 = c_\Psi^2(k^2 + \lambda^{-2})$$

is given by

$$v_g(k) = \frac{\partial\omega}{\partial k} = \frac{c_\Psi^2 k}{\sqrt{c_\Psi^2(k^2 + \lambda^{-2})}}.$$

For all admissible values of k, one has the strict inequality

$$v_g(k) \leq c_\Psi.$$

Equality holds only in the asymptotic luminal regime $k\lambda \gg 1$.

Consequently,

$$\sup_k v_g(k) = c_\Psi,$$

and no excitation of the medium propagates faster than the luminal mode.

This establishes exact causal consistency and excludes superluminal signaling.

9.3 Interpretation of the Screening Term

The term $\lambda^{-2}\Psi^2$ appearing in the action might superficially resemble a mass term. This interpretation is incorrect.

Mathematically, the term introduces a finite correlation length into the medium while preserving:

- Lorentz invariance of the equations of motion,
- isotropy of the vacuum state,
- universality of the luminal propagation speed.

Physically, λ^{-1} plays a role analogous to a plasma frequency rather than a particle rest mass. No particle excitation with rest energy $\hbar c_\Psi \lambda^{-1}$ is implied.

The Ψ-field remains a continuous medium excitation rather than a particle field.

9.4 Absence of Preferred Reference Frames

Although a medium is present, no preferred inertial frame is introduced.

All measuring devices—clocks, rods, and resonators—couple universally to the same luminal Ψ-mode. Any attempt to detect motion relative to the medium renormalizes both the measuring apparatus and the signal identically.

Operationally, all inertial observers recover identical physical laws.

The Lorentz group emerges as the symmetry group of the luminal sector, despite the presence of an underlying medium.

10 Global Isotropy and Absence of Horizon Constraints

10.1 Isotropy from Phase-Space Completeness

The isotropy of the cosmic microwave background does not require any dynamical smoothing mechanism.

The dispersion relation

$$\omega^2 = c_\Psi^2(k^2 + \lambda^{-2})$$

depends only on the scalar quantity k^2. Consequently, the phase-space measure associated with the Ψ-field is rotationally invariant.

For the stationary state, the occupation numbers satisfy

$$\langle n_\mathbf{k} \rangle = f(|\mathbf{k}|),$$

which implies that the spectral energy density obeys

$$u(\omega, \hat{\mathbf{n}}) = u(\omega)$$

for all directions $\hat{\mathbf{n}}$.

Isotropy is therefore an intrinsic property of the equilibrium state, not an emergent consequence of time evolution.

10.2 Stationary Fields and Global Definition

The Planckian state derived in previous sections is stationary in the strict mathematical sense.

The distribution function $n_\mathbf{k}$ is defined globally on phase space and does not depend on initial data specified on a spacelike hypersurface.

Formally, the stationary state satisfies

$$\frac{dn_\mathbf{k}}{dt} = 0$$

under the kinetic evolution operator.

As a result, the radiation field exists everywhere in spacetime as a sustained configuration of the medium rather than as radiation emitted from a localized event.

10.3 Elimination of the Horizon Problem

In standard cosmological models, isotropy of the CMB requires causal contact between distant regions at early times, leading to the so-called horizon problem.

In the present framework, no such problem arises.

Because the CMB corresponds to a stationary solution of the luminal Ψ-sector, the observed radiation is not propagated from an initial emission surface.

Instead, the distribution function $n_\mathbf{k}$ is defined everywhere and at all times as the equilibrium state of the medium.

Mathematically, no causal horizon enters the formulation because no finite propagation time from an initial hypersurface is required.

10.4 Effective Observation Depth

Although no distinguished emission surface exists, observations probe a finite effective depth.

The coherence length $\ell(\omega)$ associated with the weak coupling between Ψ-modes and quarkbases introduces a frequency-dependent transparency scale.

Radiation received by an observer is therefore dominated by contributions within a finite spacetime region defined by $\ell(\omega)$.

This naturally produces an apparent shell-like structure without invoking recombination, decoupling, or sudden opacity transitions.

10.5 Mathematical Consistency of Global Homogeneity

Let $\mathcal{D}$ denote a sufficiently large spacetime domain. For a homogeneous quarkbase density n_q, the stationary distribution satisfies

$$\frac{\partial n_{\mathbf{k}}}{\partial \mathbf{x}} = 0 \quad \text{in } \mathcal{D}.$$

Small inhomogeneities $\delta n_q(\mathbf{x})$ induce perturbations $\delta n_{\mathbf{k}}(\mathbf{x})$ that remain bounded and linear, as shown in previous sections.

Therefore, global homogeneity and isotropy are stable properties of the stationary solution.

11 Mathematical Structure of CMB Anisotropies

11.1 Definition of the Propagation Index Field

Let the effective propagation index of the vacuum medium be defined by

$$n_\Psi(\mathbf{x}, t) = \frac{c_\Psi}{v_g(\mathbf{x}, t)}.$$

In the homogeneous equilibrium state one has

$$n_\Psi(\mathbf{x}, t) = 1.$$

Small departures from equilibrium are described by

$$n_\Psi(\mathbf{x}, t) = 1 + \delta n(\mathbf{x}, t), \qquad |\delta n| \ll 1.$$

The function $\delta n(\mathbf{x}, t)$ encodes local variations of the medium induced by matter inhomogeneities, pressure gradients, or quarkbase density fluctuations.

11.2 Linearized Phase Accumulation

Consider a null ray trajectory $\gamma(\hat{\mathbf{n}})$ parameterized by arc length s and direction $\hat{\mathbf{n}}$.

The phase accumulated by a Ψ-mode along the trajectory is

$$\phi = \int_\gamma \omega \, n_\Psi(\mathbf{x}, t) \, ds.$$

To first order in δn, the phase shift relative to the homogeneous case is

$$\delta\phi(\hat{\mathbf{n}}) = \omega \int_{\gamma(\hat{\mathbf{n}})} \delta n(\mathbf{x}, t) \, ds.$$

This expression is exact within linear order and does not rely on any assumption about the origin of the perturbation.

11.3 Transport Equation for Temperature Fluctuations

Temperature is defined operationally through the local spectral distribution.

A small phase perturbation induces a rescaling of frequencies, which translates into a local temperature fluctuation.

To first order, the fractional temperature anisotropy is given by

$$\frac{\Delta T}{T}(\hat{\mathbf{n}}) = \int_{\gamma(\hat{\mathbf{n}})} \partial_s \delta n(\mathbf{x}, t) \, ds + \delta T_{\text{loc}}.$$

Here δT_{loc} represents strictly local contributions at emission and observation points.

This equation replaces the concept of primordial imprinted anisotropies with a transport integral through a structured medium.

11.4 Boundedness and Regularity

Assume that $\delta n(\mathbf{x}, t)$ is continuously differentiable and either compactly supported or sufficiently rapidly decaying.

Then the line integral

$$\int_\gamma \partial_s \delta n \, ds$$

is well defined for all ray directions $\hat{\mathbf{n}}$.

By the fundamental theorem of calculus, localized perturbations yield boundary terms only, ensuring finiteness of $\Delta T/T$.

11.5 Amplitude Control

Observationally, the magnitude of temperature anisotropies satisfies

$$\left| \frac{\Delta T}{T} \right| \sim 10^{-5}.$$

This implies the constraint

$$|\nabla \delta n| \ll 1,$$

which justifies the linear approximation globally.

Higher-order corrections scale as

$$\mathcal{O}(\delta n^2),$$

and are therefore suppressed well below observational sensitivity.

11.6 Absence of Mode Coupling at Linear Order

At first order in δn, different $\mathbf{k}$-modes evolve independently.

No mode-mode coupling appears in the transport equation, and the Planckian spectral form is preserved locally.

Therefore, anisotropies correspond to angular modulations of the temperature field, not to spectral distortions.

12 Redshift as Temporal Evolution of the Medium

12.1 Operational Definition of Frequency

Frequency is defined operationally as the oscillation rate of a local resonator coupled to the luminal Ψ-field.

Let ω denote the intrinsic oscillation frequency of a given Ψ-mode, and let $n_\Psi(t)$ denote the spatially averaged propagation index of the medium at cosmic time t.

The frequency measured by an observer at time t is then

$$\omega_{\text{obs}}(t) = \frac{\omega}{n_\Psi(t)}.$$

This definition involves no reference to spacetime expansion, metric stretching, or coordinate rescaling.

12.2 Redshift Relation

Consider radiation interacting with the medium at an emission time t_e and observed at time t_{obs}.

The observed redshift is defined as

$$1 + z = \frac{\omega_{\text{em}}}{\omega_{\text{obs}}}.$$

Using the operational definition of frequency, one obtains

$$1 + z = \frac{n_\Psi(t_{\text{obs}})}{n_\Psi(t_e)}.$$

This relation is exact and holds independently of the microscopic origin of the time dependence of $n_\Psi(t)$.

12.3 Preservation of the Planckian Spectrum

Let the stationary spectral energy density at time t_e be

$$u_e(\omega) = \frac{\hbar\omega^3}{\pi^2 c_\Psi^3} \frac{1}{e^{\hbar\omega/k_B T} - 1}.$$

Under temporal evolution of the medium, frequencies transform as

$$\omega \mapsto \omega_{\text{obs}} = \frac{\omega}{n_\Psi(t)}.$$

The transformed spectral density is

$$u_{\mathrm{obs}}(\omega_{\mathrm{obs}}) = n_\Psi^{-4}(t)\, u_e(n_\Psi(t)\,\omega_{\mathrm{obs}})\,.$$

Substitution yields

$$u_{\mathrm{obs}}(\omega_{\mathrm{obs}}) = \frac{\hbar\omega_{\mathrm{obs}}^3}{\pi^2 c_\Psi^3}\frac{1}{e^{\hbar\omega_{\mathrm{obs}}/k_B T_{\mathrm{obs}}} - 1},$$

with the effective temperature

$$T_{\mathrm{obs}} = \frac{T}{n_\Psi(t)}.$$

Therefore, the Planckian form is preserved exactly under arbitrary smooth temporal evolution of the medium.

12.4 Diffeomorphic Nature of the Frequency Mapping

Assume that $n_\Psi(t)$ is a smooth, positive, and monotonic function of time.

Then the mapping

$$\omega \mapsto \omega_{\mathrm{obs}} = \frac{\omega}{n_\Psi(t)}$$

is a diffeomorphism on $\mathbb{R}^+$.

Consequently:

- spectral ordering is preserved,
- no frequency crossings occur,
- no spectral distortions are generated.

This guarantees the mathematical stability of the CMB spectrum under redshift.

12.5 Absence of Metric Expansion

At no stage is a time-dependent metric or expanding scale factor introduced.

All observable effects traditionally attributed to cosmological expansion enter exclusively through the time dependence of the medium parameter $n_\Psi(t)$.

The redshift is therefore interpreted as an intrinsic temporal evolution of the vacuum medium, not as a geometric stretching of space.

12.6 Formal Equivalence with Standard Cosmological Relations

Define formally an effective scale factor

$$a(t) \equiv n_\Psi^{-1}(t).$$

With this definition, the standard redshift relation

$$1 + z = \frac{a(t_{\mathrm{obs}})}{a(t_e)}$$

is recovered identically at the algebraic level.

This correspondence does not imply physical equivalence; it establishes that the present formulation reproduces the successful kinematic relations of standard cosmology while assigning them a different physical origin.

13 Operational Lorentz Invariance

13.1 Absence of a Detectable Preferred Frame

Although the vacuum is modeled as a continuous physical medium, no observable experiment can detect motion relative to it.

The Ψ-field is frictionless, isotropic, and couples universally to all physical systems used to define clocks, rods, and signal propagation.

Let $\mathcal{O}$ be any operational observable constructed from:

- local oscillators,
- interferometric paths,
- propagating luminal Ψ-modes.

Then $\mathcal{O}$ depends only on ratios of frequencies and path lengths measured through the same medium response, and is therefore invariant under uniform boosts.

13.2 Renormalization of Kinematic Measurements

Consider an observer moving at constant velocity $\mathbf{v}$ relative to an arbitrary coordinate frame.

All physical measurement devices are constructed from matter whose internal dynamics are governed by interactions mediated by the luminal Ψ-mode.

Let τ_0 be the proper oscillation period of a local resonator at rest in the medium equilibrium frame.

For a moving observer, the effective period is renormalized according to

$$\tau(\mathbf{v}) = \gamma(\mathbf{v})\,\tau_0, \qquad \gamma(\mathbf{v}) = \frac{1}{\sqrt{1 - \frac{v^2}{c_\Psi^2}}}.$$

This renormalization arises dynamically from the response of the medium to coherent motion, not from an assumed spacetime geometry.

13.3 Michelson–Morley-Type Experiments

Consider an interferometer with orthogonal arms of equal proper length L_0.

The round-trip travel time of a luminal Ψ-mode along each arm is given by

$$T = \frac{2L}{c_\Psi},$$

where L is the dynamically renormalized arm length.

Under uniform motion through the medium, both longitudinal and transverse arm lengths undergo the same contraction factor induced by the medium response:

$$L = \frac{L_0}{\gamma(\mathbf{v})}.$$

As a result, the travel times along both arms remain equal to all orders in v/c_Ψ, and no fringe shift is produced.

Thus, null results of Michelson–Morley-type experiments follow necessarily from the structure of the theory.

13.4 Universality of the Luminal Mode

All interactions used to transmit information propagate through the same luminal sector of the Ψ-field.

Let two observers $\mathcal{A}$ and $\mathcal{B}$ exchange signals using any physical channel (electromagnetic, mechanical, or quantum).

In all cases, the signal propagation speed is bounded by

$$v \le c_\Psi.$$

No observer can access a signal propagating faster than the luminal mode, and no experiment can distinguish absolute motion through the medium.

13.5 Emergent Lorentz Group

The set of transformations preserving:

- the form of the linear Ψ-field equation,
- the invariant speed c_Ψ,
- the operational equivalence of inertial observers,

forms the Lorentz group.

Lorentz symmetry therefore emerges as the exact symmetry group of the luminal sector, not as a postulate imposed on spacetime.

13.6 Compatibility with the Variational Principle

The action functional

$$\mathcal{S}[\Psi] = \int d^3x\, dt\, \frac{1}{2}\left[(\partial_t\Psi)^2 - c_\Psi^2(\nabla\Psi)^2 - c_\Psi^2\lambda^{-2}\Psi^2\right]$$

is invariant under Lorentz transformations with invariant speed c_Ψ.

The presence of the correlation term $\lambda^{-2}\Psi^2$ does not introduce a preferred frame and does not break Lorentz symmetry.

13.7 Operational Equivalence with Special Relativity

All measurable consequences of special relativity are reproduced identically:

- time dilation,
- length contraction,

- relativistic Doppler shift,
- invariant light speed.

However, these effects are interpreted as dynamical responses of a physical medium rather than as geometric properties of spacetime.

This distinction is ontological, not observational.

14 Structural Comparison with Standard Cosmology

14.1 Minimal Kinematic Content of Cosmological Observables

All cosmological observables related to radiation depend exclusively on ratios of frequencies, angles, and intensities measured by local detectors.

No observable directly measures:

- an absolute spacetime scale,
- an intrinsic metric expansion,
- a global time slicing.

Therefore, any cosmological model reproducing the correct mapping between emitted and observed frequencies, angular correlations, and spectral shapes is observationally complete at the kinematic level.

14.2 Formal Role of the Scale Factor in ΛCDM

In standard cosmology, redshift is encoded through the scale factor $a(t)$ via

$$1 + z = \frac{a(t_{\text{obs}})}{a(t_e)}.$$

All further relations—photon dilution, surface brightness, and temperature scaling—are algebraic consequences of this mapping.

No independent dynamical measurement of $a(t)$ exists outside this frequency rescaling.

14.3 Identification of the Effective Scale Factor

In the Quarkbase framework, frequency transport is governed by the propagation index $n_\Psi(t)$.

The observed frequency is

$$\omega_{\text{obs}} = \frac{\omega}{n_\Psi(t_{\text{obs}})}.$$

For radiation associated with an earlier epoch t_e,

$$1 + z = \frac{n_\Psi(t_{\text{obs}})}{n_\Psi(t_e)}.$$

Define formally

$$a_{\text{eff}}(t) \equiv n_\Psi^{-1}(t).$$

All algebraic relations of standard cosmology are recovered identically under this substitution.

14.4 Exact Preservation of the Planck Spectrum

Let the stationary spectral density at observation time be

$$u(\omega) = \frac{\hbar\omega^3}{\pi^2 c_\Psi^3} \frac{1}{e^{\hbar\omega/k_B T} - 1}.$$

Under smooth temporal evolution of $n_\Psi(t)$, frequencies transform as

$$\omega \mapsto \omega' = \omega \frac{n_\Psi(t)}{n_\Psi(t')}.$$

The functional form of $u(\omega)$ is invariant under this diffeomorphic mapping.

Thus, Planckianity is preserved exactly without invoking adiabatic expansion or photon decoupling.

14.5 Photon Number and Energy Accounting

In ΛCDM, photon number is conserved while energy density redshifts due to expansion. In the present formulation:

- photon number is not a primitive concept,
- energy is locally conserved,
- frequency shifts arise from medium evolution.

Both descriptions yield identical observational predictions for radiation fields.

14.6 Absence of a Dynamical Metric

No spacetime metric $g_{\mu\nu}(t)$ is introduced.

Causal structure is determined by the luminal Ψ-mode, not by null geodesics of an evolving geometry.

All measurable intervals are operational constructs defined by the propagation of the Ψ-field.

14.7 Interpretative Non-Equivalence

Although kinematic relations coincide formally, the physical interpretations differ fundamentally:

- ΛCDM attributes redshift to expansion of space,
- Quarkbase Cosmology attributes redshift to temporal evolution of the vacuum medium.

These interpretations are not physically equivalent, despite mathematical correspondence.

14.8 No Requirement for Inflationary Smoothing

Standard cosmology introduces inflation to explain:

- isotropy,
- homogeneity,
- super-horizon correlations.

In the present framework, isotropy and stationarity arise from global equilibrium of the medium.

No causal amplification or rapid expansion phase is required.

14.9 Reinterpretation of the Horizon Concept

Because the CMB is not emitted from a finite-time hypersurface, no particle horizon is relevant.

The radiation field exists as a stationary global configuration.

Thus, horizon-related paradoxes do not arise mathematically.

14.10 Summary of Structural Comparison

The Quarkbase formulation reproduces all successful kinematic relations of standard cosmology while employing:

- fewer assumptions,
- a single physical ontology,
- no geometric expansion,
- no initial-condition dependence.

This establishes observational equivalence without ontological equivalence.

15 Global Stability and Nonlinear Consistency

15.1 Linear Stability of the Stationary Solution

Consider small perturbations around the stationary Planckian distribution,

$$n_{\mathbf{k}}(t) = n_{\mathbf{k}}^{(0)} + \delta n_{\mathbf{k}}(t),$$

where

$$n_{\mathbf{k}}^{(0)} = \frac{1}{e^{\hbar\omega_k/k_B T} - 1}.$$

The kinetic equation

$$\frac{dn_{\mathbf{k}}}{dt} = \mathcal{C}[n_{\mathbf{k}}]$$

linearizes as

$$\frac{d}{dt}(\delta n_{\mathbf{k}}) = \sum_{\mathbf{k}'} \mathcal{L}_{\mathbf{k}\mathbf{k}'}\, \delta n_{\mathbf{k}'}.$$

By construction, the operator $\mathcal{L}$ satisfies:

1. self-adjointness with respect to the entropy inner product,
2. non-positivity of all eigenvalues,
3. a null space spanned solely by energy-conserving modes.

Thus, all admissible perturbations decay exponentially or algebraically toward equilibrium.

15.2 Global Attractor Property

Let $\mathcal{H}[n]$ denote the entropy functional

$$\mathcal{H}[n] = -k_B \sum_{\mathbf{k}} \left[(1+n_{\mathbf{k}})\ln(1+n_{\mathbf{k}}) - n_{\mathbf{k}} \ln n_{\mathbf{k}}\right].$$

Along solutions of the kinetic equation,

$$\frac{d\mathcal{H}}{dt} \leq 0,$$

with equality if and only if $n_{\mathbf{k}} = n_{\mathbf{k}}^{(0)}$.

Therefore, the Planckian state is a global attractor in the space of admissible distributions.

No metastable stationary states exist.

15.3 Absence of Secular Growth

A potential concern in cosmological kinetic systems is secular growth of low-frequency modes.

In the present framework, the dispersion relation

$$\omega^2 = c_\Psi^2 \left(k^2 + \lambda^{-2}\right)$$

implies

$$\omega(k) \geq c_\Psi \lambda^{-1} > 0 \quad \forall k.$$

Thus, no zero-frequency or marginally stable modes exist.

All perturbations possess finite oscillation frequencies and finite damping rates.

Secular instabilities are mathematically excluded.

15.4 Control of Nonlinear Corrections

The field dynamics originate from a quadratic action.

Nonlinearities enter only through weak quarkbase coupling and higher-order corrections in Ψ/Ψ_0.

Let $\epsilon \sim |\Psi|/\Psi_0 \ll 1$ denote the perturbative parameter.

Nonlinear corrections scale as

$$\mathcal{O}(\epsilon^2),$$

and are suppressed uniformly at cosmological scales.

Therefore, linear theory is asymptotically exact in the regime relevant to the CMB.

15.5 Closure Under Mode Coupling

Any admissible perturbation admits the decomposition

$$\delta\Psi(\mathbf{x}, t) = \sum_{\mathbf{k}} \delta\Psi_{\mathbf{k}}(t)\, e^{i\mathbf{k}\cdot\mathbf{x}}.$$

Mode coupling induced by quarkbases preserves:

- total energy,
- rotational invariance,
- entropy monotonicity.

No energy cascade toward ultraviolet or infrared divergences is permitted.

15.6 No Renormalization Requirement

The theory contains no ultraviolet divergences.

All integrals converge due to:

- exponential suppression at high ω,
- finite screening length λ,
- absence of zero-frequency modes.

Consequently:

- no counterterms are required,
- no running constants are introduced,
- no renormalization group flow appears.

The formulation is mathematically closed at all relevant scales.

15.7 Thermodynamic Consistency

The stationary state satisfies:

- maximum entropy at fixed energy,
- detailed balance,
- stability under arbitrary perturbations.

No external reservoirs, boundary conditions, or initial ensembles are required. Thermodynamic consistency is intrinsic.

15.8 Absence of Fine Tuning

No parameter must be tuned to a critical value to ensure stability.

The admissible temperature interval arises dynamically from phase-coherence constraints, not from external adjustment.

Thus, the stationary state is structurally stable.

15.9 Summary of Stability Analysis

The luminal Ψ-sector exhibits:

- global asymptotic stability,
- absence of secular instabilities,
- suppression of nonlinear effects,
- mathematical closure without renormalization.

This establishes the robustness of the CMB description within Quarkbase Cosmology.

16 Dipole Anisotropy and Kinematical Reference Frame

16.1 Operational Definition of the CMB Dipole

The observed temperature field may be decomposed as

$$\Theta(\hat{\mathbf{n}}) = \Theta_{\mathrm{dip}}(\hat{\mathbf{n}}) + \Theta_{\mathrm{res}}(\hat{\mathbf{n}}),$$

where the dipole component is defined by

$$\Theta_{\mathrm{dip}}(\hat{\mathbf{n}}) = \mathbf{D} \cdot \hat{\mathbf{n}}.$$

The dipole vector $\mathbf{D}$ is empirically the largest-amplitude multipole and dominates over all higher-order anisotropies.

16.2 Kinematical Origin of the Dipole

Consider an observer moving with velocity $\mathbf{v}$ relative to the local equilibrium rest frame of the Ψ-medium.

The observed frequency transforms as

$$\omega_{\text{obs}}(\hat{\mathbf{n}}) = \omega\,\frac{1 - \mathbf{v}\cdot\hat{\mathbf{n}}/c_\Psi}{\sqrt{1 - v^2/c_\Psi^2}},$$

to first order in v/c_Ψ.

The corresponding temperature perturbation is

$$\frac{\Delta T}{T} = \frac{\mathbf{v}\cdot\hat{\mathbf{n}}}{c_\Psi} + \mathcal{O}\left(\frac{v^2}{c_\Psi^2}\right).$$

Thus,

$$\mathbf{D} = \frac{\mathbf{v}}{c_\Psi}.$$

The dipole is therefore a purely kinematical effect.

16.3 Absence of Dynamical Contribution to the Dipole

Medium-induced perturbations $\delta n(\mathbf{x})$ contribute only at second order to the dipole moment.

To linear order,

$$\int_{\gamma(\hat{\mathbf{n}})} \partial_s \delta n(\mathbf{x})\, ds$$

has vanishing monopole and dipole expectation values due to isotropy of $\langle \delta n \rangle$.

Hence,

$$\langle \Theta_{\text{med}}^{(\ell=1)} \rangle = 0.$$

The dipole uniquely identifies the observer's kinematical state.

16.4 Definition of the Medium Rest Frame

The rest frame of the Ψ-medium is operationally defined as the frame in which the dipole vanishes:

$$\mathbf{D} = \mathbf{0}.$$

This definition does not introduce a preferred frame in violation of Lorentz invariance; it defines a physical reference associated with the equilibrium state of the medium.

All inertial observers remain related by Lorentz transformations with invariant speed c_Ψ.

16.5 Lorentz Symmetry with a Physical Medium

Although a medium exists, it is:

- frictionless,

- isotropic,
- universally coupled.

As a result, rods, clocks, and signals are renormalized identically.

No experiment can detect absolute motion relative to the medium using internal observables.

The Lorentz group emerges as an exact symmetry of the luminal sector.

16.6 Dipole Subtraction and Residual Statistics

Subtracting the dipole yields

$$\Theta_{\rm res}(\hat{\mathbf{n}}) = \Theta(\hat{\mathbf{n}}) - \mathbf{D} \cdot \hat{\mathbf{n}}.$$

All higher-order statistics—two-point correlations, angular power spectrum, Gaussianity—are computed using $\Theta_{\rm res}$.

This procedure is mathematically exact and removes no physical information beyond kinematics.

16.7 Consistency with Observed Dipole Amplitude

The observed dipole amplitude corresponds to

$$|\mathbf{D}| \approx 1.23 \times 10^{-3}.$$

Thus,

$$v \approx 369\,\mathrm{km\,s^{-1}},$$

consistent with independent determinations from large-scale structure.

This agreement requires no tuning.

16.8 Absence of a Preferred Cosmological Frame

The medium rest frame is not a universal cosmological frame.

Different regions may exhibit local deviations from equilibrium, yielding local rest frames.

Only the local dipole-free frame is physically meaningful.

No global absolute frame is postulated.

16.9 Dipole Stability under Medium Evolution

If $n_\Psi(t)$ evolves smoothly in time, the dipole expression remains unchanged to first order.

Time dependence of n_Ψ rescales frequencies isotropically and does not induce dipolar distortions.

Hence, the dipole is insensitive to cosmic evolution of the medium.

16.10 Summary of Dipole Physics

The dipole anisotropy:

- is purely kinematical,
- defines the local medium rest frame,
- does not contaminate higher multipoles,
- preserves Lorentz invariance operationally.

This completes the separation between kinematics and intrinsic medium-induced anisotropies.

17 Spectral Distortions and Stability of the Planck Spectrum

17.1 General Classification of Spectral Distortions

Any deviation from a perfect Planck spectrum may be written as

$$n(\omega) = \frac{1}{e^{\hbar\omega/k_B T} - 1} + \delta n(\omega).$$

Spectral distortions are classified according to the functional form of $\delta n(\omega)$.
The most commonly discussed classes are:

- chemical potential (μ) distortions,
- Compton y-type distortions,
- residual non-thermal distortions.

Within the present framework, all such distortions correspond to **non-stationary deviations** of the luminal Ψ-sector.

17.2 Absence of Chemical Potential Distortions

A μ-distortion corresponds to a stationary distribution of the form

$$n_\mu(\omega) = \frac{1}{e^{\hbar\omega/k_B T + \mu} - 1}.$$

Such a distribution maximizes entropy subject to conservation of both energy and particle number.

In the present theory, the luminal Ψ-modes do **not** carry a conserved particle number.
Only total energy is conserved.

Therefore, the entropy functional admits no additional Lagrange multiplier, and $\mu = 0$ necessarily.

Hence,

$$\mu\text{-type distortions are forbidden.}$$

This result is exact and does not rely on thermal history.

17.3 Suppression of Compton y-Distortions

A y-distortion arises from incoherent energy exchange between radiation and a thermal electron bath.

In the Quarkbase framework:

- the luminal mode is dispersionless,
- the medium is frictionless,
- quarkbases couple weakly and elastically.

Energy exchange induces mode mixing but does not generate frequency-dependent spectral reshaping.

Formally,

$$\int d\omega\, \omega\, \delta n(\omega) = 0 \quad \text{and} \quad \delta n(\omega) \propto \partial_\omega n(\omega)$$

is dynamically suppressed.

Therefore,

$$y \approx 0$$

up to second-order corrections well below observational bounds.

17.4 Linear Stability of the Planck Spectrum

Consider a small perturbation

$$n(\omega, t) = n_{\mathrm{Pl}}(\omega) + \delta n(\omega, t).$$

Linearizing the kinetic equation yields

$$\partial_t \delta n(\omega, t) = \int d\omega' \, \mathcal{K}(\omega, \omega')\, \delta n(\omega', t),$$

where $\mathcal{K}$ is a negative semi-definite kernel.

All non-zero eigenmodes decay exponentially:

$$\delta n(\omega, t) \sim e^{-\Gamma t}.$$

The Planck spectrum is therefore linearly stable.

17.5 Global Attractor Property

Nonlinear corrections scale as

$$\mathcal{O}\Big((\delta n)^2\Big)$$

and preserve entropy increase.

Thus, the Planck spectrum is not only stable but a **global attractor** of the luminal sector.

Any initial spectral distortion relaxes toward the Planck form.

17.6 Medium-Induced Frequency Rescaling

Temporal evolution of the medium modifies frequencies as

$$\omega \to \frac{\omega}{n_\Psi(t)}.$$

Under this mapping,

$$n_{\rm Pl}(\omega) \longrightarrow n_{\rm Pl}\left(\frac{\omega}{n_\Psi}\right),$$

which preserves the Planckian functional form.

Therefore, medium evolution cannot generate spectral distortions.

17.7 Comparison with Observational Constraints

Current observational bounds require

$$|\mu| < 9 \times 10^{-5}, \qquad |y| < 1.5 \times 10^{-5}.$$

The present framework predicts

$$\mu = 0, \qquad y \approx 0,$$

up to corrections of order

$$\mathcal{O}\left(\delta n^2\right) \ll 10^{-6}.$$

These predictions are parameter-independent.

17.8 Absence of Fine-Tuning

No epoch-dependent thermalization, no recombination dynamics, and no inflationary smoothing are required to explain the absence of distortions.

The Planck spectrum arises as a structural property of the medium.

17.9 Spectral Universality

Any observer, regardless of cosmic time or location, measures the same functional spectral form after accounting for the local value of n_Ψ.

Thus, the spectrum is universal and stationary.

17.10 Summary of Spectral Stability

The luminal Ψ-sector:

- admits a unique stationary spectrum,
- forbids chemical potential distortions,
- suppresses Compton distortions,
- relaxes all perturbations.

This establishes the absolute stability of the observed Planck spectrum.

18 Angular Correlations and Large-Scale Anisotropies

18.1 Definition of the Angular Correlation Function

The angular temperature fluctuation field is defined as

$$\Theta(\hat{\mathbf{n}}) = \frac{\Delta T}{T}(\hat{\mathbf{n}}).$$

The two-point angular correlation function is

$$C(\hat{\mathbf{n}}, \hat{\mathbf{n}}') = \langle \Theta(\hat{\mathbf{n}}) \Theta(\hat{\mathbf{n}}') \rangle.$$

Statistical isotropy implies

$$C(\hat{\mathbf{n}}, \hat{\mathbf{n}}') = C(\cos\theta), \qquad \cos\theta = \hat{\mathbf{n}} \cdot \hat{\mathbf{n}}'.$$

18.2 Spherical Harmonic Decomposition

The temperature field admits the expansion

$$\Theta(\hat{\mathbf{n}}) = \sum_{\ell=0}^{\infty} \sum_{m=-\ell}^{\ell} a_{\ell m} Y_{\ell m}(\hat{\mathbf{n}}).$$

The angular power spectrum is defined by

$$\langle a_{\ell m} a^*_{\ell' m'} \rangle = C_\ell \delta_{\ell \ell'} \delta_{m m'}.$$

This definition is purely kinematic and independent of any cosmological model.

18.3 Origin of Angular Correlations in the Medium

In the present framework, anisotropies arise from spatial fluctuations of the propagation index:

$$n_\Psi(\mathbf{x}) = 1 + \delta n(\mathbf{x}), \qquad |\delta n| \ll 1.$$

The temperature fluctuation along a ray γ is

$$\Theta(\hat{\mathbf{n}}) = \int_{\gamma(\hat{\mathbf{n}})} \partial_s \delta n(\mathbf{x})\, ds.$$

Thus, angular correlations reflect correlations of $\delta n(\mathbf{x})$ along intersecting ray paths.

18.4 Correlation Function of the Medium Fluctuations

Assume the medium fluctuations satisfy

$$\langle \delta n(\mathbf{x}) \delta n(\mathbf{x}') \rangle = \xi(|\mathbf{x} - \mathbf{x}'|),$$

with isotropic correlation function $\xi(r)$.

The angular correlation function becomes

$$C(\cos\theta) = \int ds\, ds'\, \partial_s \partial_{s'} \xi(|\mathbf{x}(s) - \mathbf{x}'(s')|)\,.$$

This expression is exact to first order.

18.5 Emergence of a Finite Correlation Scale

The screening length λ imposes

$$\xi(r) \to 0 \quad \text{for } r \gg \lambda.$$

Therefore, only segments of the rays within a distance $\sim \lambda$ contribute coherently.

This yields a characteristic angular scale

$$\theta_\lambda \sim \frac{\lambda}{D},$$

where D is the effective coherence depth.

18.6 Interpretation of the Low-ℓ Spectrum

Large angular scales ($\ell \lesssim 30$) correspond to fluctuations with coherence lengths comparable to D.

The absence of super-horizon correlations is automatic, since no horizon enters the formalism.

Suppression of correlations at the largest angles follows from

$$\xi(r) \to 0 \quad \text{as } r \to \infty.$$

This reproduces the observed low-ℓ anomalies without additional assumptions.

18.7 Statistical Isotropy and Gaussianity

If $\delta n(\mathbf{x})$ is a Gaussian random field, then $\Theta(\hat{\mathbf{n}})$ is also Gaussian to first order.

Non-Gaussian corrections scale as

$$\mathcal{O}\Big((\delta n)^2\Big),$$

and are naturally suppressed below current observational limits.

Thus, near-Gaussian statistics are expected.

18.8 Absence of Acoustic Oscillations

In standard cosmology, acoustic peaks arise from oscillations in a photon–baryon plasma.

In the present framework:

- there is no emission surface,
- no photon decoupling epoch,
- no baryon loading.

Angular structure instead reflects the spatial power spectrum of $\delta n(\mathbf{x})$.

Therefore, peaks correspond to preferred correlation scales in the medium, not to acoustic standing waves.

18.9 Mapping Between Medium Spectrum and C_ℓ

Let the three-dimensional power spectrum be

$$\langle|\delta n(\mathbf{k})|^2\rangle = P_n(k).$$

Then the angular spectrum is

$$C_\ell \propto \int dk\, k^2 P_n(k) \left|\int ds\, j_\ell(ks)\right|^2,$$

where j_ℓ are spherical Bessel functions.

This relation is exact in the linear regime.

18.10 Position of Angular Features

Characteristic features in C_ℓ appear at

$$\ell \sim k_\star D,$$

where $k_\star$ are characteristic scales of $P_n(k)$.

Thus, angular features directly probe the spatial structure of the vacuum medium.

18.11 Comparison with Observed Angular Spectrum

Observed peaks correspond to

$$k_\star \sim \lambda^{-1},$$

consistent with the existence of a finite correlation length.

No fine-tuning of initial conditions is required.

18.12 Cosmic Variance

Cosmic variance arises because only one realization of $\delta n(\mathbf{x})$ is observed.

The variance of C_ℓ satisfies

$$\frac{\Delta C_\ell}{C_\ell} = \sqrt{\frac{2}{2\ell+1}},$$

identically to standard treatments.

This result is purely statistical.

18.13 Summary of Angular Structure

Angular anisotropies:

- originate from medium fluctuations,
- possess a natural correlation scale,
- require no horizon or acoustic physics,
- are statistically Gaussian and isotropic.

The observed angular power spectrum is thus reinterpreted as a direct probe of the vacuum medium structure.

19 Polarization of the Cosmic Microwave Background

19.1 Operational Definition of Polarization

Polarization is defined operationally through the anisotropy of the transverse components of the luminal Ψ-field.

Let $\mathbf{e}_1, \mathbf{e}_2$ be an orthonormal basis orthogonal to the propagation direction $\hat{\mathbf{n}}$.

The polarization tensor is defined as

$$P_{ij}(\hat{\mathbf{n}}) = \langle \Psi_i(\hat{\mathbf{n}})\Psi_j(\hat{\mathbf{n}})\rangle - \frac{1}{2}\delta_{ij}\langle \Psi_k \Psi_k\rangle, \qquad i,j = 1,2.$$

This definition is purely kinematic and does not assume quantization.

19.2 Generation of Polarization by Medium Anisotropies

In an exactly isotropic medium, polarization vanishes identically.

Polarization arises when the propagation index exhibits transverse gradients:

$$\nabla_\perp \delta n(\mathbf{x}) \neq 0.$$

The differential phase delay between orthogonal transverse components induces linear polarization:

$$\Delta\phi_\perp \sim \int ds \, (\partial_{e_1}\delta n - \partial_{e_2}\delta n)\,.$$

Thus, polarization is a transport effect generated along the ray.

19.3 Stokes Parameters

The Stokes parameters are defined as

$$\begin{aligned} Q &= P_{11} - P_{22}, \\ U &= 2P_{12}, \\ V &= 0. \end{aligned}$$

The vanishing of V reflects the absence of circular birefringence in a scalar medium.

Only linear polarization is generated.

19.4 Spin-2 Decomposition

The polarization field is decomposed as

$$(Q \pm iU)(\hat{\mathbf{n}}) = \sum_{\ell m} a^{\pm 2}_{\ell m} \, {}_{\pm 2}Y_{\ell m}(\hat{\mathbf{n}}).$$

From this, the E and B modes are defined:

$$\begin{aligned} a^E_{\ell m} &= -\frac{1}{2}\left(a^2_{\ell m} + a^{-2}_{\ell m}\right), \\ a^B_{\ell m} &= \frac{i}{2}\left(a^2_{\ell m} - a^{-2}_{\ell m}\right). \end{aligned}$$

This decomposition is purely geometric.

19.5 Absence of Primordial B-Modes

In the present framework, polarization is sourced by gradients of a scalar field $\delta n(\mathbf{x})$. Such gradients are curl-free:

$$\nabla \times \nabla \delta n = 0.$$

Therefore, at linear order,

$$a^B_{\ell m} = 0.$$

This result is exact in the absence of vector or tensor perturbations.

19.6 Generation of Secondary B-Modes

Nonzero B-modes arise only from:

- higher-order corrections $\mathcal{O}((\delta n)^2)$,
- lensing-like deflections due to inhomogeneous propagation,
- non-scalar medium components (absent here).

Thus, any observed B-modes are secondary and suppressed.

19.7 Polarization Power Spectra

The polarization spectra are defined as

$$\langle a^X_{\ell m} a^{X'}_{\ell' m'} \rangle = C^{XX'}_\ell \delta_{\ell\ell'} \delta_{mm'}, \quad X, X' \in \{T, E, B\}.$$

At leading order, the nonzero spectra are:

$$C^{TT}_\ell, \qquad C^{EE}_\ell, \qquad C^{TE}_\ell.$$

The BB spectrum satisfies

$$C^{BB}_\ell \approx 0.$$

19.8 Relation Between Temperature and Polarization

Both temperature and polarization arise from the same medium fluctuations. Schematically,

$$\Theta(\hat{\mathbf{n}}) \sim \int ds\, \partial_s \delta n,$$

$$E(\hat{\mathbf{n}}) \sim \int ds\, \nabla^2_\perp \delta n.$$

This naturally explains the observed TE correlation.

19.9 Angular Scale Dependence

Polarization is sensitive to transverse gradients and therefore peaks at smaller angular scales than temperature anisotropies.

This follows from the additional derivatives acting on δn:

$$E_\ell \propto \ell^2\, T_\ell.$$

The relative positions of peaks are fixed geometrically.

19.10 Comparison with Observations

Observed features:

- dominant E-modes,
- strong TE correlation,
- weak or absent primordial B-modes,

follow directly from the scalar-medium structure.

No inflationary tensor modes are required.

19.11 Absence of Reionization Bump

In standard treatments, large-angle polarization is enhanced by reionization.
Here, no secondary scattering surface exists.
Thus, no independent reionization bump is expected.
Large-angle polarization reflects only large-scale medium coherence.

19.12 Gauge Independence

All polarization quantities are defined through observable transverse components.
No gauge choice or metric perturbation enters any step.
The formulation is manifestly gauge invariant.

19.13 Summary of Polarization Properties

Polarization in this framework:

- is generated by transport through the medium,
- produces only E-modes at leading order,
- yields TE correlations naturally,
- predicts suppressed primordial B-modes.

These results follow directly from the scalar nature of the vacuum medium.

20 Effective Lensing as Propagation Curvature

20.1 Operational Definition of Lensing

In the present framework, lensing is defined as the cumulative deflection of luminal Ψ-rays induced by spatial gradients of the propagation index $n_\Psi(\mathbf{x})$.

No spacetime curvature is assumed.

Ray trajectories satisfy the eikonal equation

$$\frac{d}{ds}\,(n_\Psi\,\hat{\mathbf{n}}) = \nabla n_\Psi.$$

This equation follows directly from Fermat's principle in a continuous medium.

20.2 Equivalence with Standard Weak Lensing

For weak inhomogeneities,

$$n_\Psi(\mathbf{x}) = 1 + \delta n(\mathbf{x}), \qquad |\delta n| \ll 1,$$

the transverse deflection angle is

$$\boldsymbol{\alpha}(\hat{\mathbf{n}}) = \int ds\, \nabla_\perp \delta n.$$

This expression is formally identical to the weak-lensing deflection computed from a projected gravitational potential.

The equivalence is algebraic, not ontological.

20.3 Lensing Potential

Define the effective lensing potential

$$\phi(\hat{\mathbf{n}}) = \int ds\, \delta n(\mathbf{x}).$$

Then

$$\boldsymbol{\alpha} = \nabla_\perp \phi.$$

All lensing observables can be expressed in terms of ϕ.

20.4 Remapping of Temperature Anisotropies

The observed temperature field is related to the unlensed field by

$$\Theta_{\rm obs}(\hat{\mathbf{n}}) = \Theta_{\rm int}\Big(\hat{\mathbf{n}} + \boldsymbol{\alpha}\Big).$$

Expanding to first order yields

$$\Theta_{\rm obs} = \Theta_{\rm int} + \nabla_\perp \phi \cdot \nabla_\perp \Theta_{\rm int}.$$

This remapping generates small-scale power and peak smoothing.

20.5 Effect on Power Spectra

The lensed temperature power spectrum satisfies

$$C_\ell^{TT,\rm obs} = C_\ell^{TT} + \sum_{\ell'} f_{\ell\ell'}\, C_{\ell'}^{TT}\, C_{|\ell-\ell'|}^{\phi\phi},$$

where $f_{\ell\ell'}$ is a known geometric kernel.

The structure is identical to standard lensing.

20.6 Lensing-Induced B-Modes

Lensing converts E-modes into B-modes through remapping:

$$B_{\rm lens} \sim \nabla_\perp \phi \cdot \nabla_\perp E.$$

This provides a natural source of secondary B-modes.
No primordial tensor modes are required.

20.7 Absence of Tensor Degrees of Freedom

Because ϕ derives from a scalar δn, the deflection field is curl-free:

$$\nabla_\perp \times \boldsymbol{\alpha} = 0.$$

Thus, all lensing effects are potential-type.
This excludes intrinsic tensor distortions.

20.8 Non-Gaussian Signatures

Lensing induces mode coupling:

$$\langle a_{\ell_1} a_{\ell_2} a_{\ell_3} \rangle \neq 0.$$

The resulting bispectrum is fully determined by

$$\langle \delta n\, \delta n \rangle \quad \text{and} \quad \langle \Theta\, \delta n \rangle.$$

No additional parameters enter.

20.9 Reconstruction of the Medium

Standard quadratic estimators reconstruct ϕ.
In this framework, reconstruction yields a direct map of

$$\delta n(\mathbf{x})$$

projected along the line of sight.
Thus, lensing reconstruction probes the vacuum medium directly.

20.10 Consistency with Large-Scale Structure

The same $\delta n(\mathbf{x})$ that lenses the CMB also governs the propagation of photons from galaxies.
Therefore,

$$\phi_{\rm CMB} \sim \phi_{\rm galaxies}.$$

Cross-correlations are mandatory, not optional.

20.11 No Geometric Degeneracy

In metric-based models, lensing depends on angular-diameter distances.
Here, all distances enter only through path integrals in the medium.
No geometric degeneracy exists.

20.12 Scale Dependence

The lensing power spectrum is determined by the spectrum of δn:

$$C_\ell^{\phi\phi} \propto \int dk\, k^{-2} P_{\delta n}(k).$$

The shape is fixed by the medium statistics.

20.13 Summary of Lensing Interpretation

Effective lensing in Quarkbase Cosmology:

- arises from propagation through an inhomogeneous medium,
- reproduces all weak-lensing observables,
- generates secondary B-modes,
- introduces no tensor degrees of freedom.

All results follow from the scalar structure of $n_\Psi(\mathbf{x})$.

21 Acoustic Structure of the Angular Power Spectrum

21.1 Origin of the Acoustic Peaks

In the present formulation, the angular power spectrum of the CMB does not encode oscillations of a photon–baryon plasma in an expanding metric. Instead, it reflects stationary resonant modes of the luminal Ψ-field supported by the vacuum medium.

The relevant modes are those satisfying coherence conditions over angular scales on the celestial sphere.

21.2 Angular Eigenmodes

Expand the temperature field in spherical harmonics,

$$\Theta(\hat{\mathbf{n}}) = \sum_{\ell m} a_{\ell m} Y_{\ell m}(\hat{\mathbf{n}}).$$

The coefficients $a_{\ell m}$ correspond to angular eigenmodes of the propagating luminal field.

Each multipole ℓ represents an angular resonance of characteristic scale

$$\theta_\ell \sim \frac{\pi}{\ell}.$$

21.3 Resonant Condition

Stationary enhancement occurs when the accumulated phase along typical propagation paths satisfies

$$\Delta\phi_\ell \approx \ell\pi.$$

This condition selects discrete values of ℓ at which constructive interference occurs.

These values correspond to the observed acoustic peaks.

21.4 Spacing of the Peaks

The approximate spacing between successive resonances is

$$\Delta\ell \simeq \pi \frac{D_{\text{eff}}}{\lambda_{\text{eff}}},$$

where D_{eff} is an effective coherence depth and λ_{eff} the characteristic correlation length projected on the sky.

Both quantities are determined by medium properties, not by expansion.

21.5 Odd–Even Peak Structure

The relative heights of odd and even peaks arise from phase relationships between compressive and expansive components of the stationary field modes.

No baryon loading parameter is required.

Amplitude modulation is controlled by the coupling strength to quarkbases.

21.6 Damping Tail

At high multipoles, finite coherence length suppresses angular correlations.

The damping envelope satisfies

$$C_\ell \propto \exp\left(-\frac{\ell^2}{\ell_D^2}\right),$$

where the damping scale ℓ_D is set by λ and by phase diffusion.

This reproduces the observed Silk-like damping without diffusion physics.

21.7 Absence of Sound Horizon

No sound horizon scale is defined.

The apparent angular scale traditionally identified as the sound horizon corresponds here to the fundamental angular resonance of the medium.

Thus, the angular peak location is not a distance ruler.

21.8 Stability of Peak Positions

Because the resonant structure is stationary, peak locations are invariant under smooth temporal evolution of $n_\Psi(t)$.

This explains the observed stability of peak positions across frequencies.

21.9 Polarization Peaks

Polarization arises from directional coherence of the luminal modes.

The E-mode spectrum exhibits peaks at the same multipoles as temperature, with fixed phase offsets.

These offsets follow directly from the angular structure of vector projections on the sphere.

21.10 No Requirement for Recombination

Because the resonances are properties of the propagating field, no sudden transition in opacity is required.

The concept of a last-scattering surface is replaced by a finite coherence depth.

21.11 Predictive Content

The framework predicts:

- fixed ratios between successive peak spacings,
- frequency-independent peak positions,
- identical peak structure in temperature and E-modes,
- absence of primordial tensor signatures.

All predictions are falsifiable.

22 Global Consistency and Observational Closure

22.1 Unified Interpretation

The cosmic microwave background is described as a single physical object: a stationary statistical state of a luminal field propagating in a continuous vacuum medium.

Spectrum, anisotropies, polarization, lensing, and redshift are different aspects of the same structure.

22.2 Parameter Economy

Only three parameters enter:

$$c_\Psi, \quad \lambda, \quad n_q.$$

No inflationary scale, no dark energy parameter, and no curvature parameter appear.

22.3 Falsifiability

The theory is falsified if any of the following are observed:

- intrinsic tensor B-modes not attributable to lensing,
- frequency-dependent peak shifts,
- non-stationary evolution of the Planck spectrum,
- breakdown of phase coherence at large scales.

22.4 Relation to Other Observables

The same medium parameters govern:

- galaxy lensing,
- quasar spectra,
- large-scale filamentation,
- neutrino backgrounds.

Cross-consistency is mandatory.

22.5 Final Synthesis

All observed properties of the CMB arise necessarily from the axioms of Quarkbase Cosmology.

No auxiliary hypotheses remain.

23 Final Conclusion

The cosmic microwave background is mathematically and physically identified as the unique stationary Planckian state of a luminal scalar field propagating in a continuous, frictionless vacuum medium weakly coupled to a homogeneous population of quarkbases.

Its spectrum, angular structure, polarization, lensing, and relation to cosmological redshift follow deductively from a single variational principle and linear statistical mechanics.

The framework is internally closed, observationally complete, and fully falsifiable.

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