The Causal Pillars of the UAT Framework: Core and Derived Equations

Miguel Ángel Percudani, Ph.D.

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1 Introduction: The UAT as a New Metric Paradigm

The Universal Applied Time (UAT) is not an extension of the ΛCDM model but a self-consistent physical paradigm based on the **Law of Causal Regulation (LCR)**. This framework proposes two fundamental axioms that govern the cosmos from the quantum to the cosmological scale.

2 The Core: Axiomatic Equations of UAT

These two equations represent the foundational physical principles from which all UAT results are derived. They are the **Heart of the UAT**.

2.1 1. Central Cosmological Equation (The Operational Axiom)

This modified Friedmann equation dictates the regulated expansion rate of the universe, $E(z)$, and is the direct operational tool that resolves the Hubble Tension.

$$\mathbf{E}_{\text{UAT}}(z, k_{\text{early}})^2 = k_{\text{early}} \cdot \Omega_{r,0}(1+z)^4 + k_{\text{early}} \cdot \Omega_{m,0}(1+z)^3 + \Omega_{\Lambda,0} \tag{1}$$

Key Interpretation of $\mathbf{k_{early}}$*:* The factor $\mathbf{k_{early}} \approx \mathbf{0.967}$ is the **Early-Universe Modification Factor**. It emerges as the macroscopic consequence of Spacetime Quantization (LQG), acting as a **quantum brake** that reduces the effective density of matter and radiation by $\sim 3.3\%$ for $z \gg 1$. This reduction successfully shortens the sound horizon (r_d), aligning early-universe data with the high local H_0 value (73.0 km/s/Mpc).

2.2 2. Fundamental Applicable Time Equation (The Foundational Axiom)

This equation defines the very nature of time (t_{UAT}) as an emergent phenomenon of causal interactions, governed by a convolution of cosmological, relativistic, and Loop Quantum Gravity (LQG) corrections.

$$\mathbf{t}_{\text{UAT}} = t_{\text{event}} \times \underbrace{\left(\frac{1}{a(t)}\right)}_{\text{Cosmological}} \times \underbrace{\left(\frac{1}{\sqrt{1 - \frac{2GM(t)}{c^2 r}}}\right)}_{\text{Relativistic}} \times \underbrace{\left(\frac{1}{1 + \frac{\gamma l_{\text{Planck}}^2}{4\pi r^2 s}}\right)}_{\text{Quantum (LQG)}} \tag{2}$$

Key Interpretation of κ_{crit}*:* The existence of this regulated causal structure necessitates the **Causal Coherence Constant** ($\kappa_{\text{crit}} \approx \mathbf{1.0 \times 10^{-78}}$). This constant is the **axiomatic limit** of causal finitude imposed by the LCR. It prevents the divergence of Zero-Point Energy ($\rho_{\text{ZPE}} = \rho_{\text{Planck}}$), governs the threshold for quantum decoherence (wave function collapse), and acts as the fundamental scaling factor that connects E_{Planck} to the Mass Gap of Yang-Mills.

3 Derived Equations: Consequences and Extensions

These equations represent the direct **observable consequences** and **microphysical extensions** that validate the principles established by the Core Equations.

3.1 3. The Emergence of Dark Energy (Consequence of Finitude)

Derived from the LCR and the $\Omega_{\text{total}} = 1$ condition, this equation shows that the Dark Energy density (Ω_Λ) is not a free parameter but is determined by the regulated components.

$$\mathbf{\Omega_\Lambda} = 1 - k_{early}(\Omega_m + \Omega_r) \tag{3}$$

3.2 4. The Modified Sound Horizon ($r_{d,UAT}$) (Observable Consequence)

This equation integrates the expansion rate (Eq. 1) to yield the sound horizon (r_d), the primary observable that is reduced to mathematically match the high local H_0 measurement.

$$\mathbf{r_{d,UAT}} = \frac{c}{\sqrt{3}} \int_{z_{drag}}^{\infty} \frac{dz}{H_{\text{UAT}}(z)(1+z)\sqrt{1 + \frac{3\Omega_b}{4\Omega_r}(1+z)^{-1}}} \tag{4}$$

3.3 5. Causal Mass Gap Equation (Λ_{QCD}) (Microphysical Extension)

An extension of the LCR's demand for finite ZPE, this equation connects the maximum energy scale (E_{Planck}) to the minimum energy scale (Mass Gap Λ_{QCD}) via the Causal Coherence Constant (κ_{crit}).

$$\mathbf{\Lambda}_{\text{QCD}} \propto E_{\text{Planck}} \cdot (\kappa_{\text{crit}})^{\frac{1}{N}} \quad \text{where } N \approx 4 \tag{5}$$