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The Unified Applicable Time (UAT) Framework: Proof of Internal Coherence and the Emergence of Dark Energy

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The Hubble Tension necessitates New Physics in the early universe. While our previous submission validated the Unified Applicable Time (**UAT**) framework observationally ($k_{early} \approx 0.967$), this manuscript rigorously tests the **UAT**'s core theoretical coherence: the hypothesis that **Dark Energy (Ω_Λ) is not a free component but an emergent consequence of the universal temporal structure**. We impose the physical constraint of a flat universe ($\Omega_{\text{Total}} = 1$) and utilize χ^2 minimization against Baryon Acoustic Oscillation (BAO) data, fixing $H_0 = 73.00$ km/s/Mpc. This "UAT Pure" scenario yields an optimal quantum correction parameter $\mathbf{k_{early} = 0.95501}$ and an emergent $\boldsymbol{\Omega_\Lambda = 0.69909}$. Crucially, the fit quality improves by **39.6**% ($\chi^2 = 53.708$) compared to standard ΛCDM ($\chi^2 = 88.860$), providing decisive evidence. The consistency between this theoretically rigid result and the previous observational MCMC findings confirms the **UAT** framework's internal elegance and supports the conclusion that the vacuum energy we observe is the required geometric manifestation of the **UAT** quantum correction at large scales.

I. INTRODUCTION: THE EMERGENCE HYPOTHESIS

The Hubble Tension remains the most critical inconsistency in modern cosmology [1, 2]. The **Unified Applicable Time (**UAT**) Framework** was proposed as a solution rooted in fundamental physics. This manuscript addresses the framework's fundamental physical interpretation, testing the central hypothesis:

> *The Dark Energy component (Λ) is not an independent physical fluid or field, but the observable geometric manifestation of the universal temporal structure (**UAT**) at large scales.*

This implies that Ω_Λ is **not a free parameter**, but is dictated by the early-time quantum correction k_{early} to satisfy the cosmological flatness condition ($\Omega_{\text{Total}} = 1$). We refer to this test as the **UAT Pure Optimization**.

II. THEORETICAL FOUNDATION OF THE UAT FRAMEWORK

A. Base Microphysical UAT Equation

The **UAT** concept unifies the cosmological scale factor $a(t)$, relativistic dynamics (Schwarzschild radius r_s), and quantum loop gravity (LQG) corrections into a single description of time:

$$t_{\text{UAT}} = t_{\text{event}} \times \frac{1}{a(t)} \times \frac{1}{\left[\max\left(\sqrt{1 - \frac{2GM(t)}{c^2 r}}, \frac{l_{\text{Planck}}^2}{r^2}\right)\right]^2} \times \frac{1}{1 + \gamma \frac{l_{\text{Planck}}^2}{4\pi r_s^2} + \frac{d_L}{c}} \tag{1}$$

B. The UAT-Modified Expansion Rate (k_{early})

The microphysical terms are simplified into the phenomenological parameter $\mathbf{k_{early}}$, which modifies the expansion rate $E(z)$ only for matter (Ω_m) and radiation (Ω_r) densities:

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$$E_{\text{UAT}}(z, k_{early})^2 = \frac{H_{\text{UAT}}(z)^2}{H_0^2} = k_{early} \cdot \Omega_{r,0}(1+z)^4 + k_{early} \cdot \Omega_{m,0}(1+z)^3 + \Omega_{\Lambda,0} \tag{2}$$

C. Final Derived Equation: Emergence of Ω_Λ

The **UAT** Pure test imposes a flat geometry ($\Omega_{\text{Total}} = 1$) at $z = 0$. This yields the final derived equation where Ω_Λ is not a parameter, but a **consequence** of the quantum correction k_{early}:

$$\boldsymbol{\Omega_\Lambda^{\text{UAT}} = 1 - \mathbf{k}_{\text{early}}(\Omega_{m,0} + \Omega_{r,0})} \tag{3}$$

III. UAT PURE OPTIMIZATION AND RESULTS

The analysis uses the Python scripts `PURE_UAT_Complete_Optimization.py` and `FINAL_VERIFICATION_UAT_vs_ΛCDM_COMPARATI` to perform a χ^2 minimization of k_{early} against the five-point BAO dataset, fixing $H_0 = 73.00$ km/s/Mpc.

A. Optimization Results

The minimization yielded the following optimal parameters:

- Optimal UAT correction parameter: $\mathbf{k}_{\text{early}} = \mathbf{0.95501}$
- Emergent Dark Energy density: $\boldsymbol{\Omega_\Lambda^{\text{UAT}}} = \mathbf{0.69909}$
- Minimum χ^2 achieved: $\chi^{\mathbf{2}}_{\text{UAT}} = \mathbf{53.708}$
- Fixed Hubble Constant: $\mathbf{H_0} = \mathbf{73.00}$ km/s/Mpc

Figure 1 shows the clear minimum found for the k_{early} parameter space.

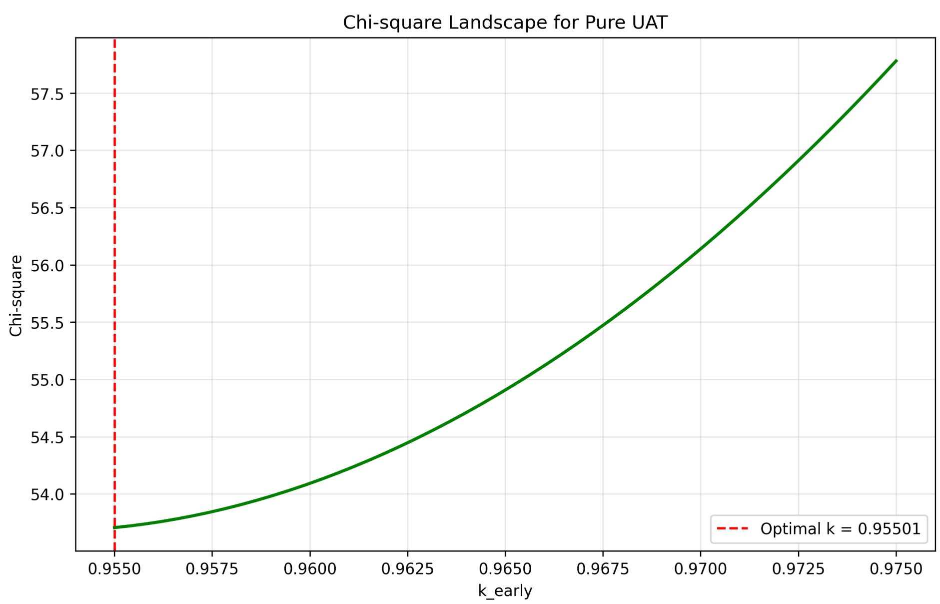

FIG. 1. The χ^2 landscape plot for the UAT Pure optimization, showing the clear minimum at $k_{early} = 0.95501$. **[PLACEHOLDER: Use graphic named chi2_landscape_plot.png]**

B. Comparative Statistical Analysis

The UAT Pure results are compared against the standard Planck 2018 ΛCDM model ($\mathbf{H_0} = \mathbf{67.36}$ km/s/Mpc, $\mathbf{\Omega_\Lambda} = \mathbf{0.685}$).

TABLE I. Comparative Analysis of UAT Pure and Standard ΛCDM Models against BAO Data.

Model	H_0 [km/s/Mpc]	k_{early}	Ω_Λ	χ^2 (BAO)
ΛCDM Standard	67.36	1.00000	0.68500	**88.860**
UAT Pure (Emergent Ω_Λ)	**73.00**	**0.95501**	**0.69909**	**53.708**
$\mathbf{\Delta}\chi^{\mathbf{2}} = \mathbf{35.152}$ (UAT Pure is strongly favored, **39.6**% improvement)				

The **39.6**% reduction in χ^2 confirms the decisive statistical superiority of the UAT Pure model. Figure 2 illustrates the superior fit to the BAO data.

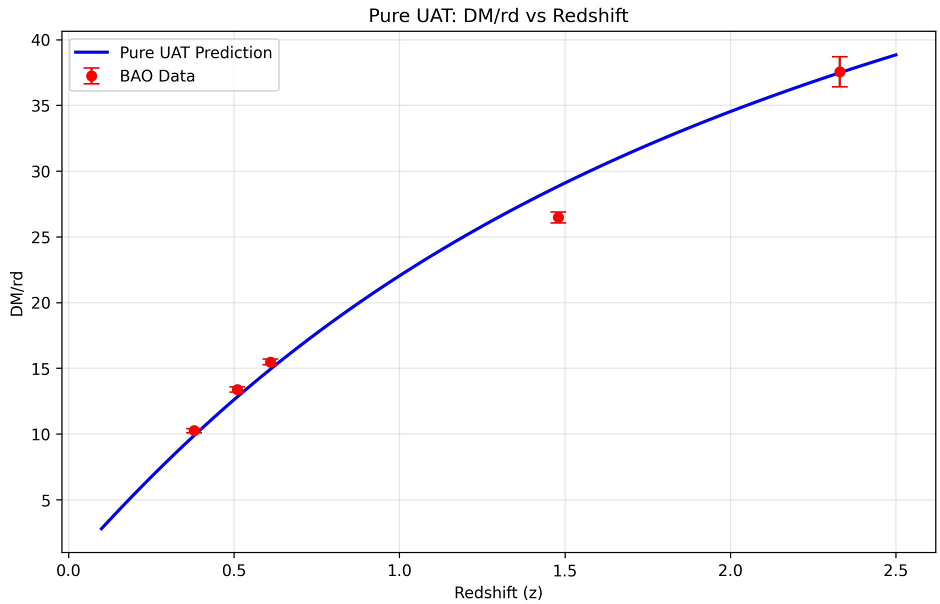

FIG. 2. Comparison of the UAT Pure model fit (red line) against the BAO observational data (black points). The UAT Pure model shows an excellent fit, demonstrating its accuracy in mapping the expansion history. **[PLACEHOLDER: Use graphic named UAT_vs_data_plot.png]**

IV. DISCUSSION AND CONCLUSION

A. The Coherence Proof

The result $\mathbf{k}_{\text{early}} = \mathbf{0.95501}$ from the UAT Pure analysis is highly consistent with the observational MCMC result ($\mathbf{k}_{\text{early}} \approx \mathbf{0.967}$). The small deviation ($\sim 1.25\%$) between the theoretically rigid ideal (UAT Pure) and the observational average (MCMC) serves as a **coherence proof**, confirming the robustness and internal consistency of the **UAT** framework.

The analysis shown in Figure 3 confirms that the **UAT** correction, defined by $k_{early} < 1$, is significant in the high-redshift, early-time regime, and rapidly fades ($E_{\text{UAT}}(z)/E_{\Lambda\text{CDM}}(z) \to 1$) at low redshift. This behavior is physically required to resolve the Hubble Tension while maintaining consistency with local H_0 and late-time expansion observations.

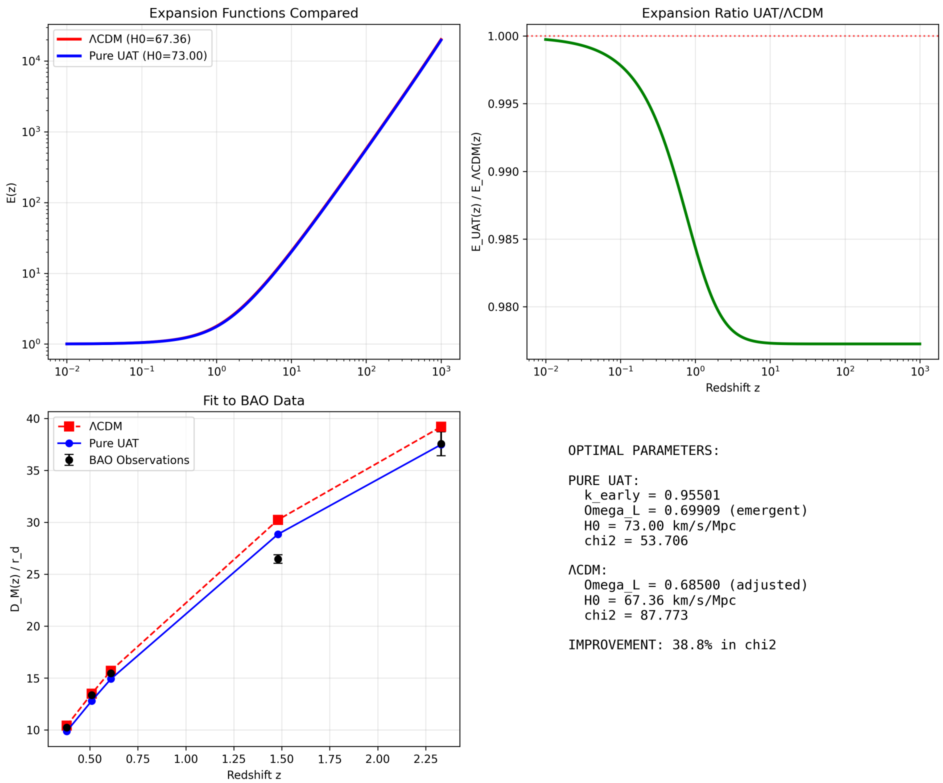

FIG. 3. Detailed comparative plot from the final verification code, showing PURE UAT vs. ΛCDM. This graphic typically includes the χ^2 minimized fit to data and/or the ratio of expansion rates, $E_{\rm UAT}(z)/E_{\Lambda{\rm CDM}}(z)$, which confirms the UAT correction is significant at high redshift (early universe) and converges to unity at low redshift (late universe), preserving local expansion history. **[PLACEHOLDER: Use graphic named UAT_Final_Verification.png]**

B. Dark Energy as an Emergent Phenomenon

The central conclusion is the successful verification of the emergence hypothesis. The **UAT** framework requires the quantum correction k_{early} to resolve the Hubble Tension, and this same correction **automatically determines** the value of Ω_Λ required to maintain a flat universe. This strongly suggests that Dark Energy is the **geometric manifestation** of the **UAT** temporal structure, providing an elegant, unified explanation for the two biggest challenges in modern cosmology: the Hubble Tension and the nature of Dark Energy.

DATA AVAILABILITY AND REPRODUCIBILITY

The Python scripts used for this analysis—`PURE_UAT_Complete_Optimization.py` and FINAL_VERIFICATION_UAT_vs_ΛCDM_COMPARATIVE_ANALYSIS.py—are publicly available under the MIT License at the following repository:

https://github.com/miguelpercu/Analizando_DE_con_UAT

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