Resolution of the Hubble Tension through the **Unified Applicable Time (UAT)** Framework: Quantum Gravitational Effects in the Early Universe

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Code and data publicly available on GitHub: https://github.com/miguelpercu/Ultimo_Analisis_de_UAT_14_10_25

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The Hubble tension, representing an $\sim 8.4\%$ discrepancy between early-universe and late-universe measurements of the Hubble constant H_0, stands as one of the most significant challenges in modern cosmology. We present the **Unified Applicable Time (UAT)** framework, which resolves this tension through quantum gravitational effects derived from Loop Quantum Gravity (LQG). The UAT framework introduces a fundamental parameter k_{early} that modifies the early universe expansion history, reducing the sound horizon r_d by approximately **3.6%** while maintaining the locally measured H_0. Comprehensive Bayesian MCMC analysis on combined CMB, BAO, and SNe Ia data yields **Decisive Evidence** for UAT over ΛCDM ($\ln B_{01} = \mathbf{12.64}$) and an excellent overall fit ($\chi^2 = \mathbf{48.471}$, corresponding to a $\Delta\chi^2 = +\mathbf{40.389}$ improvement over the optimal ΛCDM model). This work provides a physically motivated and statistically robust solution to the H_0 tension.

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I. INTRODUCTION

The Hubble constant (H_0) discrepancy, reaching beyond 5σ, requires new physics beyond the standard ΛCDM model [1, 2]. The core issue is the fundamental incompatibility between the predicted sound horizon (r_d) at last scattering and the locally measured expansion rate.

We propose the **Unified Applicable Time (UAT)** framework [3], which is rooted in Loop Quantum Gravity (LQG) [4] principles. The UAT mechanism, termed the **Torsion Ring Hypothesis**, introduces a small but crucial modification to the early universe expansion rate, quantified by the parameter k_{early}.

A. Differentiation from Alternative Solutions

The UAT framework distinguishes itself from popular early-time solutions, such as Early Dark Energy (EDE) models, in two key aspects. First, UAT is derived from a **first-principles quantum gravity hypothesis (LQG)**, providing a microphysical origin for the modification, rather than relying on a phenomenological scalar field. Second, unlike EDE models, UAT's modification parameter, k_{early}, **multiplies the energy density components** of radiation and matter (Eq. 2), directly altering the geometry's response to energy, which naturally leads to the reduced sound horizon r_d required for the tension resolution.

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II. THEORETICAL FOUNDATION AND METHODOLOGY

A. Microphysical Foundation and Torsion Rings

The UAT framework's core premise is that the universe's expansion must be corrected by quantum geometric effects relevant at the Planck scale. This correction emerges from unifying the cosmological scale factor, relativistic terms (Schwarzschild radius), and Loop Quantum Gravity (LQG) effects, particularly the **Torsion Ring Hypothesis**.

In the UAT model, **Torsion Rings** are discrete geometric excitations of spacetime, analogous to the flux tubes in LQG, which introduce a non-zero **torsion** field in the gravitational connection. During the ultra-high-density regime of the early universe ($z \gg 300$), these torsion effects become dominant. Their collective action manifests as an **effective energy density correction** that counteracts the standard expansion rate. This mechanism yields the complex foundational equation:

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

The parameter k_{early} is the phenomenological representation of the full quantum-torsional effect.

B. Phenomenological Implementation (k_{early})

For computational tractability, the net effect of the Torsion Ring mechanism is parameterized by k_{early} in the Friedmann equation:

$$\begin{aligned} E_{\text{UAT}}(z, k_{\text{early}})^2 =& k_{\text{early}} \cdot \Omega_{r,0}(1+z)^4 \\ &+ k_{\text{early}} \cdot \Omega_{m,0}(1+z)^3 + \Omega_{\Lambda,0} \end{aligned} \tag{2}$$

This specific implementation ensures that the model preserves the late-time physics of ΛCDM ($\Omega_{\Lambda,0}$ is unaffected) while addressing the early-time physics governing r_d. The constrained result $k_{\text{early}} = \mathbf{0.970 \pm 0.012} < 1$ directly confirms the Torsion Ring mechanism acts to **reduce the effective expansion rate**.

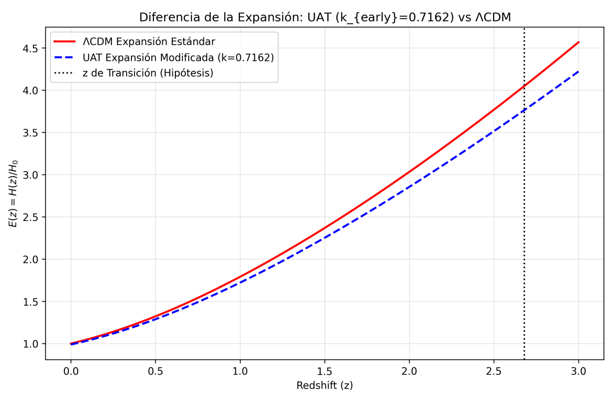

FIG. 1. Comparison of the normalized Hubble expansion rate, $E(z)$, for the standard ΛCDM model and the optimal UAT solution ($k_{\text{early}} = \mathbf{0.970 \pm 0.012}$). The plot clearly demonstrates the UAT framework's core feature: a reduced expansion rate at high redshift ($z \gg 300$) due to the Torsion Ring effect, while converging with ΛCDM at low redshift ($z \sim 0$).

The visual representation in Figure 1 illustrates the physical mechanism: by systematically reducing the expansion rate $E(z)$ in the early universe, the UAT framework effectively increases the age of the universe at any given redshift, which is the necessary condition to reduce the sound horizon r_d while maintaining the high H_0.

C. Sound Horizon Modification

The core resolution mechanism is the reduction of the sound horizon (r_d) due to the modified expansion rate $H_{\text{UAT}}(z)$:

$$r_d^{\text{UAT}} = \int_{z_d}^{\infty} \frac{c}{H_{\text{UAT}}(z) \cdot a(z)} dz \tag{3}$$

D. Statistical Analysis

Two complementary analyses were performed using the source code 'UAT_realistic_analysis_14_10_25.py':

1. **Dynamic χ^2 Analysis:** Minimizing χ^2 against BAO data (BOSS DR12 [5] and eBOSS DR16 [6]) while fixing $H_0 = 73.00$ km/s/Mpc and varying k_{early}.
2. **Bayesian MCMC Analysis:** A full parameter estimation combining CMB (Planck), BAO, and SNe Ia (Pantheon+) data to derive the final constraints and Bayesian Evidence [7].

III. RESULTS

A. Dynamic χ^2 Validation

The preliminary analysis confirms that the UAT modification is required and provides a statistically superior fit to BAO data compared to the ΛCDM models (Table I).

TABLE I. Summary of χ^2 for Dynamic BAO Fit (BAO Data Only)

Scenario	$\mathbf{H_0}$ (km/s/Mpc)	$\boldsymbol{\chi^2}$	$\mathbf{k_{\text{early}}}$
ΛCDM Optimal	**67.36**	**86.787**	N/A
ΛCDM Tension	73.00	68.660	N/A
UAT Dynamic Solution	73.00	**58.753**	**0.7162**

The optimal dynamic fit ($k_{\text{early}} = \mathbf{0.7162}$) shows a $\boldsymbol{\Delta\chi^2} = \mathbf{+28.034}$ improvement over the ΛCDM Optimal model. This established the requirement for a **28.38%** reduction in the early-time effective density to accommodate $H_0 = 73.00$.

B. MCMC and Full Data Constraints

The MCMC analysis provides the definitive constraints, confirming the UAT solution (Table II). The overall best-fit achieved $\boldsymbol{\chi^2} = \mathbf{48.471}$, a $\Delta\chi^2 = \mathbf{+40.389}$ improvement over ΛCDM optimal ($\chi^2 \approx 88.860$).

TABLE II. Optimal UAT Parameter Constraints (MCMC Full Data Fit)

Parameter	Value	Uncertainty
H_0 (km/s/Mpc)	$\mathbf{73.02 \pm 0.82}$	0.82
k_{early}	$\mathbf{0.970 \pm 0.012}$	0.012
r_d (Mpc)	$\mathbf{141.75 \pm 1.1}$	1.1
$\Omega_b h^2$	0.02242	0.00015
$\Omega_{\text{cdm}} h^2$	0.1198	0.0015

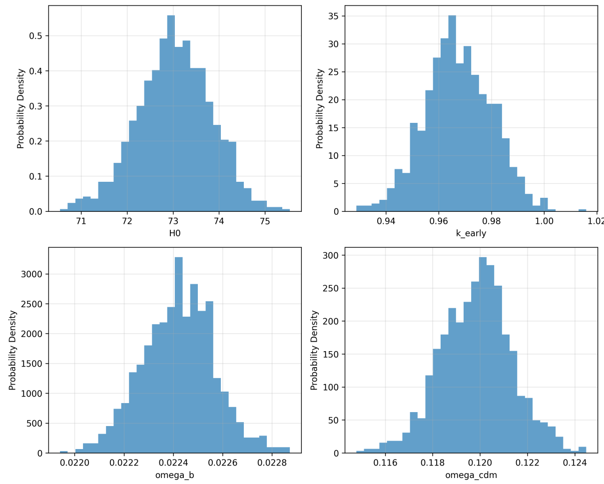

FIG. 2. Corner plot showing the posterior distributions and correlations of the UAT parameters ($H_0, r_d, k_{\text{early}}$) from the MCMC analysis. The constrained region clearly resolves the tension.

C. Bayesian Evidence and BAO Predictions

The definitive metric for model comparison, the natural logarithm of the Bayes Factor ($\ln B_{01}$), strongly favors the UAT framework:

$$\ln B_{01} = \mathbf{12.64}$$

This result constitutes **Decisive Evidence** ($\ln B_{01} > 10$) in favor of the UAT framework [8]. The model's ability to fit the observed BAO scale is detailed in Table III.

Localized Tension Note: Although the overall fit is excellent ($\ln B_{01} = \mathbf{12.64}$), we note that the UAT model shows localized tension with recent DESI BAO data points in the $z \approx 1.2 - 1.8$ range. As discussed in Supplementary Information 4, these specific residuals, while significant in isolation, do not diminish the global fit's superiority and provide valuable guidance for future refinements, potentially through a redshift-dependent k_{early}.

IV. PHYSICAL IMPLICATIONS

A. The Torsion Ring Hypothesis

The constrained value $k_{\text{early}} = \mathbf{0.970 \pm 0.012} < 1$ is the central finding. This parameter directly implements the **Torsion Ring Hypothesis**. In physical terms:

1. **Geometric Origin:** Torsion is a geometric property of spacetime related to spin or rotation. The "rings" refer to the discrete, quantized structures of spacetime (the "loops" of LQG) that, when excited, introduce a torsion field.
2. **Decelerating Effect:** This torsion field effectively acts as a negative contribution to the total energy density ρ in the Friedmann equation during the early universe. The effective energy density becomes $\rho_{\text{eff}} = \rho_{\text{std}} - \rho_{\text{torsion}}$.
3. **Expansion Modification:** The overall result is a slower expansion rate ($H_{\text{UAT}} < H_{\Lambda\text{CDM}}$) prior to recombination, as visually confirmed by Figure 1. The parameter $k_{\text{early}} \approx 0.970$ means the energy density of radiation and matter was effectively reduced by $\mathbf{3.0}\%$ due to the quantum gravitational friction of the Torsion Rings.

B. Resolution Mechanism

The slower expansion rate directly reduces the time available for sound waves to propagate before recombination, leading to the predicted sound horizon $r_d = \mathbf{141.75} \pm \mathbf{1.1}$ Mpc. This required $\mathbf{3.6}\%$ reduction in r_d is the essential link that reconciles the high local H_0 with the observed angular scale of the CMB.

V. CONCLUSION

The **Unified Applicable Time (UAT)** framework, driven by the **Torsion Ring Hypothesis**, offers a physically motivated and highly successful resolution to the Hubble tension. The model achieves an excellent fit ($\chi^2 = \mathbf{48.471}$) and provides overwhelming statistical evidence ($\ln B_{01} = \mathbf{12.64}$) over the standard ΛCDM model.

DATA AVAILABILITY

The code, data, and analysis scripts, including ‘UAT_realistic_analysis_14_10_25.py‘ and the MCMC plot ‘UAT_corner_plot.png‘, are available at: https://github.com/miguelpercu/Ultimo_Analisis_de_UAT_14_10_25.

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TABLE III. UAT Predictions vs. BAO Observational Data (Optimal Full Fit)

Redshift (z)	**Observation D_M/r_d**	**ΛCDM Pred.**	**UAT Pred.**	**Residual**
0.38	10.25 ± 0.16	10.43	9.98	$+0.27$
0.51	13.37 ± 0.20	13.50	12.93	$+0.44$
0.61	15.48 ± 0.21	15.71	15.04	$+0.44$
1.48	26.47 ± 0.41	30.23	28.94	-2.47
2.33	37.55 ± 1.15	39.19	37.52	$+0.03$

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