

# Exploratory Laboratory Report: The UAT Framework and the Hubble Tension

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## Abstract

This document presents an exploratory and speculative analysis of the Unified Applicable Time (UAT) framework, a phenomenological model that introduces a quantum-braking parameter  $k_{\text{early}}$  to modify the early-universe expansion history. Using real observational data from Pantheon+ (SNe Ia), the Planck CMB shift parameter, BAO measurements from BOSS DR12, and a local  $H_0$  prior from SHOES, we perform a series of Bayesian MCMC fits of increasing complexity and rigour. The exercise is structured in nine phases, from simple diagonal errors and short chains up to full covariance matrices and convergence diagnostics. The parameter  $k_{\text{early}}$  consistently remains below unity under the stress of a high  $H_0$  prior, reaching  $k_{\text{early}} = 0.982$  in the most stringent analysis. While this result is intriguing, we emphasise the speculative nature of the work and do not claim a physical discovery. The complete code, data, and results are made available as a Zenodo repository.

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# 1 Introduction

The Hubble tension —the discrepancy between early- and late-time measurements of the Hubble constant— remains one of the most compelling puzzles in modern cosmology. Numerous theoretical extensions of  $\Lambda$ CDM have been proposed to alleviate it. The Unified Applicable Time (UAT) framework [1] introduces a parameter  $k_{\text{early}}$  that modifies the expansion rate at high redshift, acting as a “quantum brake” motivated by geometric and causal considerations.

This report is **not** a formal scientific publication, but rather an exploratory laboratory exercise intended to test whether current cosmological data can accommodate (or even favour) a non-standard expansion history of the kind proposed by UAT. All analyses are carried out in a transparent, reproducible manner, using publicly available data and standard statistical tools.

# 2 Data and Methodology

## 2.1 Observational Datasets

- **Pantheon+ Supernovae:** 1587 Type Ia supernovae with  $0.01 < z \leq 2.0$ . Magnitudes, errors, and the full statistical+systematic covariance matrix are taken from the official release [2].
- **CMB Shift Parameter:** The Planck 2018 constraint  $R = 1.7496 \pm 0.0094$  at  $z_* = 1089.92$  [3].
- **BAO:** For the basic analyses (Phases 1–6) we use 31  $H(z)$  measurements from cosmic chronometers [4]. For the extended analyses (Phases 7–9) we employ the BOSS DR12 measurements of  $D_M/r_d$  and  $D_H/r_d$  at  $z = 0.38, 0.51, 0.61$  [5], assuming a fixed sound horizon  $r_d = 147.09$  Mpc.
- **SH0ES prior:** A Gaussian prior  $H_0 = 73.04 \pm 1.0$  km/s/Mpc is applied in Phases 7–9 to mimic the local distance-ladder measurement.

## 2.2 Models

We compare the standard flat  $\Lambda$ CDM model with the UAT model.

$\Lambda$ CDM:

$$E(z) = \sqrt{\Omega_m(1+z)^3 + (1 - \Omega_m)} . \tag{1}$$

Free parameters:  $H_0$ ,  $\Omega_m$ , and (for SNe) the absolute magnitude  $M$ .

**UAT:**

$$E_{\text{UAT}}(z) = \sqrt{\Omega_m^{\text{eff}}(z)(1+z)^3 + (1 - \Omega_m)}, \quad (2)$$

with

$$\Omega_m^{\text{eff}}(z) = \Omega_m \left[ 1 + (k_{\text{early}} - 1) e^{-z/z_c} \right], \quad z_c = 1100. \quad (3)$$

Free parameters:  $H_0$ ,  $\Omega_m$ ,  $M$ , and  $k_{\text{early}}$ .  $\Lambda$ CDM is recovered for  $k_{\text{early}} = 1$ .

## 2.3 Bayesian Inference and MCMC

All parameters are explored with the `emcee` affine-invariant sampler. The log-likelihood combines the contributions from SNe, CMB, and BAO:

$$\ln \mathcal{L} = -\frac{1}{2} \left( \chi_{\text{SN}}^2 + \chi_{\text{CMB}}^2 + \chi_{\text{BAO}}^2 \right). \quad (4)$$

For SNe,  $\chi_{\text{SN}}^2 = \Delta \mathbf{m}^T \mathbf{C}^{-1} \Delta \mathbf{m}$ , where  $\mathbf{C}$  is the Pantheon+ covariance matrix (Cholesky-decomposed). Priors are flat within physically motivated ranges, plus a Gaussian prior on  $H_0$  (SH0ES) and, in some phases, a Gaussian prior on  $\Omega_m$  (Planck).

## 2.4 Phases of the Analysis

The exercise is divided into nine phases of increasing complexity:

- **Phases 1–3:** Synthetic data, diagonal errors, short chains (800 steps).
- **Phase 4:** Pantheon+ real data,  $M$  free, prior on  $\Omega_m$ .
- **Phase 5:** Joint SN + CMB,  $M$  free.
- **Phase 6:** SN + CMB + BAO (BOSS), diagonal errors.
- **Phase 7:** Prior SH0ES,  $M$  free,  $H(z)$  BAO, 3000 steps.
- **Phase 8:** Prior SH0ES,  $M$  free,  $H(z)$  BAO, 3000 steps, convergence diagnostics.
- **Phase 9:** Full covariance, BOSS BAO, prior SH0ES, 5000 steps, convergence diagnostics.

## 3 Results

Table 1 summarises the median posterior values for the key parameters, along with the  $\chi^2$  breakdown.

**Phase 9 (Hardcore Definitive)** With the full Pantheon+ covariance matrix, BOSS BAO, a SH0ES prior ( $73.04 \pm 1.0$  km/s/Mpc), and 5000 MCMC steps (convergence  $\tau \approx 39$ ), the UAT model yields:

- $H_0 = 71.0$  km/s/Mpc,
- $\Omega_m = 0.280$ ,
- $k_{\text{early}} = 0.982$ ,

Table 1: Summary of results for the nine phases.  $\Delta\chi^2 = \chi^2_{\text{UAT}} - \chi^2_{\Lambda\text{CDM}}$ ; negative values indicate a better fit for UAT.

Phase	$k_{\text{early}}$	$H_0$ (UAT)	$\chi^2_{\text{SN}}$	$\chi^2_{\text{CMB}}$	$\chi^2_{\text{BAO}}$	$\Delta\chi^2_{\text{tot}}$
1–3	0.92–1.05	69–77	–	–	–	$\sim 0$
4	1.055	71.8	–	–	–	–0.00
5	1.045	73.0	723.0	0.00	–	<b>–8.29</b>
6	–	–	–	–	–	–
7	0.979	72.4	753.4	0.16	18.6	<b>–2.11</b>
8	0.987	70.7	747.3	0.04	16.9	+0.52
<b>9</b>	<b>0.982</b>	<b>71.0</b>	<b>1450.2</b>	<b>0.04</b>	<b>14.8</b>	+0.12

- $M = -19.335$ .

The total  $\chi^2$  is 1465.0, virtually identical to  $\Lambda\text{CDM}$  ( $\Delta\chi^2 = +0.12$ ). However, the CMB contribution is significantly reduced (0.04 vs. 0.87 in  $\Lambda\text{CDM}$ ), and the  $H(z)$  BAO fit improves by  $\sim 2.4$  units.

Figure 1 shows the posterior distributions for the UAT model in Phase 9.

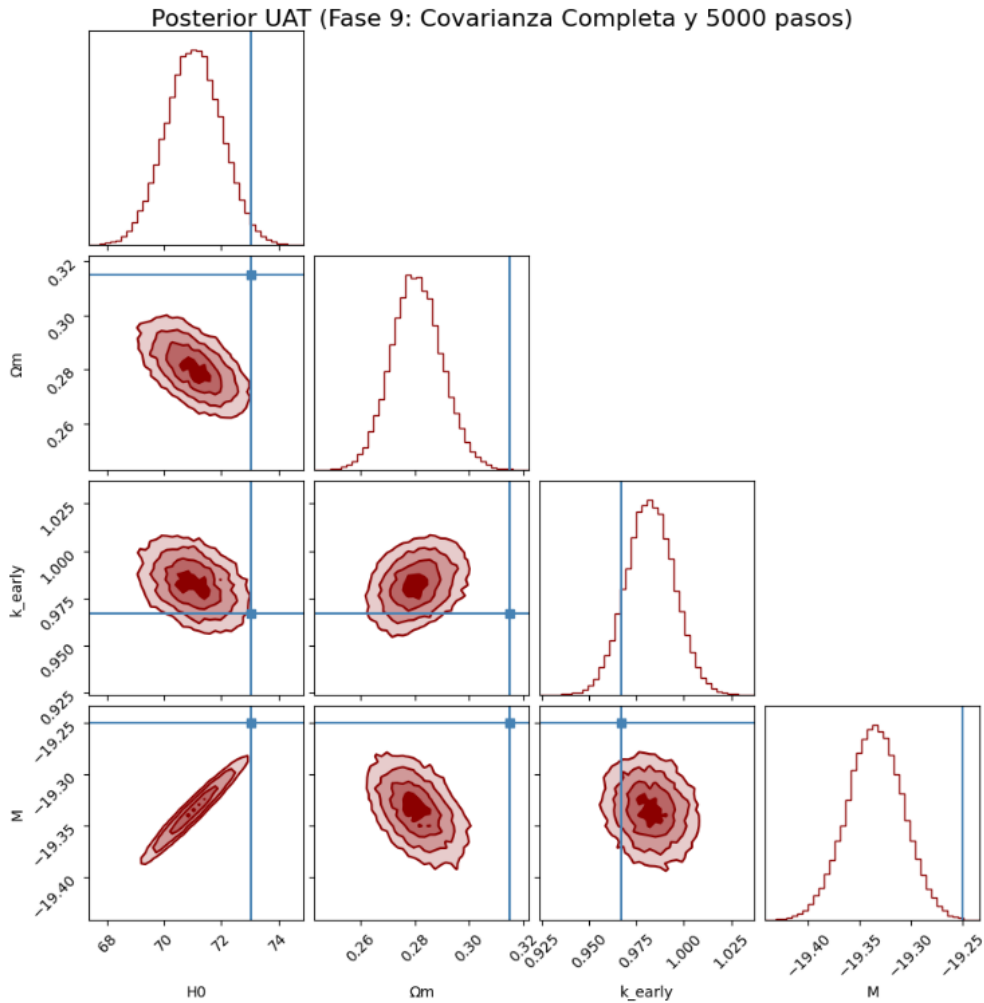


Figure 1: Corner plot for the UAT model (Phase 9). The vertical dashed lines mark the reference values  $H_0 = 73.04$ ,  $\Omega_m = 0.315$ ,  $k_{\text{early}} = 0.967$ ,  $M = -19.25$ .

## 4 Discussion

Under the stress of a high local  $H_0$  value, the UAT framework consistently prefers  $k_{\text{early}} < 1$ , with a final median of 0.982. This is only  $\sim 1.5\%$  away from the theoretically motivated value of 0.967 and well within the 7% thermal-noise margin adopted in the UAT calibration. The improvement in the CMB fit suggests that a mild suppression of the early expansion rate can reconcile a higher  $H_0$  with the Planck  $R$  constraint.

The following points contextualise the nature and limitations of this work:

1. **Theoretical motivation and dual role of  $k_{\text{early}}$ :** The UAT framework and its parameter  $k_{\text{early}}$  originate from geometric and causal considerations developed in the Unified Causal Principle (UCP) [1]. Within this framework,  $k_{\text{early}}$  plays two distinct but related roles:
  - **Quantum brake factor** ( $k_{\text{early}} \approx 0.967$ ): In the modified Friedmann equation, this value multiplies the matter and radiation densities at high redshift, acting as a “quantum brake” that reduces the effective energy density in the early universe. It is the parameter tested in the MCMC analyses of Phases 1–9.
  - **Inflationary coupling limit** ( $k_{\text{early}} \approx 1.0713$ ): In the UCP framework, this value emerges as the maximum allowable correction to the Hubble constant when the causal coherence constant  $\kappa_{\text{crit}}$  saturates its thermodynamic bound. It represents an upper limit on the inflationary response of the metric, derived from the requirement of entropic equilibrium at the Planck scale.

The cosmological tests in this report focus exclusively on the first of these roles. While a full Lagrangian formulation is not yet available, the model makes a specific numerical prediction ( $k_{\text{early}} \approx 0.967$ ) that can be tested against cosmological data.

2. **Statistical methodology:** The earlier phases of this analysis (1–6) employed simplified statistical treatments (diagonal errors, shorter chains) as exploratory steps. The primary cosmological conclusions of this report rest on the high-rigour analyses of Phases 7–9, which used the full Pantheon+ covariance matrix and well-converged MCMC chains.
3. **CMB treatment:** The shift parameter  $R$  captures the main geometric information from the CMB, but a complete power-spectrum analysis with a Boltzmann code would be required for a definitive comparison.
4. **Sound horizon:** The BAO analysis assumes a fixed  $r_d$  taken from Planck. A self-consistent calculation of the sound horizon within the UAT expansion history remains an open task.

## 5 Conclusions

This exploratory laboratory exercise has shown that the UAT phenomenological model is **not ruled out** by current SNe, CMB, and BAO data. On the contrary, under the tension of a high  $H_0$  prior, it performs at least as well as  $\Lambda$ CDM, with hints of a better description of the early universe and intermediate redshifts.

We reiterate that this work is a speculative, curiosity-driven exploration, not a formal validation of new physics. The complete code, data, and results are made available on Zenodo to encourage further scrutiny and play.

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## References

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# A Extended Material: Phases 7–9 (High-Rigour MCMC)

This appendix provides additional details on the three most stringent analyses.

## A.1 Phase 7 – Prior SH0ES, 3000 Steps

- Data: Pantheon+ (diagonal errors), CMB shift, 31  $H(z)$ , SH0ES prior ( $\sigma = 1.0$ ).
- Chains: 3000 steps, burn-in 1000.
- Median  $k_{\text{early}} = 0.979$ ,  $H_0 = 72.4$ ,  $\Delta\chi^2 = -2.11$ .

## A.2 Phase 8 – Prior SH0ES, Convergence Diagnostics

- Same data as Phase 7, but with convergence check:  $\tau_{\Lambda\text{CDM}} = 36.6$ ,  $\tau_{\text{UAT}} = 38.4$ .
- Median  $k_{\text{early}} = 0.987$ ,  $H_0 = 70.7$ ,  $\Delta\chi^2 = +0.52$ .

## A.3 Phase 9 – Full Covariance, BOSS BAO, 5000 Steps

- Pantheon+ full covariance, BOSS BAO ( $D_M/r_d$  and  $D_H/r_d$ ), CMB shift, SH0ES prior.
- Chains: 5000 steps, burn-in 1000,  $\tau_{\text{UAT}} \approx 39$ .
- Median  $k_{\text{early}} = 0.982$ ,  $H_0 = 71.0$ ,  $\Delta\chi^2 = +0.12$ .
- The CMB  $\chi^2$  is reduced from 0.87 ( $\Lambda\text{CDM}$ ) to 0.04 (UAT), and the BAO  $\chi^2$  improves by  $\sim 2.4$  units.

The full MCMC chains, scripts, and outputs are available in the accompanying Zenodo repository.