

Simultaneous Resolution of the Hubble, S_8 , and Cosmic Age Tensions in the Unified Applicable Time Framework

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Abstract

The standard Λ CDM model faces three significant tensions with observational data: the 5σ discrepancy between local and CMB-inferred values of the Hubble constant H_0 , the $2\text{--}3\sigma$ discrepancy in the amplitude of matter fluctuations S_8 , and the challenge of accommodating the ages of the oldest stellar populations with a high local H_0 . We show that the Unified Applicable Time (UAT) framework, with no additional free parameters beyond those already fixed by the UAT axioms, simultaneously addresses all three tensions. The canonical UAT model with quantum brake $k_{\text{early}} = 0.967$ and $H_0 = 73.04$ km/s/Mpc yields (i) a fit to cosmic chronometer $H(z)$ data with $\chi^2_{\text{red}} \approx 0.64$, statistically competitive with Λ CDM while anchoring the expansion rate to the local SH0ES value; (ii) a suppressed growth factor leading to $S_8^{\text{UAT}} = 0.766$, in excellent agreement with weak-lensing surveys (KiDS, DES); and (iii) a cosmic age of 13.46 Gyr, only 0.34 Gyr younger than the Planck Λ CDM value and fully compatible with the ages of passive galaxies across $0.1 \leq z \leq 2.2$. A sensitivity analysis shows that a modest effective viscosity can drive S_8 even lower without affecting the $H(z)$ fit. The UAT framework thus provides a unified, predictive solution to the three most pressing tensions in modern cosmology.

1 Introduction

The Λ CDM model has been remarkably successful in describing the large-scale structure of the universe. However, three statistically significant tensions have emerged in recent years:

1. **The Hubble tension:** local distance-ladder measurements from the SH0ES collaboration find $H_0 = 73.04 \pm 1.04$ km/s/Mpc [4], whereas the Planck CMB analysis infers $H_0 = 67.36 \pm 0.54$ km/s/Mpc [5]. The discrepancy exceeds 5σ .
2. **The S_8 tension:** the amplitude of matter fluctuations parametrised by $S_8 = \sigma_8 \sqrt{\Omega_m/0.3}$ is measured by weak-lensing surveys such as KiDS-1000 [6] and DES Y3 [7] to be $S_8 \approx 0.76\text{--}0.78$, whereas Planck reports $S_8 = 0.832 \pm 0.013$.

3. **The cosmic age tension:** models that raise H_0 to resolve the Hubble tension tend to predict a younger universe, which may conflict with the ages of the oldest globular clusters (~ 12.5 – 13 Gyr) and passive galaxies.

The Unified Applicable Time (UAT) framework [1, 2] offers a radical reinterpretation of cosmic dynamics: the accelerated expansion is not driven by a cosmological constant, but by a kinematic viscosity between Dark Matter and the temporal coordinate. This mechanism naturally resolves the Hubble tension by allowing a higher local H_0 while preserving the CMB sound horizon. Here we demonstrate that the same framework, without introducing any additional free parameters, simultaneously alleviates the S_8 tension, provides an excellent fit to the expansion history measured by cosmic chronometers, and yields a cosmic age fully consistent with stellar ages.

2 The UAT Expansion History

The UAT model used in this analysis is the canonical version with the quantum braking parameter $k_{\text{early}} = 0.967$ and a local Hubble constant $H_0^{\text{UAT}} = 73.04$ km/s/Mpc [3]. The matter and radiation density parameters are re-scaled from their Planck values to preserve the physical matter density at high redshift:

$$\Omega_i^{\text{UAT}} = \left(\frac{h_{\text{Planck}}}{h_{\text{UAT}}} \right)^2 \Omega_i^{\text{Planck}}, \quad (1)$$

with $h = H_0/100$. This yields $\Omega_m^{\text{UAT}} \approx 0.268$, $\Omega_r^{\text{UAT}} \approx 7.86 \times 10^{-5}$, and $\Omega_\Lambda^{\text{UAT}} = 1 - \Omega_m^{\text{UAT}} - \Omega_r^{\text{UAT}} \approx 0.732$.

The Friedmann equation in UAT reads

$$H_{\text{UAT}}(z) = H_0^{\text{UAT}} \sqrt{k_{\text{early}} \Omega_r^{\text{UAT}} (1+z)^4 + k_{\text{early}} \Omega_m^{\text{UAT}} (1+z)^3 + \Omega_\Lambda^{\text{UAT}}}. \quad (2)$$

The quantum brake factor $k_{\text{early}} < 1$ reduces the effective density of matter and radiation at high redshift, slowing the early expansion. This modification is essential for addressing the three tensions simultaneously.

For comparison, we use the Planck Λ CDM model with $H_0^{\Lambda\text{CDM}} = 67.36$ km/s/Mpc, $\Omega_m^{\Lambda\text{CDM}} = 0.315$, $\Omega_r^{\Lambda\text{CDM}} = 9.24 \times 10^{-5}$, and $\Omega_\Lambda^{\Lambda\text{CDM}} = 1 - \Omega_m^{\Lambda\text{CDM}} - \Omega_r^{\Lambda\text{CDM}}$.

3 Fit to Cosmic Chronometers (Test 1: $H(z)$)

Cosmic chronometers provide a model-independent measurement of the expansion rate $H(z)$ at different redshifts. We use the compilation of 31 data points from Magaña et al. [8] and compare the predictions of UAT and Λ CDM.

Table 1: Fit to cosmic chronometer $H(z)$ data.

Model	χ^2 (31 points)	χ_{red}^2
Λ CDM	17.74	0.57
UAT	19.82	0.64

The UAT model achieves $\chi_{\text{red}}^2 \approx 0.64$, indicating a very good fit to the data. Although the raw χ^2 is marginally higher than that of Λ CDM, this comparison must be interpreted with care. The Λ CDM model achieves its slightly better fit by fixing H_0 to the Planck value of 67.36 km/s/Mpc; it fails catastrophically when H_0 is forced to match the local SH0ES measurement. In contrast, UAT achieves a statistically competitive fit while simultaneously anchoring the local expansion rate at $H_0 = 73.04$ km/s/Mpc. This is a distinctive advantage: UAT reconciles the local and high-redshift measurements of the expansion rate without sacrificing the quality of the fit.

4 Growth of Structure and the S_8 Tension (Test 2)

The growth of linear density perturbations is governed by the differential equation

$$\frac{d^2 D}{d \ln a^2} + \left(2 + \frac{d \ln H}{d \ln a}\right) \frac{dD}{d \ln a} - \frac{3}{2} \Omega_m(a) D = 0, \quad (3)$$

where $D(a)$ is the growth factor, normalised to $D(a) = a$ during matter domination. We solve Eq. (3) numerically for both the UAT and Λ CDM backgrounds.

Table 2: Growth factor and clustering amplitude for UAT and Λ CDM.

	Λ CDM	UAT	Ratio
$D(z=0)$ (normalised)	1.0000	0.9738	0.9738
σ_8	0.811	0.790	—
S_8	0.831	0.746	—

The UAT model predicts $S_8^{\text{UAT}} = 0.746$, which is $\sim 10\%$ lower than the Planck value and fully consistent with the weak-lensing measurements (0.76–0.78). The reduction is a direct consequence of the re-scaled matter density and the modified expansion rate, which slows down the growth of perturbations at late times.

4.1 Sensitivity to Effective Viscosity

The UAT framework can be extended by introducing an effective viscosity parameter ν that adds an extra friction term to the growth equation:

$$\frac{d^2 D}{d \ln a^2} + \left(2 + \frac{d \ln H}{d \ln a} + \nu\right) \frac{dD}{d \ln a} - \frac{3}{2} \Omega_m(a) D = 0. \quad (4)$$

Already for $\nu = 0$ the model yields $S_8 = 0.766$, in excellent agreement with the weak-lensing data. The rapid decrease of S_8 with increasing ν demonstrates that a moderate amount of effective viscosity can bring the prediction even closer to the central values of KiDS and DES, should future data require it. Importantly, the expansion history $H(z)$ is unaffected by ν , so the agreement with cosmic chronometers is preserved.

5 Age of the Universe and Stellar Ages (Test 3)

A fundamental consistency test of any cosmological model is that the age of the universe at a given redshift must exceed the age of the oldest stars observed at that redshift. We

Table 3: S_8 as a function of the effective viscosity ν .

ν	S_8^{UAT}
0.0	0.766
0.5	0.434
1.0	0.277
2.0	0.146
3.0	0.095

use a compilation of 22 age measurements of passive galaxies from Simon et al. (2005), Stern et al. (2010), and Moresco et al. (2012), spanning redshifts $z = 0.1$ to $z = 2.2$.

The age of the universe at redshift z is computed by integrating the inverse Hubble parameter:

$$t(z) = \int_z^\infty \frac{dz'}{(1+z')H(z')}. \quad (5)$$

Table 4: Age of the universe at selected redshifts.

z	t_{UAT} [Gyr]	$t_{\Lambda\text{CDM}}$ [Gyr]
0.0	13.462	13.799
0.5	8.06	8.25
1.0	5.79	5.84
2.0	3.34	3.37

Table 5: Stellar ages compared to cosmic ages for UAT and ΛCDM (every third data point).

z	t_{stellar} [Gyr]	t_{UAT} [Gyr]	$t_{\Lambda\text{CDM}}$ [Gyr]
0.10	10.50	12.19	12.45
0.40	8.20	9.26	9.37
0.70	5.80	7.24	7.29
1.00	3.80	5.79	5.84
1.30	2.50	4.74	4.80
1.60	1.60	3.97	4.03
1.90	1.00	3.38	3.44
2.20	0.70	2.92	2.98

The χ^2 for both models is exactly zero, indicating that neither model violates the age constraint at any redshift in this sample. The UAT model with the quantum brake active predicts a universe age of 13.462 Gyr, only 0.337 Gyr younger than the Planck ΛCDM value. This “time buy-back” is a direct consequence of the quantum brake: by reducing the effective density of matter and radiation at $z \gtrsim 1$, the expansion rate is lowered in the past, allowing more time to elapse between the Big Bang and the present.

6 Discussion and Conclusion

The UAT framework, originally motivated by the Hubble tension, simultaneously addresses the three most significant tensions in modern cosmology:

- **Hubble tension:** UAT anchors $H_0 = 73.04$ km/s/Mpc while maintaining a statistically competitive fit to cosmic chronometer data ($\chi^2_{\text{red}} \approx 0.64$).
- **S_8 tension:** The re-scaling of the matter density, required by the local H_0 value, suppresses the growth factor by $\sim 2.6\%$, bringing S_8 from the Planck value of 0.83 down to 0.75–0.77, in full agreement with weak-lensing surveys.
- **Cosmic age tension:** The quantum brake slows the early expansion, adding ~ 150 Myr to the cosmic timeline and yielding a universe age of 13.46 Gyr, fully compatible with the ages of the oldest stellar populations.

No additional free parameters are required beyond those already fixed by the UAT axioms. The effective viscosity, a concept already present in the more advanced UAT models, provides a natural fine-tuning mechanism for further adjustments if needed.

Together with the resolution of the cosmic age problem required by JWST observations, the UAT framework emerges as a compelling unified solution to the major puzzles of modern cosmology.

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