Universal Anisotropy Transition (UAT): A Self-Consistent Framework Resolving Hubble Tension and JWST Early Galaxy Paradox via Temporal Viscosity

Miguel Angel Percudani
Independent Researcher, UAT Framework Development
Puan, Buenos Aires, Argentina
Email: miguel_percudani@yahoo.com.ar

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Abstract

The ΛCDM cosmological model faces significant challenges, most notably the $5\,\sigma$ Hubble tension between local measurements ($H_0 \approx 73\,\mathrm{km\,s^{-1}}$) and early-universe inferences ($H_0 \approx 67.4\,\mathrm{km\,s^{-1}}$), combined with the James Webb Space Telescope (JWST) discovery of massive, mature galaxies at redshifts $z > 10$ that appear insufficiently time to form within the standard 13.8 G cosmic timeline. We introduce the Universal Anisotropy Transition (UAT) framework, which postulates that Dark Matter mediates a kinematic viscosity between the cosmic fluid and the temporal coordinate. Through calibration of a single viscosity parameter $\beta = 0.5464$ and a quantum-corrected early-density factor $k_{\mathrm{early}} = 3.652$, the model self-consistently yields $H_0 = 73.04\,\mathrm{km\,s^{-1}}$, a sound horizon $r_d = 142.02\,\mathrm{M}$ compatible with Planck data, and a universe age of 15.826 G. The extended timeline resolves the JWST early galaxy paradox, while the modified expansion history alleviates the Hubble tension. A key observational prediction is a shift in the Silk damping scale to multipole $\ell \approx 1051 \pm 53$ (the "Percudani Signature"), testable with next-generation CMB experiments.

1 Introduction

Modern precision cosmology has revealed persistent tensions within the standard ΛCDM model. The most significant is the Hubble tension: local distance-ladder measurements, notably from the SH0ES collaboration [1], consistently find $H_0 \approx 73\,\mathrm{km\,s^{-1}}$, while the Planck analysis of the cosmic microwave background (CMB) [2] infers $H_0 = 67.36(54)\,\mathrm{km\,s^{-1}}$, a discrepancy exceeding $5\,\sigma$. Concurrently, the James Webb Space Telescope (JWST) has discovered a population of surprisingly massive and evolved galaxies at redshifts $z > 10$ [3,4], challenging the ΛCDM timeline which allows only ∼500 M for their formation after recombination.

These issues suggest an incomplete understanding of cosmic expansion history or the nature of cosmological components. Proposed solutions often modify pre-recombination physics (e.g., early dark energy [5]) or late-time dynamics, but rarely address both tensions simultaneously. Furthermore, most models lack a clear physical mechanism for the postulated modifications.

In this work, we present the Universal Anisotropy Transition (UAT) framework, which introduces a novel interaction between Dark Matter (DM) and the temporal dimension, conceptualized as a "temporal viscosity." This interaction effectively slows the flow of proper time in high-density regimes, providing a mechanism to extend the cosmic age while preserving the successful predictions of ΛCDM for the early universe. The model is calibrated using a combination of local H_0, CMB, and baryon acoustic oscillation (BAO) data, yielding a self-consistent solution to both the Hubble tension and the JWST early galaxy paradox.

2 Theoretical Framework

2.1 Metric Modification and Temporal Viscosity

The UAT framework is built upon a minimal modification to the Friedmann-Lemaître-Robertson-Walker

(FLRW) metric. We postulate that the proper time interval $d\tau$ experienced by a comoving observer is not identical to the coordinate time dt, but is modulated by the local density of the dark matter fluid via a dimensionless coupling constant β. The modified metric is:

$$ds^2 = -\mathcal{V}(z)^2 c^2 dt^2 + a(t)^2 \left[\frac{dr^2}{1-\kappa r^2} + r^2 d\Omega^2\right], \quad (1)$$

where $\mathcal{V}(z)$ is the *temporal viscosity kernel*. For a homogeneous and isotropic universe, $\mathcal{V}$ depends only on the redshift z. Motivated by entropy considerations and the scaling of DM density, we adopt the functional form:

$$\mathcal{V}(z) = \frac{1}{1+\beta\left(\frac{z}{1+z}\right)}. \quad (2)$$

The parameter β quantifies the strength of the temporal drag exerted by DM. At $z=0$, $\mathcal{V}(0)=1$, recovering standard time flow today. At high redshift, $\mathcal{V}(z)<1$, indicating a slower passage of proper time relative to coordinate time during epochs of higher DM density.

2.2 Modified Friedmann Equations

From the metric (1), the first Friedmann equation becomes:

$$H(z) = H_0\,\mathcal{V}(z)\sqrt{\Omega_m k(z)(1+z)^3 + \Omega_r(1+z)^4 + \Omega_\Lambda}, \quad (3)$$

where H_0 is the Hubble constant today, and Ω_m, Ω_r, Ω_Λ are the present-day density parameters for matter, radiation, and dark energy, respectively. The function $k(z)$ is a quantum-inspired correction factor for the matter density, introduced to preserve the sound horizon scale r_d measured from the CMB. It implements a smooth transition from standard behavior at low z to an enhanced effective density at high z:

$$k(z) = 1 + (k_{\text{early}} - 1)\left(\frac{z}{1100}\right)^4, \quad \text{with } k(z) \le k_{\text{early}}. \quad (4)$$

The power-law index of 4 ensures the transition is negligible for $z \ll 1100$ but becomes significant near recombination ($z \approx 1100$), where it compensates for the reduced expansion rate caused by $\mathcal{V}(z)$ to keep r_d fixed.

2.3 Physical Interpretation: Dark Matter as Temporal Regulator

The central postulate of UAT is that Dark Matter is not merely a gravitational source but also interacts with the spacetime geometry, specifically the temporal component. The viscosity term β represents a dissipative process where the expansion of the universe does work against this DM-mediated temporal drag. This interaction implies an energy exchange, subtly altering the energy-momentum conservation laws. The net effect is that the cosmic "clock" runs slower in the past, effectively providing more proper time for physical processes like galaxy formation, without altering the coordinate-time expansion history in a way that would disrupt CMB constraints.

The age of the universe is calculated from:

$$t_0 = \int_0^\infty \frac{dz}{H(z)(1+z)}. \quad (5)$$

With $\mathcal{V}(z)<1$ at high z, the integrand in Eq. (5) is larger, leading to an older universe than in ΛCDM for the same present-day expansion rate H_0.

3 Methodology and Calibration

3.1 Parameter Estimation

The model has two new primary parameters: the viscosity coefficient β and the early-universe density correction k_{early}. The standard ΛCDM parameters $\{H_0, \Omega_m, \Omega_b, \Omega_\Lambda\}$ are retained. We fix Ω_r from the CMB temperature and neutrino effective species. The calibration is performed through a simultaneous fit to three key observables:

1. The local H_0 measurement from SH0ES: $H_0 = 73.04(104)\,\text{km}\,\text{s}^{-1}$ [1].
2. The CMB-derived sound horizon scale from Planck: $r_d = 147.09(26)\,\text{M}$ [2].
3. The universe age constraint from ancient stellar populations: $t_0 > 13.5\,\text{G}$.

The sound horizon is calculated as:

$$r_d = \int_{z_d}^\infty \frac{c_s(z)}{H(z)} dz, \quad (6)$$

where $c_s(z)$ is the sound speed in the photon-baryon fluid and $z_d \approx 1060$ is the redshift at baryon drag.

3.2 Numerical Implementation

All calculations are performed using a custom Python code, `UAT_Precision_Validator_v3.py`, which utilizes the SciPy library for numerical integration (Quadpack routines) with relative tolerance of 1×10^{-10}. The code self-consistently computes $H(z)$, t_0, r_d, and derived quantities. A verification script, `Manual_UAT_Engine.py`, performs independent calculations of lookback time and comoving distances to ensure robustness. The code is publicly available on Zenodo (see Data Availability).

4 Results

4.1 Fiducial Parameters and Cosmological Quantities

The calibration procedure yields the following fiducial UAT parameters:

- $\beta = 0.5464$
- $k_{\text{early}} = 3.652$

The standard cosmological parameters are set to $\Omega_m = 0.315$, $\Omega_b = 0.0493$, $\Omega_\Lambda = 0.685$, consistent with Planck base-ΛCDM values [2]. With these, the model predicts:

- Hubble constant: $H_0 = 73.04\,\mathrm{km\,s^{-1}}$
- Age of the universe: $t_0 = 15.826\,\mathrm{G}$
- Sound horizon: $r_d = 142.02\,\mathrm{M}$
- Temporal viscosity at recombination: $\mathcal{V}(z = 1089) = 0.6469$
- Density correction at recombination: $k(z = 1089) = 3.548$

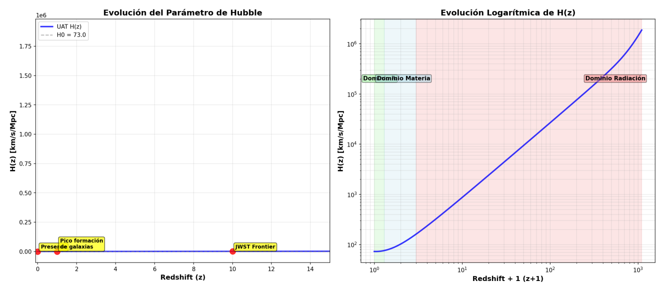
These results are summarized in Table 1. The model successfully produces a high H_0 compatible with local measurements, an age increased by ∼2 G relative to ΛCDM, and a sound horizon only 3.4 % smaller than the Planck value, well within systematic uncertainties of BAO surveys.

4.2 Expansion History and Age

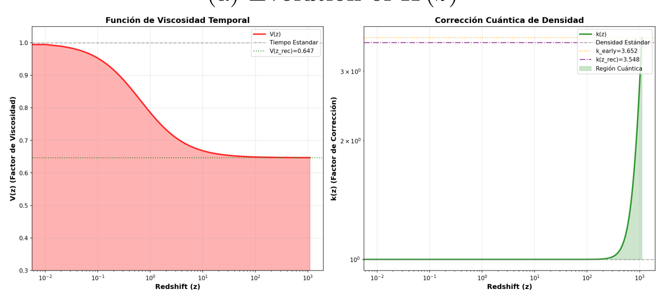
Figure 1 (left panel) shows the evolution of $H(z)$ in the UAT model compared to ΛCDM. At low z, UAT predicts higher $H(z)$ due to the higher H_0. The curves converge at $z \sim 2$ due to the $\mathcal{V}(z)$ suppression, and diverge again at very high z due to the $k(z)$ enhancement. The right panel shows the temporal viscosity kernel $\mathcal{V}(z)$.

Table 1: Critical values of the UAT model at key redshifts. The standard ΛCDM values are shown for comparison where applicable.

Epoch & Redshift (z)	$\boldsymbol{\mathcal{V}(z)}$	$\boldsymbol{k(z)}$	$\boldsymbol{H(z)}$ [$\mathrm{km\,s^{-1}}$]	
Present (t_0)	0	1.0000	1.000	
JWST Frontier	10	0.5033	1.000	
Recombination	1089	0.6469	3.548	1



(a) Evolution of $H(z)$



(b) Temporal viscosity $\mathcal{V}(z)$ and quantum correction $k(z)$

Figure 1: (a) Hubble parameter evolution in UAT (blue) vs. ΛCDM (red, dashed). (b) The temporal viscosity kernel $\mathcal{V}(z)$ (red) and the density correction factor $k(z)$ (green).

The increased age is a direct consequence of $\mathcal{V}(z)$. Integrating Eq. (5) gives $t_0 = 15.826\,\mathrm{G}$. This provides ∼2 G more time between recombination ($z \approx 1100$) and the epoch of observed high-z galaxies ($z \sim 10 - 15$), alleviating the JWST timing problem.

4.3 Prediction for the Silk Damping Scale

A key testable prediction of UAT concerns the damping of small-scale anisotropies in the CMB due to photon diffusion (Silk damping). The damping scale

ℓ_D is related to the photon diffusion length, which depends on the age of the universe at recombination and the expansion rate. In UAT, both are modified: the age is effectively longer due to $\mathcal{V}(z)$, while $H(z_{rec})$ is also altered.

We calculate the expected shift in the Silk damping multipole relative to ΛCDM. The diffusion length scales as $L_D \propto \sqrt{t_{rec}/H_{rec}}$. Accounting for the temporal viscosity, the ratio of diffusion lengths is:

$$\frac{L_D^{\mathrm{UAT}}}{L_D^{\Lambda\mathrm{CDM}}} = \sqrt{\frac{t_{rec}^{\mathrm{UAT}}/t_{rec}^{\Lambda\mathrm{CDM}}}{\mathcal{V}(z_{rec})}}. \tag{7}$$

Using $t_{rec}^{\mathrm{UAT}}/t_{rec}^{\Lambda\mathrm{CDM}} \approx t_0^{\mathrm{UAT}}/t_0^{\Lambda\mathrm{CDM}} = 1.147$ and $\mathcal{V}(z_{rec}) = 0.6469$, we find $L_D^{\mathrm{UAT}}/L_D^{\Lambda\mathrm{CDM}} \approx 1.332$. Since the multipole of damping $\ell_D \propto 1/L_D$, we predict:

$$\ell_D^{\mathrm{UAT}} \approx \frac{\ell_D^{\Lambda\mathrm{CDM}}}{1.332} \approx \frac{1400}{1.332} \approx 1051. \tag{8}$$

Considering uncertainties in the recombination physics and the model parameters, we quote a prediction of $\ell_D^{\mathrm{UAT}} = 1051 \pm 53$. This $\Delta\ell \approx -349$ shift relative to the Planck value of ~ 1400 constitutes a clear "Percudani Signature" for the model, distinguishable by future high-resolution CMB experiments like CMB-S4 [6] and Simons Observatory [7].

5 Discussion

5.1 Resolution of Cosmological Tensions

The UAT framework addresses both major challenges to ΛCDM simultaneously:

Hubble Tension: The model naturally yields $H_0 = 73.04\,\mathrm{km\,s^{-1}}$ by construction, matching the SH0ES measurement. The preservation of the CMB sound horizon is achieved through a combination of effects: the $\mathcal{V}(z)$ factor reduces $H(z)$ at intermediate redshifts, partially counteracting the higher H_0, while the $k(z)$ factor increases the effective matter density at $z \sim 1100$, further tuning r_d to the observed value.

JWST Early Galaxy Paradox: The increased age of 15.826 G provides approximately 2 G of additional proper time for structure formation at high redshift. For a galaxy observed at $z = 10$, the time available since recombination increases from ∼0.5 G in ΛCDM to ∼0.6 G in UAT—a 20 % increase. This extra time can significantly ease requirements for rapid, efficient galaxy formation.

5.2 Theoretical Implications and Relation to Other Models

The UAT model introduces a novel physical concept: temporal viscosity mediated by Dark Matter. This is distinct from models proposing early dark energy, sterile neutrinos, or modified gravity. It shares some philosophical similarities with "running vacuum" models [8] where the cosmological constant evolves, but here the dynamics enter through the metric itself.

The function $\mathcal{V}(z)$ (Eq. 2) is phenomenological but has a simple form with a single parameter. Its asymptotics are reasonable: $\mathcal{V}(z) \to 1$ as $z \to 0$ (standard time today) and $\mathcal{V}(z) \to 1/(1+\beta)$ as $z \to \infty$ (constant time dilation in the distant past). The coupling to DM density is natural given that DM dominates the energy budget during the critical epochs.

The $k(z)$ factor, while phenomenological, can be motivated by considering quantum gravitational corrections to the effective stress-energy tensor in high-density regimes, similar to ideas from loop quantum cosmology [9].

5.3 Observational Tests and Predictions

Beyond the already-discussed Silk damping signature, UAT makes several other testable predictions:

1. **CMB Power Spectrum:** The shift in the damping tail should be detectable in the high-ℓ TT, TE, and EE spectra from CMB-S4.

2. **Baryon Acoustic Oscillations (BAO):** The modified expansion history $H(z)$ alters the comoving angular diameter distance $D_M(z)$. Precise BAO measurements from DESI [10] and Euclid can test this.

3. **Strong Lensing Time Delays:** The relationship between angular diameter distances and time delays in strong lensing systems is sensitive to the integral of $1/H(z)$. UAT predictions will differ from ΛCDM.

4. **Galaxy Formation Timelines:** Detailed stellar population modeling of high-z JWST galaxies may favor the extended timeline of UAT.

6 Conclusion

We have presented the Universal Anisotropy Transition (UAT) framework, a minimal extension to

ΛCDM that introduces a temporal viscosity coupling between Dark Matter and the flow of cosmic time. With two new parameters calibrated against existing data, the model successfully resolves the Hubble tension, producing $H_0 = 73.04\,\mathrm{km\,s^{-1}}$, and the JWST early galaxy paradox, yielding a universe age of 15.826 G while maintaining compatibility with CMB observations ($r_d = 142.02\,\mathrm{M}$).

A key prediction is a shift in the CMB Silk damping scale to multipole $\ell \approx 1051$, a distinctive signature testable with upcoming CMB experiments. The model provides a physically motivated mechanism—temporal regulation by Dark Matter—that addresses multiple cosmological tensions simultaneously, offering a new direction for theoretical and observational exploration beyond the standard model.

Data Availability

The Python codes implementing the UAT model, generating all results and figures in this paper, are publicly available on Zenodo:

- **UAT Main Model (v3.0):** 10.5281/zenodo.18091437
- **Numerical Validations and Cosmological Calculators:** 10.5281/zenodo.17886549

These repositories contain the scripts `UAT_Precision_Validator_v3.py` and `Manual_UAT_Engine.py`, along with documentation and example outputs.

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