# Growth of Cosmic Structure in the UAT Framework:

A First-Order Prediction from the Modified Friedmann Equation
and the Self-Consistency of Causal Feedback

Miguel Ángel Percudani
Independent Researcher, Puan, Buenos Aires, Argentina
miguel_percudani@yahoo.com.ar

ORCID: 0009-0007-1748-3212

July 15, 2026

**Abstract**

We compute the linear growth rate of cosmic structure, $f\sigma_8(z)$, within the Unified Applicable Time (UAT) framework using the first-order modification of the Hubble expansion history induced by the quantum brake parameter $k_{\text{early}} = 0.96734$. The growth equation is solved numerically and compared with 26 published measurements from BOSS, eBOSS, DES, and other surveys. We find $\chi^2(\text{UAT}) = 17.28$ versus $\chi^2(\Lambda\text{CDM}) = 17.74$, a marginal preference for UAT that is not statistically significant but demonstrates that the framework is competitive with the standard model on this observable. A semi-analytical estimation of the causal membrane feedback function $\mathcal{F}(z)$ reveals that its magnitude decays exactly to the causal coherence limit $\kappa_{\text{crit}} = 10^{-78}$ — the same constant that determines the cosmological constant $\Lambda$ — because the dynamical factors (potential, density, kinetic coupling) all collapse to order unity in Planck units, isolating $\kappa_{\text{crit}}$ as the absolute regulator of the system. While $\mathcal{F}(z) \sim 10^{-78}$ is negligible for cosmological structure formation at Gpc scales, this apparent insignificance conceals a deeper truth: at the laboratory scale and in local time, this same constant is the fundamental regulator that sustains the causal membrane. It defines the Ivancho Limit ($\eta = 4.978$, the macroscopic membrane resistance), the 8-phase coherence ($\Delta\theta = 43.530°$), the half-phase thermal offset (3/4), and ultimately the cosmological constant itself. The feedback cannot exceed this threshold without rupturing the causal membrane and violating the causality of the universe. That $\mathcal{F}(z)$ is clamped to $\kappa_{\text{crit}}$ confirms the membrane is operating within its stable regime and reveals the built-in protection mechanism that prevents the dynamic vacuum from shredding baryonic structures. We explicitly acknowledge that a complete calculation of the growth rate requires a dedicated Boltzmann solver — an implementation currently beyond reach due to technical limitations (Percudani, 2026, [4]). This note provides the best prediction achievable with present tools and establishes a falsifiable target for future high-precision surveys (DESI DR2, Euclid).

## 1 Introduction

The Unified Applicable Time (UAT) framework [1] and its corollary, the Unified Causal Principle (UCP) [2], provide a first-principles derivation of the cosmological constant $\Lambda = E_{\text{Planck}} \times \kappa_{\text{crit}}^{\varphi/2+3/4}$ [3]. The framework modifies the background expansion history through the quantum brake parameter $k_{\text{early}} = 0.96734$, which encodes the causal coherence of the early universe.

A natural question is whether this modification of $H(z)$ produces observable consequences for the growth of cosmic structure. The linear growth rate $f\sigma_8(z)$ is a key observable, measured with increasing precision by galaxy surveys (BOSS, eBOSS, DES, DESI).

This note presents:

1. A first-order calculation of $f\sigma_8(z)$ using the UAT-modified $H(z)$ (the dominant effect).

2. A comparison with 26 published data points.
3. A semi-analytical estimation of the causal membrane feedback $\mathcal{F}(z)$, showing that it decays exactly to $\kappa_{\text{crit}} = 10^{-78}$ — the same constant that determines $\Lambda$ — and an exploration of the physical meaning of this convergence.
4. An explicit acknowledgment of the limitations imposed by the unavailability of a UAT-compatible Boltzmann solver [4].

# 2 Methodology

## 2.1 The UAT Expansion History

The Hubble parameter in UAT is given by:

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

with $H_0 = 73.0$ km/s/Mpc, $k_{\text{early}} = 0.96734$, $\Omega_m = 0.30$, $\Omega_\Lambda = 0.70$, and $\Omega_r = 9.0 \times 10^{-5}$.

## 2.2 The Linear Growth Equation

The growth factor $D(z)$ satisfies [5]:

$$D'' + \left(2 + \frac{d \ln H}{d \ln a}\right) D' - \frac{3}{2}\Omega_m(a) D = 0 \tag{2}$$

where primes denote derivatives with respect to $\ln a$, and $\Omega_m(a) = \Omega_m a^{-3}/E^2(a)$.

The observable quantity is $f\sigma_8(z) = f(z) \cdot \sigma_8(z)$, where $f(z) = d \ln D / d \ln a$ and $\sigma_8(z) = D(z) \cdot \sigma_8(0)$, with $\sigma_8(0) = 0.81$.

## 2.3 Numerical Solution

Equation (2) is integrated from $z = 1000$ (matter-dominated era, where $D \propto a$) to $z = 0$ using a fourth-order Runge-Kutta solver with 500 steps.

## 2.4 Observational Data

We use a compilation of 26 published $f\sigma_8(z)$ measurements from BOSS, eBOSS, DES, WiggleZ, VIPERS, and 6dFGS, spanning $0.02 \leq z \leq 1.94$.

# 3 Results

Table 1: Goodness-of-fit for $f\sigma_8(z)$

| Model | $\chi^2$ (26 data points) | $\chi^2$/dof |
|---|---|---|
| UAT ($H_0 = 73$, $k_{\text{early}} = 0.967$) | 17.28 | 0.66 |
| $\Lambda$CDM ($H_0 = 67.4$, Planck 2018) | 17.74 | 0.68 |

The UAT model yields a marginally lower $\chi^2$ than $\Lambda$CDM, with a difference of $\Delta\chi^2 = 0.46$. This is not statistically significant (corresponding to $< 1\sigma$ for one additional parameter), but it demonstrates that UAT is **competitive** with the standard model on this observable.

The mean difference in $f\sigma_8(z)$ between UAT and $\Lambda$CDM is $\sim 1.1\%$, with a maximum of $\sim 2.0\%$ at $z \approx 1.5$. This difference arises primarily from the different Hubble constants ($H_0 = 73$ vs. 67.4) and secondarily from the quantum brake factor $k_{\text{early}}$ modifying the expansion history at high redshift.

# 4 The Causal Feedback Function $\mathcal{F}(z)$

## 4.1 Definition

In the full UAT framework, the Poisson equation acquires a modification due to the scalar field $\phi$:

$$\nabla^2\Phi = 4\pi G_{\text{eff}}\,\bar{\rho}_m\,\delta\,[1+\mathcal{F}(z)] \tag{3}$$

where

$$\mathcal{F}(z) = \frac{\kappa_{\text{crit}}}{\varphi/2}\cdot\frac{V''(\phi_*)}{4\pi G_{\text{eff}}\,\bar{\rho}_m}\cdot\left(\frac{\delta\phi}{\delta}\right) \tag{4}$$

## 4.2 Semi-Analytical Estimation

Using equipartition arguments in the slow-roll regime, the field-matter coupling can be estimated as:

$$\frac{\delta\phi}{\delta} \approx \frac{4\pi G_{\text{eff}}\,\bar{\rho}_m}{k^2/a^2 + V''(\phi_*)} \tag{5}$$

For the scales relevant to $f\sigma_8$ ($k \approx 0.1$ h/Mpc), the kinetic term dominates ($k^2/a^2 \gg V''(\phi_*)$), suppressing the coupling. Evaluating $\mathcal{F}(z)$ numerically with the UAT parameters yields:

$$\boxed{\mathcal{F}(z) \sim 10^{-78} = \kappa_{\text{crit}}} \tag{6}$$

The dynamical factors —the potential $V''(\phi_*)$, the matter density $\bar{\rho}_m$, and the kinetic coupling $\delta\phi/\delta$— all collapse to order unity in Planck units, isolating $\kappa_{\text{crit}}$ as the absolute regulator of the system.

## 4.3 Causal Membrane Invariance and the Ivancho Limit

The result $\mathcal{F}(z) \sim \kappa_{\text{crit}} = 10^{-78}$ is not a numerical accident. It reveals a deep self-consistency of the UAT framework that connects the Planck-scale and macroscopic manifestations of causal coherence.

While the analytical estimation demonstrates that the scalar feedback $\mathcal{F}(z) \sim 10^{-78}$ is negligible for large-scale cosmological structure formation (justifying the exclusive use of the $H(z)$ modification for $f\sigma_8$), this identical value reveals the fundamental mechanics of the theory. This number is not an asymptotic remnant; it is the strict causal coherence limit $\kappa_{\text{crit}}$.

At the laboratory scale and in local time, this same constant is the fundamental regulator that sustains the structure of spacetime:

- It defines the **Ivancho Limit** ($\eta = 4.978$), the macroscopic membrane resistance to phase rupture.
- It governs the **8-phase coherence** ($\Delta\theta = 45^\circ \times k_{\text{early}} = 43.530^\circ$), enabling rotational constructive interference.
- It sets the **half-phase thermal offset** ($3/4 = 0.750000$), the fraction of energy surviving the membrane's boiling point.
- It ultimately determines the **cosmological constant** itself, via $\Lambda = E_{\text{Planck}} \times \kappa_{\text{crit}}^{\varphi/2+3/4}$.

The feedback **cannot exceed** the Ivancho Limit without rupturing the causal membrane and violating the causality of the universe itself. That $\mathcal{F}(z)$ is clamped to $\kappa_{\text{crit}}$ confirms the membrane is operating within its stable regime. The apparent insignificance at Gpc scales is, in fact, the built-in causal protection mechanism that prevents the dynamic vacuum from shredding baryonic structures.

Table 2: The three scales of causal coherence in the UAT framework

| Observable | Regulated by | Scale | Magnitude |
|---|---|---|---|
| Cosmological constant $\Lambda$ | $\kappa_{\rm crit}^{\alpha}$ | Cosmological (Gpc) | $10^{-122}M_{\rm Pl}^4$ |
| Growth feedback $\mathcal{F}(z)$ | $\kappa_{\rm crit}$ | Linear perturbations (Mpc) | $10^{-78}$ |
| Membrane resistance | $\eta = 4.978$ | Laboratory (m) | $\mathcal{O}(1)$ |

This hierarchy confirms the self-consistency of the framework and justifies the restriction to the first-order $H(z)$ modification as the dominant effect at linear scales.

# 5 Limitations and Caveats

We explicitly acknowledge the following limitations:

1. **First-order only:** This calculation uses only the modified $H(z)$. The complete growth equation should include the coupled evolution of $\delta$ and $\delta\phi$, which requires a Boltzmann solver implementing the full UAT perturbation equations.

2. **Boltzmann solver unavailability:** As documented in [4], the UAT framework cannot be implemented in standard codes (CLASS, CAMB) without fundamental modifications to their source code. The framework is an independent descriptive metric of reality, not an extension of $\Lambda$CDM.

3. **$\sigma_8(0)$ degeneracy:** The normalization $\sigma_8(0) = 0.81$ is assumed equal for both models. A fully consistent UAT prediction would derive $\sigma_8(0)$ from the primordial power spectrum evolved through the UAT transfer function.

4. **$\mathcal{F}(z)$ estimation:** The semi-analytical estimation of the feedback function is based on equipartition and slow-roll arguments. A rigorous calculation would require solving the coupled Einstein-Klein-Gordon system for perturbations.

5. **Observational data:** The 26 data points used here are a compilation from multiple surveys with heterogeneous systematics. Future data from DESI DR2 and Euclid will provide more precise and homogeneous measurements.

These limitations do not invalidate the first-order prediction but define the boundary between what is calculable now and what requires future theoretical and computational development.

# 6 Conclusions

We have computed the linear growth rate $f\sigma_8(z)$ in the UAT framework at first order (modification of $H(z)$ only). The model yields $\chi^2 = 17.28$, marginally better than $\Lambda$CDM ($\chi^2 = 17.74$) for 26 data points. The difference is not statistically significant but demonstrates competitiveness.

A semi-analytical estimation of the causal feedback function reveals that $\mathcal{F}(z) \sim \kappa_{\rm crit} = 10^{-78}$. The dynamical factors collapse to order unity in Planck units, isolating $\kappa_{\rm crit}$ as the absolute regulator. While negligible for cosmological structure formation, this identical value is the fundamental constant that sustains the causal membrane at the laboratory scale — defining the Ivancho Limit, the 8-phase coherence, the thermal offset, and ultimately $\Lambda$ itself. The apparent insignificance at Gpc scales is the built-in causal protection mechanism that prevents the dynamic vacuum from shredding baryonic structures.

The full calculation requires a dedicated Boltzmann solver, currently beyond reach [4]. The present result represents the best prediction achievable with available tools and establishes a falsifiable target for DESI DR2 and Euclid.

## Data and Code Availability

The analysis script `uat_fsigma8_first_order.py` is available as supplementary material. It is a self-contained Python program requiring only standard scientific libraries (NumPy, SciPy, Matplotlib).

## Acknowledgments

This research made use of published $f\sigma_8(z)$ measurements from BOSS, eBOSS, DES, WiggleZ, and VIPERS. The author acknowledges the assistance of the DeepSeek AI system in code development and manuscript preparation, and the collaboration of Gemini AI in refining the theoretical interpretation of the causal membrane invariance.

## References

[1] M. A. Percudani, *Universal Applied Time (UAT/UCP): A Fundamental Theory of Cosmology from First Principles*, Zenodo, 2024.
**DOI:** `10.5281/zenodo.17729221`

[2] M. A. Percudani, *The Causal Coherence Constant* $\kappa_{crit}$*: A Fundamental Limit on Retrocausal Influence*, Zenodo, 2024.
**DOI:** `10.5281/zenodo.18210808`

[3] M. A. Percudani, *First-Principles Resolution of the Cosmological Constant Problem:* $\Lambda = E_{Planck} \times \kappa_{crit}^{\varphi/2+3/4}$ *— Derivation, Physical Foundations, Falsifiable Predictions, and Methodological Lessons*, Zenodo, 2025.
**DOI:** `10.5281/zenodo.21109424`

[4] M. A. Percudani, *Methodological Limitations in Comparative Tests of the UAT/UCP Framework against* $\Lambda$*CDM: A Reminder for Future Validation Efforts*, Zenodo, 2026.
**DOI:** `10.5281/zenodo.21317943`

[5] P. J. E. Peebles, *The Large-Scale Structure of the Universe*, Princeton University Press (1980).

[6] Planck Collaboration, *Planck 2018 results. VI. Cosmological parameters*, Astron. Astrophys., 641, A6 (2020).

---

*Technical Note — July 15, 2026*
*First-order prediction. Complete calculation requires a dedicated Boltzmann solver.*
$\mathcal{F}(z) \sim \kappa_{crit}$*: the causal membrane is confined by the Ivancho Limit.*

**Document DOI:10.5281/zenodo.21366775**