Parameter-Free Predictions of the Holographic Unspooling Framework for DESI DR2, Euclid, and CMB-S4

Abstract The standard ΛCDM cosmological model faces mounting late-time observational tensions, notably the S8 matter-clustering anomaly. The recently submitted Holographic Unspooling Framework (HUF) resolves this tension (S8 ≈ 0.763) without phenomenological tuning by deriving a dynamic effective gravitational coupling parameterized by the logarithmic Bekenstein-Hawking entropy. With zero free parameters in the gravity sector, the HUF makes strict, falsifiable predictions. In this letter, we formally establish the framework's predictions for the dynamic equation of state w(z) (testable by DESI DR2), the gravitational slip \eta (testable by Euclid/Roman), and redshift space distortions (f\sigma_8), while proving its exact preservation of the Baryon Acoustic Oscillation (BAO) standard ruler.

1. Preservation of the Baryon Acoustic Oscillation (BAO) Scale

A primary constraint on any alternative cosmology is the preservation of the early-universe comoving sound horizon, r_s. In the HUF, the informational field \psi(a) represents the logarithmic accumulation of unspooled macroscopic entanglement entropy. Because the universe has not accumulated this holographic information in the deep past, the normalization dictates that \psi \to 0 at high redshift. At the drag epoch (z ≈ 1060), the field evaluates to \psi = 0 to machine precision.

Consequently, the effective background scaling F(\psi) = 1 + \epsilon(0) = 1 and the entropic dark energy potential V(\psi) = 0. Therefore, the HUF expansion history is mathematically identical to standard ΛCDM at z ≥ 1060. The comoving sound horizon is explicitly unchanged (\Delta r_s = 0.000000 Mpc). The HUF alters the universe exactly where the late-time tensions exist while inherently protecting the standard BAO ruler utilized by DESI and SDSS.

2. Dynamic Equation of State (w(z)) for DESI DR2

Standard ΛCDM assumes a rigid cosmological constant (w = -1). The HUF natively predicts a time-varying equation of state driven by boundary thermodynamics. The framework predicts a specific, monotonically evolving trajectory that becomes progressively more negative toward the present epoch. The predicted equation of state values are summarized below:

Table 1: Predicted Equation of State Trajectory

Redshift (z)	Predicted w(z)
3.00	-0.808
2.00	-0.831
1.00	-0.871
0.50	-0.906
0.00	-0.977

This parameter-free trajectory is a definitive test for the upcoming DESI DR2 release. If DESI DR2 observes this monotonic trend of w becoming progressively more negative over time, the HUF is heavily supported. Conversely, if DESI DR2 observes a phantom crossing (w < -1) the framework is explicitly falsified.

3. The Gravitational Slip Test (\eta) for Euclid

The unspooling boundary dynamically modifies the effective gravitational coupling. In the modern era, the HUF predicts near-equal suppression of both growth and lensing gravity:

- **Growth coupling:** \mu \approx 0.9529
- **Lensing coupling:** \Sigma \approx 0.9518

The resulting gravitational slip is \eta = \mu / \Sigma \approx 1.001. This establishes a clean, three-way discriminator for the Euclid telescope and the Roman Space Telescope. If observations find equal suppression of both parameters with near-unity slip, the HUF is confirmed. If observations find one sector suppressed but not the other ($\eta \neq 1$), the framework is falsified. If neither is suppressed ($\mu=1$, $\Sigma=1$), standard General Relativity is confirmed.

4. Redshift Space Distortions and the $f\sigma_8(z)$ Profile

The time-varying effective gravity natively suppresses late-time structure growth, yielding excellent agreement with intermediate redshift measurements. At $z = 0.57$ (BOSS CMASS), the framework predicts $f\sigma_8 = 0.439$ aligning within 0.45σ of the observed 0.426 ± 0.029. However, because the suppression is strongest at $z = 0$ (where $\psi = 1$), the model currently exhibits a systematic under-prediction at the lowest redshifts. At $z = 0.15$ (6dFGS), the HUF predicts $f\sigma_8 = 0.426$ versus the observed 0.49, representing a 1.7σ tension. This tension indicates either the need for subtle refinement of the late-time suppression profile or the presence of systematics in the lowest-redshift RSD measurements, identifying a clear target for future theoretical and observational scrutiny.

Note on Initial Conditions: The predicted S8 ranges from 0.757 to 0.763 depending on the initialization epoch $z_{init} \in [100, 999]$; both values are within 0.5σ of the KiDS-1000 measurement. All tabular calculations in this letter use $z_{init} = 100$, consistent with the submitted companion paper.

5. Analytical Prediction of the Growth Index γ and the Euclid Falsification Criterion

While the suppression of the linear growth rate ($f\sigma_8$) and the resolution of the S8 tension provide critical validation, the most definitive and mathematically pure test of the theory lies in the scale-independent growth index, γ. In standard General Relativity (GR), the growth rate of cosmic structure is parameterized by $f(z) \simeq \Omega_m(z)^\gamma$, where $\gamma \approx 0.555$.

Because the HUF's unspooling of macroscopic entanglement entropy drives a dynamic effective gravitational coupling ($\mu(z) < 1$), this thermodynamic modification inherently alters the growth index. From first principles, we derive an analytically exact expression for the modified growth index:

Because gravity is suppressed ($\mu(z) < 1$) and $\Omega_m(z) < 1$ at late times, both natural logarithms yield negative values, ensuring their ratio is strictly positive. Consequently, the HUF demands that γ is strictly elevated above the GR baseline. This deviation amplifies at higher redshifts as $\Omega_m \to 1$, which minimizes the denominator and amplifies the modification from $\mu(z)$. This geometry scales cleanly from $\epsilon = 1/(2\pi^2)$ and is verified against the quasi-static ODEs to within 0.4% precision across all observable redshifts. Averaged across the redshift range of upcoming Stage-IV surveys ($z \in [0.1, 1.5]$), the framework predicts a mean growth index of **$\gamma_{HUF} = 0.626$**.

Table 2: The Observational Picture and Predictive Timeline

Cosmological Test	HUF Prediction	GR / ΛCDM	Current Observational Tension	Euclid/DESI Discriminator
S8 (Weak Lensing)	0.757	0.832	Fully Resolved (0.45σ)	—
$f\sigma_8$ ($z=0.57$)	0.439	0.471	Fully Resolved (0.45σ)	—
γ (mean $z=0.1$–1.5)	**0.626**	**0.555**	**Consistent (BOSS: 1.3σ)**	**7.1σ Departure**

Currently, this γ shift is safely consistent with existing BOSS measurements, sitting at a statistically unremarkable 1.3σ deviation given current observational uncertainties. However, Euclid and DESI are projected to measure \gamma to a precision of ±0.01. At this precision, the HUF prediction of \gamma = 0.626 represents a **7.1σ departure** from the ΛCDM expectation. Because this prediction requires no mass calibration or early-universe transfer function, it stands as the sharpest falsifiable discriminator of the framework, projected to be definitively answered circa 2027.

6. The A_{lens} Anomaly and CMB-S4

The primary open problem in the HUF is the CMB lensing amplitude, which currently presents a 6.1σ tension with Planck 2018 data. Resolving this requires the derivation of a decoherence-based transfer function to bridge the high-redshift acoustic peaks with the modified late-time lensing potential. The upcoming CMB-S4 observatory will serve as the binary decider for the true nature of this anomaly, determining whether this tension is a failure of the framework or a physical signature of the macroscopic decoherence process.

References

- [1] Curiel, A. J. (2026). "The Holographic Unspooling Framework: Geometric Growth Suppression and the Resolution of the S8 Tension." Zenodo. https://doi.org/10.5281/zenodo.20517417
- [2] Aghanim, N., et al. (Planck Collaboration). "Planck 2018 results. VI. Cosmological parameters." Astronomy & Astrophysics, 641, A6 (2020).
- [3] Asgari, M., et al. "KiDS-1000 Cosmology: Cosmic shear constraints and comparison between two point statistics." Astronomy & Astrophysics, 645, A104 (2021).
- [4] Abbott, T. M. C., et al. (DES Collaboration). "Dark Energy Survey Year 3 results: Cosmological constraints from galaxy clustering and weak lensing." Physical Review D, 105(2), 023520 (2022).
- [5] Verlinde, E. P. "Emergent gravity and the dark universe." SciPost Physics, 2(3), 016 (2017).
- [6] Bekenstein, J. D. "Black holes and entropy." Physical Review D, 7(8), 2333 (1973).
- [7] Hawking, S. W. "Particle creation by black holes." Communications in Mathematical Physics, 43(3), 199-220 (1975).
- [8] Alam, S., et al. (BOSS Collaboration). "The clustering of galaxies in the completed SDSS-III Baryon Oscillation Spectroscopic Survey: cosmological analysis of the DR12 galaxy sample." Monthly Notices of the Royal Astronomical Society, 470(3), 2617-2652 (2017).
- [9] Adame, A. G., et al. (DESI Collaboration). "DESI 2024 VI: Cosmological Constraints from the Measurements of Baryon Acoustic Oscillations." arXiv preprint, arXiv:2404.03002 (2024).
- [10] Bertotti, B., Iess, L., & Tortora, P. "A test of general relativity using radio links with the Cassini spacecraft." Nature, 425(6956), 374-376 (2003).
- [11] Dutcher, D., et al. (SPT-3G Collaboration). "Measurements of the E-mode polarization and temperature-E-mode correlation of the CMB from SPT-3G 2018 data." Physical Review D, 104(2), 022003 (2021).