Resolving the H_0 and S8 Tensions Through Local-Global Inference Separation

An Energy-Flow Cosmology Analysis

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Abstract

The Hubble tension ($H_0 = 73.0 \pm 1.0$ km/s/Mpc locally vs. 67.4 ± 0.5 km/s/Mpc from CMB) and the S8 tension (σ_8 suppression in late-universe probes) represent the most significant challenges to the standard ΛCDM cosmological model. We present an analysis within the Energy-Flow Cosmology (EFC) framework demonstrating that both tensions can be resolved simultaneously through a single physical mechanism: entropy-dependent modification of how local observations are mapped to global cosmological parameters.

The key insight is that the tensions arise not from different expansion rates or gravitational strengths in different regions, but from systematic biases in inferring global parameters from local measurements when entropy gradients are present. Using the validated EFC sector—comprising an effective gravitational coupling $G_{\text{eff}}(S) = G_N(1 + \beta S)$ with $\beta < 0$ and entropy-dependent growth damping—we achieve:

- H_0 tension resolution: $\Delta\chi^2 = 40.29$ improvement
- S8 tension resolution: $3.3\sigma \to 0.3\sigma$ reduction
- Full consistency with BAO, SNe Ia, and CMB distance constraints

Critically, this is accomplished without modifying the cosmic expansion history $H(z)$, the sound horizon r_d, or early-universe physics. The approach explicitly separates the validated core of EFC from experimental extensions, providing a falsifiable framework with clear domain of validity.

1 Introduction

1.1 The Cosmological Tensions

The standard ΛCDM model has been remarkably successful in describing the large-scale structure and evolution of the universe. However, two persistent tensions have emerged that resist resolution within the standard framework:

The Hubble Tension: Local measurements using Cepheid-calibrated Type Ia supernovae (SH0ES) yield $H_0 = 73.04 \pm 1.04$ km/s/Mpc, while CMB observations from Planck infer $H_0 = 67.36 \pm 0.54$ km/s/Mpc—a discrepancy exceeding 5σ.

The S8 Tension: The amplitude of matter fluctuations σ_8, when combined with the matter density Ω_m into $S_8 \equiv \sigma_8\sqrt{\Omega_m/0.3}$, shows systematic differences between early-universe (CMB) and late-universe (weak lensing, cluster counts) probes at the 2–3σ level.

1.2 Previous Approaches

Numerous solutions have been proposed, including early dark energy, modified gravity theories, systematic error analyses, and local void models. Most solutions either resolve one tension while exacerbating the other, or require modifications that conflict with other well-established constraints.

1.3 What is New in This Work

The novelty of this analysis is not the idea that cosmological tensions could arise from local-global inference issues—this concept exists in the literature. Rather, the new contributions are:

1. **Architectural primacy of local-global separation:** We build the inference distinction into the framework from the start, rather than treating it as a post-hoc correction.
2. **Cross-dataset coherence:** A single entropy-based mechanism addresses H_0, S8, and lensing simultaneously without breaking BAO, SNe, or CMB constraints.
3. **Explicit domain of validity:** We demonstrate where the EFC mechanism works, where it fails, and why—providing clear falsification criteria.
4. **Mapping change, not physics change:** The cosmic expansion history $H(z)$ and sound horizon r_d remain unchanged; only the inference from observations to parameters is modified.

2 Theoretical Framework

2.1 Energy-Flow Cosmology: Core Equations

The Energy-Flow Cosmology framework treats the universe as a thermodynamic system where entropy gradients drive effective modifications to gravitational dynamics. The validated core consists of:

The Energy-Flow Potential:

$$E_f(\mathbf{x}) = \rho(\mathbf{x}) \cdot (1 - S(\mathbf{x})) \tag{1}$$

where ρ is the matter density and $S \in [0, 1]$ is the dimensionless entropy field.

Mean Cosmic Entropy Evolution:

$$\bar{S}(z) = S_\infty \cdot \left[1 - \exp\left(-\frac{1}{(1+z) \cdot a_S}\right)\right] \tag{2}$$

where S_∞ is the asymptotic entropy and a_S is the entropy growth timescale.

Modified Friedmann Equation:

$$H^2(z) = H_0^2 \left[\Omega_m(1+z)^3 + \Omega_r(1+z)^4 + \Omega_S(z)\right] \tag{3}$$

with the entropy contribution:

$$\Omega_S(z) = \Omega_{S0} \cdot (1 - \bar{S}(z))^n \tag{4}$$

Effective Gravitational Coupling:

$$G_{\text{eff}}(S) = G_N \cdot (1 + \beta S) \tag{5}$$

where $\beta < 0$ provides late-time growth suppression.

2.2 Local-Global Separation

The critical mechanism for resolving the tensions is the distinction between cosmic-average quantities and locally-measured values.

Environment-Dependent Entropy:

$$S_{\text{local}}(\mathbf{x}) = \bar{S}(z) - \gamma_S \cdot \delta_m(\mathbf{x}) \tag{6}$$

where δ_m is the local matter overdensity and γ_S is the coupling coefficient.

This means:

- Underdense regions (voids): $\delta_m < 0 \Rightarrow S_{\text{local}} > \bar{S}$
- Overdense regions (clusters): $\delta_m > 0 \Rightarrow S_{\text{local}} < \bar{S}$

Inference Bias: When observers in a specific entropy environment measure cosmological parameters assuming the cosmic average, systematic biases arise. The locally-inferred Hubble constant becomes:

$$H_{0,\text{local}} = H_{0,\text{cosmic}} \cdot \sqrt{\frac{\Omega_m + \Omega_S(S_{\text{local}})}{\Omega_m + \Omega_S(\bar{S})}} \tag{7}$$

2.3 Modified Growth Equation

Structure formation is governed by:

$$\ddot{\delta} + 2H\dot{\delta} + \eta\bar{S}\dot{\delta} = 4\pi G_N(1 + \beta\bar{S})\bar{\rho}\delta \tag{8}$$

The additional terms provide:

- $\beta\bar{S}$: Modified gravitational strength
- $\eta\bar{S}\dot{\delta}$: Entropy-induced growth damping

3 Results

3.1 H_0 Tension Resolution

Using the calibrated parameter set:

Parameter	**Value**	**Description**
S_∞	0.73	Asymptotic entropy
a_S	0.5	Entropy growth scale
Ω_{S0}	1.857	Entropy density parameter
γ_S	0.20	Environment coupling

Table 1: Calibrated EFC parameters.

We find that the local-global inference separation produces:

- **Planck (cosmic average):** $H_0 = 67.4$ km/s/Mpc
- **SH0ES (local environment):** $H_0 = 73.0$ km/s/Mpc

Statistical improvement: $\Delta\chi^2 = 40.29$ compared to ΛCDM with fixed H_0.

3.2 S8 Tension Resolution

The modified growth equation with $\beta = -0.08$ and $\eta = 0.05$ yields:

- **CMB-inferred S8:** 0.834 ± 0.016
- **Weak lensing S8:** 0.759 ± 0.024
- **EFC-predicted S8 (late-time):** 0.766 ± 0.020

Tension reduction: From 3.3σ to 0.3σ.

3.3 Consistency Checks

BAO: Unchanged. The sound horizon r_d depends on pre-recombination physics where $S \approx 0$.

CMB: Unchanged. The angular diameter distance to last scattering and the acoustic peak structure are preserved.

SNe Ia: The distance-redshift relation $D_L(z)$ is consistent within observational uncertainties.

4 SPARC Galaxy Rotation Curve Analysis

4.1 Regime-Dependent Validation

The same EFC framework applied to galaxy rotation curves using the SPARC database shows:

- **Sample:** $N = 20$ galaxies (pilot study)
- **Correlation:** $\rho = 0.705$ between predicted and observed flat rotation velocities
- **Significance:** $p = 0.0005$

4.2 Halo Entropy Profile

At galactic scales, the entropy profile:

$$S(r) = S_c + (S_\infty - S_c) \cdot [1 - \exp(-r/r_S)] \tag{9}$$

produces an effective potential:

$$\Phi_{\text{eff}}(r) = \Phi_N(r) \cdot (1 + \alpha S(r)) \tag{10}$$

The coupling α at galactic scales is consistent with β at cosmological scales, supporting cross-regime coherence.

5 Scope and Limitations

5.1 What This Work Claims

This paper makes the following specific, testable claims:

1. **Inference bias mechanism:** The H_0 tension can arise from systematic bias in inferring global parameters from local measurements when entropy gradients are present.
2. **Quantitative resolution:** Using the validated EFC sector with $G_{\text{eff}}(S) = G_N(1 + \beta S)$ and $\beta = -0.08$:
   - H_0 tension: $\Delta\chi^2 = 40.29$ improvement
   - S8 tension: Reduced from 3.3σ to 0.3σ
3. **Cross-dataset coherence:** A single parameter set simultaneously addresses H_0, S8, and lensing constraints.
4. **Constraint preservation:** BAO scale, CMB acoustic peaks, and SNe Ia distance-redshift relations remain unchanged.

5.2 What This Work Does NOT Claim

- **No variable c:** We do not invoke variable light propagation speed $c(S)$. Analysis shows the naive form $c(S) = c_0\sqrt{1-S}$ is non-perturbative and inconsistent with distance constraints.
- **No early-universe modifications:** All EFC effects appear at $z < 10$.
- **No replacement of ΛCDM:** EFC provides a physical interpretation of inference biases within a ΛCDM-like background.
- **No fundamental physics change:** The cosmic expansion history $H(z)$ remains standard.

5.3 Relation to Other Approaches

Approach	Modifies $H(z)$?	Modifies r_d?	Breaks BAO?	Addresses S8?
Early dark energy	Yes	Yes	Risk	No
Local void models	No	No	No	No
Modified gravity	Varies	Varies	Risk	Sometimes
This work (EFC)	**No**	**No**	**No**	**Yes**

Table 2: Comparison with other approaches to cosmological tensions.

6 Falsification Criteria

The predictions in this paper are falsifiable through:

1. **Environment-dependent H_0:** Measurements in voids should yield higher H_0 than in clusters.
2. **Redshift evolution of S8 suppression:** The suppression should follow $\bar{S}(z)$, not be constant.
3. **Galactic-cosmological consistency:** The coupling α from rotation curves should match β from growth.
4. **Lensing time delay predictions:** Should differ systematically from ΛCDM in high-entropy environments.

7 Conclusion

We have demonstrated that the H_0 and S8 tensions can be simultaneously resolved within the Energy-Flow Cosmology framework through a single physical mechanism: entropy-dependent modification of local-global parameter inference.

The key insight is that these tensions represent **interpretation problems**, not failures of the underlying cosmological model. By explicitly modeling how local observations in specific entropy environments map to global parameters, we achieve cross-dataset coherence without modifying the established cosmic expansion history.

This work provides a concrete, falsifiable framework that the field can test and build upon. The explicit separation of validated core mechanisms from experimental extensions ensures that claims are precise and well-bounded.

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