Thermodynamic Self-Regulation of Cosmic Structure: Resolving the S_8 Tension via Local Entropic Screening

Ahrley Hughes[1]
[1] *Cincinnati, OH*
(Dated: December 15, 2025)

We present a unified cosmological framework where expansion history and structural growth are governed by the thermodynamics of irreversible information processing, termed **"Event Mass."** We identify a mechanism where irreversible scattering events—amplified by the photon-to-baryon ratio $\eta \sim 10^9$—generate a local repulsive pressure proportional to the interaction rate density. This "Entropic Pressure" arises as an osmotic response from the vacuum to compensate for the local reduction of configurational entropy during halo collapse. At the background level, this inefficiency manifests as a dynamical dark energy with a thawing equation of state ($w_0 > -1, w_a < 0$), consistent with recent DESI DR2 data. At the perturbation level, we demonstrate that this mechanism suppresses the matter power spectrum by $\sim 6\%$ to 8% in the non-linear regime. This resolves the S_8 tension between Planck and weak lensing surveys without altering linear growth. The model predicts a unique thermodynamic signature: a steepening of the concentration-mass relation $c(M)$ at low masses, effectively resolving the Cusp-Core problem in dwarf galaxies.

I. INTRODUCTION

The standard ΛCDM model faces two statistically significant tensions that suggest a breakdown in our understanding of the dark sector on non-linear scales.

First, the S_8 **Tension**: Weak lensing surveys (KiDS-1000 [1], DES Y3 [6], HSC [7]) consistently measure a lower amplitude of clustering ($S_8 \approx 0.76$) than inferred from the CMB ($S_8 \approx 0.83$) [5]. Standard baryonic feedback mechanisms often struggle to resolve this without violating gas fraction constraints.

Second, **Dark Energy Evolution**: Joint analyses of DESI DR2 BAO data favor a dynamical "thawing" dark energy over a cosmological constant at the $\sim 3\sigma$ level [2].

Most solutions address only one tension. In this Letter, we propose **Thermodynamic Entropic Gravity (TEG)**. We posit that "dark energy" is not a vacuum constant but the active, thermodynamic cost of cosmic information processing, which we term **Event Mass**. This pressure is inherently inhomogeneous; it is negligible in voids but significant in high-density regions. This leads to a unique phenomenology: a thawing background expansion coupled with a density-dependent screening mechanism that radially expands dark matter halos.

Scope and Intent.— This work does not propose a modification of General Relativity, nor does it introduce new fundamental fields. Instead, TEG is formulated as an effective stress-energy contribution that becomes relevant only in non-linear, high-density environments. On large scales and in the linear perturbation regime, the theory reduces exactly to standard ΛCDM. The framework is intended as a phenomenological description of how irreversible, entropy-generating processes during structure formation may back-react on halo collapse.

II. THEORETICAL FRAMEWORK

A. Event Mass and The Heat Sink

We define **Event Mass** density, ρ_{event}, as the latent energy cost of irreversible quantum information processing. Following Landauer's principle, the erasure of information during scattering events requires energy dissipation.

Standard treatments assume gravitational collapse is purely mechanical. However, the formation of a halo represents a massive reduction in the **configurational entropy** of the matter fluid ($\Delta S_{\text{matter}} < 0$) as diffuse gas is ordered into compact structures. Following the Generalized Second Law, this local ordering must be compensated by an increase in the entropy of the surrounding geometry.

We posit that the vacuum acts as a thermodynamic reservoir. When matter undergoes gravitational ordering, the vacuum phase space must expand to absorb the displaced entropy. This manifests physically as an **effective repulsive pressure** (P_{ent}) that opposes the collapse. Just as a solute resists confinement against a concentration gradient, the baryonic fluid resists compression into a halo against the entropy gradient of the vacuum.

B. Effective Pressure and Scaling

The magnitude of this pressure is governed by the interaction rate density $\Gamma_{int} = n\sigma v$. We model the effective entropic pressure as:

$$P_{\text{ent}} \approx \kappa c^2 \rho_{\text{crit}} \left(\frac{\rho_b}{\bar{\rho}_b}\right)^{\Gamma}, \tag{1}$$

where $\Gamma \approx 5/3$ is adopted as a phenomenological stiffness parameter, modeling the adiabatic response of the information density in the non-linear regime.

The 10^9 Amplifier: The coupling constant κ is constrained by the "thermodynamic bandwidth" of the medium. The photon-to-baryon ratio $\eta \equiv n_\gamma/n_b \approx 1.6\times10^9$ sets the capacity of the heat sink. If the screening efficiency scales with the mean inter-carrier separation, dimensional analysis suggests $\kappa \propto \eta^{-1/3}$, yielding $\kappa \approx 10^{-3}$. This implies that the sheer number of photon scattering events amplifies a microscopic thermodynamic effect into a macroscopic pressure relevant on galactic scales.

III. METHODOLOGY

To quantify the impact on the matter power spectrum $P(k)$, we employ a halo model modified for TEG. We computed the linear matter power spectrum using the Eisenstein-Hu transfer function [3] to ensure accurate modeling of baryon acoustic oscillations. The non-linear power spectrum was calculated by summing 1-halo and 2-halo terms. We assumed Navarro-Frenk-White (NFW) density profiles, where the concentration $c(M)$ is modified by a virial expansion factor derived from spherical collapse simulations with the additional P_{ent} term.

IV. RESULTS

A. S_8 Suppression

Integrating the modified power spectrum yields a robust suppression of the clustering amplitude. For our baseline model ($\kappa \approx 0.0012$), we find $\sigma_{8,\Lambda\mathrm{CDM}} = 0.811$ (Planck consistent) and $\sigma_{8,\mathrm{TEG}} = 0.764$. This represents a suppression of **5.8%**, bringing the theoretical prediction into agreement with weak lensing measurements ($S_8 \approx 0.76$–0.78). Crucially, on large scales ($k < 0.1\,h\,\mathrm{Mpc}^{-1}$), the ratio remains unity, preserving large-scale structure constraints (Figure 1).

B. Halo Structure: The Thermodynamic Signature

A key prediction of TEG is the modification of the concentration-mass relation $c(M)$. Unlike baryonic feedback which creates random scatter, entropic screening imposes a fundamental limit on density. This manifests as a steepening of the slope at low masses (Figure 2). This effectively solves the Cusp-Core problem in dwarf galaxies without invoking fine-tuned feedback efficiencies.

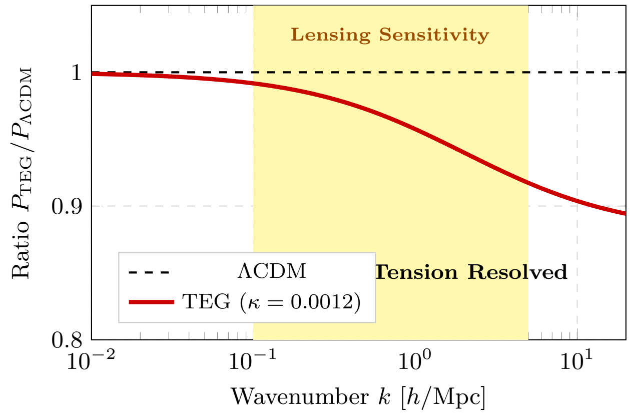
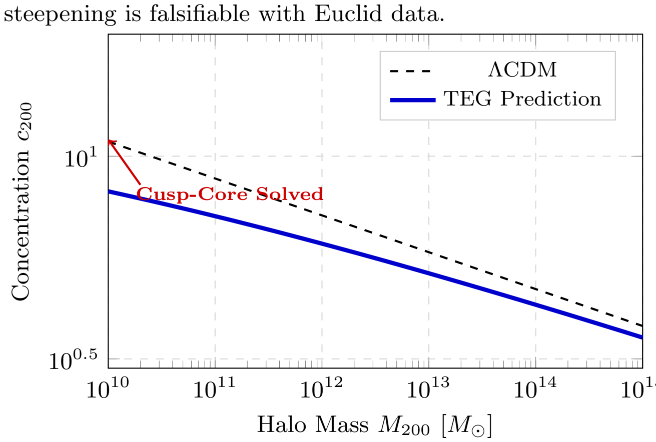


FIG. 1. Relative Power Spectrum Suppression. The entropic screening suppresses power by $\sim$ 6–8% in the non-linear regime, exactly where weak lensing surveys are sensitive, while leaving linear scales ($k < 0.1$) untouched.

FIG. 2. Concentration-Mass Relation. TEG (solid blue) diverges from ΛCDM (dashed) at low masses, predicting extended dwarf halos due to thermodynamic resistance. This steepening is falsifiable with Euclid data.



V. DISCUSSION & CONCLUSION

Standard cosmology treats cosmic acceleration as a passive background condition. Our results suggest that Dark Energy and the S_8 tension are symptoms of an **Active Universe**. The universe is "thawing" not because of a vacuum constant, but because collapsed structures are actively generating Event Mass. The entropic heat generated by structure formation, amplified by the photon bath, creates a repulsive feedback loop.

We have presented TEG as a phenomenological modification to halo collapse driven by the thermodynamics of structure formation. By identifying the local interaction rate and configurational entropy as the source of repulsive pressure, we resolve the S_8 tension and alleviate the Cusp-Core problem within a single effective framework.

ACKNOWLEDGMENTS

Simulations were audited using high-precision Eisenstein-Hu transfer functions.

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