EFC Weak Lensing Phenomenology: A Testable $\mu(k, z)$ Framework and DES Y6 Validation Protocol

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Abstract

We present a phenomenological framework for testing Energy-Flow Cosmology (EFC) against weak gravitational lensing observations. Starting from the EFC field equations, we demonstrate that the published EFC field equations do not predict modified lensing without additional structure. We introduce a minimal operational closure (Postulat A) that linearly couples entropy production to matter density, yielding an explicit modified gravity parameter $\mu(k, z)$ in standard cosmological perturbation form. We derive the resulting weak lensing predictions and present a complete validation protocol against Dark Energy Survey Year 6 (DES Y6) 3×2pt data, including explicit pass/fail criteria. This work does not claim that EFC explains the S_8 tension; rather, it provides the minimal theoretical infrastructure required to test whether it can. All code is publicly available.

1 Introduction

Energy-Flow Cosmology (EFC) is a field-theoretic framework in which entropy and energy flow are treated as fundamental degrees of freedom generating spacetime curvature (Magnusson, 2025). The theory aims to explain cosmic structure without invoking dark matter or dark energy, instead attributing gravitational effects to thermodynamic gradients.

A critical test for any alternative gravity theory is weak gravitational lensing, which probes the spacetime geometry directly through the deflection of light from distant galaxies. The Dark Energy Survey Year 6 (DES Y6) results (DES Collaboration, 2026) report $S_8 = 0.789 \pm 0.012$, approximately 2.6σ lower than CMB-based predictions from Planck. This tension motivates testing whether modified gravity frameworks like EFC can provide a natural explanation.

However, as we demonstrate in this paper, EFC as currently formulated does *not* automatically predict modified lensing. The entropy field $S(x)$ in EFC evolves according to its own dynamics without direct coupling to matter density perturbations. To obtain testable predictions, we must introduce an additional assumption.

The purpose of this paper is threefold:

1. Demonstrate explicitly why EFC requires additional structure for lensing predictions
2. Introduce a minimal, operationally motivated closure (Postulat A)
3. Provide a complete falsification protocol against DES Y6 data

We emphasize that this is a *phenomenology* paper, not a claim that EFC explains observations. We provide the theoretical infrastructure for testing.

2 EFC Field Equations

We begin with the EFC action as presented in Magnusson (2025):

$$S = \int d^4x\sqrt{-g}\left[\frac{R}{16\pi G} - \frac{\kappa_S}{2}(\nabla S)^2 - V(S) - \frac{\kappa_J}{2}J_\mu J^\mu + \gamma\nabla_\mu S\, J^\mu + \lambda(\nabla_\mu J^\mu - \Sigma)\right] \tag{1}$$

where:

- $S(x) \in [0,1]$: normalized entropy potential
- J^μ: energy/entropy flow four-vector
- $\Sigma \geq 0$: entropy production rate
- $\kappa_S, \kappa_J, \gamma$: dimensionless coupling constants
- $V(S) = V_0 + \frac{1}{2}m_S^2(S - S_0)^2$: entropic potential

Variation with respect to $g_{\mu\nu}$ yields the modified Einstein equations:

$$G_{\mu\nu} = 8\pi G\left(T_{\mu\nu}^{(m)} + T_{\mu\nu}^{(S,J)}\right) \tag{2}$$

with the entropy-flow stress-energy tensor:

$$\begin{aligned} T_{\mu\nu}^{(S,J)} = \kappa_S &\left[\nabla_\mu S\nabla_\nu S - \frac{1}{2}g_{\mu\nu}(\nabla S)^2\right] - g_{\mu\nu}V(S) \\ &+ \kappa_J\left[J_\mu J_\nu - \frac{1}{2}g_{\mu\nu}J_\alpha J^\alpha\right] + \gamma\left[\nabla_{(\mu}S\, J_{\nu)} - \frac{1}{2}g_{\mu\nu}\nabla_\alpha S\, J^\alpha\right] \end{aligned} \tag{3}$$

The equations of motion for S and J^μ are:

$$\kappa_S\Box S - V'(S) + \gamma\nabla_\mu J^\mu = 0 \tag{4}$$

$$\kappa_J J_\mu = \gamma\nabla_\mu S + \nabla_\mu\lambda \tag{5}$$

$$\nabla_\mu J^\mu = \Sigma \tag{6}$$

3 The Matter Coupling Problem

3.1 Why EFC Does Not Predict Lensing Automatically

Combining equations (4) and (6), the entropy field evolves as:

$$\kappa_S\Box S - V'(S) + \gamma\Sigma = 0 \tag{7}$$

Critical observation: The entropy production Σ appears as the only source term for δS. However, in the EFC action as written, Σ is *not defined as a function of matter density.* It is a free function constrained only by $\Sigma \geq 0$.

This means that matter perturbations δ_m do not automatically source entropy perturbations δS. Without this coupling, the entropy sector evolves independently, and there is no mechanism by which structure formation modifies the gravitational potentials through entropy gradients.

3.2 The Gap in the Current Framework

To obtain a prediction for weak lensing, we need one of the following:

(A) An explicit coupling $\Sigma = \Sigma(\rho_m, T, \ldots)$

(B) A direct coupling in the action, e.g., $\int f(S)T\sqrt{-g}\, d^4x$

(C) A coupling of S to curvature scalars, e.g., $f(S)R$

None of these appear in the published EFC field equations. This is not a criticism of the theory—it simply means the theory is incomplete for making lensing predictions in its current form.

4 Postulat A: Minimal Operational Closure

We introduce the following operational assumption:

Postulat A: Entropy production is linearly coupled to matter density:

$$\delta\Sigma(k, z) = \xi\, \rho_m(z)\, \delta_m(k, z)\, g(z)\, h(k) \tag{8}$$

where ξ is a coupling constant, $g(z)$ is a regime-gating function, and $h(k)$ is a scale filter. Note that ξ carries the dimensions required to make Σ a scalar of dimension $[\text{time}^{-1}]$, since κ_S, κ_J, and γ are dimensionless and S is normalized.

This is explicitly an *assumption*, not a derivation. We introduce it because:

- It is the minimal structure needed to obtain predictions
- It is physically motivated (entropy production should correlate with matter)
- It yields a testable, falsifiable framework
- It can be replaced by a derived coupling in future work

For this paper, we adopt:

$$g(z) = \Theta(z_t - z), \quad z_t = 2 \tag{9}$$

$$h(k) = \frac{1}{1 + k^2/k_*^2}, \quad k_* = 0.1\, h/\text{Mpc} \tag{10}$$

The Heaviside function ensures no modification at $z > 2$, preserving early-universe physics (CMB, BBN). The scale filter concentrates effects on scales relevant to DES observations.

5 Derivation of $\mu(k, z)$

5.1 Linear Perturbation Theory

We perturb around a flat FRW background in Newtonian gauge:

$$ds^2 = -(1 + 2\Psi)dt^2 + a^2(1 - 2\Phi)\delta_{ij}dx^i dx^j \tag{11}$$

Perturbing $S = \bar{S}(t) + \delta S$ and using the quasi-static, sub-horizon approximation ($k \gg aH$, time derivatives subdominant):

$$\left(\kappa_S \frac{k^2}{a^2} + m_S^2\right) \delta S \approx \gamma\, \delta\Sigma \tag{12}$$

Substituting Postulat A:

$$\delta S \approx \frac{\gamma \xi \rho_m \delta_m\, g(z)\, h(k)}{\kappa_S k^2/a^2 + m_S^2} \tag{13}$$

5.2 Modified Poisson Equation

In linear perturbation theory, the dominant contribution to $\delta\rho_S$ comes from the potential term:

$$\delta\rho_S \approx V'(\bar{S})\,\delta S = m_S^2(\bar{S} - S_0)\,\delta S \tag{14}$$

The modified Poisson equation becomes:

$$k^2\Psi = 4\pi G a^2\,[\rho_m\delta_m + \delta\rho_S] = 4\pi G a^2\,\mu(k,z)\,\rho_m\delta_m \tag{15}$$

where we define:

$$\boxed{\mu(k,z) = 1 + A_\mu\,\Theta(z_t - z)\,\frac{1}{1 + k^2/k_*^2}} \tag{16}$$

with the amplitude:

$$A_\mu = \frac{m_S^2(\bar{S} - S_0)\,\gamma\xi}{\kappa_S k_*^2 + m_S^2} \tag{17}$$

Equation (16) applies strictly in the linear perturbation regime. Non-linear corrections would require a full modified N-body treatment or an effective halo model extension.

5.3 Gravitational Slip

In this minimal framework, we find negligible anisotropic stress at linear order, yielding:

$$\eta \equiv \frac{\Phi}{\Psi} \approx 1 \tag{18}$$

The lensing parameter is therefore:

$$\Sigma_{\text{lens}}(k,z) = \frac{\mu(k,z)}{2}(1+\eta) \approx \mu(k,z) \tag{19}$$

Important: In this minimal model, the same function controls both growth and lensing. A richer model with gravitational slip would allow independent modification of these observables.

6 DES Y6 Validation Protocol

6.1 Data

We target the DES Y6 3×2pt analysis (DES Collaboration, 2026):

- Cosmic shear (shape-shape correlations)
- Galaxy clustering (position-position)
- Galaxy-galaxy lensing (position-shape)

Key measurements: $S_8 = 0.789 \pm 0.012$, $\Omega_m = 0.333$ (CDM baseline).

6.2 Model Comparison

Model 0 (Baseline): Standard CDM with DES Y6 likelihood

Model 1 (EFC-A): CDM + A_μ with $z_t = 2$, $k_* = 0.1\,h/\text{Mpc}$ fixed

6.3 Parameters and Priors

Parameter	Prior	Notes
$\Omega_m, \Omega_b, h, n_s, A_s$	DES Y6 standard	Cosmology
Shear calibration m_i	DES Y6 standard	Nuisance
Photo-z shifts	DES Y6 standard	Nuisance
Intrinsic alignments	DES Y6 standard	Nuisance
Galaxy bias b_i	DES Y6 standard	Nuisance
A_μ	Flat $[-0.5, +0.5]$	EFC parameter

6.4 Pass/Fail Criteria

Criterion	Pass	Fail
$\Delta\chi^2$ (Model 1 vs Model 0)	≥ 6	< 2
A_μ significance	$> 2\sigma$ from 0	consistent with 0
AIC/BIC	prefers Model 1	prefers Model 0
Nuisance absorption	A_μ uncorrelated	A_μ degenerate with nuisance

6.5 Control Tests

To ensure robustness:

1. Run cosmic shear only
2. Run 2×2pt (clustering + galaxy-galaxy lensing)
3. Run full 3×2pt

If signal appears only in shear but vanishes in 3×2pt, suspect systematics.

6.6 CMB Consistency Check

Compute CMB lensing power spectrum $C_\ell^{\phi\phi}$ with DES best-fit. If significantly discrepant with Planck CMB lensing, the model is ruled out.

7 What Would Falsify This Framework

We explicitly state the conditions under which this framework fails:

1. **A_μ consistent with zero**: If DES Y6 data prefer $A_\mu = 0$, then EFC with Postulat A provides no improvement over CDM for weak lensing.
2. **Wrong sign**: If data prefer $A_\mu > 0$ (stronger lensing), this contradicts the hypothesis that EFC explains the low S_8 values.
3. **Scale dependence mismatch**: If data prefer a k-dependence inconsistent with equation (16), the specific form of Postulat A is falsified.
4. **CMB lensing conflict**: If the best-fit model strongly disagrees with Planck CMB lensing, the model is ruled out.
5. **Nuisance degeneracy**: If A_μ is completely degenerate with intrinsic alignments or photo-z uncertainties, the test is inconclusive.

8 Limitations

We are explicit about what this paper does *not* do:

1. **Postulat A is not derived**: The matter coupling is an operational assumption. A complete theory would derive $\Sigma(\rho_m)$ from the action.

2. **No data fit performed**: We present predictions and test design, not results. The actual DES Y6 fit is future work.

3. **No unique EFC signature**: Currently, $\mu(k, z)$ in equation (16) resembles generic modified gravity parametrizations. Distinguishing EFC from other MG theories requires additional observables or theoretical predictions.

4. **Minimal slip**: We assume $\eta \approx 1$. A richer model with $\eta \neq 1$ would allow independent probes of growth and lensing.

5. **Fixed regime parameters**: We fix $z_t = 2$ and $k_* = 0.1\,h/\text{Mpc}$ rather than fitting them, to avoid over-parametrization.

9 Discussion

This paper occupies a specific position in the scientific literature: it is a *phenomenology* paper that bridges formal theory and observational testing. We have:

- Identified a gap in EFC (no automatic lensing prediction)
- Introduced a minimal closure (Postulat A)
- Derived testable predictions ($\mu(k, z)$)
- Designed a falsification protocol

This is analogous to how many modified gravity theories are developed: the action is proposed first, phenomenological consequences are worked out, and data comparison follows. We are at the second stage.

The value of this work is not in claiming EFC explains observations, but in providing the infrastructure to test whether it can.

10 Conclusion

We have presented a phenomenological framework for testing Energy-Flow Cosmology against weak lensing observations. The key results are:

1. EFC as published does not automatically predict modified lensing

2. Postulat A (linear entropy-matter coupling) provides minimal closure

3. The resulting $\mu(k, z)$ is given by equation (16)

4. A complete DES Y6 test protocol is provided with pass/fail criteria

All code is available at `https://github.com/supertedai/EFC` and archived on Figshare.

The next step is to run the actual fit against DES Y6 data. Regardless of the outcome, this paper provides the theoretical foundation for that test.

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