# Energy-Flow Cosmology
# Master Formal Specification

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# 1 EFC-D: Energy-Flow Dynamics

# 2 EFC-D: Dynamical Sector

The dynamical sector EFC-D describes how the energy-flow field $E_f$, the effective potential $\Phi(E_f, S)$ and the expansion rate $H$ emerge from the entropy field $S$ and its gradients. It forms the bridge between thermodynamics and the observable evolution of structures.

## 2.1 Energy-Flow Field

We define the scalar energy-flow field

$$E_f : \mathbb{R}^3 \to \mathbb{R},$$

which encodes the strength and directionality of energy transport along entropy gradients. In regions with strong gradients $\nabla S$, the magnitude $|E_f|$ is large, while in nearly uniform regions $E_f$ approaches zero.

To leading order the flow aligns with the negative gradient of entropy,

$$E_f \propto -\nabla S,$$

reflecting the tendency of energy to organize along entropy-driven channels.

## 2.2 Effective Potential $\Phi(E_f, S)$

The effective potential is defined as

$$\Phi(E_f, S) = A_\Phi \, E_f \, (1 + S),$$

where $A_\Phi$ is a constant setting the amplitude. This baseline form captures how the interaction between energy flow and the entropy level builds the potential landscape.

A more general non-linear family is given by

$$\Phi(E_f, S) = A_\Phi E_f \big(1 + S^\beta\big),$$

where $\beta$ modulates the strength of the coupling. The baseline implementation adopts the linear case $\beta = 1$.

## 2.3 Expansion Rate $H(E_f, S)$

EFC defines an effective expansion rate as a derived quantity:

$$H(E_f, S) = \sqrt{|E_f|}\,(1 + S). \tag{1}$$

This functional form reflects two contributions:

- $\sqrt{|E_f|}$ captures how the magnitude of energy flow sets the dynamical scale.
- $(1 + S)$ represents the thermodynamic modulation of expansion.

In this formulation, late-time acceleration can arise naturally from changes in $(E_f, S)$ without introducing an external dark-energy component.

### 2.4 Rotation Curves and the Potential Gradient

For stationary configurations, the effective circular velocity at radius $r$ follows from the potential gradient:

$$v(r) = \sqrt{r \, \frac{\partial \Phi}{\partial r}} \, .$$

Because $\Phi$ depends on both $E_f$ and $S$, and these are shaped by the entropy landscape, the resulting rotation curves arise as thermodynamic signatures. They do not require additional dark-matter components but emerge from the coupled roles of grid resistance, energy flow and the entropy field.

### 2.5 Coupling to the Effective Light Speed

The dynamical sector is intrinsically linked to the entropy-dependent effective light speed

$$c(S) = c_0 \left(1 + a_{\text{edge}} \, x(S)^2\right) .$$

Even with fixed underlying fields $E_f$ and $\Phi$, the inferred dynamical quantities depend on how light samples $c(S)$ along lines of sight. Observed velocities, accelerations, lensing time delays, and distance measures are all modified through this coupling.

Thus EFC-D and the light-propagation sector form a joint dynamical system rather than independent modules.

### 2.6 Summary

EFC-D provides thermodynamic definitions of:

- the energy-flow field $E_f$,
- the effective potential $\Phi(E_f, S)$,
- the expansion rate $H(E_f, S)$,
- and the coupling of these quantities to the entropy-dependent light speed $c(S)$.

Together these quantities generate large-scale structure evolution, acceleration, and rotation-curve behaviour in a unified framework.

# 3 EFC-S: Structure Model

# 4 EFC-S: Structural Sector

EFC-S describes how structures form and persist within the entropy field $S$ and the energy-flow potential $\Phi(E_f, S)$. Structure arises from thermodynamic balance between focusing/defocusing tendencies and the propagation properties encoded in $c(S)$.

## 4.1 Entropy and Structural Regimes

The entropy endpoints

$$S_0, \qquad S_1,$$

mark low-entropy focusing and high-entropy defocusing regimes. The mid-entropy value

$$S_{\text{mid}} = \frac{1}{2}(S_0 + S_1)$$

defines a natural transition zone.

## 4.2 Entropy-Driven Stability Band

Because the effective light speed $c(S)$ reaches its minimum near the mid-entropy level $S_{\text{mid}}$, propagation slows in this region:

$$c_{\min} = c(S_{\text{mid}}).$$

This creates a natural *stability band* in which energy-flow structures form persistent halo-like configurations. Reduced propagation speed increases effective confinement and stabilizes the rotation-curve plateau without requiring non-baryonic dark matter.

## 4.3 Coupling to the Potential

Structure formation reflects a balance among:

$$E_f, \qquad \Phi(E_f, S), \qquad c(S).$$

The potential

$$\Phi(E_f, S) = A_\Phi E_f (1 + S)$$

together with the propagation law $c(S)$ reproduces observed galactic structural features as emergent thermodynamic behavior.

# 5 s0–s1 Light Propagation Dynamics

## s0–s1 Light Propagation Dynamics

### Entropy Endpoints

We define two entropy endpoints:

- $s_0$: low-entropy, high-structure endpoint
- $s_1$: high-entropy, high-diffusion endpoint

The midpoint is

$$S_{\text{mid}} = \frac{1}{2}(s_0 + s_1),$$

and the entropy span is

$$\Delta S = s_1 - s_0.$$

Define the normalized entropy coordinate:

$$x(S) = \frac{S - S_{\text{mid}}}{\Delta S/2}.$$

### Speed of Light Variation

The effective speed of light becomes:

$$c(S) = c_0 \left(1 + a_{\text{edge}} x(S)^2\right).$$

### Light Travel Time

For a photon moving along a path $\gamma$, the travel time becomes:

$$t_{\text{obs}} = \int_\gamma \frac{dl}{c(S(l))}.$$

### Lensing Behavior

Low-entropy endpoints act as focusing wells; high-entropy endpoints contribute to large-scale defocusing.

This generates a dual-lens profile consistent with observed halo asymmetries.

# 6 Observables

# 7 Observables in Energy-Flow Cosmology

Energy-Flow Cosmology (EFC) predicts that all observable quantities are modulated by the entropy field $S(\mathbf{x})$, the energy-flow field $E_f(\mathbf{x})$, and the derived effective light speed $c(S)$. This section summarizes how these quantities appear in observations.

## 7.1 Light Propagation

The light-travel time along a photon trajectory $\gamma$ is

$$t_{\text{obs}} = \int_\gamma \frac{dl}{c(S(l))},$$

where $c(S)$ is the entropy-dependent effective speed of light.

Because $c(S)$ varies across the grid:

- regions near $s_0$ (low entropy, high structure) increase the local speed of light, producing focusing;
- regions near $s_1$ (high entropy, structural loosening) increase $c(S)$ at large scales, producing defocusing;
- mid-entropy regions produce the slowest propagation and the longest delays.

These effects modify classical interpretations of redshifts, distances, time-delays in lensing systems, and luminosity-distance relations.

## 7.2 Lensing

In GR, lensing depends only on the mass distribution. In EFC, lensing depends on *both* mass and entropy structure:

$$\text{Lensing} = \text{Mass Distribution} + S(\mathbf{x}) + c(S).$$

Consequently:

- focusing from $s_0$ regions can mimic excess mass;
- defocusing from $s_1$ regions can mimic mass deficits;
- time-delay ratios between lens images become modified;
- apparent shear patterns depend on how photon paths sample $S(\mathbf{x})$.

### 7.3 Rotation Curves

Circular velocities follow from the EFC potential:

$$v(r) = \sqrt{r \frac{\partial \Phi}{\partial r}}.$$

Because $\Phi(E_f, S)$ depends on both $E_f$ and $S$, the resulting rotation curves can flatten without invoking dark matter. In particular:

- stable regions around $S_{\text{mid}}$ produce broad bands of self-regulated velocities;
- transitions toward $s_0$ and $s_1$ produce characteristic slow variations;
- observational inferences of $v(r)$ must account for entropy-modulated $c(S)$.

### 7.4 Expansion Rate

The EFC expansion rate is:

$$H(E_f, S) = \sqrt{|E_f|}\,(1 + S),$$

which implies that cosmic acceleration arises from the joint evolution of $(E_f, S)$ rather than from dark energy or a cosmological constant.

### 7.5 Diagram of Dependencies

The core dependency chain for observables is:

$$S(\mathbf{x}) \implies E_f(\mathbf{x}) \implies \Phi(E_f, S) \implies c(S) \implies \text{Observables}.$$

This captures the full thermodynamic origin of structure formation, photon propagation, and cosmic expansion within EFC.

# 8 Figures

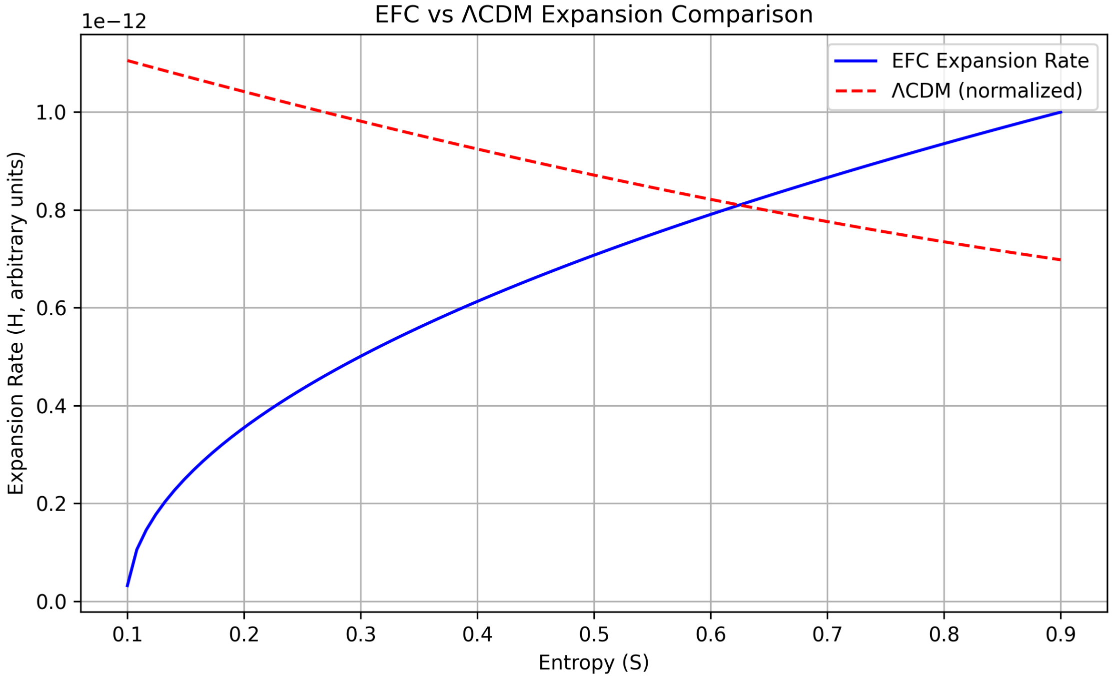


Figure 1: EFC vs. ΛCDM comparison.