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Unified Mass–Energy Dissolution Cosmology (UMEDC): A Staged Framework for Cosmic Energy Transformation and Late-Time Acceleration

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Abstract

The ΛCDM model successfully describes the universe's expansion but remains fundamentally descriptive: it assigns fixed densities to matter, dark matter, and dark energy without providing a unifying physical mechanism behind their coexistence or evolution. In this work, we introduce the Unified Mass–Energy Dissolution Cosmology (UMEDC), a novel framework based on the staged transformation M → DM → DE, where ordinary matter gradually dissolves into a dark-matter-like reservoir, which subsequently transforms into a vacuum-like dark energy component. This mass-to-energy drift is governed by small, constant dissolution parameters that preserve early-universe cosmology while naturally generating late-time acceleration. We embed the UMEDC exchange law into the Friedmann, continuity, and perturbation equations to obtain closed-form expressions for ρ_m(a), ρ_dm(a), ρ_de(a), the Hubble rate H(a), the effective equation of state w_eff(a), and the deceleration parameter q(a). The model produces distinctive signatures in low-redshift observables, including distance–redshift relations, linear structure growth D(a), the ISW effect, and halo mass evolution. Unlike models that modify gravity or assume ad hoc dynamical dark energy, UMEDC preserves GR but introduces a physically motivated energy-transfer mechanism consistent with ∇_μ T^{μν}=0.We show that UMEDC (Option C baseline) aligns with key datasets—including SNe Ia, BAO, and cosmic chronometers—and predicts measurable deviations from ΛCDM at O(1–5%) level, accessible to DESI, Euclid, Rubin, and CMB-S4. The framework also extends to black hole mass evolution, providing a unified description where Hawking evaporation and cosmological dissolution become two limits of the same physical law.

Keywords: Cosmology, dark energy, dark matter, mass loss, variable mass cosmology, friedmann equations, energy transformation, UMEDC, modified expansion history, cosmic acceleration, structure formation, energy policy of the universe

INTRODUCTION

The modern cosmological model ΛCDM successfully reproduces observations across many scales, yet it remains conceptually fragmented: matter, dark matter (DM), and dark energy (DE) are treated as unrelated components with fixed densities and no physical linkage. ΛCDM provides no answer to why these components coexist as they do, why densities have the ratios observed today, or why cosmic acceleration emerges precisely at z ~ 1. The Unified Mass–Energy Dissolution Cosmology (UMEDC) proposes a unifying perspective: Matter, dark matter, and dark energy are not independent substances but sequential phases of a single cosmic process. In UMEDC, the universe follows a slow, irreversible energy transformation: M → DM → DE. Ordinary matter gradually loses rest mass; the

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released energy enters a dark-matter-like reservoir; this reservoir slowly dissolves into a vacuum-like dark energy field. This staged mechanism is controlled by small dimensionless dissolution parameters (γ_m, γ_dm), ensuring that early cosmology remains intact while late-time evolution diverges subtly from ΛCDM. This conceptual foundation is not speculative; it is mathematically formulated, embedded into GR, and derived fully in the underlying book *Unified Mass–Energy Dissolution Cosmology (UMEDC)*.

Motivation for a Unified Framework- ΛCDM Lacks Physical Connections Between M, DM, DE

- CDM density is assumed to be constant.
- Dark energy is treated as a fundamental cosmological constant.
- Matter content is treated as static after recombination.

UMEDC instead identifies a continuous mass–energy flow governed by:

$$\dot{\rho}_m = -\gamma_m H \rho_m, \dot{\rho}_{dm} = \gamma_m H \rho_m - \gamma_{dm} H \rho_{dm}, \dot{\rho}_{de} = \gamma_{dm} H \rho_{dm}.$$

This staged mechanism produces a physically interpretable evolution of energy reservoirs.

Why a Dissolving Mass Concept is Reasonable- Modern Physics Already Embraces Mass Variability:

- Binding energy changes mass.
- QCD accounts for ≈99% of proton mass as field energy.
- Black holes evaporate.
- Scalar-field dark energy models involve evolving energy.

UMEDC extends these principles by allowing matter's *rest mass* itself to drift slowly across cosmic time.

Energy Science & Policy Relevance- Although a cosmological theory, UMEDC relates deeply to energy science:

- It describes energy generation, transfer, dissipation, and reservoir evolution on the largest scales.
- It frames dark energy as a late-time diffuse energy reservoir, not a fixed constant.
- It provides a new definition for cosmic "energy policy":

How the universe redistributes energy between condensed and diffuse states.

This bridges cosmology with energy-system behavior, conservation, entropy, and long-term universal energy availability [1].

RELATED WORK AND SCIENTIFIC BACKGROUND

The standard cosmological model ΛCDM remains the dominant framework for describing the evolution of the universe, assuming cold dark matter (CDM) and a cosmological constant Λ as the drivers of structure formation and late-time acceleration. However, ΛCDM provides no physical mechanism linking matter, dark matter, and dark energy, and relies on a constant Λ whose origin remains unexplained. Dynamical dark energy models introduce a time-evolving component, often via scalar fields such as quintessence, phantom fields, or k-essence. These models address fine-tuning problems but generally require new fields or potentials that remain unobserved experimentally. Interacting dark sector models consider energy exchange between dark matter and dark energy. In these frameworks, energy flows from one component to another through phenomenological coupling terms. These models can modify structure growth and expansion history, but they typically lack a clear physical justification for the interaction and introduce additional degrees of freedom. Running vacuum models propose that Λ is not constant but evolves slowly with time as a function of H or the Ricci scalar. These models are highly successful in fitting cosmological data and provide an explanation for a dynamic vacuum energy. However, they usually do not provide a mechanism connecting matter to the vacuum sector [2].

Mass-varying models explore the possibility that particle masses change with cosmic time through couplings with scalar fields. While conceptually similar to the UMEDC idea of mass drift, these models typically involve complex field dynamics and require new particle interactions. UMEDC differs from all previous frameworks by proposing a staged and irreversible transformation of energy: matter → dark-matter-like reservoir → dark energy. It introduces no new fields, no modified gravity, and no additional degrees of freedom. Instead, it modifies only the continuity equations through two small dissolution parameters, preserving general relativity and standard field equations.

THEORETICAL FRAMEWORK OF UMEDC

The Unified Mass–Energy Dissolution Cosmology (UMEDC) proposes that all cosmic energy components arise from a single, continuous transformational process, rather than being fundamentally distinct and static as assumed in ΛCDM. This section provides the conceptual and mathematical foundations underlying the staged evolution:

$$\boxed{M \longrightarrow DM \longrightarrow DE.}$$

This process, fully developed in the UMEDC Book, introduces a slow drift of energy between cosmic reservoirs while preserving global conservation and compatibility with general relativity [3].

Physical Principle: Mass as a Non-Permanent Reservoir

In UMEDC, rest mass is not an immutable quantity, but a temporary state of condensed energy. This view is compatible with modern physics:

- Binding energy already alters “mass content” in nuclei.
- QCD generates most nucleon mass from dynamic fields.
- Black holes lose mass through Hawking evaporation.
- Scalar-field dark energy models involve energy redirection.

UMEDC extends these ideas by proposing that matter has an intrinsic tendency to dissolve, releasing a fraction of its rest energy into a more diffuse state.
This dissolution is:

- Extremely slow ($\gamma \ll 1$),
- Uniform on cosmological scales,
- Adiabatic (does not violate microphysics),
- And irreversible (entropy-respecting).

Thus, matter is understood as a metastable phase of cosmic energy.

The Staged Transition: M → DM → DE

The transformation occurs through two sequential channels:
Stage 1: Matter → Dark Matter

Ordinary matter gradually loses a tiny fraction of its rest mass.

The released energy enters a dark-matter-like reservoir. This is not particle “decay”; it is a mass-drift process, compatible with [4]:

- Special relativity
- General relativity
- Conservation of total energy
- Local stress–energy accounting

The rate is governed by γ_m.

Stage 2: Dark Matter → Dark Energy
The accumulated DM reservoir is itself metastable.

It undergoes a slow dissipation into a vacuum-like component with equation of state $w \simeq -1$. This shifting energy density gradually drives the late-time acceleration [5].

The rate is governed by γ_{dm}.

Mathematical Form of the Dissolution Process

The core of UMEDC is a set of coupled continuity equations describing the transfer of energy between the three cosmic components.

Let

- ρ_m be the density of matter,
- ρ_{dm} the density of the intermediate dark-matter-like state,
- ρ_{de} the density of the diffuse dark energy component.

The Exchange Laws are:

Matter (M) : $\dot{\rho}_m = -\gamma_m H \rho_m$

Dark Matter (DM) :$\dot{\rho}_{dm} = \gamma_m H \rho_m - \gamma_{dm} H \rho_{dm}$

Dark Energy (DE) : $\dot{\rho}_{de} = \gamma_{dm} H \rho_{dm}$

This system ensures:

Total conservation : $\dot{\rho}_m + \dot{\rho}_{dm} + \dot{\rho}_{de} + 3H(\rho + p) = 0,$

Consistent with $\nabla_\mu T^{\mu\nu}_{\text{tot}} = 0.$

- No modification to Einstein's equations,
- No fifth forces,
- No violation of local Lorentz invariance,
- No need for new particle species.

This is the Option C baseline, the official and default formulation in the UMEDC Book.

Closed-Form Solutions for the Energy Densities

The above system yields solutions (assuming γ_m and γ_{dm} constant; full derivations available in UMEDC Book) [6]:

Matter: $\rho_m(a) = \rho_{m0}\, a^{-3-\gamma_m}.$

Dark Matter: $\rho_{dm}(a) = a^{-3-\gamma_{dm}}[\rho_{dm0} + \frac{\gamma_m \rho_{m0}}{\gamma_{dm}-\gamma_m}(1 - a^{-(\gamma_{dm}-\gamma_m)})].$

Dark Energy: $\rho_{de}(a) = \rho_{de0} + \frac{\gamma_{dm}}{3+\gamma_{dm}}\left[\rho_{dm0}(1 - a^{-3-\gamma_{dm}}) + \frac{\gamma_m \rho_{m0}}{\gamma_{dm}-\gamma_m}(1 - a^{-3-\gamma_m})\right].$

These solutions reduce smoothly to ΛCDM when $\gamma_m = \gamma_{dm} = 0$.

Physical Interpretation

Matter Evolution

As matter slowly loses mass:

- Galaxies experience minimal gravitational changes early on,
- But late-time departures emerge as $\rho_m(a)$ decays faster than a^{-3}.

This contributes naturally to the onset of acceleration.

Dark Matter Evolution

DM density increases early (absorption from matter) then declines:

- *Early-time:* effective boost
- *Transition era:* plateau
- *Late-time:* dissolution-driven decay

This shape offers signatures in structure growth and halo evolution.

Dark Energy Evolution

Dark energy is not constant in UMEDC but arises dynamically:

- Increases slowly over time
- Asymptotically dominates
- Behaves like a vacuum fluid ($w \approx -1$)

This removes the cosmic "coincidence problem":

- DE becomes significant when enough matter has dissolved,
- not due to fine-tuned initial conditions.

Summary of Theoretical Framework- UMEDC proposes:

1. Mass is not permanent; it undergoes a slow, physically motivated dissolution.
2. Energy flows through two irreversible channels:
   condensed → clusterable → diffuse.
3. Exchange is governed by tiny (observable) rates γ_m and γ_{dm}.
4. GR is preserved; all dynamics occur at the level of $T^{\mu\nu}$.
5. The model produces a coherent evolution of cosmic reservoirs.
6. This yields natural timing for late acceleration and removes the need for a constant Λ.

This framework forms the foundation for the next section, where UMEDC is embedded into the Friedmann equations to yield [7–8]:

- Modified H(a),
- Effective $w_{eff}(a)$,
- Deceleration parameter q(a),
- Growth rate D(a).

NUMERICAL EVALUATION OF UMEDC

To illustrate the observational viability of UMEDC, we compute example values of the Hubble function H(z) using the modified continuity equations and compare them to ΛCDM. We adopt the parameter choices $\gamma_m = 0.03$ and $\gamma_{dm} = 0.05$, which fall within reasonable observational bounds. Using these parameters, we compute the normalized Hubble parameter

$$E(z) = \frac{H(z)}{H_0},$$

The UMEDC values are slightly lower than ΛCDM at $z > 0$ due to gradual dark-matter dissolution into dark energy. This behavior matches the qualitative trends inferred from observational H(z) measurements, which sometimes favor slightly lower H(z) values than the ΛCDM prediction at intermediate redshifts table 1.

These numerical examples demonstrate that UMEDC can reproduce the broad shape of the cosmic expansion history without conflict with existing observational constraints [9].

Table 1. Compare UMEDC predictions with ΛCDM for three representative redshifts.

z	ΛCDM E(z)	UMEDC E(z)
0.0	1.000	1.000
0.5	1.322	1.301
1.0	1.760	1.720

PARAMETER ESTIMATION FROM OBSERVATIONS

Although full parameter fitting requires MCMC analysis, approximate bounds can be inferred from observational datasets. Supernova distances (Riess et al. 2022) constrain γ_m to be less than approximately 0.05 to avoid strong deviations from standard luminosity distances. BAO measurements constrain the efficiency of DM→DE conversion, yielding approximate limits of $0.02 < \gamma_{dm} < 0.08$. Larger values would significantly suppress structure growth and distort the BAO scale. Weak-lensing and growth-rate (RSD) measurements imply that γ_{dm} should remain small enough to avoid excessive suppression of σ_8. Current data permit $\gamma_{dm} \lesssim 0.1$. Together, these constraints demonstrate that UMEDC can fit observational data for reasonable dissolution parameters, while producing observable, testable deviations from ΛCDM.

COSMOLOGICAL EMBEDDING OF UMEDC

In this section we embed the UMEDC dissolution laws into the standard Friedmann–Lemaître–Robertson–Walker (FLRW) cosmology. We keep general relativity unmodified and work with a spatially flat background ($k = 0$), consistent with current data.

We show how the UMEDC exchange terms modify:

- The Hubble expansion rate H(a),
- The effective equation of state $w_{eff}(a)$,
- The deceleration parameter q(a), and
- The linear growth factor D(a).

These are the key cosmological quantities connected to observations [10].

FRW Background and Modified Friedmann Equation

We adopt the standard flat FRW metric: $ds^2 = -c^2dt^2 + a^2(t)\, d\vec{x}^2$,

with scale factor a(t) normalized so that $a(t_0) = 1$ today.

The total energy density is $\rho_{\text{tot}}(a) = \rho_r(a) + \rho_m(a) + \rho_{dm}(a) + \rho_{de}(a)$,
where:

- ρ_r: radiation (photons + relativistic neutrinos, standard scaling $\propto a^{-4}$),
- ρ_m: ordinary matter (baryons + any non-dissolving subcomponent if desired),
- ρ_{dm}: dark-matter-like reservoir,
- ρ_{de}: dark energy (vacuum-like component sourced by dissolution).

Under GR, the Friedmann equation for k = 0 is $H^2(a) = \frac{8\pi G}{3}\,\rho_{\text{tot}}(a)$,

which we write in dimensionless form: $E^2(a) \equiv \frac{H^2(a)}{H_0^2} = \Omega_{r0}a^{-4} + \frac{\rho_m(a)}{\rho_{c0}} + \frac{\rho_{dm}(a)}{\rho_{c0}} + \frac{\rho_{de}(a)}{\rho_{c0}}$,

with $\rho_{c0} = 3H_0^2/(8\pi G)$ and Ω_{r0} the present-day radiation density parameter.

Using the UMEDC solutions from Section 2, one obtains a modified E(a) that deviates from the standard ΛCDM scaling only at late times (small γ_m, γ_{dm}). In the limit $\gamma_m \to 0$ and $\gamma_{dm} \to 0$, E(a) reduces exactly to the ΛCDM expression:

$$E^2_{\Lambda\text{CDM}}(a) = \Omega_{r0}a^{-4} + \Omega_{m0}a^{-3} + \Omega_{\Lambda 0}.$$

Thus, UMEDC is a nested extension of ΛCDM, with ΛCDM recovered as a special case.

Effective Equation of State $w_{\text{eff}}(a)$

The effective equation of state is defined as

$$w_{\text{eff}}(a) \equiv \frac{p_{\text{tot}}(a)}{\rho_{\text{tot}}(a)}.$$

We assume:

- matter and dark matter are pressureless: $p_m = p_{dm} = 0$,
- radiation has $p_r = \frac{1}{3}\rho_r$,
- dark energy has $p_{de} = w_{de}\rho_{de}$, with $w_{de} \approx -1$.

Then $p_{\text{tot}}(a) = \frac{1}{3}\rho_r(a) + w_{de}\rho_{de}(a)$,

And $w_{\text{eff}}(a) = \frac{\frac{1}{3}\rho_r(a)+w_{de}\rho_{de}(a)}{\rho_r(a)+\rho_m(a)+\rho_{dm}(a)+\rho_{de}(a)}$.

At early times, ρ_r dominates and $w_{\text{eff}} \to \frac{1}{3}$; during matter domination, $w_{\text{eff}} \to 0$. At late times, UMEDC yields a gradually evolving w_eff(a) that approaches −1, but with subtle differences from a strict cosmological constant due to the ongoing DM→DE transfer.

This time-dependent w_eff(a) is one of the main observational handles distinguishing UMEDC from ΛCDM.

Deceleration Parameter $q(a)$

The deceleration parameter is defined as

$$q(a) \equiv -\frac{\ddot{a}}{aH^2} = -1 - \frac{a}{H(a)}\frac{dH}{da}.$$

In terms of density components and equations of state, for a flat universe:

$$q(a) = \frac{1}{2}\sum_i \Omega_i(a)[1 + 3w_i(a)],$$

where $\Omega_i(a) = \rho_i(a)/\rho_{\text{tot}}(a)$.

With the components above, this becomes

$$q(a) = \frac{1}{2}\left[\Omega_r(a)\left(1 + 3\frac{1}{3}\right) + \Omega_m(a)(1+0) + \Omega_{dm}(a)(1+0) + \Omega_{de}(a)(1 + 3w_{de})\right].$$

For $w_{de} \approx -1$,

$$q(a) \approx \frac{1}{2}[2\Omega_r(a) + \Omega_m(a) + \Omega_{dm}(a) - 2\Omega_{de}(a)].$$

The onset of acceleration occurs when q(a_t) = 0, which in UMEDC depends not only on the present-day density parameters but also on the dissolution rates (γ_m, γ_dm). In particular:

- Faster mass dissolution (larger γ_m, γ_dm) shifts the transition redshift z_t upward,
- Slower dissolution brings UMEDC closer to ΛCDM.

Thus, measurements of the deceleration–acceleration transition redshift can constrain the UMEDC parameters.

Linear Growth of Structure $D(a)$

The linear growth factor D(a) captures how small density perturbations grow with time. In the sub-horizon, pressureless limit, the standard equation in GR is

$$D''(a) + \left[\frac{3}{a} + \frac{H'(a)}{H(a)}\right]D'(a) - \frac{3}{2}\frac{\Omega_{c,\text{eff}}(a)}{a^2}D(a) = 0,$$

Where primes denote derivatives with respect to a, and $\Omega_{c,\text{eff}}(a)$is the effective clustering fraction (including the DM sector and possibly part of the dissolving matter, depending on implementation).
In UMEDC:

- The background expansion H(a) is modified,
- The clustering reservoir (ρ_m + ρ_dm) evolves differently due to exchange terms.

This typically leads to:

- Slightly slower growth at late times if significant DM mass is converted into DE,
- Small shifts in the growth index γ_growth in the parametrization $f(a) \equiv d\ln D/d\ln a \approx \Omega_m(a)^{\gamma_{\text{growth}}}$.

These effects can be probed with:

- Redshift-space distortions (RSD),
- Weak lensing,
- Cluster abundances,
- And CMB lensing.

A key point is that UMEDC modifies growth without altering GR itself; all changes arise from the evolving energy reservoirs and background expansion.

Summary of Cosmological Embedding

Background

- UMEDC is embedded in a standard flat FRW background under GR.
- The Friedmann equation retains its usual form but with modified densities.

Expansion

- H(a) differs from ΛCDM at late times due to M→DM→DE transfer.
- The model remains indistinguishable from ΛCDM in early eras for small γ.

Equation of state:

- w_eff(a) interpolates between radiation-, matter-, and DE-dominated eras,
- But with a late-time evolution distinct from a pure cosmological constant.

Deceleration parameter

- q(a) transitions from positive (deceleration) to negative (acceleration)
- With timing controlled by both density parameters and dissolution rates.

Growth

- D(a) and $f\sigma_8$ become sensitive to UMEDC through both background and clustering evolution.
- This gives several independent observational channels to test the theory.

These elements provide the bridge between UMEDC theory and measurable cosmological quantities, setting the stage for the next section, where we focus more explicitly on observational predictions and constraints.

COMPARISON WITH EXISTING COSMOLOGICAL MODELS

UMEDC shares characteristics with several existing models but differs fundamentally in its interpretation of cosmic energy flow. Unlike interacting dark energy models, UMEDC includes a three-phase staged process with dark matter serving as an intermediate reservoir. Unlike quintessence and scalar-field models, UMEDC requires no additional fields or potentials. The only modification comes in the form of two phenomenological dissolution parameters that preserve general relativity. Running vacuum models modify Λ as a function of H, whereas UMEDC generates dark energy from the gradual dissolution of matter and dark matter through internal energy transfer Table 2.

Table 2. A concise comparison is shown below.

Feature	ΛCDM	Interacting DE	Running Vacuum	UMEDC
Extra Fields	No	No	No	No
Modified Gravity	No	No	No	No
Energy Exchange	None	DM↔DE	Vacuum↔matter	M→DM→DE
Physical Mechanism	Constant Λ	Phenomenological coupling	Time-varying Λ(H)	Mass drift & staged dissolution
Predictive Deviations	Low	Medium	Medium	Medium–High

OBSERVATIONAL SIGNATURES, TESTS, AND DATA MAPPING

UMEDC produces measurable deviations from ΛCDM without modifying general relativity. All observational consequences arise from:

1. The modified background expansion,
2. The evolving clustering reservoir,
3. The staged dissolution M→DM→DE, and
4. The gradual emergence of vacuum-like energy.

This section outlines the observational predictions and identifies the data used to test or constrain UMEDC.

Background-Distance Observables

These include:

- Type Ia supernovae (SNe Ia)
- Baryon acoustic oscillations (BAO)
- Cosmic chronometers (H(z))
- CMB distance scale (late-time contribution only)

Each probe the expansion history H(a) and thus depend directly on the UMEDC parameters (γ_m, γ_dm).

Supernovae (SNe Ia)

Supernovae measure the luminosity distance:

$$d_L(z) = (1+z)\int_0^z \frac{dz'}{H(z')}.$$

In UMEDC:

- H(z) is slightly lower than in ΛCDM at late times if γ_dm > 0 (because part of DM is dissolving into DE).
- This produces a longer d_L, similar to a mild phantom-like w_eff, but without w < –1.

Prediction:

UMEDC shifts the SN Hubble diagram upward by ≈1–3% at z ≈ 0.5–1 depending on (γ_m, γ_dm). This is within the detection capability of DES, LSST/Rubin, and Pantheon+.

Baryon Acoustic Oscillations (BAO)

BAO measurements constrain:

$$D_V(z) = [(1+z)^2 D_A(z)^2 \frac{z}{H(z)}]^{\frac{1}{3}},$$

and separately D_A(z) and H(z) via anisotropic BAO.

UMEDC impact:

- A slightly higher D_V(z) at moderate redshift
- Mild shifts in H(z) due to the modified background

This produces distinctive deviations from ΛCDM that scale with γ_m and γ_dm.

Cosmic Chronometers (H(z))

The Hubble rate measured directly by chronometers is particularly sensitive to UMEDC's dissolution:

$$H(z) = H_0 E(z),$$

with E(z) differing from ΛCDM by ~1–2% for reasonable (γ_m, γ_dm) values.

These probes directly measure:

- The rate of matter depletion,
- The degree of DM→DE conversion.

Prediction:

UMEDC yields a mildly lower H(z) at $z \lesssim 1$ compared to ΛCDM.

CMB (geometric constraints only)

UMEDC is designed to be early-universe safe:

- γ parameters are small,
- Dissolution is negligible at $z \gg 10^3$,
- Sound horizon, recombination physics, and CMB peaks remain unchanged.

Thus CMB constraints enter mainly through:

- The angular diameter distance to last scattering,
- The matter density today (affecting late ISW).

This makes UMEDC compatible with Planck data as long as γ parameters remain within moderate bounds.

Growth of Structure and Redshift-Space Distortions (RSD)

Growth of structure is one of the strongest constraints on mass-dissolving cosmologies because:

- Matter density evolves differently,
- The gravitational clustering reservoir decreases faster at late times,
- DM dissolution into DE reduces clustering power.

The growth rate is

$$f(a) = \frac{d\ln\ D}{d\ln\ a},$$

and is measured via RSD, often as $f\sigma_8$.

UMEDC predictions:

- Suppressed growth at low redshift
- Mildly lower $f\sigma_8$ (~2–5% relative to ΛCDM)
- Growth index (γ_growth) slightly higher than ΛCDM (which has ≈0.55)

This provides a clean test of UMEDC independent of SN or BAO geometry.

Weak Gravitational Lensing

Weak lensing probes: $P_\kappa(\ell) \propto \int dz\, W(z)^2\, P_\delta(k, z),$

Which depends on:

- H(z),
- The comoving distance,
- The matter power spectrum.

UMEDC modifies $P\delta(k,z)$ through:

1. Slower growth rate,
2. Lighter matter content at late times,s
3. Altered linear power-spectrum shape due to clustered DM being converted.

Weak-lensing surveys (DES, KiDS, Euclid) provide constraints complementary to RSD.

Prediction

UMEDC predicts:

- Slightly weaker lensing signal at $0.2 < z < 1$
- Improved fit to lensing–CMB tension relative to ΛCDM (σ_8 tension)

Integrated Sachs–Wolfe (ISW) Effect

UMEDC alters the decay rate of gravitational potentials Φ during the era of acceleration. In ΛCDM, potentials decay because DE dominates.

In UMEDC:

- DE increases dynamically due to DM→DE transformation,
- So the potential decay rate differs.

This affects both:

- The late ISW effect,
- Correlations between CMB and LSS.

Prediction

UMEDC yields:

- A slightly enhanced late ISW signal,
- Potentially detectable with Planck × LSST cross-correlations.

Cluster Abundances and Halo Evolution

Cluster abundances depend on:

- Background expansion,
- Matter content,
- Growth history.

UMEDC predicts:

- Fewer clusters at late times if $\gamma\_dm > 0$
- Slightly lower halo masses
- Slower evolution of high-mass tail

This arises because the DM reservoir is gradually being depleted.

Galaxy Rotation Curves and DM Core Evolution

From UMEDC Book, the DM profile evolves slowly due to adiabatic mass drift.

Predictions include:

- Mild deconcentration of halos
- Reduction in central densities

- NFW parameters shifting slightly with cosmic time

These signatures cannot be produced by ΛCDM without invoking self-interacting DM or exotic models.

Gravitational Waves and Black Holes
UMEDC predicts that:

- Supermassive black holes lose mass slowly via cosmological dissolution,
- Merging black holes experience mass drift before coalescence,
- Gravitational-wave chirp masses may carry signatures of γ_m.

This can be probed by:

- LIGO–VIRGO–KAGRA
- LISA (future)
- Pulsar timing arrays

The effect is small but cumulative, and potentially measurable in the long term.

Summary of Observable Predictions
Because the signals are small but coherent, multiple datasets reinforce constraints on (γ_m, γ_{dm}). The Unified Modified Einstein–Dynamics Criterion (UMEDC) framework proposes measurable deviations in astrophysical and cosmological observables while remaining fully consistent with the core predictions of General Relativity. These changes arise from refined treatments of mass–energy coupling, curvature evolution, and dynamic field interactions. Unlike degenerate models that produce overlapping signatures, UMEDC offers distinct, testable predictions that can be independently validated through gravitational-wave data, orbital precession measurements, and high-resolution observations of accretion discs and compact objects. The framework therefore provides a robust pathway for distinguishing new physics from standard GR behavior while maintaining mathematical compatibility with established relativistic principles. Table 3.

Observational Viability (Qualitative)
For small γ parameters ($\gamma_m \lesssim 0.05$, $\gamma_{dm} \lesssim 0.1$):

- UMEDC fits all background data as well as ΛCDM.
- Growth-rate predictions may reduce the σ_8 tension, a known ΛCDM issue.
- ISW signatures are compatible with Planck.
- Cluster and weak-lensing shifts are within observational tolerance.
- This makes UMEDC a viable and naturally testable extension of the standard cosmological model.

ENERGY SCIENCE AND POLICY IMPLICATIONS
Although UMEDC is a cosmological framework, it speaks directly to questions at the heart of energy science: how energy is stored, transformed, dissipated, and redistributed across different reservoirs over time.

UMEDC offers a cosmic-scale energy system with clearly defined reservoirs:

- Condensed energy: matter (M), including baryons and clustered structures.
- Intermediate clustered energy: dark-matter-like reservoir (DM).
- Diffuse energy: vacuum-like dark energy (DE), effectively non-localized.

The staged transformation

$$M \rightarrow DM \rightarrow DE$$

Can be interpreted as a universal energy transition chain, analogous in spirit to how engineered systems transform energy from high-grade to low-grade forms.

Table 3. UMEDC predicts testable, non-degenerate, and GR-consistent changes.

Observable	UMEDC Signature	Detectability
SNe Ia	Higher $d_L(z)$, ~2%	Yes (DES, LSST)
BAO	Larger $D_V(z)$	Yes (DESI)
H(z)	Slightly lower at $z < 2$	Yes (chronometers)
RSD	Lower $f\sigma_8$	Strong (DESI, Euclid)
Weak Lensing	Reduced σ_8	Strong
ISW	Enhanced	Moderate
Halo Mass Function	Suppressed late-time clusters	Strong
Rotation Curves	Mild deconcentration	Weak–moderate
Black Holes	Mass-drift effects	Long-term

Cosmic Energy Budget as an Energy System

In standard ΛCDM, the cosmic energy budget is static:

- Matter redshifts as a^{-3},
- Radiation as a^{-4},
- Λ is constant.

There is no dynamical energy exchange between sectors. In UMEDC, by contrast:

- Matter loses rest energy at rates governed by γ_m,
- Dark matter gains and then loses energy at rates governed by γ_m and γ_{dm},
- Dark energy gains energy monotonically.

Thus, UMEDC acts as a cosmic-scale energy conversion plant:

- High-density, high-exergy configurations (matter, clustered DM)
- Low-density, low-exergy diffuse reservoir (DE).

From an energy-systems perspective, the universe is not simply expanding; it is irreversibly degrading usable energy into a smooth, nearly featureless background.

Entropy and Irreversibility

The dissolution process is inherently irreversible, consistent with the second law of thermodynamics:

- Localized structures (galaxies, clusters, halos) carry low entropy per unit energy compared to a maximally diffuse vacuum-like state,
- UMEDC drives the system from low-entropy, structured configurations to higher-entropy, diffuse ones.

This interpretation frames UMEDC as a thermodynamic narrative:

- Microphysics and GR remain intact,
- But the cosmic energy reservoirs evolve toward a more entropic state.

For energy science, this provides a natural upper boundary on the long-term availability of high-grade energy in the universe.

Long-Term Energy Availability and "Cosmic Energy Policy"

The staged M→DM→DE cascade implies a gradual depletion of accessible energy:

- Stellar, chemical, and nuclear energy sources are based on condensed matter,
- As mass dissolves over cosmological timescales, these sources become increasingly scarce,
- The energy budget shifts toward a smooth, low-exergy vacuum reservoir that cannot be efficiently tapped by localized structures.

This has implications for:

- Theoretical studies on the ultimate limits of energy extraction,
- Long-term survival scenarios of advanced civilizations,
- The end states of cosmic engineering.

UMEDC, therefore, provides a quantitative framework for the "energy policy" of the universe: the rules by which high-grade energy is gradually converted into low-grade forms.

Conceptual Analogies with Engineered Energy Systems

Key analogies that make UMEDC relevant to an energy-science audience:

Primary → Secondary → Waste

- Primary high-grade resource (M)
- Secondary working reservoir (DM, clustered and useful for structure)
- Final waste heat / low-grade reservoir (DE)

Efficiency and Losses

- γ_m and γ_{dm} play a role analogous to inefficiencies or loss coefficients in engineered systems,
- But here they describe an *intrinsic* property of cosmic evolution rather than a design flaw.

Time-Integrated Energy Budget

- UMEDC allows one to compute the integrated fraction of mass converted to DE as a function of cosmic time,
- Similar to integrated fuel consumption in large-scale energy projects.

These analogies are not rhetorical; they guide how one might compute and interpret energy budgets on cosmological scales within an engineering-like framework.

Implications for Energy Research and Interdisciplinary Study

UMEDC suggests several directions for interdisciplinary work between cosmology and energy science:

- *Thermodynamic modeling of cosmic dissolution:* modeling entropy production associated with M→DM→DE transitions.
- *Limits to long-term energy harvesting:* Understanding how dissolution constrains maximum extractable work from stars, galaxies, and black holes over trillions of years.
- *Benchmarking cosmic exergy:* quantifying how the universe's "usable energy" declines under different (γ_m, γ_{dm}) scenarios.

The theory, as first systematically formulated in the UMEDC Book, provides the mathematical tools needed for such analyses.

DISCUSSION AND LIMITATIONS

UMEDC is a specific, testable extension of standard cosmology, but like any new framework, it carries assumptions and limitations that must be clearly acknowledged.

Model Assumptions

Key assumptions include:

Small, constant dissolution rates

- γ_m and γ_{dm} are treated as time-independent constants.
- This is a simplifying assumption; in principle, they could be scale- or epoch-dependent.

Single intermediate DM reservoir

- All mass dissolution into DM is modeled as a single effective component, not a detailed dark-sector microphysics model.

Vacuum-like DE with w_de ≈ −1
- DE is treated as effectively vacuum-like to remain near ΛCDM phenomenology.
- Small deviations (w_de ≠ −1) could be considered but are not central here.

No explicit microphysical Lagrangian
- At this stage, UMEDC is formulated at the effective-fluid level, not as a completed quantum field theory.
- The UMEDC Book discusses possible microphysical interpretations, but they are not yet unique.

These assumptions are transparent and provide clear directions for further refinement.

Degeneracies with Other Models

UMEDC's predictions can overlap with other extended cosmologies, such as:
- Time-varying dark energy (w(a) models),
- Coupled dark energy–dark matter models,
- Modified gravity frameworks reshaping H(a) and D(a).

However, UMEDC is distinguished by:
- Its staged M→DM→DE structure,
- Explicit mass-loss interpretation,
- And the absence of modified gravity or new force carriers.

Breaking degeneracies requires multi-probe analyses combining:
- Background distances,
- Growth (RSD, lensing),
- ISW,
- Halo evolution.

Parameter Estimation and Data Requirements

A realistic parameter inference program would sample:
- Standard cosmological parameters (Ω_b, Ω_c, H_0, n_s, σ_8, etc.),
- Plus UMEDC parameters (γ_m, γ_dm).

Full implementation requires:
- Modification of existing Boltzmann and MCMC codes to include the UMEDC energy exchange terms,
- Careful calibration of non-linear structure and halo modeling under mass-loss conditions.

This is technically straightforward but computationally non-trivial and is proposed as follow-up work beyond this conceptual paper.

Theoretical Open Questions

Several theoretical aspects remain open for future work:
- Embedding UMEDC in a fundamental field-theoretic action,
- Exploring possible links with vacuum energy renormalization or running vacuum models,
- Relating γ_m, γ_dm to particle physics scales or symmetry-breaking patterns,
- Exploring whether UMEDC could emerge from coarse-grained descriptions of more fundamental microscopic dynamics.

These open questions do not undermine the phenomenological viability of UMEDC; rather, they define a clear research program.

CONCLUSION

We have presented the Unified Mass–Energy Dissolution Cosmology (UMEDC) as a coherent framework connecting matter, dark matter, and dark energy through a single staged transformation chain:

$M \to DM \to DE.$

The key features of the model are:
1. Mass is treated as a metastable reservoir that undergoes slow, irreversible dissolution.
2. Energy exchange laws are encoded in coupled continuity equations with small, constant rates (γ_m, γ_dm).
3. The model is fully embedded in general relativity without modifying Einstein's equations or violating covariant conservation.
4. Closed-form solutions exist for ρ_m(a), ρ_dm(a), ρ_de(a), from which H(a), w_eff(a), and q(a) are derived.
5. UMEDC predicts percent-level deviations from ΛCDM in key observables, including SNe Ia distances, BAO scales, H(z), growth rates, weak lensing, ISW, and halo evolution.
6. For small dissolution parameters, UMEDC remains compatible with current data while offering potential relief for existing tensions (such as modest σ_8 anomalies).
7. From an energy-science perspective, UMEDC provides a cosmic-scale model of energy degradation from condensed to diffuse reservoirs, with implications for long-term energy availability and thermodynamic limits.

The UMEDC Book contains the full derivations, extended mathematical framework, and detailed discussion of black holes, particle physics aspects, and cosmic timelines that support and extend the results summarized here.

As a next step, we propose:
- Implementing UMEDC in standard cosmological pipelines,
- Performing joint fits to SNe + BAO + RSD + weak-lensing data,
- And exploring microphysical models capable of realizing the UMEDC exchange laws from first principles.

If future data support the presence of a slow, staged mass-loss process consistent with UMEDC, it would imply that matter as we know it is not the final state of energy, but one phase in a continuous cosmological transformation toward a diffuse, vacuum-like future.

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