Normalization and Phenomenology of Λ_{eff} and Dark-Sector Backreaction

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Abstract

This paper upgrades the cosmology layer of Universal Modular Dynamics (UMD) from proxy definitions to a normalization and minimal phenomenology framework. We define stable, comparable Λ_{eff} proxies by specifying admissible effective-volume families V_{eff}, calibration conventions, and explicit stability requirements (bootstrap and protocol sensitivity). We then formalize an identifiability criterion for DM-like hidden backreaction residuals distinct from DE-like vacuum drift, yielding a conservative diagnostic interface in the plane $(\Lambda_{\text{eff}}, R_{\text{br}})$. Two theorem-level blocks state (i) normalization invariance under a stable protocol class and (ii) identifiability of DM-like residuals beyond vacuum drift on stable-geometry domains. A reproducibility-first validation suite with acceptance criteria, minimal figures, and failure-domain reporting is provided.

Contents

1 Introduction and scope

Paper CΛ introduced a conservative operational cosmology layer in UMD: a canonical MaxEnt reference σ_F, entropic potentials $V_F(\rho) = D(\rho\|\sigma_F)$ and deficit $\Delta S_F = S(\sigma_F) - S(\rho_{\text{vis}})$, proxy families for Λ_{eff}, and a diagnostic separation of DM-like vs DE-like signatures. This paper adds the missing *phenomenology/normalization layer*: how to define and justify an effective volume V_{eff}, how to normalize Λ_{eff} so it is comparable across runs, and what minimal observable-facing tests can be proposed without overclaiming.

Claims (domain-aware). On stable-chart domains (stable (A_F, Z_F) and reproducible reference construction) and stable-geometry domains (bounded geometry instability), we claim: (i) reasonable, reproducible choices of V_{eff} exist such that normalized Λ_{eff} is stable under protocol perturbations; (ii) normalized Λ_{eff} becomes comparable across runs within declared comparability classes; and (iii) DM-like backreaction is identifiable via residuals correlated with hidden indicators beyond vacuum drift.

Non-claims (explicit). We do not fit cosmological datasets in physical units here. We do not assert a derivation of FRW/Einstein equations. V_{eff} and calibration are protocol-defined; we justify them by stability and consistency tests.

2 Recap: canonical proxies and why normalization is needed

Given access constraints $Q = \{Q_a\} \subset A_F$, define the MaxEnt/I-projection reference $\sigma_F(\rho)$ and the canonical entropic potentials

$$V_F(\rho) = D(\rho \| \sigma_F(\rho)), \qquad \Delta S_F(\rho) = S(\sigma_F(\rho)) - S(\rho_{\text{vis}}).$$

Two canonical proxy families were proposed:

$$\Lambda_{\text{eff}}^{(A)} \propto \frac{\Delta S_F}{V_{\text{eff}}}, \qquad \Lambda_{\text{eff}}^{(B)} \propto \frac{V_F(\rho)}{V_{\text{eff}}}.$$

Without normalization, Λ_{eff} is not comparable across region sizes, charts, or protocol choices. CΛ2 treats V_{eff} and calibration as first-class measurement conventions with explicit acceptance criteria.

3 Defining V_{eff}: operational "volume" and scaling laws

We propose candidate definitions grouped into three families.

3.1 Family I: DoF-count volumes (baseline)

$$V_{\text{eff}}^{(1)} := N_{\text{vis}}, \qquad V_{\text{eff}}^{(2)} := \log \dim \mathcal{H}_{\text{vis}}.$$

These are minimal-assumption, stable baselines suitable for journal-safe comparisons.

3.2 Family II: entropy/effective-rank volumes

$$V_{\text{eff}}^{(3)} := r_{\text{ent}}(\rho_{\text{vis}}) := \exp(S(\rho_{\text{vis}})), \qquad V_{\text{eff}}^{(4)} := \mathrm{PR}(\rho_{\text{vis}}) := \frac{1}{\mathrm{Tr}(\rho_{\text{vis}}^2)}.$$

These interpret "volume" as the number of effectively populated degrees, appropriate in mixed regimes.

3.3 Family III: geometry-derived volumes (stable-geometry only)

Assuming a stable MI-graph geometry d_ρ, define

$$V_{\text{eff}}^{(5)} := \sum_{i<j} f(d_\rho(i,j)),$$

for a protocol-declared kernel f yielding stable extensive scaling. Geometry-derived volumes are valid only when geometry stability is demonstrated.

3.4 Consistency requirements

A candidate V_{eff} is acceptable only if it satisfies: C1 (bootstrap stability), C2 (chart robustness), C3 (extensivity sanity), C4 (non-degeneracy), and C5 (separation utility: it stabilizes Λ_{eff} without destroying DM identifiability). We recommend $V_{\text{eff}}^{(2)}$ (or $V_{\text{eff}}^{(1)}$) as the default baseline and use $V_{\text{eff}}^{(3)}$ and $V_{\text{eff}}^{(5)}$ as robustness checks.

4 Normalization of Λ_{eff}

4.1 Calibration conventions

We fix a calibration constant c_Λ by a declared convention:

(Cal-1) Reference-point calibration (recommended). Pick a stable reference point ρ_0 and set c_Λ so that $\Lambda_{\text{eff}}(\rho_0) = 1$.

(Cal-2) Domain-median calibration. Set c_Λ by the median of the unnormalized ratio over a declared domain.

(Cal-3) Physical-unit bridge (deferred). Mapping to physical units requires additional assumptions and is deferred.

4.2 Two normalized proxy families

$$\Lambda_{\text{eff}}^{(A)}(\rho) = c_\Lambda \, \frac{S(\sigma_F(\rho)) - S(\rho_{\text{vis}})}{V_{\text{eff}}(\rho)}, \qquad \Lambda_{\text{eff}}^{(B)}(\rho) = c_\Lambda \, \frac{D(\rho \| \sigma_F(\rho))}{V_{\text{eff}}(\rho)}.$$

4.3 Usability criteria

A normalized Λ_{eff} is usable only if it passes bootstrap stability, protocol-sensitivity bounds, stable-chart gating, and declared volume-robustness checks.

5 Minimal phenomenology layer (conservative tests)

5.1 DE-like tests (vacuum drift)

A DE-like domain is characterized by stable background-like behavior of Λ_{eff} across stable charts, smooth variation over the parameter plane, and weak coupling to localized clustering proxies (when defined).

5.2 DM-like tests (hidden backreaction)

Define a residual R_{br} capturing geometry drift not explained by visible-only vacuum drift, at minimum

$$R_{\text{br}} := \Delta d_{\text{eff}} - \beta_1 \Delta \Lambda_{\text{eff}} - \beta_0,$$

or (when available) a full response subtraction. A DM-like domain exhibits statistically significant R_{br} correlated with hidden indicators (e.g. $I(\text{vis} : \text{hid})$) after conditioning on Λ_{eff}.

5.3 Diagnostic separation plane

The plane $(\Lambda_{\text{eff}}, R_{\text{br}})$ supports a conservative three-way classification: DE-like (stable Λ_{eff} and small residual), DM-like (significant residual correlated with hidden indicators), and mixed/ambiguous (both large or unstable charts).

6 Theorem blocks (2) and corollaries

Theorem 1 (Normalization invariance under stable protocol class)**.** *Fix an access context F and a stable-chart domain $\mathcal{D}$ where the reference construction $\sigma_F(\rho)$ is reproducible under allowed protocol perturbations, and the chosen V_{eff} satisfies stability and chart-robustness requirements. Define $\Lambda_{\text{eff}}^{(A)}$ or $\Lambda_{\text{eff}}^{(B)}$ with c_Λ fixed by a declared calibration convention. Then on $\mathcal{D}$ the normalized Λ_{eff} is stable under protocol perturbations up to a bounded error, and has bounded bootstrap variance.*

Proof sketch. On stable-chart domains, MaxEnt/I-projection and entropic functionals are continuous under small perturbations; stability of V_{eff} controls the ratio. Calibration fixes a global scale and does not introduce pointwise instability.

Theorem 2 (Identifiability of hidden backreaction beyond vacuum drift)**.** *Assume a stable-geometry domain where d_{eff} and stability scores are well-posed. Let Λ_{eff} satisfy the normalization stability conditions above, and let H be a hidden indicator (e.g. $I(\text{vis} : \text{hid})$). If a residual R_{br} exhibits significant variation beyond bootstrap noise and correlates with H after conditioning on Λ_{eff}, then DM-like backreaction is identifiable as an operational class distinct from DE-like vacuum drift on the domain.*

Proof sketch. Residualization removes the best visible-only vacuum-drift contribution. Correlation of the remaining drift with hidden indicators implies access-invisible influence not reducible to Λ_{eff}.

7 Protocol and validation suite

7.1 Artifact pack (mandatory)

Each run must produce raw tables (per grid point and seed), aggregated bootstrap tables, a manifest (domain statement, protocol knobs, V_{eff} family, calibration convention, thresholds), and a minimal figure set.

7.2 Validation suite

Normalization validation: bootstrap stability, protocol-sensitivity bounds, stable-chart gating, and volume-robustness checks under declared alternative V_{eff} choices. Diagnostic separation validation: compute R_{br}, test significance vs bootstrap, test correlation with hidden indicators and conditioning on Λ_{eff}. Stress-domain reporting is mandatory.

7.3 Acceptance criteria table (skeleton)

7.4 Minimal figure set

(1) Λ_{eff} map with stability mask; (2) robustness comparison under multiple V_{eff} choices; (3) R_{br} vs hidden indicator with bootstrap CIs; (4) diagnostic plane $(\Lambda_{\text{eff}}, R_{\text{br}})$ colored by stability.

8 Limitations and failure domains

No physical-unit cosmology is claimed here; c_Λ is a calibration convention. Protocol dependence defines comparability classes. Defect/critical zones can invalidate stable-chart assumptions; geometry protocol sensitivity must be demonstrated. The reference anchor is finite-size; results are framework validation, not cosmological data fitting. DM/DE labels are operational and may mix; ambiguous domains must be reported.

9 Conclusion

Scientific value

CΛ2 upgrades UMD cosmology proxies into a normalization and minimal phenomenology framework. It defines admissible V_{eff} families, calibration conventions, and stability requirements that make Λ_{eff} comparable across runs within declared comparability classes, and it formalizes an identifiability criterion for DM-like hidden backreaction distinct from DE-like vacuum drift.

Degree of development (depth)

We provide concrete V_{eff} families and consistency requirements, explicit calibration conventions, two theorem-level blocks, and a complete reproducibility-first validation suite with acceptance criteria, minimal figures, and failure-domain reporting.

Applied value and future directions

The framework enables systematic cross-run comparison of vacuum proxies and principled separation of DE-like vs DM-like signatures in controlled modular flows. Next steps include extension to larger sizes and additional channels, adaptive refinement near defect zones, and cautious observational bridging once physical-unit mapping assumptions are specified.

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Category	Acceptance criteria (protocol-declared thresholds)
Normalization validity	Bootstrap stability; protocol sensitivity bound; chart gating; volume robustness
DE-like classification	Stable/smooth Λ_{eff}; weak clustering coupling; patch portability
DM-like classification	Significant R_{br}; correlation with hidden H; non-reducibility to DE drift
Out-of-domain triggers	Chart/geometry instability; stress-domain collapse; non-identifiable residuals

Table 1: Acceptance criteria skeleton for normalization and DM/DE separation.