Paper

Abstract

The Cosmological Explanation Diagnostic Audit (CEDA) is presented as a diagnostic and auditing framework for early-universe cosmology. Rather than proposing a new dynamical mechanism for cosmic expansion or attempting to replace inflationary cosmology, CEDA provides a conservation-honest language and a structured set of tests for distinguishing genuine physical dynamics from effective bookkeeping in models of the early universe. The framework focuses on how causal structure, state accessibility, and coarse-grained stability determine which degrees of freedom contribute to an interior effective description and how changes in that description are often misinterpreted as dynamical effects.

CEDA emerged from an investigation into whether horizon-mediated reconfiguration of dynamically accessible quantum states could, by itself, generate inflation-like accelerated expansion. A sequence of internal stress tests, culminating in a strictly constrained diagnostic (WF1.2), demonstrates that under conservative assumptions—where exchange terms are derived explicitly from system–environment partition evolution and all degrees of freedom obey their underlying dilution laws—horizon-driven accessibility changes do not generically produce vacuum-like equations of state or accelerated expansion. This null result motivates a decisive reframing of the framework's role.

In its diagnostic formulation, CEDA formalizes the concepts of causal horizons, state accessibility, constraint-layer stability, and horizon reconfiguration events as bookkeeping operations rather than sources of physical agency. It introduces a structured stress-test suite and a catalogue of diagnostic failure modes designed to expose hidden assumptions, privileged coarse-graining choices, and inflation-mimicking constructions that rely on descriptive reweighting rather than new dynamics. The framework clarifies why successful inflationary models require genuine additional structure, while also identifying where alternative proposals collapse into reinterpretation without explanatory gain.

CEDA does not challenge the empirical adequacy of inflation or ΛCDM. Its contribution is methodological: it sharpens the boundary between dynamics and description in early-universe modeling and provides a general-purpose audit tool for evaluating the conceptual integrity of proposed mechanisms under changing causal structure.

1. Introduction and Framework Motivation

Modern cosmology rests on a remarkably successful empirical foundation. General Relativity, quantum field theory, and the ΛCDM model together account for an extensive range of observations, from the cosmic microwave background to large-scale structure and primordial nucleosynthesis. Inflationary cosmology, in particular, provides an effective mechanism that explains large-scale homogeneity and isotropy, near-flat spatial geometry, and the origin of primordial perturbations. These successes establish inflation as a central component of the standard cosmological model, irrespective of ongoing debates about its microphysical realization.

At the same time, the early universe remains a domain where explanatory language often outruns conceptual precision. Inflationary scenarios are frequently discussed using a mixture of dynamical claims, effective descriptions, and bookkeeping conventions that are not always sharply distinguished. Concepts such as entropy, horizon size, causal contact, and vacuum energy are routinely invoked as if they were interchangeable sources of physical agency. This does not undermine the empirical adequacy of inflation, but it does obscure which features of early-universe modeling arise from genuine new dynamics and which arise from how effective descriptions are constructed under changing causal structure.

The Cosmological Explanation Diagnostic Audit (CEDA) originated as an attempt to explore whether some phenomena commonly attributed to inflation—particularly rapid early expansion and low initial entropy—could be reinterpreted as consequences of horizon-mediated changes in which quantum degrees of freedom are dynamically accessible. Early formulations asked whether horizon reconfiguration alone, treated strictly as a change in causal bookkeeping rather than a source of energy or force, might generically yield inflation-like behavior without introducing new fields or modifying known dynamics.

That question has now been decisively answered in the negative. A sequence of internal stress tests, culminating in the WF1.2 diagnostic, demonstrated that under conservative, conservation-respecting assumptions, horizon-driven accessibility reconfiguration does not generically produce vacuum-like equations of state or accelerated expansion. When exchange terms are derived explicitly from system–environment partition evolution and all constituent degrees of freedom dilute according to their underlying dynamics, the resulting behavior remains radiation-like. Inflation-like expansion appears only when additional structure is introduced, either explicitly or implicitly, at which point the construction collapses into inflation in disguise.

Rather than constituting a failure of the framework, this null result clarifies its proper role. The Horizon-Enabled Expansion Framework is not best understood as a candidate mechanism for early-universe expansion. Its value lies instead in its ability to expose where apparent mechanisms rely on descriptive reweighting, privileged coarse-graining, or hidden dynamical assumptions. This transition—from mechanism-seeking to diagnostic discipline—is not a retreat but an expression of epistemic integrity. A framework that survives only by ignoring its own null results is not scientifically useful; one that sharpens its scope in response to them is.

Accordingly, this paper presents **CEDA**, a reformulated Horizon-Enabled Expansion Framework explicitly positioned as a **diagnostic and auditing framework** for early-universe cosmology. Its purpose is not to replace inflation or ΛCDM, but to provide a conservation-honest language and a structured set of tests for distinguishing genuine dynamical content from effective bookkeeping. In this role, CEDA serves as a methodological tool for clarifying what early-universe models actually assume, what they genuinely explain, and where their explanatory power truly originates.

2. Conceptual Foundations

CEDA operates entirely at the level of effective description. It introduces no new particles, fields, symmetries, or equations of motion, and it assumes the validity of General Relativity and standard quantum mechanics within their established domains. The framework's purpose is not to modify dynamics, but to enforce precision about how effective descriptions are constructed under causal constraints and how changes in those constraints affect physical interpretation.

2.1 Horizons as Causal Constraints

Within CEDA, a horizon is defined operationally as a **causal boundary** that limits interaction, correlation, and dynamical participation. Horizons are not physical objects, sources of energy, or agents of evolution. They do not exert forces, inject stress–energy, or generate dynamics. Their role is purely structural: they delimit which degrees of freedom can participate in a given region's interior effective description.

Degrees of freedom beyond a causal horizon may exist in a global description, and they may remain entangled with interior degrees of freedom, but they are dynamically inaccessible. As a result, they cannot contribute directly to the interior region's effective stress–energy tensor except through boundary bookkeeping such as tracing-out procedures, renormalized parameters, or entropy accounting. Treating horizons as regulators of participation rather than as drivers of evolution is a foundational constraint of the framework.

2.2 State Accessibility

State accessibility refers to the subset of degrees of freedom that are dynamically permitted to participate in the evolution of a causal region. Accessibility is not a statement about what states exist in principle, nor about what states are known or observable. It is a physical restriction imposed by causal structure, geometry, energy conditions, and quantum dynamics.

Crucially, accessibility must be distinguished from thermalization and from entropy production. Thermalization redistributes energy among degrees of freedom that are already accessible. Accessibility reconfiguration changes which degrees of freedom belong to the interior effective description at all. Conflating these processes leads to spurious inferences, such as attributing geometric expansion to local entropy production or treating bookkeeping changes as sources of negative pressure. CEDA enforces this distinction strictly.

2.3 Constraint Layers and Effective Description

CEDA treats effective physical descriptions as constrained by multiple, simultaneously operating limitation regimes—referred to here as **constraint layers**. These include spacetime geometry, causality, conservation laws, quantum structure, and horizon-defined accessibility. Constraint layers are not physical strata or separate sectors; they are conceptual delimiters that jointly determine which effective descriptions are admissible.

In ordinary regimes, these constraints align in such a way that a stable semiclassical description exists. Small changes in how inaccessible degrees of freedom are traced out or how coarse-graining is implemented lead only to small changes in physically relevant observables. This robustness is what allows semiclassical gravity and effective field theory to function.

2.4 Constraint-Layer Stability

An **interior effective description** is said to be stable when its physically relevant observables—such as the renormalized stress–energy tensor, effective equation of state, and resulting geometric evolution—remain approximately invariant under legitimate variations in how the description is constructed. These variations include small shifts in horizon definition, changes in coarse-graining scale, and reassignment of degrees of freedom near the system–environment boundary.

Loss of stability occurs when infinitesimal variations in these choices produce order-unity changes in physical observables. When this happens, the problem is not a breakdown of General Relativity or quantum mechanics. The problem is that no single coarse-grained interior description can simultaneously satisfy the relevant constraint layers. The effective description itself ceases to be well-defined.

This notion of **constraint-layer stability** unifies the framework's treatment of horizons, accessibility, and coarse-graining. It provides a precise criterion for diagnosing when a given effective description is physically meaningful and when it is not. Subsequent sections build on this concept to define horizon reconfiguration events, diagnostic stress tests, and failure modes in a way that is theory-neutral and conservation-honest.

3. Diagnostic Architecture

The core contribution of CEDA is not a reinterpretation of early-universe dynamics, but a diagnostic architecture for determining when apparent physical effects arise from genuine dynamics and when they arise from descriptive bookkeeping under changing causal structure. This section presents the operational components of that architecture: horizon reconfiguration events as bookkeeping operations, a structured stress-test suite, and a catalogue of diagnostic failure modes. Together, these elements define how the framework is applied in practice.

3.1 Horizon Reconfiguration Events as Bookkeeping Operations

Within CEDA, a Horizon Reconfiguration Event (CDT) is defined as a transition in which an existing interior effective description loses stability under causal coarse-graining and must be replaced by a new description defined by a re-partitioned causal boundary. Crucially, CDTs are not dynamical mechanisms. They do not inject energy, generate forces, or alter the underlying equations of motion. Their role is strictly descriptive: they mark the point at which a previously admissible bookkeeping scheme ceases to yield a self-consistent interior description.

A CDT is permitted when physically relevant observables—most importantly the renormalized stress–energy tensor used to source spacetime evolution—become order-unity sensitive to infinitesimal variations in how the system–environment partition is defined. When no coarse-grained description remains robust under legitimate variations, the effective description itself fails. The redefinition of the causal boundary restores descriptive stability by establishing a new partition in which an interior effective description can again be constructed.

This framing removes any temptation to treat horizon reconfiguration as a physical agent. Geometry responds only to the reorganized effective stress–energy through the standard Einstein and Friedmann equations. Any appearance of accelerated expansion or vacuum-like behavior must therefore be traced to the content of the effective stress–energy after re-partitioning, not to the reconfiguration event itself.

3.2 Accessibility Accounting and Conservation Discipline

CEDA enforces a strict accounting discipline for how state accessibility enters an interior effective description. Accessibility parameters encode which degrees of freedom participate in the description; they do not represent forces, pressures, or dynamical drivers. When the system–environment partition evolves, exchange terms may appear in the effective continuity equations, but these terms must arise solely from bookkeeping associated with partition evolution.

A central diagnostic principle follows directly:
if all constituent degrees of freedom obey radiation-like dilution, no re-partitioning of those degrees of freedom can generically produce vacuum-like behavior without additional structure.

This principle was established explicitly by the WF1.2 diagnostic, which demonstrated that when exchange terms are derived honestly from partition evolution and no privileged coarse-graining is imposed, horizon-crossing of radiation-like modes yields radiation-like effective behavior. Any construction that produces sustained negative pressure under such conditions must therefore be introducing new dynamical content, whether acknowledged or not.

This accounting discipline provides a clear criterion for identifying inflation-mimicking behavior. If negative pressure appears only after accessibility parameters are tuned, smoothed, or stabilized by hand, the construction fails as a mechanism and collapses into descriptive reweighting.

3.3 The Stress-Test Suite

The diagnostic architecture of CEDA is formalized through a structured stress-test suite designed to expose hidden assumptions and category errors. These tests are not intended to establish observational agreement; their purpose is to determine whether a proposed model remains conceptually and structurally coherent under conservative scrutiny.

The stress tests are organized into tCDTe progressive layers.

Conceptual Integrity Tests probe foundational assumptions. These tests enforce strict separation between entropy and geometry, prohibit horizon agency, and require explicit conservation of energy–momentum. Any proposal that treats entropy production as a driver of expansion, or horizons as sources of physical influence, fails at this level.

Structural Stability Tests examine the robustness of effective descriptions. These tests vary coarse-graining scales, horizon definitions, and partition assignments to determine whether physically relevant observables remain stable. Order-unity sensitivity under such variations signals descriptive failure and triggers reclassification of the proposal as bookkeeping-dependent.

Mechanism Audit Tests target inflation mimicry directly. These tests ask where negative pressure enters, whether it survives removal of privileged parameters, and whether it persists under honest exchange-term derivation. Models that reproduce inflationary behavior only by encoding slow-roll–like control variables in accessibility parameters are flagged as inflation in disguise.

Together, these tests define the operational meaning of “diagnostic” within CEDA. A proposal need not fail observationally to fail diagnostically; conceptual incoherence alone is sufficient.

3.4 Diagnostic Failure Catalogue

Recurring failure modes identified by the stress-test suite are organized into a diagnostic failure catalogue. Each failure mode corresponds to a specific violation of the framework’s principles and is associated with characteristic observable signatures.

Examples include treating entropy as a causal driver, attributing agency to horizons, conflating bookkeeping choices with dynamics, and relying on privileged coarse-graining to stabilize effective equations of state. These failures do not imply that a model is numerically incorrect; they indicate that its explanatory claims exceed what its structure supports.

For clarity and reuse, the failure catalogue is presented as a typological appendix rather than embedded in the main text. Its function is to provide reviewers and model-builders with a shared reference for identifying and naming conceptual pathologies without resorting to informal critique.

3.5 Summary of the Diagnostic Role

The diagnostic architecture of CEDA establishes a clear division of labor. Horizon reconfiguration events mark transitions in descriptive validity, accessibility accounting enforces conservation-honest bookkeeping, and the stress-test suite distinguishes genuine dynamics from reinterpretation. The framework does not compete with inflationary cosmology or other early-universe mechanisms. It determines, in a theory-neutral way, when such mechanisms are truly present.

In this sense, CEDA functions as an audit instrument rather than a generative model. Its success is measured not by producing expansion, but by clarifying when expansion has been earned.

3.6 Diagnostic Application Protocol

This section specifies the operational procedure for applying the Horizon-Enabled Expansion Framework (CEDA) to a proposed early-universe model. The protocol is diagnostic rather than evaluative: it does not assess observational viability or empirical fit, but determines whether claimed physical effects arise from genuine dynamical structure or from descriptive bookkeeping under a particular effective description. The protocol is designed to be theory-neutral and conservation-honest, and it can be applied to inflationary, non-inflationary, or alternative cosmological proposals.

Run Validity Gate (Mandatory)

A diagnostic run is considered **valid** under CEDA *only if all of the following conditions are satisfied*:

1. **Completed Model Card**
   Sections A–J of the Model Card must be completed explicitly.
   Any missing, ambiguous, or deferred entry results in an automatic **Underspecified** classification.
   No diagnostic test may override or compensate for an incomplete Model Card.

2. **Forbidden Moves Enforcement**
   If the analysis employs any Forbidden Move (F-01 through F-08), the run is immediately classified as **Reinterpretation**, regardless of performance on other tests.
   Forbidden Moves are category errors, not fixable deficiencies.

3. **Diagnostic Report Required**
   Each run must produce a Diagnostic Report documenting:

   - which tests were executed (D1–D4),
   - pass/fail outcomes,
   - evidence cited,

    - and the final diagnostic verdict.

4. **Null Results Are Binding**
   A confirmed null result (e.g., D1) constrains all downstream interpretation.
   No reinterpretation, parameter adjustment, or descriptive reframing is permitted to evade a null result within the same run.

Any run failing this gate is **invalid** and may not be cited as evidence for or against a proposed mechanism.

Step 1: Translation into Accessibility and Coarse-Graining Language

The first step is to translate the proposed model into CEDA's descriptive primitives.

All degrees of freedom relevant to the proposal must be classified according to:

- which degrees of freedom are treated as dynamically participating in the interior effective description, and
- which degrees of freedom are traced out, averaged over, or otherwise excluded due to causal structure, scale separation, or modeling assumptions.

This step requires explicit identification of:

- the assumed causal domain,
- the horizon or boundary defining the system–environment partition,
- the coarse-graining scale(s) at which the effective description is constructed.

No physical claims are evaluated at this stage. The goal is to make explicit what the model counts as accessible, what it treats as inaccessible, and where descriptive choices enter. Proposals that cannot be expressed in these terms are not rejected, but are flagged as insufficiently specified for diagnostic analysis.

Step 2: Identification of System–Environment Partitions and Exchange Terms

Next, the system–environment partition implicit in the model is made explicit.

For each sector contributing to the effective stress–energy tensor, the analysis must identify:

- whether the sector is treated as closed or open within the effective description,
- whether energy–momentum exchange terms are present, and
- how such exchange terms arise.

Crucially, any exchange term must be traceable to evolution of the system–environment partition (e.g., changing accessibility, horizon growth, or coarse-graining reassignment). Exchange terms introduced as closure assumptions, effective pressures, or phenomenological sources without explicit derivation from partition evolution are flagged for further scrutiny.

This step establishes whether the model's effective dynamics are genuinely dynamical or partially encoded through partition-dependent bookkeeping.

Step 3: Explicit Enforcement of Conservation Accounting

The third step enforces conservation discipline.

All energy–momentum accounting must be written in a form that makes global conservation manifest. In particular:

- continuity equations for each sector must be specified,
- exchange terms must appear with equal and opposite contributions across the system–environment boundary,
- no term may appear that represents net creation or destruction of energy–momentum.

If a model produces effective negative pressure, accelerated expansion, or vacuum-like behavior, this step determines whether such behavior arises from:

- the intrinsic dynamics of accessible degrees of freedom, or
- reclassification of degrees of freedom across the partition.

Any proposal that requires implicit violation of conservation laws, horizon-mediated energy injection, or undefined global accounting fails the diagnostic at this stage.

Step 4: Application of the Stress-Test Suite

With the bookkeeping structure explicit, the proposal is subjected to the CEDA stress-test suite.

At minimum, the following classes of tests are applied:

1. **Conceptual Integrity Tests**
   These test for prohibited category errors, including:
   - entropy treated as a causal driver,
   - horizons treated as physical agents,
   - conflation of thermalization with accessibility reconfiguration.
2. **Structural Stability Tests**
   These test robustness of the effective description under:
   - small variations in horizon definition,
   - changes in coarse-graining scale,
   - reassignment of near-boundary degrees of freedom.
     Order-unity sensitivity of observables indicates descriptive instability.
3. **Mechanism Audit Tests**
   These identify whether inflation-like behavior depends on:
   - privileged parameters,
   - tuned accessibility functions,
   - implicit slow-roll–like control variables.
     Removal of such structure is used to test whether the claimed mechanism survives.

Failure of a stress test does not imply the model is observationally wrong; it implies that its explanatory claims exceed what its structure supports.

Step 5: Identification of Bookkeeping-Dependent Behavior

The fifth step isolates which aspects of the model's behavior depend on descriptive choices rather than dynamics.

Specifically, the analysis asks:

- Does the claimed effect persist under alternative admissible coarse-grainings?
- Does it survive honest derivation of exchange terms?
- Does it disappear when accessibility parameters are no longer privileged?

If a claimed phenomenon (e.g., vacuum-like equation of state, accelerated expansion) vanishes under these checks, it is classified as bookkeeping-dependent. Such behavior may still be a valid effective description, but it does not constitute a new physical mechanism.

Step 6: Diagnostic Verdict

Finally, the proposal is assigned a diagnostic classification based on the preceding analysis:

- **Mechanism**
  The model introduces genuine new dynamical structure that survives conservation enforcement, coarse-graining variation, and stress testing. Inflationary models with explicit fields and potentials typically fall into this category.
- **Reinterpretation**
  The model reproduces known behavior primarily through descriptive reweighting, partition choices, or language substitution without adding new dynamics.
- **Ambiguous**
  The analysis cannot conclusively distinguish between dynamics and bookkeeping due to incomplete specification or unresolved dependencies. Further formalization is required.

This verdict is not a judgment of empirical success. It is a statement about explanatory structure. A model may be empirically viable yet diagnostically classified as reinterpretive; conversely, a genuine mechanism may still fail observational tests.

Scope and Use

The Diagnostic Application Protocol is intended as a reusable method. It may be applied by authors, referees, or reviewers to clarify what a model actually assumes, what it explains dynamically, and where its explanatory power originates. The protocol does not privilege any particular cosmological scenario and does not presuppose the correctness or incorrectness of inflation, ΛCDM, or alternative frameworks.

Notes

Cosmological Explanation Diagnostic Audit (CEDA)

A Diagnostic Framework for Early-Universe Cosmology

Status: For External Review

(Conceptual framework; not a theory; not a replacement for inflation or ΛCDM)

Abstract

The Cosmological Explanation Diagnostic Audit (CEDA) is a diagnostic and constraint-based framework for analyzing early-universe cosmological models through the lens of causal structure, state accessibility, and coarse-grained stability. Unlike earlier formulations, CEDA makes no claim that horizon-mediated accessibility reconfiguration generically produces inflationary expansion. Instead, motivated by decisive conservation-honest null results obtained under strict exchange-term and coarse-graining control, the framework is reformulated as a rigorous auditing tool designed to identify where apparent inflation-like behavior arises from genuine dynamics versus descriptive bookkeeping. CEDA enforces strict separation between causal boundaries and dynamical agency, preserves standard conservation laws, and provides a structured taxonomy of failure modes applicable to inflationary and non-inflationary early-universe proposals alike.

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1. Introduction

- Empirical success of ΛCDM and inflation acknowledged
- Persistent conceptual ambiguity in early-universe modeling:
    - dynamics vs effective description
    - causal structure vs entropy language
- Motivation for a diagnostic framework rather than a competing mechanism
- Summary of why earlier “horizon-driven inflation” interpretations fail under conservative assumptions

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2. Framework Status and Scope

CEDA does not rank models by plausibility, elegance, or empirical fit. A model may pass all CEDA audits and still fail observational tests, or fail CEDA while remaining empirically adequate. The framework evaluates explanatory structure only.

- CEDA is a **framework**, not:
  - a fundamental theory
  - a phenomenological model
  - a mechanism for inflation
- Operates strictly at the level of **effective descriptions**
- Assumes:
  - General Relativity
  - Quantum Field Theory
  - Standard conservation laws
- Intended use:
  - stress-testing early-universe models
  - clarifying hidden assumptions
  - diagnosing descriptive vs dynamical inputs

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3. Core Conceptual Primitives

Horizons are treated as a specific and common instance of causal boundaries in cosmology.

3.1 Horizons

- Defined operationally as causal boundaries
- Regulate interaction, correlation, and participation
- Explicitly non-dynamical and non-agentive

3.2 State Accessibility

- Accessibility ≠ existence
- Accessibility ≠ thermalization
- Accessibility ≠ entropy production
- Determines which degrees of freedom contribute to an interior effective description

3.3 Constraint Layers

- Geometry, causality, conservation, quantum structure, horizons
- Constraints delimit admissible effective descriptions
- Failure occurs at the descriptive level, not the fundamental level

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4. Interior Effective Descriptions and Stability

4.1 Interior Effective Description

- Defined by coarse-graining under a causal boundary
- Necessarily incomplete and partition-dependent

4.2 Stability Criterion

An interior effective description is stable if physically relevant observables remain invariant up to perturbative corrections under:

- small variations in horizon definition
- changes in coarse-graining scale
- reassignment of traced-out degrees of freedom

4.3 Breakdown of Stability

- Order-unity sensitivity signals descriptive failure
- Does not imply breakdown of GR or quantum mechanics

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5. Causal Description Transitions (CDTs)

5.1 Definition

An CDT is a forced redefinition of causal bookkeeping when no stable interior effective description exists.

5.2 Physical Meaning

- Repartitioning of system/environment
- Reorganization of effective stress–energy sourcing
- No creation or destruction of energy or states

5.3 Explicit Non-Claims

- CDTs do not generically imply:
    - inflation

    - vacuum-like equations of state
    - accelerated expansion

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6. Trigger Taxonomy (Diagnostic, Not Causal)

- **Class I:** Global descriptive inconsistency
- **Class II:** Constraint misalignment across coupled domains
- **Class III:** Accessibility saturation (candidate; reducibility required)
- **Class IV:** Horizon bookkeeping ambiguity (edge case)

Each trigger class is:

- horizon-scale
- conservation-respecting
- explicitly falsifiable

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7. Coarse-Graining as a Physical Constraint

7.1 Coarse-Graining Is Mandatory

- Not optional
- Not epistemic
- Enforced by causal structure

7.2 Coarse-Graining Failure

- Occurs when no admissible partition yields stable observables

- Necessitates horizon redefinition

7.3 Diagnostic Question

Does a proposed model rely on a privileged coarse-graining to function?

If yes, the model fails as a mechanism and reduces to interpretation.

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8. Accessibility Accounting and Bookkeeping Discipline

- Accessibility parameters encode participation, not dynamics
- Exchange terms reflect partition evolution
- Strict prohibition on:
    - entropy as a driver
    - horizon agency
    - hidden slow-roll variables

WF1.2 result established as canonical:

> Horizon-crossing of radiation-like degrees of freedom remains radiation-like under honest bookkeeping.

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9. Stress-Test Suite (Primary Deliverable)

9.1 Conceptual Tests

- Local entropy vs geometric response
- Conservation integrity
- Horizon vs thermal effects

- Area vs volume entropy

9.2 Structural Tests

- Coarse-graining sensitivity tests
- Exchange-term provenance tests
- Inflation-in-disguise detection

9.3 Inflation Audit

- Identifies precisely where negative pressure enters
- Distinguishes genuine dynamics from descriptive reweighting

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10. Failure Registry

Formal catalog of recurring failure modes:

- Entropy-as-driver
- Horizon agency
- Dynamics/bookkeeping conflation
- Tuned accessibility parameters
- Descriptive collapse misidentified as physics

Each failure linked to:

- violated principle
- observable signature
- failed diagnostic test

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11. Relationship to Standard Inflation

- Inflation survives many CEDA tests because it introduces real new structure
- CEDA clarifies:
    - what inflation genuinely explains
    - what is merely rephrased
- Framework sharpens theory boundaries without replacement claims

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12. Open Questions (Bounded)

- What minimal additional structure is required for vacuum-like behavior?
- Can such structure avoid collapsing into inflation in disguise?
- Are there observable regimes sensitive to coarse-graining failure?

No speculative answers admitted without diagnostic survival.

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13. Conclusion

CEDA reframes early-universe inquiry around a single diagnostic demand:

Where does cosmology require genuine dynamics, and where is it only bookkeeping?

The framework's value lies not in producing expansion, but in cleanly exposing where expansion claims originate—and where they fail.

Tests

let

Diagnostic Test D2

Diagnostic Test D2

Coarse-Graining Stability of Effective Dynamics

Purpose

Diagnostic Test D2 evaluates whether a proposed early-universe mechanism exhibits **coarse-graining stability**—that is, whether its physically relevant predictions remain invariant under **admissible variations** in coarse-graining scale, horizon definition, and system–environment partitioning.

Within **CEDA**, this test distinguishes **genuine dynamical physics** from **bookkeeping artifacts**. A mechanism that only functions under a specific descriptive scheme does not represent robust dynamics.

Setup

The test is applied to a model already expressed in **accessibility and partition language** (per the *Diagnostic Application Protocol*).

At a specified coarse-graining scale, an **interior effective description** is constructed, yielding:

- an **effective stress–energy tensor**,
- an **effective equation of state** w(a)w(a)w(a),
- and a corresponding **geometric evolution**.

The model is then re-evaluated under small but **admissible variations** in:

- **Coarse-graining scale**,
- **Horizon placement**,
- **Partition assignment** of near-boundary degrees of freedom.

Throughout this process:

- No new degrees of freedom or dynamical terms may be introduced.
- The **underlying microphysics remains fixed**.

Definition: Admissible Small Variations

For the purposes of Diagnostic Tests D2 and D3, an admissible variation is defined as a change that:

- preserves the validity regime of the effective description,
- introduces no new degrees of freedom or equations of motion,
- and requires no post-variation parameter retuning.

Operationally, admissible variations include:

Horizon Definition Variation

- Replace one physically equivalent horizon definition with another
  (e.g., apparent ↔ Hubble; particle ↔ event where applicable), or
- Apply a fractional shift in horizon placement
  with $\delta R / R \lesssim 1\%$.

Coarse-Graining Scale Variation

- Vary the coarse-graining or renormalization scale μ by
  $\mu \to \mu(1 \pm \delta)$ with $\delta \lesssim 0.1$,
  provided the EFT or effective description remains valid.

Partition Assignment Variation

- Reassign degrees of freedom within a narrow band near the system–environment boundary,
  without altering microphysics or interaction structure.

These variations are mandatory stressors, not optional modeling choices.

Failure Criterion (clarified)
If any of the following occur under admissible variation, the model fails D2/D3:

- order-unity change in the sign or magnitude of w+1w + 1w+1,
- loss of acceleration or vacuum-like behavior,
- emergence of dominant or ill-defined exchange terms,
- restoration of behavior only via parameter retuning or auxiliary smoothing.

Interpretive note
These tCDTsholds are not claims about nature. They are bookkeeping tolerances chosen to distinguish robust dynamics from descriptively fragile constructions.

Constraints

All variations must satisfy the following:

1. Variations stay within the **validity regime** of the effective description.
2. **No parameter re-tuning** is allowed after variation.
3. No auxiliary **smoothing, averaging, or stabilization procedures** may be added.
4. **Conservation laws** must hold explicitly under all partitions.
5. **Exchange terms** must arise solely from partition evolution.

These constraints ensure the test probes **descriptive robustness**, not **model flexibility**.

Null Hypothesis (H_0)

H_0: The physically relevant observables—particularly the effective equation of state and acceleration behavior—remain invariant under admissible variations in coarse-graining and system–environment partitioning.

Under H_0, any genuine dynamical mechanism should retain its qualitative behavior when the effective description is reformulated in an equivalent physical representation.

Pass / Fail Criteria

Pass (Null Confirmed)

The test **passes** if:

- The qualitative form of w(a)w(a)w(a) is **preserved** under coarse-graining variation.
- Any inflationary or acceleration regime **persists** without parameter retuning.
- Observable quantities change only **perturbatively**, not at order unity.
- No new **instability or divergence** arises solely from repartitioning.

Such behavior demonstrates **coarse-graining stability**, a hallmark of genuine physical dynamics.

Fail (Null Rejected)

The test **fails** if any of the following occur:

- Inflationary or vacuum-like behavior **disappears** under admissible repartitioning.
- The sign or magnitude of w+1w + 1w+1 changes at **order unity**.
- Acceleration **depends** on a specific horizon placement or averaging scheme.
- Exchange terms become **dominant or ill-defined** under minor descriptive shifts.

Failure indicates that the apparent dynamics depend on a **privileged bookkeeping choice** rather than genuine physics.

Outcome Classification

Classification	Diagnostic Meaning
Stable Mechanism	Passes D2 — Dynamics survive coarse-graining variation.
Descriptively Tuned	Fails D2 — Apparent behavior depends on a special effective description.
Underspecified	Cannot be evaluated due to incomplete accounting or ambiguous partitions.

Diagnostic Interpretation

Coarse-graining is not a matter of convenience or observer choice—it is **dictated by causal structure and scale separation**.
A physical mechanism must therefore remain **invariant under reasonable descriptive reformulation**.

Diagnostic Test D2 identifies models whose apparent success depends on:

- a particular **slicing of degrees of freedom**,
- a **fixed or frozen partition choice**, or
- an **implicit stabilization** of exchange terms.

Such dependence signals **interpretive fragility**, not physical explanation.

Role Within CEDA

Diagnostic Test D2 builds directly on **Test D1**:

- **D1** establishes that **horizon reconfiguration does not create dynamics**.
- **D2** establishes whether **claimed dynamics remain stable** once bookkeeping is enforced honestly.

Together, they delineate the diagnostic boundary between:

- **Genuine mechanisms**,
- **Descriptive reinterpretations**, and
- **Structurally unstable proposals**.

Status

Test D2: Defined.
Application: Pending worked examples and empirical instantiations within the CEDA framework.

Diagnostic Test D2 to Starobinsky Inflation

4.2 Worked Diagnostic Example

Application of Diagnostic Test D2 to Starobinsky Inflation

This section applies **Diagnostic Test D2 (Coarse-Graining Stability)** to Starobinsky inflation. The purpose is to determine whether the model's inflationary behavior depends on a privileged effective description or whether it remains robust under admissible variations in coarse-graining and system–environment partitioning.

The analysis is explicitly diagnostic. No attempt is made to reassess observational viability or parameter fitting.

Step 1: Baseline Effective Description

In Starobinsky inflation, the effective description consists of:

- spacetime geometry governed by General Relativity,
- a single scalar degree of freedom (the scalaron),
- a potential that dynamically controls the equation of state.

At the baseline coarse-graining scale, the scalaron stress–energy dominates, yielding an effective equation of state close to
w≈−1w \approx -1w≈−1
and sustained accelerated expansion.

This baseline description is already known to pass Diagnostic Test D1 by introducing genuine dynamical structure.

Step 2: Admissible Coarse-Graining Variations

The model is then re-expressed under admissible variations that preserve physical equivalence, including:

- modest changes in coarse-graining scale,
- alternative but equivalent horizon placements,

- reassignment of near-boundary modes between system and environment,
- reformulation between Jordan-frame and Einstein-frame descriptions.

No new degrees of freedom are introduced, no parameters are retuned, and no auxiliary stabilization procedures are applied.

Step 3: Conservation and Exchange Accounting

Under all admissible variations:

- the scalaron remains dynamically accessible,
- no system–environment exchange terms become dominant,
- global energy–momentum conservation remains explicit,
- the scalar field's equation of motion is unchanged.

Crucially, negative pressure continues to arise from the scalar potential rather than from partition evolution or accessibility reassignment.

Step 4: Stability Assessment

Across all admissible coarse-graining choices, the following hold:

- The qualitative behavior of w(a)w(a)w(a) is preserved.
- The inflationary phase persists without retuning.
- Deviations in observables remain perturbative.
- No order-unity sensitivity to horizon placement or partition choice is observed.

Acceleration does not depend on a special slicing of degrees of freedom or a frozen bookkeeping convention.

Diagnostic Verdict

Verdict: Stable Mechanism

Starobinsky inflation **passes Diagnostic Test D2**.

Its inflationary behavior is invariant under admissible coarse-graining variation because it is sourced by genuine local dynamics rather than descriptive reweighting. The mechanism does not rely on a privileged effective description.

Diagnostic Interpretation

This result illustrates the core purpose of Diagnostic Test D2.

Starobinsky inflation succeeds because:

- the degrees of freedom responsible for acceleration are dynamically present,
- negative pressure arises from intrinsic dynamics,
- coarse-graining changes do not remove or suppress the mechanism.

In contrast, models that source inflation-like behavior through horizon bookkeeping or accessibility tuning typically fail D2, as their behavior depends sensitively on how the effective description is constructed.

Role of This Example

This worked example demonstrates that CEDA:

- does not penalize successful inflationary models,
- correctly identifies robustness where it exists,
- and cleanly separates genuine dynamics from descriptive fragility.

Passing Diagnostic Test D2 confirms that Starobinsky inflation earns its behavior through mechanism-level physics, not through privileged bookkeeping.

Diagnostic Test D1

Diagnostic Test D1

Horizon Reconfiguration Without Additional Dynamical Structure

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Purpose

Diagnostic Test D1 addresses the central question motivating the Cosmological Explanation Diagnostic Audit (CEDA):

Can horizon-mediated reconfiguration of dynamically accessible degrees of freedom—treated purely as a bookkeeping operation and without introducing new fields, modified gravity, or tunable control variables—by itself generate inflation-like accelerated expansion?

Within the diagnostic formulation (CEDA), this test functions as a **baseline null diagnostic**. Its purpose is not to validate a proposed mechanism, but to determine whether horizon reconfiguration alone can act as a sufficient source of vacuum-like behavior under conservative, conservation-respecting assumptions.

Setup

The test is defined on a homogeneous and isotropic cosmological background governed by the standard Friedmann equations of General Relativity.

The matter content consists exclusively of degrees of freedom whose intrinsic dynamics yield radiation-like dilution when dynamically accessible. No fundamental scalar fields, modified kinetic terms, higher-derivative corrections, or altered gravitational couplings are introduced.

The effective description partitions the total degrees of freedom into:

- a **system sector** (dynamically accessible degrees of freedom), and
- an **environment sector** (dynamically inaccessible degrees of freedom),

with the partition defined by a causal horizon. As the horizon evolves, accessibility changes, leading to a time-dependent system–environment partition.

The interior effective stress–energy tensor is constructed by tracing over the environment sector. Any energy–momentum exchange between system and environment arises solely from evolution of this partition. No external sources or phenomenological inputs are invoked.

Constraints

The following constraints are imposed to enforce bookkeeping integrity:

- All exchange terms are derived explicitly from system–environment partition evolution.
- No phenomenological stress–energy term is introduced to enforce a desired equation of state.
- No accessibility parameter functions as a slow-roll analogue or control variable.
- No horizon-mediated energy injection is permitted.
- All constituent degrees of freedom obey their intrinsic dilution laws.
- Global energy–momentum conservation is enforced at all times.

These constraints define the admissible class of descriptions to which the null hypothesis applies.

Null Hypothesis (H_0)

> **H_0:** Horizon-mediated reconfiguration of dynamically accessible degrees of freedom, acting solely through conservation-respecting system–environment partition evolution and without additional dynamical structure, does **not** generically produce a vacuum-like equation of state or sustained accelerated expansion.

Under H_0, any effective stress–energy tensor constructed from radiation-like constituents remains radiation-like,
w≈13w \approx \tfrac{1}{3}w≈31, regardless of how accessibility is repartitioned.

Pass / Fail Criteria

Pass (Null Confirmed)

The null hypothesis is confirmed if all of the following conditions are met:

- The effective equation of state remains radiation-like,
  w≈13w \approx \tfrac{1}{3}w≈31, throughout evolution.

- No sustained regime satisfies the acceleration condition
  ρ+3p<0.\rho + 3p < 0 .ρ+3p<0.
- Any transient deviations from radiation-like behavior arise only from explicitly introduced additional structure or privileged parameter choices, not from horizon reconfiguration itself.

Fail (Null Rejected)

The null hypothesis is rejected if any of the following occur:

- A sustained vacuum-like regime with
  w≈−1w \approx -1w≈−1 emerges without introducing new dynamical degrees of freedom.

- Accelerated expansion persists under honest partition evolution and conservation enforcement.

- Negative pressure arises purely from horizon-driven accessibility reconfiguration.

Outcome

Under the stated assumptions and constraints, the null hypothesis is **confirmed**.

When exchange terms are derived strictly from system–environment partition evolution and all dynamically accessible degrees of freedom dilute according to their intrinsic dynamics, the effective equation of state remains radiation-like. Horizon crossing and accessibility re-partitioning alone do not generate vacuum-like behavior or accelerated expansion.

Inflation-like expansion arises only when additional structure is introduced, either explicitly (e.g., new dynamical fields or modified gravitational dynamics) or implicitly (e.g., tuned accessibility parameters acting as hidden control variables). In such cases, the construction no longer represents horizon reconfiguration alone and collapses into a re-expression of inflationary dynamics.

Diagnostic Interpretation

Horizon reconfiguration is a **bookkeeping operation**, not a dynamical mechanism.
Repartitioning accessibility cannot, by itself, alter the intrinsic equation of state of the contributing degrees of freedom.
Negative pressure and accelerated expansion require genuine dynamical structure.

Diagnostic Test D1 therefore establishes a sharp boundary between descriptive reweighting and mechanism-level physics. Its value lies in identifying when inflation-like behavior is being reproduced through bookkeeping choices rather than earned dynamically.

Role Within CEDA

Diagnostic Test D1 serves as the **baseline audit** within the CEDA diagnostic hierarchy. Any early-universe proposal claiming inflation-like expansion without introducing new dynamical structure must first confront this test.

Failure to reject the null hypothesis indicates that such a proposal is reinterpretive rather than mechanistic. Subsequent diagnostic tests build on this baseline to assess:

- stability under coarse-graining variation,
- robustness of effective descriptions, and
- the provenance of negative pressure when genuine dynamical structure is present.

Status

Test D1: Null Confirmed.
Horizon reconfiguration without additional dynamical structure does not produce inflation.