1 Dynamical Regime Transitions in Cosmology: A CMB-Safe Framework

Morten Magnusson

ORCID: https://orcid.org/0009-0002-4860-5095

Independent Research

DOI: 10.6084/m9.figshare.31096951

Date: January 20, 2026

1.1 Abstract

We present a framework for testing regime-dependent cosmological modifications while maintaining compatibility with cosmic microwave background (CMB) observations. Using Landau theory for phase transitions, we construct a gating function G(z) that is dynamically suppressed at recombination (G_CMB 10 ^{12}) while allowing late-time activation. The key innovation is a control parameter (z) that evolves with cosmic structure formation, driving a smooth transition between regimes without requiring fine-tuning. We demonstrate CMB safety numerically, provide a CLASS implementation strategy, and identify observable signatures in late-time cosmology. This framework provides a regime-safe testbed for EFC-type theories, and is broadly applicable to any theory requiring regime-dependent behavior, including modified gravity and early dark energy.

Keywords: cosmology, CMB, regime transitions, Landau theory, modified cosmology

1.2 1. Introduction

The cosmic microwave background (CMB) provides stringent constraints on early-universe physics. Any cosmological model that modifies recombination-era dynamics risks shifting acoustic peak positions (constrained to <0.1%) or altering the sound horizon. This has proven a major obstacle for alternative cosmological theories, including modified gravity [1], early dark energy [2], and more exotic proposals.

Previous attempts to test Energy-Flow Cosmology (EFC) against CMB data failed due to direct modifications of the expansion rate H(z) or Thomson scattering rate, both of which immediately affect observables at z 1100. Additionally, parameter degeneracies (e.g., between added energy density and the Hubble parameter h) created false signals that disappeared under proper multi-parameter analysis [3].

1.2.1 1.1 Core Problem

How can a theory have late-time effects ($z < 10$) without contaminating the CMB (z 1100)?

Our solution: Dynamical gating through a phase transition mechanism borrowed from condensed matter physics.

1.2.2 1.2 Key Innovation

Instead of modifying physics uniformly across all redshifts, we introduce a **gating function** G(z) that:

- Equals zero at recombination → standard ΛCDM applies exactly
- Grows to unity by $z = 0$ → modifications can manifest
- Emerges from solving a differential equation, not imposed by hand

Figure 1 shows the complete dynamical solution demonstrating this mechanism in action: the control parameter (z) crosses its critical threshold at z 50, yet the gating function G(z) remains suppressed (G 10 ^{12}) throughout the CMB era before activating at z<2.

1.3 2. Theoretical Framework

1.3.1 2.1 Landau Theory for Cosmological Transitions

We model the regime transition using Landau's theory of second-order phase transitions [4]. Define an **order parameter** (z) where:

- = 0: system in linear regime (ΛCDM physics)
- > 0: transition to non-linear regime occurring

The dynamics are governed by:

```
(d /dt) = -a( ) - b ³
```

where:

- > 0 is the relaxation time
- b > 0 provides cubic stabilization

- a( ) = (_c -) is the Landau coefficient
- (z) is a **control parameter** characterizing system state

Critical behavior:

- < _c: a > 0 → relaxes to zero (inactive)
- > _c: a < 0 → can grow (active)
- = _c: bifurcation point (tipping point)

1.3.2 2.2 Control Parameter

The control parameter (z) must:

1. Be physically motivated (e.g., measures structure formation)
2. Evolve monotonically: small at early times, large at late times
3. Cross the critical threshold _c somewhere between CMB and today

Phenomenological form (this work):

```
(z) = _mid - _amp × tanh((z - z_t)/Δz)
```

This provides a smooth transition centered at z = z_t.

Physical candidates (future work):

- Entropy gradient: | S|/S
- Dissipation measure: (energy dissipated)/(critical threshold)
- Structure amplitude: $\Delta^2(k, z)$

1.3.3 2.3 Gating Function

To couple this to observables in a bounded way:

`G( ) = ²/( ² + ²)`

Properties:

- G(0) = 0 (completely off)
- G(∞) = 1 (fully on)
- G( ) = 1/2 (half-saturation)
- Smooth and monotonic

Physical coupling:

`[Observable](z) = [ΛCDM value](z) + × G(z) × [modification]`

where is the coupling strength.

1.3.4 2.4 Redshift Evolution

Converting from time t to redshift z:

`d /dz = [ ( _c - ) + b ³] / [(1+z)H(z) ]`

Integration: Solve from z = 3000 → 0 using 4th-order Runge-Kutta with initial condition (3000) = 10 .

1.4 3. Numerical Results

1.4.1 3.1 Fiducial Parameters

We use Planck 2018 cosmology [5]:

Cosmology:

- H = 67.36 km/s/Mpc
- Ω_b = 0.0494, Ω_c = 0.2646, Ω_Λ = 0.685

Regime transition:

- _early = 0.2, _late = 2.5
- z_transition = 50, Δz = 30
- = 10.0, _c = 1.0, b = 1.0, = 0.1, = 1.0

1.4.2 3.2 Solution

Numerical integration yields:

z	(z)	(z)	G( )	Regime
3000	0.20	10	10^{12}	Linear (L0)
1100	0.20	10	10^{12}	**CMB**
100	0.28	10	10^{12}	L0
50	1.35	10	10^{12}	Buffer (_c)
10	2.35	10	10^{1}	Buffer
2	2.42	0.58	0.25	Activating
0	2.42	10.0	0.9999	**Active**

Key observation: Although crosses _c at z 50, the order parameter grows slowly due to Hubble damping (1+z)H(z) in the denominator. This creates a natural "delayed response" - activation occurs long after the tipping point.

1.4.3 3.3 CMB Safety Verification

Point evaluation:

```
G(z=1100) = 1.00 × 10^12
```

Visibility-weighted (proper CMB average):

`G_CMB =   g(z) G(z) dz /   g(z) dz = 1.00 × 10` ^{12}

where g(z) is the CMB visibility function.

Safety margin: 8 orders of magnitude below the 10   detection threshold.

Extended window test: For z   [900, 1300], max(G) = 1.2×10^{12} → still safe.

1.5 4. Observable Predictions

1.5.1 4.1 CMB (z 1100)

Prediction: No modification to acoustic peaks, sound horizon, damping tail, or polarization.

Reason: G_CMB 10 12 acts as suppression factor. Even with ~ 10 , effect is ~ 10 1 , far below precision.

Status: Guaranteed by construction.

1.5.2 4.2 Late-Time Observables

Depends critically on:

1. **Physical form of (z)** - determines when activation occurs
2. **Coupling channel** - what physical quantity gets modified
3. **Coupling strength** - amplitude of effect

With phenomenological (z) used here:

- G(z=10) 10 1 → no ISW effect
- G(z=2) 0.25 → partial activation
- G(z=0) 1 → full activation

Potential observables (if (z) activates earlier):

- Late-time ISW (< 50)
- CMB lensing (C_^)
- Structure growth (f)
- Weak lensing (cosmic shear)

1.5.3 4.3 Testable Channels

Different physical couplings have different sensitivities:

1. Anisotropic stress (tested here):

```
_total = _std + _ × G(z) × k²
```

Affects lensing potential.

2. Dark matter viscosity:

```
_DM(z) =   × G(z)
```

Affects small-scale structure, not CMB.

3. Effective sound speed:

```
c_s²(k,z) = c_s²_std × [1 +  c² × G(z) × f(k)]
```

Scale-dependent, observable in matter power spectrum.

1.6 5. Comparison to Previous Approaches

Approach	CMB Safety	Observability	Theoretical Depth	This Work
Direct H(z) modification	Failed	Would be high	Low	Safe
Modified Thomson scattering	Failed	Would be high	Low	Safe
Parameter degeneracy	Artifact	Fake signal	N/A	Avoided
Early dark energy	Marginal	Controversial	Medium	Better
Modified gravity (f(R))	Difficult	Potentially high	High	Similar

Key advantages of this framework:

1. CMB safety by dynamics, not tuning
2. Clear separation of regimes
3. Testable predictions
4. Applicable beyond EFC

1.7 6. Discussion

1.7.1 6.1 Why This Works

Previous failures:

- Modified H(z) directly → changed sound horizon r_s → shifted peaks
- Modified ˙ (Thomson scattering) → affected recombination physics
- Single-parameter scans → parameter degeneracies created false signals

This approach:

- No background modification (H(z) = ΛCDM)
- Gating function G(z) 0 at CMB from dynamics
- Multi-parameter framework from the start

1.7.2 6.2 Physical Interpretation

What is physically?

- Fraction of cosmic volume in non-linear regime
- Measure of regime transition progress
- Proxy for departure from linearity

What is physically?

- Must be derived from theory (not chosen arbitrarily)
- Should track structure formation
- Natural candidates exist (entropy gradients, dissipation measures)

Why the delay (crosses _c at z=50 but G stays low until z<2)?

- Finite relaxation time prevents instantaneous response
- Hubble damping (1+z)H(z) suppresses growth at high z
- This is a feature, not a bug - provides natural CMB safety

1.7.3 6.3 Limitations

This work:

- Establishes mathematical framework

- Demonstrates CMB safety numerically
- Provides CLASS implementation strategy
- Uses phenomenological (z) (not derived from theory)
- Tests only one coupling channel
- No full likelihood analysis yet

Next steps:

1. Derive physical (z) from first principles
2. Test multiple coupling channels
3. Run MCMC with Planck+BAO+structure growth data
4. Compare to other late-time theories

1.7.4 6.4 Broader Applicability

This framework is **not specific to EFC**. Any theory requiring regime-dependent behavior can use it:

- **Modified gravity:** Screen GR modifications at early times
- **Quintessence:** Activate dark energy late
- **Neutrino physics:** Vary effective mass with environment
- **Baryogenesis:** Separate early from late dynamics

1.8 7. Conclusions

We have demonstrated that regime-dependent cosmological modifications can be made compatible with CMB observations through **dynamical gating** rather than fine-tuning. The key innovation is a control parameter (z) driving a Landau-type phase transition, producing a gating function G(z) that:

- Is ~10^{12} at recombination (8 orders below detection)
- Grows to ~1 by z=0 (potentially observable late-time effects)
- Emerges from solving a differential equation (not imposed by hand)

This work does not demonstrate an observational preference for EFC, but establishes a mathematically controlled framework in which such tests can be meaningfully conducted. The regime-safety mechanism presented here addresses the longstanding CMB compatibility problem that has hindered alternative cosmological theories.

Main results:

1. CMB safety verified numerically and analytically
2. Framework is CLASS-compatible and computationally feasible
3. Observability depends on physical (z) and coupling channel
4. Method applicable to broad class of regime-dependent theories

Scientific value:

- Negative results on specific couplings constrain parameter space
- Positive framework for future theory testing
- Educational demonstration of parameter degeneracy pitfalls
- Fully reproducible (code and data openly available)

This is not a discovery - it is a **testbed**. Whether any specific theory (EFC or otherwise) produces observable effects requires deriving (z) from first principles and testing against multiple datasets.

1.9 8. Figures

1.9.1 Figure 1: Complete Regime Transition Dynamics

(See vippepunkt_korrekt.png in repository)

Figure 1 Caption: Complete numerical solution showing: (Top) Control parameter (z) crossing critical threshold _c at z 50. (Main) Gating function G(z) demonstrating CMB safety with G 10 ^{12} at recombination, 8 orders below 10 threshold. (Bottom) CMB zoom and late-time activation showing delayed response.

1.9.2 Figure 2: CLASS Integration Results

(See efc_minimal_demo.png in repository)

Figure 2 Caption: CLASS v3.2.0 results showing: (1) G(z) verification, (2) Baseline ΛCDM C_ spectrum, (3) ISW region, (4) CMB peaks unchanged, (5) Summary metrics.

Both figures available at DOI: 10.6084/m9.figshare.31096951

1.10 Data Availability

All code, numerical solutions, and analysis scripts are openly available at:

DOI: 10.6084/m9.figshare.31096951

Includes:

- Landau equation solver (Python, RK4)
- G(z) computation and verification
- CLASS baseline runs
- Complete documentation
- Reproduction instructions (~2 hours runtime)

1.11 References

[1] Clifton, T. et al. (2012). Modified Gravity and Cosmology. *Phys. Rept.* 513, 1-189.

[2] Poulin, V. et al. (2019). Early Dark Energy Can Resolve The Hubble Tension. *Phys. Rev. Lett.* 122, 221301.

[3] This work. Parameter degeneracy analysis in H(z) vs h parameter space.

[4] Landau, L.D. & Lifshitz, E.M. (1980). *Statistical Physics, Part 1.* Pergamon Press.

[5] Planck Collaboration (2020). Planck 2018 results VI. *Astronomy & Astrophysics* 641, A6.

[6] Blas, D. et al. (2011). The Cosmic Linear Anisotropy Solving System (CLASS) II. *JCAP* 07, 034.

[7] Hu, W. & Sugiyama, N. (1996). Small-Scale Cosmological Perturbations: an Analytic Approach. *ApJ* 471, 542.

[8] Sachs, R.K. & Wolfe, A.M. (1967). Perturbations of a Cosmological Model and Angular Variations of the Microwave Background. *ApJ* 147, 73.

1.12 Acknowledgments

This work used the CLASS Boltzmann code and Planck 2018 data. Numerical computations performed using Python scientific stack.

1.13 Author Contributions

M.M.: Conceptualization, methodology, software, validation, analysis, writing.

1.14 Competing Interests

The author declares no competing interests.

Correspondence: Via Figshare repository (DOI: 10.6084/m9.figshare.31096951)

Citation: Magnusson, M. (2026). Dynamical Regime Transitions in Cosmology: A CMB-Safe Framework. *figshare*. DOI: 10.6084/m9.figshare.31096951