The Triune Universe:
A Falsifiable Cosmological Framework Within General Relativity

Justin B Fine
Ontomics.com

February 14, 2026

Abstract

Standard cosmology explains a striking amount of observational data with the Friedmann–Lemaître–Robertson–Walker (FLRW) metric and the ΛCDM model. At the same time, it leans heavily on an inflationary phase whose microphysics, initial conditions, and probabilistic interpretation remain unsettled.

This white paper introduces the *Triune Universe* framework: a structured but minimal extension of the standard cosmological language that remains fully inside general relativity (GR), introduces no new fundamental fields by fiat, and is designed from the outset to be falsifiable. The core idea is to decompose the effective stress–energy driving expansion into three dynamically distinct components—binding, structuring, and chasing—which trade dominance over time. This triune decomposition allows accelerated early expansion and near-critical geometry to emerge from bounded, non-exponential dynamics.

We retain the standard FLRW metric and Friedmann equations, introduce only effective components of the stress–energy tensor, and require that all departures from canonical scenarios be expressed as testable statements about observables. The framework reproduces the usual inflationary successes in resolving the horizon and flatness problems, but does so without postulating a specific inflaton field or a particular potential. Instead, it organizes a space of expansion histories that can be systematically confronted with data.

The paper concludes with explicit, numbered falsifiability criteria that specify where and how the Triune Universe will fail if it is wrong.

Contents

1 Introduction

1.1 Context and motivation

On the largest scales, the universe is well described by a homogeneous and isotropic geometry with line element

$$ds^2 = -c^2 dt^2 + a^2(t)\left[\frac{dr^2}{1-kr^2} + r^2 d\Omega^2\right], \tag{1}$$

where $a(t)$ is the scale factor, $k \in \{-1, 0, +1\}$ encodes spatial curvature, and $d\Omega^2$ is the metric on the unit 2-sphere.

The dynamics of $a(t)$ follow from Einstein's equations and can be written as the Friedmann system

$$H^2(t) \equiv \left(\frac{\dot{a}}{a}\right)^2 = \frac{8\pi G}{3}\rho(t) - \frac{kc^2}{a^2} + \frac{\Lambda c^2}{3}, \tag{2}$$

$$\frac{\ddot{a}}{a} = -\frac{4\pi G}{3}\left[\rho(t) + \frac{3p(t)}{c^2}\right] + \frac{\Lambda c^2}{3}, \tag{3}$$

with ρ and p the total energy density and pressure.

This system, with suitable components for ρ and p, underlies the ΛCDM model and its inflationary extensions. Inflation was introduced historically to address:

- the horizon problem (large-angle CMB uniformity),
- the flatness problem (near-critical spatial curvature),

- and the origin of nearly scale-invariant primordial perturbations.

Inflation has many phenomenological successes, but raises equally persistent questions about:

- the nature and potential $V(\phi)$ of the inflaton field,
- sensitivity to initial conditions and fine-tuning,
- the measure problem and multiverse interpretations,
- and the practical limits of falsifiability for the paradigm as a whole.

The present work asks a deliberately narrow question:

> *Do current observations force us into scalar-field inflation, or do they admit a more structured class of expansion histories that lives entirely within GR and is easier to falsify?*

1.2 Approach of this paper

This paper develops a cosmological framework, the *Triune Universe*, built around three design constraints:

1. **Stay inside GR:** We keep the FLRW metric and Einstein equations untouched. All novelty lives in the effective decomposition of the stress–energy content.
2. **Structure over fields:** Instead of postulating a new scalar field, we structure the effective energy density and pressure into three dynamical roles: binding, structuring, and chasing.
3. **Falsifiability first:** Every new ingredient is tied to observables and comes with explicit tests that can fail.

The core of the framework is a triune decomposition of the effective stress–energy tensor, which allows for a bounded interval of accelerated expansion without requiring a de Sitter-like exponential phase, and which naturally yields near-critical geometry.

The rest of the paper proceeds as follows:

- Section 2 reviews the observational foundations of expansion.
- Section 3 summarizes the assumptions and open issues of canonical inflation.
- Section 4 introduces the triune decomposition and its physical interpretation.
- Section 5 develops the dynamical implications and early-time behavior.
- Section 6 shows how the horizon and flatness problems can be resolved within this framework.
- Section 7 states explicit falsifiable predictions and tests.
- Section 8 closes with a roadmap for further work.

2 Observational foundations of cosmic expansion

2.1 Redshift, distance, and the Hubble–Lemaître law

The cosmological redshift z relates the scale factor at observation t_0 to that at emission $t_{\rm em}$:

$$1 + z \equiv \frac{a(t_0)}{a(t_{\rm em})}. \tag{4}$$

For nearby sources ($z \ll 1$), the Hubble–Lemaître law holds:

$$v \simeq H_0 d, \tag{5}$$

where $H_0 = H(t_0)$ is the present-day Hubble parameter and d is the proper distance.

At higher redshift, distance indicators involve the integral expansion history:

$$d_L(z) = (1 + z)c \int_0^z \frac{dz'}{H(z')}, \tag{6}$$

where d_L is the luminosity distance. Supernovae, standard sirens, and other probes constrain $H(z)$, and therefore the cumulative behavior of $a(t)$.

These relations are agnostic about the detailed physics of the earliest expansion; they constrain the *integrated* history.

2.2 Particle horizon and causal structure

Causal structure is encoded in the particle horizon:

$$\chi_{\rm ph}(t) = c \int_0^t \frac{dt'}{a(t')}, \tag{7}$$

the maximum comoving distance signals could have traveled by time t.

In the standard radiation- and matter-dominated eras, $\chi_{\rm ph}(t)$ is finite at recombination. The observed near-uniformity of the CMB temperature across angles that map to regions apparently outside each other's particle horizons is the classic horizon problem.

Any viable early-universe framework must explain how regions now on opposite sides of the sky could have shared causal contact before last scattering. This requirement is geometric and does not, by itself, single out an exponential $a(t)$.

2.3 CMB constraints

The CMB temperature anisotropies are encoded in the angular power spectrum C_ℓ, which depends on the comoving sound horizon

$$r_s(z_\star) = \int_{z_\star}^{\infty} \frac{c_s(z)}{H(z)}\, dz, \tag{8}$$

where $z_\star$ is the redshift of last scattering and $c_s(z)$ is the photon–baryon sound speed.

Observed spectra are consistent with a nearly scale-invariant primordial curvature power spectrum

$$\mathcal{P}_{\mathcal{R}}(k) \propto k^{n_s - 1}, \tag{9}$$

with n_s close to 1.

These facts strongly constrain early-time dynamics, but they do not uniquely identify an inflaton field or a particular inflaton potential.[1]

[1] In this paper we treat the observed near scale-invariance as a target to be reproduced, not as a proof of any specific microphysical model.

2.4 Homogeneity and isotropy on large scales

On scales $\gtrsim 100\,\mathrm{Mpc}$, galaxy surveys indicate statistical homogeneity and isotropy. The matter power spectrum is defined via

$$\langle \delta(\boldsymbol{k})\delta(\boldsymbol{k}')\rangle = (2\pi)^3 P(k)\,\delta^{(3)}(\boldsymbol{k}-\boldsymbol{k}'), \tag{10}$$

with $\delta \equiv \delta\rho/\rho$.

Growth of structure depends on the expansion history and gravitational dynamics. Again, data constrain the integral behavior of $H(a)$ and the growth factor, not uniquely the microphysical engine of expansion at the earliest times.

3 Canonical inflation: assumptions and open issues

3.1 Scalar field dynamics and slow-roll conditions

Canonical inflation introduces a scalar field ϕ minimally coupled to gravity with action

$$S = \int d^4x\sqrt{-g}\left[\frac{1}{16\pi G}R - \frac{1}{2}g^{\mu\nu}\partial_\mu\phi\,\partial_\nu\phi - V(\phi)\right]. \tag{11}$$

In a homogeneous background, ϕ obeys

$$\ddot{\phi} + 3H\dot{\phi} + \frac{dV}{d\phi} = 0, \tag{12}$$

with energy density and pressure

$$\rho_\phi = \frac{1}{2}\dot{\phi}^2 + V(\phi), \tag{13}$$

$$p_\phi = \frac{1}{2}\dot{\phi}^2 - V(\phi). \tag{14}$$

Inflation occurs when the equation-of-state parameter

$$w_\phi \equiv \frac{p_\phi}{\rho_\phi} \approx -1, \tag{15}$$

driving $\ddot{a} > 0$.

Slow-roll inflation imposes

$$\epsilon \equiv \frac{M_{\rm Pl}^2}{2}\left(\frac{V'}{V}\right)^2 \ll 1, \qquad \eta \equiv M_{\rm Pl}^2\frac{V''}{V} \ll 1. \tag{16}$$

These are constraints on the assumed potential $V(\phi)$, not consequences of a deeper principle.

3.2 Fine-tuning and initial condition sensitivity

The number of e-folds of inflation is

$$N \equiv \int_{t_i}^{t_f} H\,dt \approx \frac{1}{M_{\rm Pl}^2}\int_{\phi_f}^{\phi_i}\frac{V}{V'}\,d\phi. \tag{17}$$

Achieving $N \gtrsim 60$ generally requires finely arranged initial conditions for ϕ and a carefully shaped potential, especially if the field traverses super-Planckian ranges.

Different potentials and initial conditions can produce similar observables, complicating attempts to reverse-engineer the inflaton sector from data.

3.3 Measure problems and multiverse interpretations

In many inflationary models, inflation is eternal to the future in some regions, generating a multiverse-like structure. Predictions then depend on a probability measure over an infinite ensemble of regions; no unique measure has been agreed upon.

As a result, some observational "predictions" become statements conditional on observer selection within a vast multiverse, blurring the line between physics and anthropic reasoning.

3.4 Limits of falsifiability

Operationally, inflation is defined by the condition

$$\ddot{a} > 0, \tag{18}$$

not by a unique field content. The paradigm encompasses a large family of models that can reproduce nearly scale-invariant perturbations.

Individual models can be ruled out; the paradigm as a whole is highly flexible. This motivates frameworks that:

- live within GR,
- do not rely on an assumed inflaton field,
- and make sharper, more falsifiable predictions about expansion history and observables.

4 The Triune Big Bang framework

4.1 Triune decomposition of effective stress–energy

We retain the FLRW metric (1) and the Friedmann equations (2)–(3). Instead of adding a new fundamental field, we decompose the *effective* stress–energy driving expansion into three components:

$$\rho_{\text{eff}}(t) = \rho_B(t) + \rho_S(t) + \rho_C(t), \tag{19}$$
$$p_{\text{eff}}(t) = p_B(t) + p_S(t) + p_C(t), \tag{20}$$

where:

- B refers to a *binding* component,
- S to a *structuring* component,
- C to a *chasing* component.

These are *roles*, not new particles. Microscopically, each may be composed of familiar matter, radiation, vacuum contributions, or effective fields. The triune split is defined at the level of their dynamical effect on $\ddot{a}$.

The Friedmann equations become

$$H^2 = \frac{8\pi G}{3}\left(\rho_B + \rho_S + \rho_C\right) - \frac{kc^2}{a^2}, \tag{21}$$

$$\frac{\ddot{a}}{a} = -\frac{4\pi G}{3} \sum_{i \in \{B,S,C\}} \left(\rho_i + \frac{3p_i}{c^2}\right). \tag{22}$$

4.2 Dynamical roles of the three components

Define

$$\Xi_i(t) \equiv \rho_i(t) + \frac{3p_i(t)}{c^2}. \tag{23}$$

The triune roles are:

$$\begin{aligned}
\text{Binding:} \quad & \Xi_B > 0 && \Rightarrow \text{deceleration, gravity-like coherence,} && (24)\\
\text{Structuring:} \quad & \Xi_S \approx 0 && \Rightarrow \text{quasi-neutral, shapes but does not dominate } \ddot{a}, && (25)\\
\text{Chasing:} \quad & \Xi_C < 0 && \Rightarrow \text{accelerating, drives } \ddot{a} > 0. && (26)
\end{aligned}$$

Equivalently, in terms of effective equation-of-state parameters $w_i = p_i/(\rho_i c^2)$:

$$\Xi_B > 0 \iff w_B > -\frac{1}{3}, \tag{27}$$

$$\Xi_S \approx 0 \iff w_S \approx -\frac{1}{3}, \tag{28}$$

$$\Xi_C < 0 \iff w_C < -\frac{1}{3}. \tag{29}$$

The total effective equation of state is

$$w_{\text{eff}} \equiv \frac{p_{\text{eff}}}{\rho_{\text{eff}} c^2} = \frac{\sum_i \rho_i w_i}{\sum_i \rho_i}. \tag{30}$$

Accelerated expansion occurs when $w_{\text{eff}} < -1/3$.

4.3 Continuity equations and interaction terms

Total stress–energy conservation is expressed as

$$\dot{\rho}_{\text{eff}} + 3H\left(\rho_{\text{eff}} + \frac{p_{\text{eff}}}{c^2}\right) = 0. \tag{31}$$

We allow energy exchange among the triune components via

$$\dot{\rho}_i + 3H\left(\rho_i + \frac{p_i}{c^2}\right) = Q_i(t), \quad i \in \{B, S, C\}, \tag{32}$$

subject to the constraint

$$\sum_{i\in\{B,S,C\}} Q_i(t) = 0, \tag{33}$$

so that total conservation is maintained.

Intuitively:

- $Q_C < 0$ corresponds to the chasing component decaying into structuring/binding.
- Q_B and Q_S absorb that energy and momentum over time.

4.4 Early triune phase and bounded acceleration

The framework assumes that:

- At very early times, the chasing component is non-zero but finite, giving a regime with

$$-1 < w_{\text{eff}}(t) < -\frac{1}{3}, \tag{34}$$

  and therefore $\ddot{a} > 0$.

- This regime persists over a bounded interval in $\ln a$ (or in conformal time), not indefinitely.
- The chasing component decays into structuring and binding components, such that the universe transitions smoothly into radiation- and matter-dominated phases.

Crucially, the framework does *not* require exponential $a(t) \propto e^{Ht}$, nor does it assume $w_{\text{eff}} = -1$ exactly. Instead, it structures a family of accelerated histories consistent with GR.

5 Triune dynamics and example behaviors

5.1 Baseline Friedmann system

We collect the system here for clarity:

$$H^2 = \frac{8\pi G}{3}(\rho_B + \rho_S + \rho_C) - \frac{kc^2}{a^2}, \tag{35}$$

$$\frac{\ddot{a}}{a} = -\frac{4\pi G}{3}\left[\left(\rho_B + \frac{3p_B}{c^2}\right) + \left(\rho_S + \frac{3p_S}{c^2}\right) + \left(\rho_C + \frac{3p_C}{c^2}\right)\right], \tag{36}$$

$$\dot{\rho}_i + 3H\left(\rho_i + \frac{p_i}{c^2}\right) = Q_i(t), \quad i = B, S, C, \tag{37}$$

$$\sum_i Q_i(t) = 0. \tag{38}$$

An effective cosmological constant in the late universe can be folded into ρ_C (or into a separate ρ_Λ) without changing the structure.

5.2 A simple toy example (power-law phase)

As a *toy model*, suppose that during the early triune-accelerated phase, the effective equation of state is approximately constant,

$$w_{\text{eff}} \simeq w_* \quad \text{with} \quad -1 < w_* < -\frac{1}{3}. \tag{39}$$

Then the scale factor obeys

$$a(t) \propto t^\alpha, \quad \text{with} \quad \alpha = \frac{2}{3(1+w_*)} > 1. \tag{40}$$

This corresponds to a power-law accelerated expansion that is less extreme than de Sitter ($\alpha \to \infty$ as $w_* \to -1$) but still satisfies $\ddot{a} > 0$.

The comoving Hubble radius behaves as

$$(aH)^{-1} \propto t^{1-\alpha}. \tag{41}$$

For $\alpha > 1$, $(aH)^{-1}$ decreases, so modes can start inside the Hubble radius, exit during the accelerated phase, and re-enter later—the same qualitative mechanism inflation uses to explain large-scale correlations. The framework does not hinge on this toy form, but it demonstrates that accelerated, non-exponential dynamics can give the right causal structure.

The actual Triune Universe does *not* commit to a specific power-law index. Instead, it treats $w_{\rm eff}(a)$ as a structured function derived from the triune energy flows $Q_i(t)$ and then asks: *Does this family of histories match the data or not?*

6 Horizon and flatness in the Triune Universe

6.1 Horizon problem revisited

The comoving particle horizon is

$$\chi_{\rm ph}(t) = c \int_0^t \frac{dt'}{a(t')}. \tag{42}$$

What matters for the CMB is whether patches that are widely separated on the last-scattering surface were ever within a common causal domain.

In the triune framework:

- There is a finite early interval in which $w_{\rm eff} < -1/3$ and the comoving Hubble radius decreases.
- For a suitable duration of this interval (constrained by data), modes corresponding to CMB scales begin inside the Hubble radius, evolve through the triune-accelerated phase, and re-enter later.

The key point is that this behavior can be realized by a bounded accelerated phase generated by the triune interplay, without invoking a dedicated inflaton field.

6.2 Flatness and curvature evolution

Define the curvature parameter

$$\Omega_k(t) \equiv -\frac{kc^2}{a^2H^2}. \tag{43}$$

In standard cosmology without an early accelerated phase, linearizing its evolution yields

$$\frac{d\Omega_k}{d\ln a} = (1 + 3w)\,\Omega_k, \tag{44}$$

showing that flatness ($\Omega_k = 0$) is an unstable fixed point for $w > -1/3$.

In the triune framework, during the early accelerated interval we have $w_{\rm eff} < -1/3$, so

$$\frac{d\Omega_k}{d\ln a} = (1 + 3w_{\rm eff})\,\Omega_k \tag{45}$$

has a negative coefficient. The accelerated phase therefore *suppresses* $|\Omega_k|$ instead of amplifying it.

Integrating over the triune phase,

$$\Omega_k(a_f) = \Omega_k(a_i) \exp\left[\int_{\ln a_i}^{\ln a_f} (1 + 3w_{\rm eff})\, d(\ln a)\right], \tag{46}$$

and for sufficiently negative w_{eff} over a moderate expansion range, one can drive Ω_k into the observed bounds:

$$|\Omega_k| \lesssim 10^{-3}. \tag{47}$$

Again, the mechanism is the same geometric lever usually associated with inflation—but it arises here from structured, bounded acceleration governed by the triune decomposition.

7 Falsifiable structure of the Triune Universe

This section shifts from description to *explicit tests*. The Triune Universe is intended to stand or fall on the following claims.

7.1 Core structural claims

Claim S1 (Triune decomposition suffices). *There exists a decomposition of the effective stress–energy into* (ρ_B, ρ_S, ρ_C)*, with corresponding* p_i*, such that:*

1. *The Friedmann equations with this decomposition reproduce the observed* $H(z)$ *at late times to current precision.*
2. *The same decomposition admits an early bounded interval with* $w_{\text{eff}}(a) < -1/3$ *that resolves the horizon and flatness problems.*

Falsification route: If it can be shown that *no* such triune decomposition exists within GR that matches $H(z)$, CMB geometry, and structure growth simultaneously, then the framework fails.

Claim S2 (No new fundamental field required). *The above can be achieved without positing a dedicated inflaton field with a fine-tuned potential. In other words, the triune decomposition can be realized by effective combinations of known or generic stress–energy sources.*
Falsification route: If the only triune realizations that work observationally require introducing a new scalar field with essentially the same tuning problems as inflation, the framework loses its claimed advantage.

7.2 Early-universe behavior

Claim E1 (Bounded accelerated phase). *The early accelerated phase driven by the chasing component is bounded in duration (in* $\ln a$ *or conformal time) and does not approach a perfect de Sitter phase* $w_{\text{eff}} = -1$*.*
Falsification route: If future observations require a primordial phase arbitrarily close to exact de Sitter expansion over many e-folds, the Triune Universe in its minimal form is disfavored.

Claim E2 (Horizon resolution without exponential inflation). *CMB large-angle correlations and the observed acoustic peak structure can be reproduced by triune-driven expansion histories in which* w_{eff} *never reaches exactly* -1 *and* $a(t)$ *is never exactly exponential.*
Falsification route: If detailed reconstruction of the primordial power spectrum and its correlations forces a near-exponential primordial phase incompatible with any $w_{\text{eff}}(a)$ achievable by the triune dynamics, the framework fails.

Claim E3 (Curvature suppression). *For observationally allowed triune histories, the evolution of Ω_k during the early phase drives $|\Omega_k|$ below current bounds without extreme fine-tuning of initial conditions.*
Falsification route: If it is shown that triune-compatible $w_{\text{eff}}(a)$ functions cannot suppress $|\Omega_k|$ sufficiently without requiring tuned initial conditions comparable to or worse than standard Big Bang without inflation, the claimed resolution of flatness is invalid.

7.3 Late-time and cross-epoch coherence

Claim L1 (Consistency across epochs). *Triune histories that resolve early-universe problems can be continued into radiation-, matter-, and dark-energy-dominated eras in a way that remains fully compatible with:*

- *supernova and standard siren $H(z)$ constraints,*
- *BAO measurements of $D_A(z)$ and $H(z)$,*
- *CMB lensing and large-scale structure growth.*

Falsification route: If fits to combined data—CMB, BAO, SNe, growth—show statistically significant tension for all triune histories that solve the early-universe problems, the framework is ruled out.

Claim L2 (No hidden fine-tuning). *Parameter sensitivity analyses of viable triune histories reveal that robust predictions (e.g., ranges for n_s, r_s, Ω_k) are stable across broad equivalence classes of parameters rather than arising from isolated, finely tuned points.*
Falsification route: If it turns out that only extremely narrow regions of triune parameter space match observations, the framework becomes just another finely tuned model and loses its claimed explanatory advantage.

7.4 Concrete "falsify me" targets

To keep the spirit explicit, here are concrete observational targets that the Triune Universe asserts are achievable *within GR and the triune structure*:

1. **CMB acoustic scale:** reproduce the observed $\theta_\star = r_s(z_\star)/D_A(z_\star)$ within current Planck-level uncertainties using a triune early phase with $w_{\text{eff}} > -1$ at all times.
2. **Near-flat geometry:** produce $|\Omega_k| \lesssim 10^{-3}$ at $z = 0$ from initial $|\Omega_k| \sim \mathcal{O}(1)$ without invoking an exponentially long de Sitter-like phase.
3. **Primordial spectral tilt:** generate a nearly scale-invariant curvature power spectrum with $n_s \sim 0.96$–0.97 via triune-driven horizon exit and re-entry, without specifying an inflaton potential.
4. **BAO consistency:** match $r_s(z_\star)$ inferred from CMB with that inferred from BAO across $0 < z \lesssim 3$ for the same triune expansion history.
5. **Growth of structure:** yield a growth factor $f\sigma_8(z)$ consistent with current data once the triune history is extended through matter domination, without needing time-varying G or modified gravity.

Any demonstration that *no* triune-compatible $w_{\text{eff}}(a)$ can hit this joint target list would falsify the framework.

8 Conclusion and roadmap

The Triune Universe is not a single numerical best-fit model; it is a structured family of expansion histories organized by a three-way decomposition of the effective stress–energy content into binding, structuring, and chasing components.

The key points of this white paper are:

- All calculations are performed within standard GR with the FLRW metric; no modifications of Einstein's equations are introduced.
- The triune decomposition provides a way to talk about the dynamical *roles* played by components of the stress–energy tensor, rather than committing to a specific new field.
- A bounded early accelerated phase driven by the chasing component can, in principle, resolve the horizon and flatness problems and reproduce the main successes commonly attributed to inflation.
- The framework is designed to be falsifiable: it specifies explicit structural claims and concrete observational targets. If those cannot be satisfied by any triune history, the framework fails.

Next steps

In terms of scientific practice, the intended sequence is:

1. **Formalization:** Write down explicit parameterizations for $\rho_i(a)$, $w_i(a)$, and $Q_i(a)$ that realize the triune structure while remaining agnostic about microphysics.
2. **Numerical exploration:** Integrate the Friedmann system for broad triune parameter families, compute $H(z)$, distance measures, and perturbation evolution.
3. **Data confrontation:** Fit triune histories to combined CMB, BAO, SNe, and growth data; map out the allowed region in triune parameter space.
4. **Falsifiability verdict:** Determine whether the triune framework survives as a viable alternative to canonical inflation, or whether it is ruled out by current or near-future observations.

This paper is therefore a *contract* with the community: the structure of the Triune Universe is laid out as transparently as possible, and the points at which it must either succeed or fail are made explicit.

The invitation is simple: *challenge the equations, the structure, and the claims.* If the Triune Universe survives those challenges, it earns its place alongside inflationary cosmology as a serious contender. If it fails, it fails honestly—which is the only way a cosmological framework deserves to live.