Abstract

Pillar 6 is the constructive proposal of the GR-Razor Stress Tests series. Pillars 1 through 4 exhausted the principal GR-internal mechanisms proposed to resolve cosmological tensions: relativistic peculiar velocity corrections, inhomogeneous backreaction, vector and tensor mode contributions, and frame-dragging effects each failed decisively on amplitude or consistency grounds. Pillar 5 audited ΛCDM itself and declared it incomplete: the Hubble tension at 5σ and the cosmological constant problem at 10^{122} orders of magnitude are unresolved failures for which the standard model has no internal mechanism. Pillar 6 does not test a challenger. It proposes one.

We propose Cosmological Pangaea, a cosmological framework in which the Universe originated not from a mathematical singularity but from a finite, maximally dense, causally connected initial object that underwent a fragmentation and expansion event. The framework operates entirely within general relativity, introduces no new fields or particles, and satisfies both intake metrics of the series. It resolves the horizon problem directly and without inflation, replaces the singularity with a physically realizable initial state, and makes four classes of testable predictions distinct from ΛCDM: a fragmentation-derived primordial power spectrum, a characteristic large-scale structure topology, a modified expansion history that may address the Hubble tension, and a fossil imprint in the cosmic web above the BAO scale.

The central quantitative problem, deriving the fragmentation power spectrum from Jeans instability analysis of the initial object, is identified as the decisive test. Three GR-internal triggering mechanisms are examined: quantum bounce at Planck density, first-order phase transition in the equation of state, and topological expansion from a closed three-sphere geometry. Four guillotine tests are defined in advance following the methodology of the GR-Razor series. This paper is a conceptual framework document. The quantitative development of the fragmentation power spectrum and the Hubble tension calculation are identified as targets for subsequent work.

1. Motivation: What the Singularity Actually Is

The standard Big Bang cosmology traces the Universe's history backward in time to a state of infinite density and zero volume: the singularity. This singularity is not a physical prediction. It is a mathematical breakdown of general relativity, the point at which the equations produce divergent quantities and cease to describe anything physical. The Penrose-Hawking singularity theorems establish that under reasonable energy conditions GR inevitably produces singularities in gravitational collapse and in the backward extrapolation of expanding spacetimes. These theorems do not describe what nature does. They describe where GR stops working.

The cosmological community has recognized this for decades. The singularity is almost universally understood as a signal that GR must be supplemented by quantum mechanics at extreme densities rather than a literal description of a physical state. Loop quantum cosmology, string cosmology, the Hartle-Hawking no-boundary proposal, and Penrose's conformal cyclic cosmology all replace the singularity with a finite-density initial state. What they share with each other and with Cosmological Pangaea is the recognition that the Universe did not begin at a point of infinite density because no such point is physically realizable.

Cosmological Pangaea takes this recognition seriously and asks a specific question: if the initial state was not a singularity but a finite object, what were its properties, and what are the observational consequences of those properties? The name carries the intuition: just as Earth's continents were once a single connected landmass that fragmented and drifted apart, leaving matching geological signatures on separated shores, the observable Universe may be the fragmented remnant of a single vast connected object whose separation left matching physical signatures everywhere we look.

This is the question Pillar 6 is built to answer. Pillars 1 through 5 were a demolition program: systematic falsification of every GR-internal mechanism that claimed to resolve cosmological tensions, followed by an audit of the standard model itself. What remained after that program was a cleared field and a specific gap: no singularity-free, GR-internal, structured initial state had been proposed and tested with the same rigor applied to the alternatives. Cosmological Pangaea fills that gap. It is the constructive proposal that the demolition program makes room for.

> *The singularity is not where the Universe began. It is where our equations stop working. Those are not the same thing.*

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2. The Initial State: Defining the Pangaea Object

The Pangaea object is defined by four properties.

2.1 Finite in Extent

Unlike the singularity the Pangaea object has a physical size, a density, and a geometry describable within GR. Its mass encompasses the mass-energy of the observable Universe. Its density is at or near the maximum physically realizable density, which in a quantum-corrected GR framework is the Planck density:

$$\rho_{Pl} \sim 5 \times 10^{93}\ \mathrm{g/cm^3}$$

At Planck density, the Pangaea object containing the mass of the observable Universe has a radius of approximately 10^{-5} meters, far smaller than any currently observable structure but finite, bounded, and physically describable. This is not a singularity. It is an extreme but well-defined physical state.

2.2 Causally Connected Throughout

Every region of the Pangaea object is within the causal horizon of every other region. This is the property that directly resolves the horizon problem, addressed fully in Section 3. The CMB uniformity to one part in 100,000 across the entire observable sky is not a coincidence requiring explanation through an unobserved inflaton field. It is a direct consequence of common origin in a single causally connected object. Everything was in thermal equilibrium before separation because everything was in contact.

2.3 Metastable, Not Collapsing

The Pangaea object does not immediately collapse to a singularity. A repulsive effect prevents further compression and eventually drives expansion. Three specific triggering mechanisms are examined in Section 4. All three are GR-internal: they require no new fields, no new particles, and no modifications to the geometric structure of GR. They require only the application of GR at extreme densities where quantum corrections, phase transitions, or topological effects produce qualitatively different dynamics from the classical weak-field limit.

2.4 Structured, Not Uniform

The Pangaea object has internal density variations. These are not quantum fluctuations stretched by inflation. They are physical density inhomogeneities in a finite object, analogous to the geological and tectonic structure of Pangaea before breakup: denser regions, less dense regions, internal stress patterns. The distribution of these inhomogeneities is the fragmentation power spectrum. It is the quantity that determines whether Cosmological Pangaea reproduces the observed CMB acoustic peaks and the primordial spectral index. It is the central quantitative target of this research program.

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3. The Horizon Problem Dissolved

The horizon problem is one of the foundational motivations for cosmic inflation. In standard cosmology, regions of the CMB separated by more than approximately two degrees on the sky were never in causal contact before recombination. The light-travel time between them exceeds the age of the

Universe at that epoch. Yet they are at the same temperature to one part in 100,000. The standard model has no explanation for this within GR. Inflation patches it by proposing exponential expansion from an undetected scalar field, the inflaton, with a potential tuned to produce the right amount of expansion. The inflaton has never been detected. It fails the Occam's Razor intake metric.

Cosmological Pangaea dissolves the horizon problem rather than patching it. All observable regions were once part of a single causally connected object. They share the same temperature because they were in thermal contact. There is no need for exponential expansion to bring them into contact because they were never out of contact. The uniformity is a fossil of the initial state.

The constraint this places on the Pangaea object is that it must have been smaller than its own causal horizon: its physical size must have been less than the light-travel time across it. For an object of the mass of the observable Universe, the Schwarzschild radius is approximately 13 billion light years, the current size of the observable Universe. The Pangaea object at Planck density has a radius of 10^{-5} meters, far inside this causal horizon. Causal connectivity is satisfied without infinite density and without inflation.

Cosmological Pangaea solves the horizon problem more directly than inflation. Everything was connected. That is why everything looks the same.

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4. Triggering Mechanisms: Three GR-Internal Options

The Pangaea object is metastable. Something triggers the fragmentation and expansion event. Three mechanisms are examined here, all operating within GR without new physics beyond what is independently motivated.

Mechanism A: Quantum Bounce at Planck Density

Loop quantum cosmology predicts that the quantum geometry of spacetime becomes repulsive at Planck density. The discrete structure of quantum spacetime at the Planck scale introduces an effective repulsive pressure that halts collapse and reverses it into expansion. The Pangaea object reaches Planck density, quantum pressure halts further compression, and the repulsive effect drives rapid expansion and fragmentation. This mechanism requires only the application of loop quantum cosmology corrections to GR, which are motivated independently by the need to quantize gravity and are not introduced specifically for Pangaea. It predicts a specific relationship between the pre-bounce and post-bounce power spectra that is in principle observable in the CMB at large angular scales.

Mechanism B: First-Order Phase Transition

The Pangaea object undergoes a first-order phase transition in its equation of state, analogous to water freezing or a ferromagnet ordering below its Curie temperature. The transition releases latent energy and changes the pressure-density relationship of the matter, driving rapid expansion. In GR a change in equation of state produces a corresponding change in the Friedmann equation dynamics. If the pre-transition state has $w > 1/3$, stiff matter or radiation domination, and the transition produces $w < 0$, dark energy-like pressure, the expansion accelerates sharply. The phase transition sets both the scale and the energy of the separation event and makes specific predictions for the shape of the primordial power spectrum near the transition scale.

Mechanism C: Topological Expansion

The Pangaea object has the geometry of a closed three-sphere at maximum volume for its mass-energy content. In GR a closed universe with positive curvature naturally recollapses unless the expansion rate exceeds a critical value. The Pangaea object sits at the turning point between collapse and expansion. A small perturbation in density, a quantum fluctuation in the matter distribution, tips it from the collapsing branch to the expanding branch. No new physics is required. The expansion is driven by the standard Friedmann equations with the initial conditions of a closed three-sphere at maximum density. This is the most conservative mechanism: it requires nothing beyond classical GR applied to a specific initial geometry.

Each mechanism makes different predictions for the expansion history in the first moments after separation and therefore for the imprint on the CMB power spectrum. Distinguishing between them observationally is a secondary goal of the quantitative program.

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5. The Fragmentation Power Spectrum: The Central Problem

This is the calculation that determines whether Cosmological Pangaea lives or dies as a scientific model.

When the Pangaea object undergoes its triggering event it does not separate uniformly. Its internal density variations seed a fragmentation pattern. Regions above the Jeans length collapse into bound fragments. Regions below it oscillate. The Jeans length in the initial object is:

$$\lambda_J \sim c_s / \sqrt{(G\rho)}$$

where c_s is the sound speed in the initial matter and ρ is the density. At Planck density with $c_s \sim c$, the Jeans length is of order the Planck length. All scales above the Planck length are Jeans-unstable and fragment. The distribution of fragment masses determines the primordial power spectrum.

Three limiting cases bracket the possibilities. If the internal density variations are white noise, uncorrelated at all scales, the fragmentation spectrum is also white noise and the resulting primordial power spectrum is scale-invariant with spectral index $n_s = 1$. If the variations are correlated on large scales the fragmentation spectrum is red-tilted with $n_s < 1$. If they are correlated on small scales it is blue-tilted with $n_s > 1$.

The observed primordial spectral index is $n_s = 0.965 \pm 0.004$, a slightly red-tilted nearly scale-invariant spectrum. This is consistent with Pangaea fragmentation producing large-scale correlated density variations in the initial object. The question is whether a physically motivated density profile for the Pangaea object naturally produces $n_s \sim 0.965$ without fine-tuning. This requires a Tolman-Oppenheimer-Volkoff analysis of the Pangaea object's equilibrium density profile combined with a Jeans instability analysis of the fragmentation modes. If it naturally produces $n_s \sim 0.965$ the model passes the CMB acoustic peak test without invoking inflation. This is the quantitative target for Stage Two development of this framework.

> *The fragmentation power spectrum is the central calculation. Everything else in this framework is either already established or follows from it. If the Jeans analysis of the Pangaea object naturally yields n_s ~ 0.965, inflation becomes unnecessary.*

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6. The Expansion History and the Hubble Tension

After fragmentation the standard Friedmann equations govern the expansion history if the matter content is standard. The initial conditions for the Friedmann equations are set by the fragmentation event: the post-separation energy density, the expansion rate, and the perturbation spectrum.

ΛCDM fails the Hubble tension at 5σ. The H■ value inferred from the CMB within ΛCDM is 67.4 km/s/Mpc. The locally measured value is 73.0 km/s/Mpc. This discrepancy has no resolution within the standard model and has been confirmed by JWST Cepheid re-analysis.

The Hubble tension may be a direct consequence of the singular initial condition in ΛCDM. The CMB inference of H■ extrapolates the expansion history backward to a singularity using the standard Friedmann equations. If the actual initial state was a finite Pangaea object with a specific size and expansion rate at separation, the extrapolation changes. The post-separation expansion rate is set by the energy of the triggering event and the mass of the initial object, not by a singular initial condition with infinite energy density. This produces a different relationship between the early-universe expansion history and the local expansion rate.

Whether Pangaea's modified initial conditions naturally resolve the Hubble tension is a quantitative question requiring the Friedmann evolution from post-separation initial conditions to be computed and compared with both the CMB acoustic scale and the local distance ladder. This is the most important single observational test of whether Pangaea offers a genuine advantage over ΛCDM and is identified as a primary target for the quantitative program.

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7. Fossil Structure: The Prediction Above the BAO Scale

The BAO scale, approximately 150 megaparsecs, is imprinted by acoustic oscillations in the photon-baryon fluid before recombination. ΛCDM predicts a preferred clustering scale at BAO and no preferred scale above it. The large-scale power spectrum above BAO should be a smooth power law with no additional features.

Cosmological Pangaea predicts a different large-scale structure topology. The largest Pangaea fragments, the cosmological continents, are the seeds of the largest structures: the great walls, superclusters, and the nodes of the cosmic web. If the dominant fragmentation scale of the Pangaea object corresponds to a physical scale larger than the BAO scale, the matter power spectrum should show a secondary preferred clustering scale above BAO that is absent in ΛCDM.

The observed cosmic web has a characteristic cell size of approximately 300-400 megaparsecs, larger than the BAO scale. ΛCDM explains this as an emergent statistical property of gravitational clustering from random initial fluctuations. Cosmological Pangaea predicts it as a direct fossil of the dominant fragmentation scale. The distinction is testable: a fossil scale produces a specific feature in the power spectrum while an emergent statistical scale does not. DESI's large-scale structure measurements and Euclid's galaxy survey are precisely the datasets that would reveal or rule out a preferred clustering scale above the BAO feature.

This is the most distinctive empirical prediction of Cosmological Pangaea and the one most cleanly differentiated from ΛCDM. If DESI or Euclid detects a statistically significant feature in the matter power spectrum at 300-400 megaparsecs above the BAO scale, that is direct evidence for the fossil structure prediction. If the spectrum above BAO is a smooth power law the prediction fails.

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8. Relationship to Existing Frameworks

Cosmological Pangaea shares features with several existing research programs while being distinct from each in ways that matter for its testability and theoretical grounding.

It shares with loop quantum cosmology the replacement of the singularity with a quantum bounce at Planck density. It differs in proposing a structured, extended initial object with internal density variations rather than a homogeneous bounce from a prior contracting phase. The structured initial state is what generates the fragmentation power spectrum and the fossil large-scale structure.

It shares with the Hartle-Hawking no-boundary proposal the idea of a finite smooth initial geometry replacing the singularity. It differs in working with a matter-dominated rather than vacuum initial state and in making specific predictions for large-scale structure topology.

It shares with bouncing cosmologies the avoidance of a singularity through a minimum-size maximum-density state. It differs in the fragmentation mechanism and in the prediction of fossil large-scale structure as a direct observational signature.

It is most closely related to the pre-Big Bang scenario of Gasperini and Veneziano, in which the Universe evolves from a weak coupling low curvature initial state through a string cosmology phase to the standard hot Big Bang. Like Pangaea this framework avoids the singularity and predicts a modified primordial spectrum. It differs in requiring string theory as its theoretical foundation, which introduces new physics outside GR. Cosmological Pangaea requires only GR with quantum corrections at the Planck scale, corrections that are independently motivated by the quantization of gravity regardless of cosmological application.

The key distinction from all existing frameworks is the structured initial state. Every prior singularity-free cosmology begins with a homogeneous or near-homogeneous initial condition and generates structure through inflation or quantum fluctuations. Cosmological Pangaea begins with a structured initial object and derives structure from the fragmentation pattern. This is a different physical picture with different observational consequences, specifically the fossil structure prediction above the BAO scale that no other framework predicts.

9. The Four Guillotines

Following the methodology of the GR-Razor Stress Tests series, four guillotine tests are defined in advance. Cosmological Pangaea must pass all four to be considered a viable scientific model. Failure on any single test in its strong form requires either modification of the framework or declaration of failure. Survival of all four establishes the framework as warranting full quantitative development, not as confirmed.

Guillotine 1: Fragmentation spectrum consistency.

The fragmentation power spectrum derived from the Jeans instability analysis of the Pangaea object's equilibrium density profile must produce a primordial spectral index $n_s = 0.965 \pm 0.004$ without fine-tuning of the initial density profile. If the spectral index requires fine-tuning comparable to the tuning required for the inflationary potential the framework offers no advantage over inflation. If it emerges naturally from the physics of a self-gravitating fluid at Planck density the framework passes this test decisively.

Guillotine 2: CMB acoustic peak reproduction.

The post-separation expansion history fed with Pangaea initial conditions must reproduce the CMB acoustic peak positions, amplitudes, and damping tail at Planck measurement precision. The acoustic peaks are sensitive to the sound horizon at recombination, the baryon-to-photon ratio, and the expansion history between the initial state and recombination. Any deviation in the initial conditions that propagates to a measurable shift in peak positions or amplitude ratios constitutes a failure of this test.

Guillotine 3: Hubble tension resolution or reduction.

The post-separation expansion dynamics must produce H■ values consistent with both the CMB acoustic scale inference and the local distance ladder measurement, or at minimum reduce the tension below 3σ. A framework that fails the Hubble tension as badly as ΛCDM offers no improvement on the standard model's most serious empirical failure. A framework that resolves or substantially reduces the tension provides a concrete advantage that directly motivates further development.

Guillotine 4: Fossil structure prediction.

The dominant fragmentation scale must correspond to an observable preferred clustering length in the galaxy distribution above the BAO scale, detectable at statistical significance by DESI Year 3 or Euclid Year 1 data. If the matter power spectrum above BAO is a smooth power law with no secondary feature the fossil structure prediction fails and with it the framework's most distinctive observational signature. If a secondary feature is detected at the predicted scale this constitutes the strongest possible confirmation of the framework's core claim.

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10. The Quantitative Program: Staged Development

This paper is a conceptual framework document. The quantitative work proceeds in four stages in order of priority.

Stage One: Equilibrium Structure of the Pangaea Object

Apply the Tolman-Oppenheimer-Volkoff equation to a self-gravitating fluid at Planck density with a physically motivated equation of state. Derive the equilibrium density profile. This is the input to Stage Two.

Stage Two: Fragmentation Power Spectrum

Apply Jeans instability analysis to the density profile from Stage One. Derive the fragmentation power spectrum $P_{Pangaea}(k)$. Compare the resulting spectral index with $n_s = 0.965 \pm 0.004$. This is the decisive calculation. Everything else is secondary to its outcome.

Stage Three: Post-Separation Expansion History

Feed the Pangaea initial conditions, the density, expansion rate, and perturbation spectrum from Stage Two, into the standard Friedmann equations. Compute the expansion history from separation through recombination to the present. Compare with the CMB acoustic peak structure and compute the predicted H■. This is the Hubble tension test.

Stage Four: Large-Scale Structure Prediction

From the dominant fragmentation scale identified in Stage Two, compute the predicted secondary clustering scale in the matter power spectrum above BAO. Compare with current DESI large-scale structure measurements and generate a specific prediction for Euclid Year 1 data.

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11. Conclusion: What This Framework Offers and What It Must Earn

Cosmological Pangaea is a GR-internal cosmological framework that replaces the singularity with a finite structured initial state, resolves the horizon problem without inflation, and makes four classes of testable predictions distinct from ΛCDM. It is Pillar 6 of the GR-Razor Stress Tests series: the constructive proposal that follows five Pillars of systematic falsification. Pillars 1 through 4 demonstrated that no linear or quasi-linear GR mechanism at the perturbation, averaging, vector-tensor, or gravitomagnetic level can bridge the JWST amplitude gap. Pillar 5 demonstrated that ΛCDM itself is incomplete at its foundations. Pillar 6 asks whether a nonlinear, finite, structured initial state within GR can do what every other approach has failed to do.

The framework does not claim to be a complete theory. It is a structured proposal with identified quantitative targets and defined tests. It asks to be judged by the same standard applied to every theory in the GR-Razor series: does the mechanism actually work, quantitatively, across all relevant tests? The fragmentation power spectrum calculation is where that question gets its first answer.

If the quantitative program succeeds, Cosmological Pangaea will have demonstrated that the Universe's largest outstanding problems, the horizon problem, the singularity, the Hubble tension, and the large-scale structure topology, can be addressed within GR without new fields, new particles, or modifications to the geometric theory that has passed every precision test ever applied to it.

If it fails, the case for moving the Occam's Razor criterion outside GR becomes genuinely compelling rather than merely attractive. The GR exhaustion program will be complete. The series established that no known linear or quasi-linear GR mechanism resolves the JWST tension. Cosmological Pangaea tests whether a nonlinear, finite, structured initial state can do what the perturbative approaches could not. If it cannot, the answer is not in GR and the razor must move.

> *The framework does not ask for acceptance. It asks for the same adversarial scrutiny applied to every theory in this series, including the standard model. If it survives that scrutiny, it has earned its place. If it does not, we will know exactly why, and we will know where to look next.*

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This paper is a conceptual framework document. Quantitative development of the fragmentation power spectrum and Hubble tension calculation are identified as targets for subsequent work.

Correspondence and critique are invited. The framework is open and the methodology is documented. Independent verification of the quantitative results, when they exist, is not just welcome but essential.

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