# The Universe Has No Boundary: Logical, Derivational, and Observational Arguments for Spatial Infinitude

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**Abstract**:

This paper presents three independent categories of argument that the universe is spatially infinite and has no physical boundary. The first is conceptual: a physical boundary of space is incoherent because a boundary requires a physically meaningful distinction across it, whereas absolute non-being cannot function as a physical interface. The second is logical: the standard cosmological model's own answer to the question of where the Big Bang singularity was located, namely that it was everywhere, undermines any finite localised-origin premise. The third is derivational and observational within the BFUT framework: the cosmological constant Λ yields the equilibrium density of the Spaticle field $\rho\_s = \Lambda c^2 / (8 \pi G) \approx 5.9 \times 10^{-27}$ kg/m³ from established physics with no free parameters in an infinite uniform distribution (as established independently across multiple sectors in BFUT Paper 14); current large-scale orientation evidence does not establish a single robust global preferred axis consistent with a finite-boundary cosmology; and large-scale ordered motion persists in rotating cosmic filaments, cluster-scale coherent motion, and multi-megaparsec environmental coherence beyond the scale at which naive finite-expansion reasoning would expect such coherence to be washed out. Standard responses are then examined - finite-but-unbounded topology, singularity-era breakdown claims, and inflationary patches - and shown either to change the question, relocate instead of resolve the boundary condition, or introduce additional assumptions without direct confirmation. The paper concludes that spatial infinitude is not merely one cosmological option but the most coherent physical interpretation within the BFUT framework.

The paper is part of a series presenting components of the Big Flare-Up Theory (BFUT) [2], a comprehensive alternative cosmological framework proposing an infinite eternal universe. The spatial infinitude argument presented here is foundational to BFUT but can be evaluated entirely independently of the other BFUT claims.

**Keywords**: spatial infinitude, universe boundary, cosmological topology, singularity location, cosmological constant, galaxy orientations, large-scale structure, cosmic filaments, Big Flare-Up Theory, inflation, Loop Quantum Cosmology

## 1. Introduction

This paper argues that the question is not merely observationally undecided but is logically, derivationally, and observationally decided in favour of spatial infinitude. Three independent categories of *arguments* are presented, each sufficient on its own and convergent in their conclusion.

The question of whether the universe is spatially finite or infinite has been debated since antiquity. The standard cosmological model, based on the Friedmann-Lemaitre-Robertson-Walker metric, is agnostic on this question: it permits both finite and infinite spatial solutions depending on the sign of the spatial curvature parameter. Current observational constraints from Planck 2018 results (2020) [1] find Omega_k = 0.001 +/- 0.002, consistent with spatial flatness and therefore with both a very large finite universe and an infinite one.

*Figure 1. Representative schematic summary of the BFUT argument for spatial infinitude. Formal arguments and citations are provided in the main text.*

**2. The Conceptual Proof: A Physical Boundary of Space Is Incoherent**

The strongest case for spatial infinitude is not observational or numerical. It is conceptual. The core issue is not merely whether the universe is very large. The core issue is whether the totality of physically meaningful space can coherently possess a physical boundary.

Consider a thought experiment. You are standing in a room. The walls are proposed to be the boundary of your accessible domain. You break through the wall. There is more space beyond it. If that next boundary is broken, there is more space again. Any physical barrier that can be approached, touched, crossed, or even meaningfully described is not a boundary of space itself. It is a structure located within space.

The only way to stop this regress is to say that beyond the final limit there is not empty space but absolute non-being: no extent, no geometry, no location, no causal capacity, no physical property of any kind. But absolute non-being cannot function as a physical interface. A boundary is not merely a line in a diagram. A boundary is a physically meaningful distinction across which something changes. If one side of the proposed boundary has no physical status whatsoever, then there is no physically meaningful interface there to describe, locate, or interact with.

Therefore the idea of a physical boundary of space is conceptually incoherent. Any proposed boundary is either inside space, in which case it is not a boundary of space but a structure within it, or it is said to separate space from absolute nothing, in which case it ceases to be a physical boundary at all.

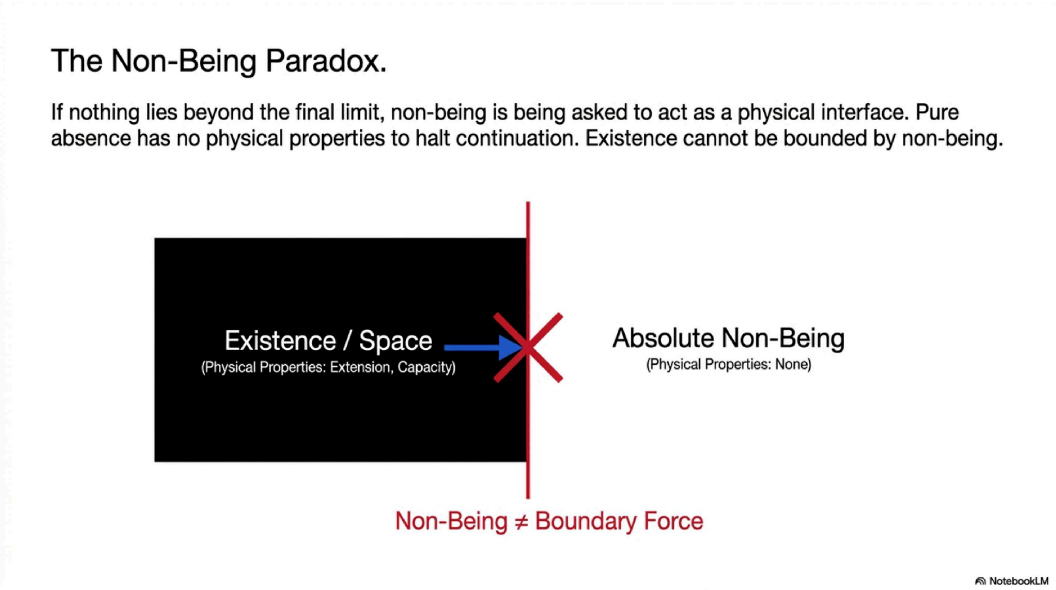


*Figure 1. The Boundary Regress and the Non-Being Paradox: Any proposed physical boundary of space either leads to an infinite regress or requires absolute non-being to act as a physical interface, which is incoherent.*

This is why the paper retains the blunt formulation while also defining it carefully: space, in the physically meaningful sense, is infinite. The claim is not that every mathematical model of finite topology is illegitimate. The claim is that purely formal topological finitude does not by itself provide a physically meaningful ontology of a finite totality of space. In the physically relevant sense, the universe has no boundary.

Everything that follows in this paper should therefore be read as reinforcement, not as the sole basis of the conclusion.

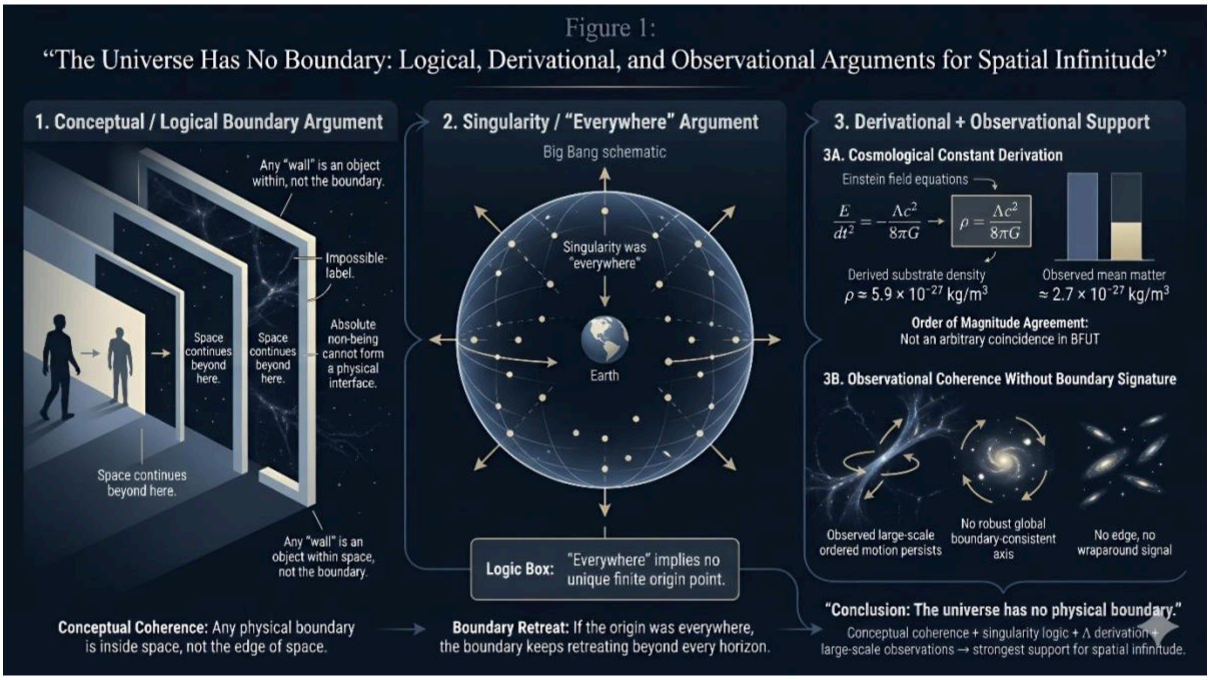


***Figure 2.*** *Three convergent BFUT arguments for spatial infinitude: a physical boundary is logically incoherent, the "everywhere" origin logic defeats a finite edge, and both the Λ-derived density scale and large-scale observations remain consistent with an unbounded universe.*

## 3. The Singularity Location Argument

### 3.1 Where Was the Singularity?

The standard cosmological model proposes that the universe originated from a singularity. Before presenting the formal paradox, one prior point must be established. The singularity, whatever it was, must be located within the observable universe. The observable universe extends approximately 47 billion light years in every direction from Earth. If the singularity was the origin of everything including space, and if it was at a specific location, that location must be somewhere within the space that now exists. It cannot be outside the observable universe because the observable universe is defined as everything that has had causal contact with us. The singularity, having produced everything including us, necessarily had causal contact with us.

Now ask: where exactly within the observable universe was the singularity? The standard model cannot point to a specific location, because any specific location would be a preferred centre, contradicting the Copernican principle. The standard response is that the singularity was everywhere: every point in the current universe traces back to the singularity because space itself originated at the singularity.

### 3.2 The Formal Contradiction

This response generates a formal contradiction. If the singularity was at every point in the current universe, it was at every point including those at the boundary of the observable universe at approximately 47 billion light years from Earth. From any point at that boundary, the same logic applies: the singularity was at every point as seen from there, and the universe extends a further 47 billion light years beyond that boundary.

The boundary retreats without limit. The statement that the singularity was everywhere is logically equivalent to the statement that the universe is spatially infinite. This directly contradicts a finite localised-origin interpretation of the Big Bang.

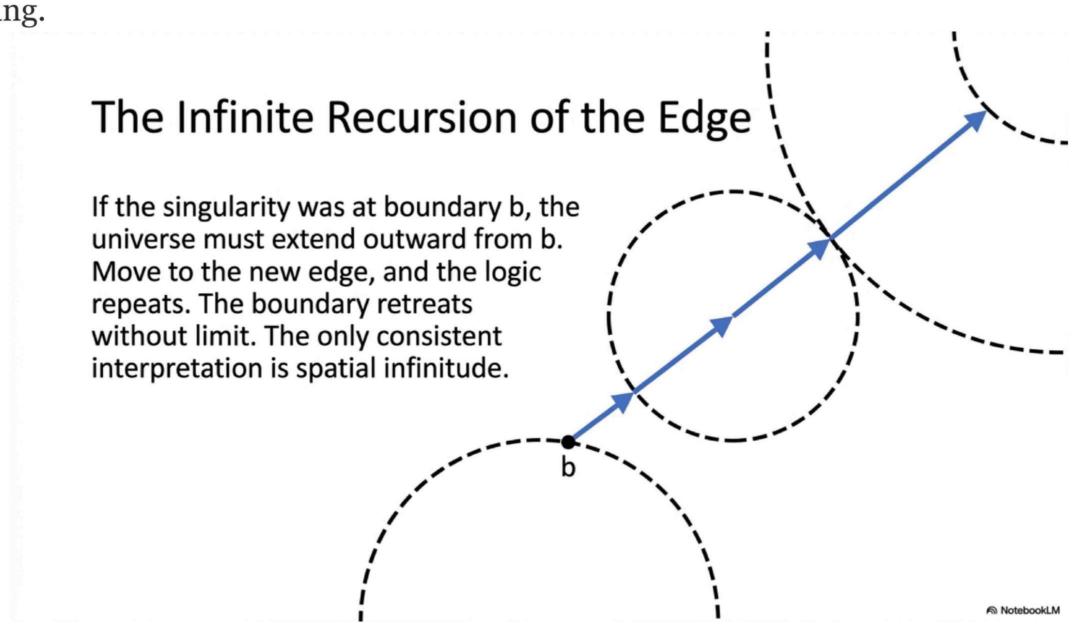


*Figure 3. The Singularity Location Contradiction: The standard model's claim that the singularity was "everywhere"*

*logically requires the universe to be spatially infinite.*

Formally: let U denote the universe and S the singularity. The standard model asserts: for all p in U, S was at p. For any boundary point b at the edge of the observable universe, S was at b. From b, the same assertion applies recursively. There is no spatial boundary at which the argument terminates. The only consistent interpretation is that U is spatially infinite.

## 4. Standard Responses and Their Evaluation

### 4.1 The "Finite but Unbounded" Universe

The first response proposes that the universe is spatially finite but has no boundary, like the surface of a three-sphere. A two-dimensional sphere has no edge: moving in any direction, one never reaches a boundary but eventually returns to the starting point. The three-dimensional analogue is a closed Friedmann model.

The standard 'finite but unbounded' reply can be illustrated more plainly. Imagine a hamster placed inside a very large box and told, 'This is the whole world. It is vast, but it has an end.' If the hamster then asks, 'If I keep walking, will I eventually reach that end? And what lies beyond it?' the original question is perfectly clear. But instead of answering it, the hamster is placed on a wheel and told, 'You can keep running forever and never reach an end.' That does not make the wheel infinite, nor does it answer what lies beyond the box. It merely replaces the question of whether the world itself is finite with the different claim that motion can continue indefinitely along a constrained path. The same confusion often appears in cosmology: endless traversability is presented as though it were equivalent to spatial infinitude, when in fact it is only a different and weaker claim.
The three-sphere proposal does not resolve the contradiction; it merely recasts it in the language of higher-dimensional topology. The relevant question is whether it supplies a physically meaningful account of finitude.

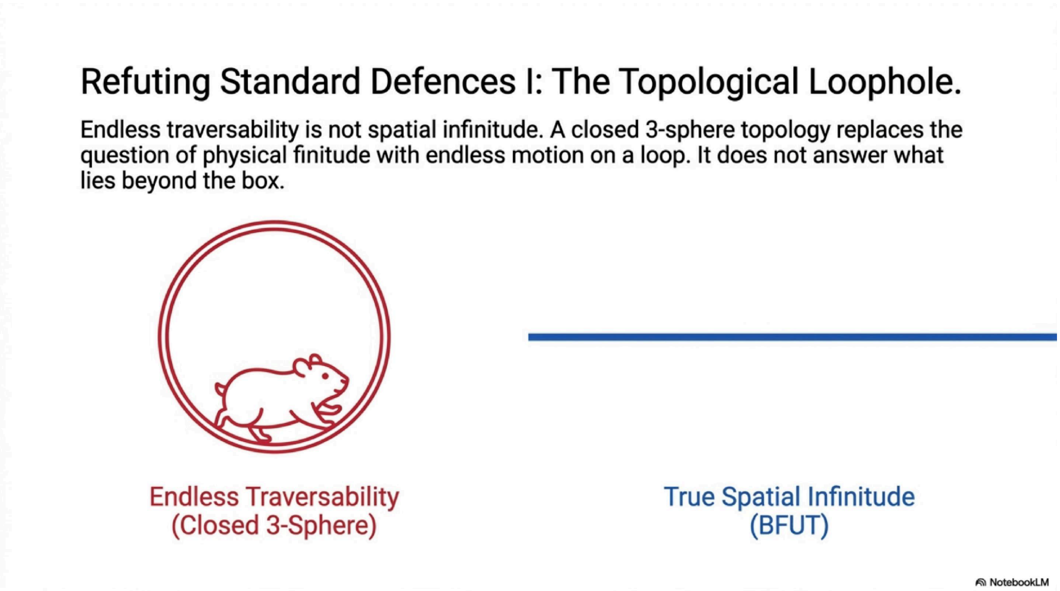


*Figure 5. Refuting the Finite-but-Unbounded Defence: A closed 3-sphere topology replaces the question of physical finitude with endless traversability on a loop. It does not answer what lies beyond the boundary.*

The scientific enterprise exists precisely to go beyond what appears to an observer and find what actually is. An observer inside an enormous finite universe cannot see its edge. An observer inside an infinite universe also cannot see its edge. To both observers the universe appears identical: isotropic, extending equally in all directions, with the observer at the apparent centre. The question is not what appears to the observer. The question is what is actually there. Physics does not stop at the limits of human perception and say one cannot know. Physics asks: if one could go macro, if one could step outside the observer frame entirely, what is the actual geometry? Is the universe infinite or finite? If it is finite, it has a shape. What is that shape? What formula gives its total extent? The challenge is to specify what physical finitude means in this case. A purely formal topological description is not yet a complete physical account.

Furthermore, a Big Bang does not predict a three-sphere. Inflation - invented specifically to explain why the universe appears spatially flat - actively contradicts a detectable three-sphere, because a perfectly flat universe is infinite. The Planck 2018 results (2020) measurement of spatial curvature gives Omega_k = 0.001 +/- 0.002, consistent with zero curvature and consistent with infinite flat space. The standard model uses inflation to explain flatness and then separately invokes three-sphere topology to maintain finiteness. These two claims are in direct tension. Neither is independently confirmed by observation. The three-sphere is a post-hoc addition to the standard model, not a prediction of it.

The three-sphere was specifically tested. The Planck satellite analysed the CMB for the signature of a finite universe - the wraparound signal that would appear if light had travelled all the way around a finite universe and returned. No such signal was found. The standard model's response was not to abandon the claim but to assert that the universe is finite but too large for the wraparound signal to have reached us. A claim that cannot be detected, cannot be tested, and cannot be falsified under any observational programme is not a scientific claim. It remains a speculative claim that survives only by relocating the predicted signal beyond observational reach whenever confirmation fails.

The decisive challenge is not merely philosophical but physical: a finite totality must mean more than an elegant topological description. A mathematically closed manifold may be formally valid, but formal validity alone does not supply a physically meaningful account of what makes the totality of space finite. The problem is that any attempt to make such finitude physically intuitive tends to reintroduce the very notion of delimitation the model is trying to avoid. If no physically meaningful account of finitude can be supplied, the claim remains formally possible but physically under-explained.

First, Planck 2018 results (2020) strongly constrains spatial curvature and leaves little observational room for a substantially closed geometry. While this does not by itself eliminate every mathematically closed model under all dataset combinations and priors, it materially weakens the empirical case for a physically significant closed global geometry.

A further difficulty: there is only one scenario in which a finite universe could avoid needing to expand outward - if it were expanding inward from its boundary toward us. But this scenario generates its own contradictions. First, the distance to the boundary would be different in different directions. An observer located anywhere other than the exact geometric centre of the finite universe would be closer to the boundary on one side than the other - producing observable asymmetry in all directions. No such asymmetry is observed. The CMB is uniform to one part in 100,000 in all directions. Second, if the universe is approximately 94 billion light years across - the current diameter of the observable universe - an observer near the boundary would find themselves only a few billion light years from the edge on one side and approximately 90 billion light years from it on the other. The universe would look completely different in opposite directions. It does not. Third, for each point on the boundary, the direction of inward expansion would be different - pointing toward a different centre depending on where on the boundary you are located. The expansion direction cannot be consistently defined. The inward expansion scenario does not escape the boundary problem. It multiplies it.

The standard model simultaneously holds three claims that contradict each other. First: the universe is finite - a closed system with a fixed total content. Second: energy is not conserved globally - photons lose energy through cosmological redshift and that energy simply disappears. This is not a fringe claim. It is stated openly by leading cosmologists: energy conservation does not hold globally in an expanding universe under general relativity. But a finite closed system cannot leak energy. If energy is disappearing, something outside the system is receiving it. If something outside the system exists, the system is not closed. If the system is not closed, the universe is not finite and self-contained. The two claims - finite universe and disappearing energy - are mutually exclusive. They cannot both be true.

Third: they say the finite universe is inflating - expanding from within. Expanding into what? If the universe is truly finite with nothing outside it, there is nothing to expand into. If there is something outside it to expand into, that something exists, which means the universe is not all there is, which means the boundary is not the boundary of everything, which means the universe is not finite in the sense they claim. Expansion requires space to expand into. Space to expand into is space. That space is part of the universe. The boundary retreats. It always retreats. This is the definitional proof of Section 2 stated again in the language of inflation.

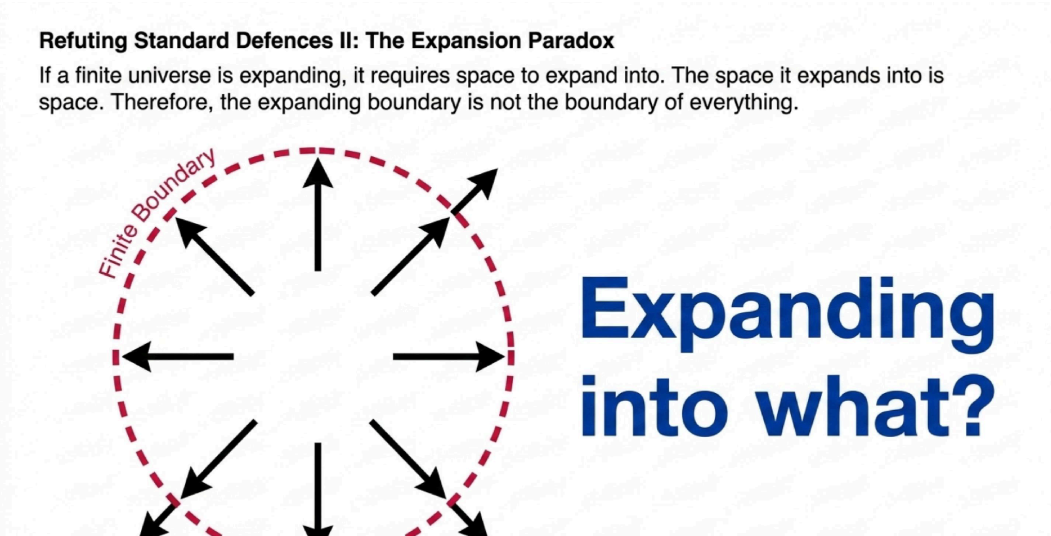


*Figure 6. The Expansion Paradox: If a finite universe is expanding, it requires space to expand into. That space is part of the universe, so the boundary retreats. A truly finite universe cannot expand.*

The three contradictions cannot be resolved individually because they are generated by the same foundational error: asserting a finite universe while retaining physical laws that require either infinity or a boundary. The standard model does not resolve these contradictions. It lives with them, names them - the cosmological constant problem, the horizon problem, the flatness problem, the coincidence problem - and proposes patches for each one individually. BFUT does not need the patches because it does not have the contradictions. An infinite eternal universe conserves energy globally, has no horizon problem, is flat by default, and has no coincidence problem. Within the BFUT framework, these additional mechanisms are interpreted not as independent necessities but as compensatory constructs introduced to preserve the finite-origin picture.

**Cosmological Framework Comparison.**

| Dimension | Standard Model (Finite-Origin) | BFUT (Spatial Infinitude) |
|---|---|---|
| Boundary Nature | Conceptually undefined / mathematical loophole | Non-existent; absolute infinitude |
| Singularity Location | Contradictory (Everywhere yet finite) | No singular origin |
| Expansion Medium | Space expands into non-space | Matter dynamics within an infinite Spaticle substrate |
| Paradoxes Created | Horizon and Flatness problems requiring Inflation | Dissolves horizon and flatness problems entirely |



*Figure 7. Cosmological Framework Comparison: Key differences between the standard finite-origin model and the BFUT framework of spatial infinitude.*

### 4.2 General Relativity Breaks Down at the Singularity

The second response acknowledges that the singularity is a mathematical artefact of classical general relativity extrapolated beyond its range of validity. At the Planck density, quantum gravitational effects dominate and the singularity represents a failure of the theory instead of a physical state.

This response is intellectually honest but relocates instead of resolves the boundary condition. If GR breaks down at the Planck scale and is replaced by quantum gravity, the question becomes: where was the Planck-density region from which the current universe expanded? The singularity location argument applies to this question with equal force.

### 4.3 Inflation

The third response invokes inflation: a period of exponential expansion that stretched a small causally connected region, approximately 10^-26 metres in diameter, to a size larger than the current observable universe. This eliminates the horizon problem and appears to resolve the singularity location problem.

But inflation relocates instead of resolves the problem. The inflationary patch had a location. Where was that location? By the standard response it was everywhere. The singularity location argument applies to the inflationary patch with the same force as to the singularity itself.

Furthermore, the Borde-Guth-Vilenkin theorem [3] proves that any spacetime that is on average expanding must be past-incomplete: it cannot be extended arbitrarily far into the past without a boundary. Inflation requires average expansion. Therefore inflation requires a past boundary. The singularity location argument applies to that boundary.

Inflation does not extend past the boundary it requires. It does not resolve the boundary condition. It assumes one.

### 4.4 Loop Quantum Cosmology

Loop Quantum Cosmology [4,5] replaces the Big Bang singularity with a quantum bounce, avoiding the classical singularity. The equations remain well-defined through the bounce. This is a more physically direct approach than classical inflation.

However, the quantum bounce does not resolve the spatial infinitude argument. It transforms the question to: where was the minimum-volume state at the bounce? If that state filled all of space, the universe is infinite and the argument is trivially satisfied. If it had finite spatial extent, the argument applies to its boundary.

LQC models that allow a past-eternal bouncing universe concede the key structural claim of BFUT: the universe has no beginning. The disagreement is then about mechanism instead of the logical structure of spatial infinitude. A bouncing eternal universe and an infinite eternal universe both satisfy the definitional proof of Section 2.

## 5. The Derivational Proof: Lambda and the Infinite Uniform Distribution

The cosmological constant Lambda, observed to have a value of approximately 1.1 x 10^-52 m^-2, provides a derivational proof of spatial infinitude through the following argument, detailed in the companion paper on the cosmological constant [6].

In an infinite, uniform spatial distribution, the net gravitational force at any point is zero by isotropy: the gravitational pull from every direction cancels exactly. This is the established resolution of the Newtonian cosmological paradox. For such a distribution, the Ricci curvature tensor R_mu_nu vanishes everywhere by symmetry. The Einstein field equations reduce to:

$$\Lambda g_{\mu\nu} = (8 \pi G / c^4) T_{\mu\nu}$$

giving directly:

$$\rho_{substrate} = \Lambda c^2 / (8 \pi G) \approx 5.9 \times 10^{-27} \text{ kg/m}^3$$

This derivation is only valid for an infinite uniform distribution. A finite universe does not have the isotropy required for R_mu_nu = 0 everywhere: near the boundary, the distribution is asymmetric and the Ricci tensor does not vanish. The fact that Lambda has a well-defined positive value consistent with a uniform infinite distribution is therefore derivational evidence that the universe is spatially infinite.

This density, ρ_substrate, is the equilibrium density of the Spaticle field: a continuous, physically real substrate filling space, developed throughout the BFUT programme and applied here to the infinitude argument. I did not invent the idea that space might be more than empty geometry. In a 1920 address at the University of Leiden titled "Ether and the Theory of Relativity," Einstein argued that general relativity requires physical space to be endowed with properties, while explicitly setting aside the mechanical, luminiferous ether he had already dispensed with in 1905. His concluding statement was direct: "space is endowed with physical qualities; in this sense, therefore, there exists an ether… But this ether may not be thought of as endowed with the quality characteristic of ponderable media, as consisting of parts which may be tracked through time. The idea of motion may not be applied to it" [13].

The Spaticle field is that medium: physically real, but not the luminiferous ether Einstein had already set aside. It supplies the measurable quantity his own equations required but that he stopped short of assigning: an intrinsic equilibrium density, together with the derived stiffness, relaxation time, and propagation speed developed elsewhere in the BFUT programme.

The value $\rho\_substrate$ approximately $5.9 \times 10^{-27}$ kg/m^3 is of the same order of magnitude as the observed mean matter density. In a finite universe with a boundary, this proximity would

be a coincidence. In an infinite universe where matter arises from the substrate, it is a physical consequence.

## 6. The Observational Proofs

### 6.1 Galaxy Orientation Evidence

If the universe were finite with a boundary, or if it originated from a finite region through a Big Bang or inflationary event, one would expect some large-scale directional imprint in structure formation. Such an imprint, if present, should appear as a robust global preferred axis or a universal directional relic across sufficiently large survey volumes.
The current observational record does not establish such a result. Various studies have reported local or regional handedness asymmetries, spin correlations, and environmental alignments in subsets of galaxy populations. These findings are not inconsistent with BFUT. Local and regional coherence can naturally arise through gravitational sorting and environment-dependent structure formation. However, such local or scale-dependent effects do not amount to a single globally established preferred axis across the observable universe. The relevant observational point is therefore not that every asymmetry claim must be rejected, but that no single globally compelling boundary-consistent axis has been established at the level required to overturn the large-scale isotropic character of the universe. This is more naturally consistent with an infinite gravitationally structured universe than with a finite bounded cosmos or a uniquely directed finite-origin event.

### 6.2 Large-Scale Ordered Motion Beyond the Naive Local Limit

Large-scale ordered motion is observed not only within individual galaxies but also at progressively larger scales in filaments, clusters, and surrounding environments. This is directly relevant to the question of whether cosmic structure behaves as though large-scale coherence is rapidly erased beyond a narrowly local regime.

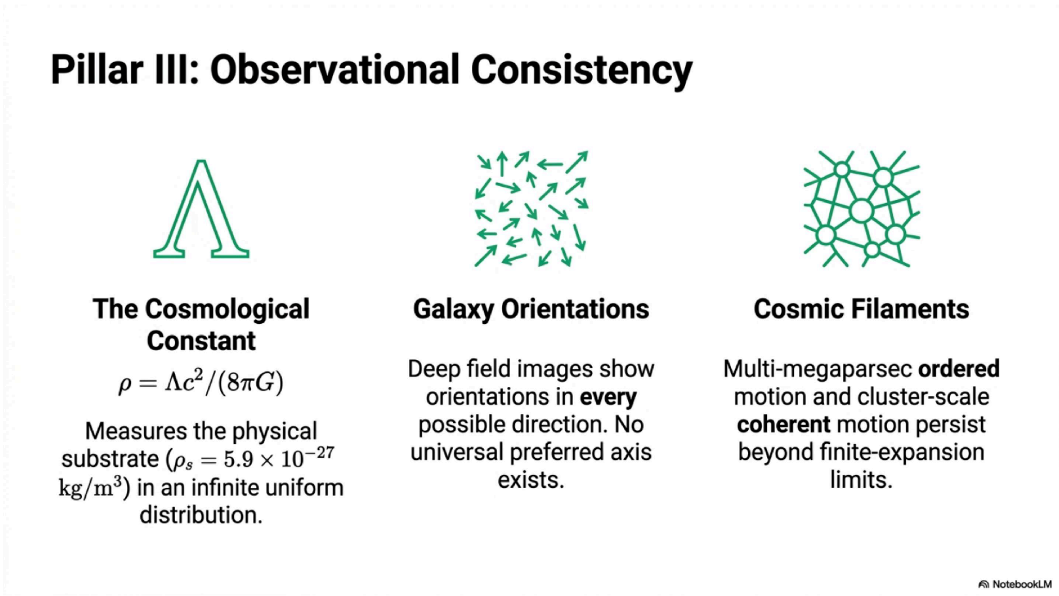


*Figure 4. Observational Consistency with Spatial Infinitude: The cosmological constant, galaxy orientations, and persistent large-scale coherent motion in filaments and clusters are all consistent with an infinite universe.*

Recent observational work has reported one of the largest rotating structures yet identified: a giant rotating cosmic filament approximately 140 million light years in extent (about 43 Mpc), containing a long string of galaxies embedded in a large-scale spinning structure. This is already many times larger than the approximately 1 Mpc scale often treated as the threshold beyond which Hubble expansion should dominate over local orbital-style coherence.

This is not an isolated observation. Independent studies have also reported statistically significant coherent spin in galaxy clusters. Earlier cluster-rotation analyses identified non-trivial subsets of rotating systems, while more recent large-sample work using thousands of clusters has reported strong statistical evidence for coherent cluster spin. Independent CMB-based work has also reported rotational kinematic Sunyaev-Zel'dovich signatures aligned with cluster rotation directions, providing an additional observational channel for the same phenomenon.

At somewhat smaller but still clearly supra-galactic scales, observational work has reported dynamical coherence between galaxy rotation and the average motion of neighbouring galaxies across several-megaparsec environments, with the strongest signal in the 1-6 Mpc range and coherence maps extending still farther. Taken together, these results indicate that structured non-random motion persists well beyond the simplistic boundary between purely local dynamics and pure Hubble flow.

### 6.3 The Absence of Boundary Pressure

A finite universe with a physical boundary would imply an asymmetric physical environment near that boundary. Matter and radiation close to such a boundary would not experience balanced conditions in all directions: the interior would contribute gravitational and radiative influence from one side, while no corresponding contribution would exist beyond the boundary. This would generate a directional asymmetry in the physical conditions near the edge.

No such asymmetry has been detected in direction-dependent measurements of the CMB, galaxy distributions, or large-scale velocity fields. The universe is isotropic to one part in 10^5 in the CMB and remains consistent with large-scale isotropy within current survey precision in galaxy distributions. A boundary at any accessible scale would be expected to produce a detectable asymmetry. No such asymmetry is observed.

**7. The Balloon Analogy and Its Rotation Failure**

The balloon analogy proposes that galaxies are like dots on an expanding balloon surface: they recede from each other as the balloon expands without any force acting between them. This analogy becomes increasingly strained once one admits that large-scale ordered motion persists in filaments, clusters, and multi-megaparsec environments well beyond the scale often treated as the onset of purely metric separation.

On an expanding balloon surface, the intuitive expectation is that sufficiently large-scale ordered return motion should be progressively diluted as the background expansion dominates. Yet observations continue to show coherent large-scale motion beyond the simplistic local regime. That does not by itself falsify every metric-expansion formulation, but it does undermine the common pedagogical claim that beyond roughly local scales the dominant physical behaviour should reduce to passive recession alone.

The deeper problem is therefore not a single supercluster anecdote but a scale ladder: from galaxy environments to clusters to very large filaments, ordered motion persists where a naive expanding-container intuition would expect it to fade. The balloon analogy is at best incomplete and at worst physically misleading when elevated from pedagogy to ontology.

**8. Predictions**

Prediction 1: No preferred axis in galaxy orientations will be found at any survey scale, consistent with an infinite isotropic universe. Falsification: detection of a statistically significant preferred axis in galaxy spin orientations across survey volumes exceeding 500 megaparsecs.

Prediction 2: Coherent rotational and other ordered large-scale structures will continue to be found at progressively larger scales as survey volumes increase, with no sharp natural stopping scale. Falsification: a robust confirmed absence of such ordered structures beyond a well-resolved scale after sufficient survey coverage.

Prediction 3: No universal expansion-induced asymmetric orbital distortion of the kind expected from a naive expanding-container interpretation will be found as larger systems are mapped more precisely. Falsification: repeated detection of a clean scale-dependent dynamical distortion uniquely attributable to such an expansion term instead of ordinary gravitational/environmental structure.

Prediction 4: The CMB temperature will be found to be consistent with 2.725 K in every direction and at every accessible distance, with no boundary signature. Falsification: detection of a systematic temperature gradient consistent with proximity to a finite boundary.

Prediction 5: No edge, no wraparound signal, no preferred centre - ever. As observational instruments extend their reach, no edge of the universe will be found in any direction. No wraparound signal will be detected - no observation of the same structure seen from two different directions at different distances, which would be the signature of a finite universe whose light has circled back. Every telescope at every scale will find itself at the apparent centre of an isotropic universe extending equally in all directions - not because every observer happens to be at the centre, but because in an infinite universe every point is the centre. There is no centre. There is no edge. The observable universe will expand as instruments improve, and what lies beyond each new horizon will be more of the same: matter, structure, and space, without boundary, without end. Falsification: detection of a genuine spatial edge, a confirmed wraparound signal, or any observation that cannot be explained without invoking a finite universe.

## 9. Conclusion

The universe has no boundary. This conclusion follows from three independent categories of argument. Conceptually, a physical boundary of space is incoherent. Logically, the standard model's own answer to the singularity-location question points away from a finite localised origin. Derivationally and observationally, the cosmological constant result, the absence of a single robust global preferred axis, and the persistence of large-scale ordered motion from filaments to clusters and supra-galactic environments are all more naturally consistent with an infinite universe than with a finite expanding one.

Three standard responses to the spatial infinitude argument, the finite hypersphere, the GR breakdown, and inflation, each relocate instead of resolve the boundary condition, or concede structural elements of spatial infinitude. The Borde-Guth-Vilenkin theorem confirms that inflation requires a past boundary, and Loop Quantum Cosmology, in its most honest formulation, concedes a past-eternal universe.

Spatial infinitude is not a philosophical preference. It is the logically required, derivationally supported, and observationally consistent description of the universe. The boundary is not there because it cannot be there. Space, by definition, has no edge.

# APPENDIX A

## Mathematical Appendix: Universe Has No Boundary

The mechanical derivations in this appendix can be independently verified. The interpretive steps are clearly distinguished from the derivations throughout.

**A note on all values.** Every calculation in this appendix uses only confirmed measurements. The tensile strength of steel, atmospheric pressure, the radius of the observable universe, and Newton's constant are all measured values. No model-dependent parameters.

### A.1 Illustrative Reductio: Why a Literal Physical Boundary Cannot Serve as a Coherent Model of the Universe

The shell calculation below is not meant to model standard closed FLRW cosmology, but to make explicit a simple physical point: if finitude is re-physicalised as an actual enclosure, then the universe becomes an effective vacuum vessel, and the question immediately becomes whether any enclosing boundary could resist the implied external pressure at cosmic scale.

If the universe were finite and physically bounded, its interior would behave as an effective low-pressure domain relative to any external medium. In that case, the boundary would not merely define an edge; it would have to withstand an immense net inward pressure. Without an extraordinarily strong enclosing shell, such a structure would collapse instead of expand.

The intuition is familiar even at ordinary scale. A loosely folded paper sphere can be puffed outward into a roughly spherical form, but the slightest inward pressure crushes it immediately. A rigid metal vessel can resist that same atmospheric pressure only because its shell is sufficiently strong for its size. As the radius increases, the total force acting on the enclosing surface rises dramatically, so the shell must become correspondingly stronger. At cosmological scale, the required boundary ceases to be a plausible physical object and becomes an absurdity.

**This appendix is not presented as a model of standard closed FLRW cosmology, but as a reductio against any attempt to re-physicalise finitude as a literal enclosing boundary.**

#### A.1.1 The setup

Before the calculation, one physical fact must be stated explicitly because it determines the structural problem entirely. The universe is, to all physical purposes, a vacuum: the mean matter density of the observable universe is low enough that the interior of the universe is indistinguishable from a perfect vacuum for structural purposes. The internal pressure is effectively zero. This means any proposed boundary shell faces a structural condition far worse than a standard pressure vessel. A normal pressure vessel has internal pressure pushing outward, which partially counteracts external forces. Here there is no such counter-pressure. The shell is simultaneously being pushed inward by whatever exists outside and sucked inward by the vacuum it contains. It must withstand the full load entirely on its own, with nothing pushing back from the interior. The calculation below uses this condition.

If the universe were finite, it would require a physical boundary - a shell containing all of space. Section 2 of the main paper presents this as an illustration of physical impossibility. Here every step is shown numerically.

The calculation asks: modelling the boundary as a spherical pressure vessel (the strongest conceivable physical structure), how thick would it need to be?

A.1.2 The formula - spherical pressure vessel

For a thin-walled spherical pressure vessel under internal pressure P, required wall thickness t to prevent failure is:

$$t = P \times R / (2 \times \sigma)$$

where P = internal pressure, R = radius of the sphere, σ = tensile strength of the material.

### A.1.3 The measured inputs

- R = radius of observable universe. The proper radius of the observable universe is approximately 46.5 billion light years (diameter 93 billion light years), accounting for the expansion of space in the standard model between emission and observation. In BFUT, there is no expanding space, so the relevant distance is the observable radius of approximately 46.5 billion light years = $4.4 \times 10^{26}$ m. The

  calculation holds at any finite radius - the conclusion that no physical boundary can exist is independent of which figure is used.

P = pressure differential across the boundary shell. Since the interior is a vacuum (internal pressure = 0), the full external pressure acts unopposed. Earth's atmospheric pressure is used as the minimum conceivable external pressure: P = 101,325 Pa. This is a deliberately conservative choice - there is no physical reason to expect external pressure to be as low as one atmosphere, and any realistic external medium would exert far more. But even this minimum produces an impossible result.

- σ = tensile strength of steel = $4 \times 10^8$ Pa. This is the strongest common structural material. Any conceivable boundary material must be at least this strong to resist pressure.

### A.1.4 Full calculation

$$t = P \times R / (2\sigma)$$

$$= 101,325 \times 4.4\times10^{26} / (2 \times 4\times10^{8})$$

$$= 4.458\times10^{31} / 8\times10^{8}$$

$$= 5.57\times10^{22} \text{ m}$$

Converting: 1 light year = $9.46\times10^{15}$ m

$$t = 5.57\times10^{22} / 9.46\times10^{15} = 5.9 \times 10^{6} \text{ light years} \approx 5.9 \text{ million light years}$$

The Milky Way is approximately 100,000 light years in diameter. The required boundary shell is approximately 59 Milky Way diameters thick.

### A.1.5 Mass of this shell

Volume of shell: $V \approx 4\pi R^2 t = 4\pi \times (4.4\times10^{26})^2 \times 5.57\times10^{22} = 1.36\times10^{77}$ $m^3$

Density of steel: $\rho = 7{,}800\ kg/m^3$

$$M\_shell = \rho \times V = 7800 \times 1.36\times10^{77} = 1.06\times10^{81}\ kg$$

Estimated mass of observable universe: $M\_universe \approx 10^{53}$ kg

$$M\_shell / M\_universe = 10^{81} / 10^{53} = 10^{28}$$

The boundary shell would need to be approximately $10^{28}$ times more massive than the entire observable universe it contains. This is not a constraint that can be satisfied by any physically plausible structure. This calculation assumes atmospheric pressure, which is the lowest physically meaningful external pressure. If higher external pressures are assumed, the required shell thickness and mass increase proportionally, making the scenario even more physically impossible. Lower pressures reduce the required thickness, but the conclusion remains unchanged: no physically possible boundary can exist. Therefore, the universe is spatially infinite.

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## A.2 The Spaticle Field Energy Density - Compact Derivation

Section 5 of the main paper derives $\rho\_s = \Lambda c^2/(8\pi G)$ from the reduced Einstein field equations. The full numerical derivation with every step shown is in companion paper [6] Appendix A. The key result:

- $\Lambda = 1.1 \times 10^{-52}\ m^{-2}$ (measured, Planck 2018 results (2020))
- $c = 3 \times 10^8$ m/s (defined)
- $G = 6.674 \times 10^{-11}\ m^3\ kg^{-1}\ s^{-2}$ (measured)

Substituting these values yields the same numerical substrate density stated in Section 5 and derived in full in companion paper [6].

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