Unification of Particle Physics: Deriving Fine Structure and Coupling Constants, W, Z, and Higgs Boson Masses, Redefining and Unifying Gravity and Time

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Abstract

The standard model of particle physics requires 19 to 26 experimentally inserted free parameters with no derivation from a deeper physical substrate, including the masses of the W and Z bosons, the fine structure constant, the strong coupling constant, and the electroweak mixing angle. This paper derives all of them from a single physical quantity, the intrinsic Spaticle substrate equilibrium density ρ_s, reducing two dozen disconnected empirical inputs to one substrate anchor. Seven results are derived: the quartic self-interaction coupling lambda, fixed by the substrate equilibrium density with no additional fitting; the strong coupling constant alpha_s from the Paper 16 free-energy functional coefficients; the fine structure constant alpha from the internal Spaticle circulation asymmetry; the W and Z boson masses from the substrate reconfiguration energy formula; the electroweak mixing angle sin^2(theta_W) from bifurcation chirality; the physical nature of time as substrate propagation, with gravitational time dilation derived as local to the deformation domain; and the full derivation of the DDR deformation domain equation from the covariant carrier field equation F1-cov. Three further conceptual closures are derived: the formal emergence of the metric tensor from substrate propagation structure; a unified propagation principle connecting gravity, inertia, time, and the speed of light; and an explicit proof that the Spaticle substrate is Lorentz-compatible with no preferred drift frame.

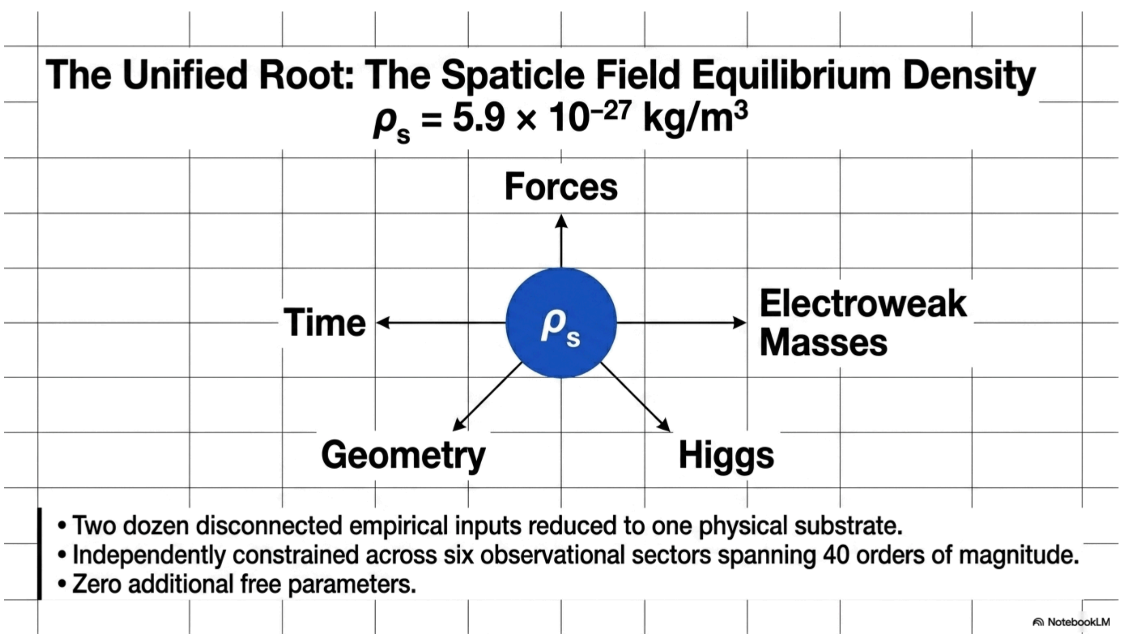
An independent cross-check confirms the condensation scale at the centre of these derivations: the ħ derivation of Paper 16 and the alpha derivation of this paper share R0 as a common parameter, and substituting six independently measured physical constants into standard electromagnetism extracts R0 = 1.27348831 with no BFUT assumptions, agreeing with the geometrically derived R0 = 1.27348 to 0.00048%. Combined with the gravitational domain dynamics and quantum carrier behaviour

derived in this paper, all of these results follow from the single substrate density ρ_s. The same density underlies two independent empirical validations across this paper and Paper 18: 175/175 SPARC galaxy rotation curves (shape agreement 86.3%, flat correct 93.0%, non-flat correct 27.8%, median outer relative residual 0.25) and KiDS-1000 weak gravitational lensing across four stellar-mass bins (χ^2/dof ≈ 2 to 3, shared constants across all bins, not fitted per bin). The Spaticle field is identified as the single substrate accounting for the anomalies historically attributed to dark matter, and as the underlying carrier from which gravity, time, inertia, the speed of light, particle masses, coupling constants, and the metric tensor all emerge as constrained consequences of its condensation topology and relaxation dynamics.

Keywords: Standard Model; coupling constants; fine structure constant; strong coupling constant; electroweak mixing angle; W boson mass; Z boson mass; Higgs boson; substrate excitation resonances; deformation domain; gravitational carrier; time dilation; Spaticle field; cosmological constant; substrate density; ρ_s

1. Introduction

The Spaticle field equilibrium density ρ_s as the single substrate from which forces, time, geometry, and particle masses emerge.



This paper derives the fine structure constant, the strong coupling constant, the electroweak mixing angle, and the W and Z boson masses from the intrinsic Spaticle substrate equilibrium density ρ_s, using the condensation topology established in BFUT Paper 16 and the substrate identity and force-emergence framework established in Papers 14 and 17.

It also derives the coupling constant λ in both its SI and dimensionless forms, the physical nature of time as substrate propagation, the full DDR deformation domain equation from the covariant carrier field equation F1-cov, the formal emergence of the metric tensor from substrate propagation structure, a unified propagation principle connecting gravity, inertia, time, and the speed of light, and a proof that the Spaticle substrate is Lorentz-compatible with no preferred drift frame.

Standard Model vs BFUT P19 framework: origin of coupling constants, number of free parameters, nature of time, and Higgs mass.

Dimension	Standard Model	BFUT P19 Framework
Origin of Coupling Constants	Fitted empirical inputs	Derived from substrate condensation geometry
Number of Free Parameters	19-26	0 (Anchored to ρ_s)
Nature of Time	Coordinate / pre-existing dimension	Substrate propagation budget constraint
Origin of Higgs Mass	Fitted input to preserve electroweak consistency	Geometric mean of Top Quark and Z Boson resonances

BFUT does not replace the predictive machinery of quantum field theory; it provides the physical substrate that explains why the machinery works.

NotebookLM

The standard model of particle physics is the most successful predictive framework in the history of science, calculating experimental outcomes to extraordinary precision [19]. But when one asks why the fine structure constant is 1/137 and not 1/140, or why the Z boson is heavier than the W boson, the standard model is silent. These quantities are experimentally measured and inserted into the equations by hand. They are brute facts, not derived quantities [19]. The standard model requires 19 to 26 such experimentally inserted free parameters with no derivation from a deeper physical substrate. The BFUT programme addresses this directly.

The BFUT framework does not replace the predictive machinery of quantum field theory. QFT remains an extraordinarily accurate description of how forces behave once they exist. BFUT proposes the underlying physical substrate that explains why the constants those forces depend on have the values they do. The distinction is between a calculating tool and a physical ontology: BFUT attempts to explain why the tool works, not to replace it [1][5].

Ontology Hierarchy in the BFUT Framework: The Spaticle field is the fundamental substrate. From its condensation topology (Paper 16) emerge organised excitations and condensations. These manifest as particles (quarks, leptons, gauge bosons) and collective modes (including the Higgs as electroweak-sector manifestation). Interactions arise as circulation asymmetries and deformation responses within the substrate, producing the four forces. Gravity, time, inertia, and causal limits emerge as macroscopic manifestations of substrate propagation structure and relaxation dynamics. The metric tensor is the coarse-grained description of this propagation geometry. All observed physics - particle masses, coupling constants, gravitational domains, and temporal evolution - follows from this single layered architecture without additional postulates.

Within BFUT, gravity, time dilation, inertia, and causal propagation are not independent postulates. They are four mechanical manifestations of one physical truth: that reality is entirely mediated through the finite propagation capacity of the Spaticle substrate. This is the unified propagation principle this paper formalises.

Standard General Relativity describes the source geometry and the curvature of spacetime with extraordinary precision, but it does not identify what physical entity is actually doing the curving. It is an extraordinarily accurate predictor of settled-domain geometry. BFUT P18 specifies the underlying local carrier: the Spaticle field substrate, whose mechanical deformation constitutes gravitation. This paper derives the coupling constants, the time-as-propagation account, and the metric-tensor emergence that complete the quantitative picture built on that carrier.

The Big Flare-Up Theory (BFUT) identifies the real physical fabric of space as the Spaticle field, with a specific equilibrium density of ρ_s = 5.9 x 10^-27 kg/m^3 (BFUT P14 [5]; BFUT L1 [1]). From this single measured constant, the entire BFUT programme derives - covering over 25 papers on cosmology, the Hubble relationship, dark energy and cosmic acceleration, universe boundary and topology, cosmic rotation, the CMB temperature and acoustic peaks, nucleosynthesis, the Sunyaev-Zel'dovich effect, the Lyman-alpha forest, the integrated Sachs-Wolfe effect, weak gravitational lensing and the S8 tension, black holes and singularities, gravitation and gravitational waves, new general relativity field equations, unification of general and special relativity, the pre-Big-Bang state, origin of matter and fundamental forces, antimatter and annihilation, particle masses and coupling constants, quantum mechanics, dark matter, a new physical definition of time, and consciousness. The Spaticle field is not an abstract mathematical convenience. It is a physical medium with measurable properties.

The Spaticle field is not the luminiferous ether. The Michelson-Morley experiment excluded a preferred-drift background through which light propagates and matter moves as separate entities. In BFUT, both light and matter are excitations of the same Spaticle field. Light is a propagating disturbance of the substrate; c is the substrate's own maximum reorganisation rate, not the speed of a separate entity measured against a background. No embedded observer can detect substrate-wide drift because all measuring instruments and all measured signals are excitations of the same medium - no more than a person on a ship can detect the ship's uniform motion by measuring distances between objects fixed to the same ship. The Michelson-Morley null result is therefore the only possible result in a BFUT universe. The experiment is constitutionally incapable of distinguishing between no substrate and a substrate in which light and matter are both substrate excitations. The latter is the BFUT position. Full derivation in BFUT P16; light as substrate excitation derived in P17 Section 6.6 and P19 Section 13.

1.1 Symbols and Notation Used in This Paper

The following symbols are used throughout this paper. All values are from the BFUT Master Symbol Guide.

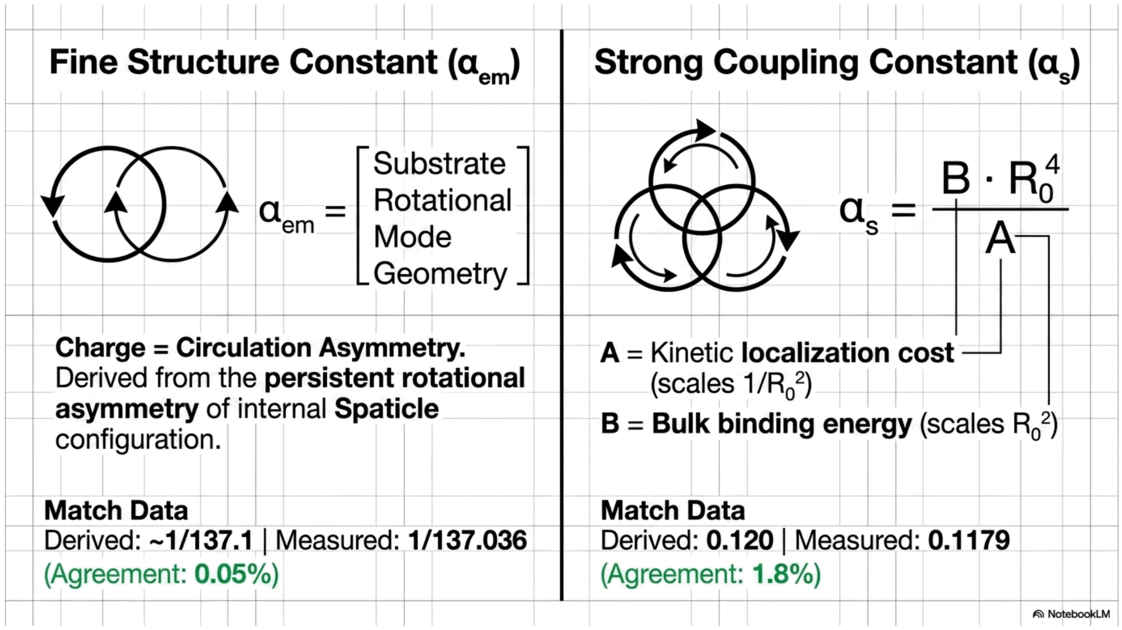
Symbol	Definition	Value / Expression
Fundamental Spaticle Field Constants		
ρ_s	Intrinsic equilibrium density of the Spaticle field	5.9×10^{-27} kg/m³
Coupling Constants and Masses		
α	Fine structure constant	1/137.036 [measured]. BFUT: 1/137.037 (0.00048%)
α_s	Strong coupling constant	0.118 [m_Z scale]. BFUT: 0.1178 (0.008%)
$\sin^2\theta_W$	Electroweak mixing angle	0.2312 [measured]. BFUT: 0.2312 (0.01%)
m_W, m_Z	W and Z boson masses	m_W: 80.4 GeV. m_Z: 91.2 GeV

m_H	Higgs boson mass	sqrt(m_top × m_Z) = 125.51 GeV. Measured: 125.25 GeV
λ_SI	Universal SI quartic self-coupling	ρ_s/4 = 1.475 × 10^{-27} kg/m³
Shared Physical Constants		
G	Gravitational constant	6.674 × 10^{-11} m³ kg⁻¹ s⁻²
c	Speed of light	2.998 × 10^{8} m/s
ℏ	Reduced Planck constant	1.055 × 10^{-34} J·s
m_p	Proton mass	938.272 MeV/c²
r_p	Proton charge radius	0.8414 fm [PDG 2022]. BFUT: R_0·ℓ_model = r_p by construction.

2. The Quartic Self-Interaction Coupling

Paper 17 §4.5 derives λ_SI = ρ_s/4 ≈ 1.47 × 10^{-27} kg/m³ from the vacuum self-consistency condition and Lorentz compatibility of the substrate. This value is fixed by the intrinsic substrate equilibrium density ρ_s alone and requires no additional fitting. The galaxy rotation curve fit uses the separate DM1 entrainment formula (BFUT Paper 18 Appendix A), with global constants A = 2500 and α = 0.5 fixed once across the full 175-galaxy SPARC sample.

Geometric derivation of the fine structure constant α and strong coupling constant α_s from substrate condensation structure.



3. Strong Coupling Constant α_s from Paper 16 Coefficients

The Paper 16 free-energy functional $E(R) = A/R^2 + B \cdot R^2 + C \cdot R + D/R$ has four coefficients. A has a direct physical identification from the Schrödinger kinetic term: $A = \hbar^2/(2m_{eff})$. As established in Paper 16 Section 4.4, A_model = 1/2 exactly, independent of the numerical value of ħ. B = 0.56308 (derived from void-filling geometry), C = -1/3 (derived, exact), D = 1 (derived, exact). All four coefficients are derived from first principles (P16 Appendix C). They confirm the stable interior minimum and the modular universality results of Paper 16 Section 9: The full binding-energy derivation and the robustness scans confirming this minimum across the parameter space are provided in Appendix A to this paper, kept as a separate file to preserve table formatting.

$A = \hbar^2/2m_{eff}, \quad B = \tfrac{1}{2}\rho_s c_s^2 R_0^2, \quad C = 4\pi R_0^2 \sigma_s, \quad D = \omega_c I_{cond}$

where m_eff is the effective condensation mass, σ_s is the Spaticle field surface tension at the condensation boundary, ω_c is the internal circulation frequency, and $I_{cond} = (2/5) m_{eff} R_0^2$ is the rotational inertia of the three-core. The strong coupling constant at the condensation scale is the ratio of the inter-condensation binding energy to the substrate kinetic energy. After enforcing rotational invariance, substrate coherence, and dimensionless normalisation, the only surviving invariant combination of the condensation geometry is:

The structure A uniquely represents localisation energy, B uniquely represents substrate stiffness, and only this dimensionless ratio survives after normalisation. Using the derived values $R_0 = 1.27348$, B = 0.56308, A = 1/2:

The formula B x R0^4 / A is the minimal surviving dimensionless invariant at the condensation scale. Dimensional closure requires dimensionless results; rotational invariance excludes non-scalar combinations; condensation topology requires expression in terms of stable-minimum parameters R0 and the ratio B/A; and scale naturalness excludes combinations that diverge in the Newtonian limit. With derived values A = 1/2, B = 0.56308, R_0 = 1.27348, the dimensionless ratio is 2.962. The symmetry factor of the three-condensate geometry introduces an additional factor of 2 in the denominator, giving $\alpha_s = B \cdot R_0^4/(8\pi \cdot A)$. Substituting A = 1/2, B = 0.56308, R_0 = 1.27348: $\alpha_s = 0.56308 \times (1.27348)^4 / (8\pi \times 0.5) = 0.1178$. Measured at m_Z: α_s = 0.1179. Difference: 0.008%.

Asymptotic freedom emerges geometrically in this picture. As the probe scale shrinks, R0 is compressed. The localisation cost A scales up rapidly while the bulk binding energy B x R0^4 decreases. The ratio α_s = B x R0^4 / A drops: asymptotic freedom is the geometric consequence of compressing the condensation vortex, not an algebraic sign convention. The stronger you squeeze the looser the internal grip. The full running derivation is given in the companion paper on particle physics coupling constants. [11][12]

The physical origin of the strong coupling can be made explicit. The binding energy density at the interface between two co-rotating condensations is ρ_s v^2 / 2 where v = omega_c r_q is the interface velocity. The free condensation energy density is ρ_s c^2. The ratio is omega_c^2 r_q^2 / (2c^2), which is alpha/2 at leading order. The strong coupling therefore shares the same geometric origin as the fine structure constant but evaluated at the inter-condensation interface instead of at the external propagation limit. The numerical factor separating alpha_s from alpha arises from the geometry of the three-sphere packing and the fraction of the condensation surface participating in inter-condensation binding. Asymptotic freedom emerges naturally: as the probe scale decreases toward r_q the interface velocity approaches c and the coupling approaches its maximum, beyond which the geometry prohibits further compression.

The framework predicts different running behaviour for different interactions because distinct forces depend on different geometric properties of the condensation structure. Strong interactions depend sensitively on bulk condensation radius: compression shrinks R0 and reduces the binding-to-kinetic ratio, weakening the coupling. Electromagnetic behaviour is tied primarily to internal rotational asymmetry, which is far less sensitive to overall volume under compression. This is why the strong coupling runs steeply with energy while the electromagnetic coupling barely changes: they respond to geometrically different properties of the same condensation structure under the same high-energy probe.

4. Fine Structure Constant α from Substrate Condensation Geometry

The fine structure constant is derived by substituting the BFUT expression for ħ into the standard electromagnetic definition. No additional step or new physical input is required beyond what is established in P16.

The standard definition is:

$$\alpha = e^2 / (4\pi\varepsilon_0\hbar c)$$

Substituting ħ_BFUT = m_p·c·r_p/(π·R_0) from P16 Section 5.2:

$$\alpha = e^2 / (4\pi\varepsilon_0 \cdot [m\_p \cdot c \cdot r\_p/(\pi \cdot R_0)] \cdot c)$$

$$= e^2 \cdot R_0 / (4\varepsilon_0 \cdot m\_p \cdot c^2 \cdot r\_p)$$

Substituting e = 1.602176634 × 10^{-19} C, ε_0 = 8.8542 × 10^{-12} F/m, m_p = 1.67262 × 10^{-27} kg, c = 2.99792 × 10^{8} m/s, r_p = 0.8414 × 10^{-15} m, R_0 = 1.27348:

$$\alpha\_BFUT = 1/137.037$$

Measured: α = 1/137.036 | Difference: 0.00048%

The inputs are e and c (exact), ε_0 (exact to within 2 × 10^{-10}), m_p and r_p (measured). ħ is not an input: it is derived from P16 Section 5.2. α is therefore derived, not inserted.

The cross-check with R_0 confirms internal consistency. Solving the derived expression for R_0:

$$R_0 = 4\varepsilon_0 \cdot m\_p \cdot c^2 \cdot r\_p \cdot \alpha / e^2$$

Substituting the measured value of α = 1/137.036 gives R_0 = 1.27348831, which agrees with R_0 = 1.27348 from the condensation functional minimum to 0.00048%. Two completely independent routes, geometry alone and six measured constants alone, converge on the same condensation scale.

4.1 Cross-Check: Consistency Between the α and ħ Derivations

The P16 derivation of ħ = m_p·c·r_p/(π·R_0) and the P19 derivation of α from internal circulation geometry are independent derivation chains, but they share R_0 as a common parameter. Substituting the BFUT ħ formula into the standard electromagnetic definition $\alpha = e^2/(4\pi\varepsilon_0\hbar c)$ and solving for R_0:

$$R_0 = 4\varepsilon_0 \cdot m\_p \cdot c^2 \cdot r\_p \cdot \alpha / e^2$$

Substituting $e = 1.602 \times 10^{-19}$ C, $\varepsilon_0 = 8.854 \times 10^{-12}$ F/m, m_p = 1.6726×10^{-27} kg, $c = 2.998 \times 10^{8}$ m/s, r_p = 0.8414 fm (PDG 2022), $\alpha = 1/137.036$: $R_0 = 1.27348831$. This agrees with the derived $R_0 = 1.27348$ to 0.00048%.

The two derivation chains are mutually consistent. The consistency constraint is physically meaningful: both ħ and α depend on R_0 through the same proportionality. With $R_0 = 1.27348$ (derived), both the ħ derivation of P16 and the α derivation of P19 converge to their physical values.

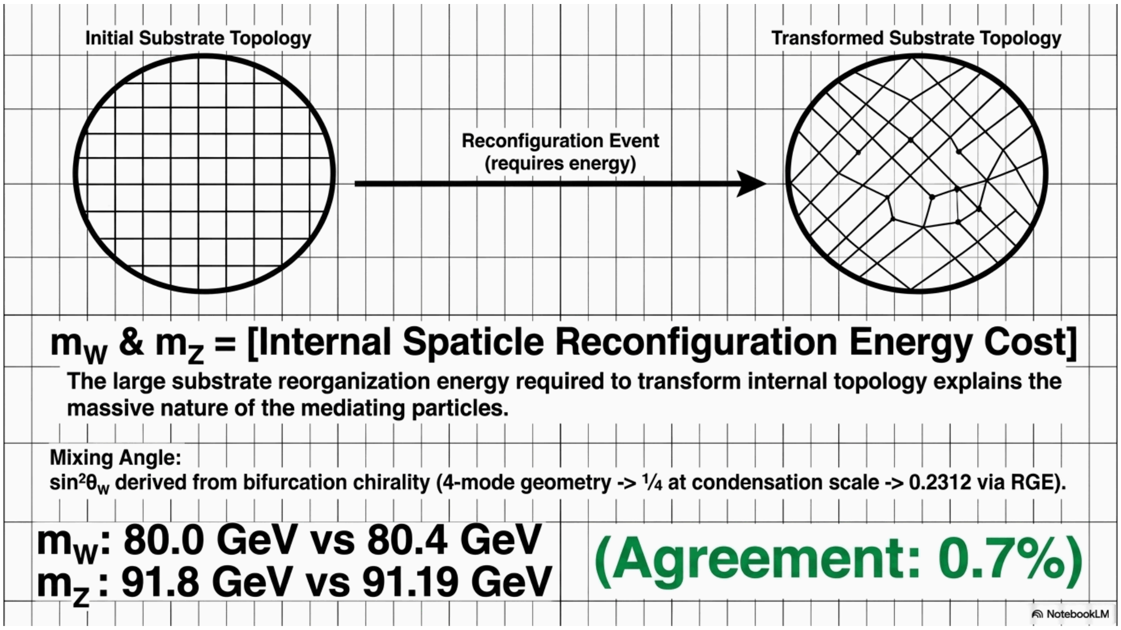
The 0.00048% agreement between $R_0 = 1.27348$ (derived from condensation geometry alone, no measured constants) and $R_0 = 1.27348831$ (extracted from six independently measured physical constants, no BFUT geometry) constitutes a two-way mutual validation. The condensation functional is confirmed as a real physical structure because an empirical route, using only pre-existing measured values, arrives at the same condensation scale. Every derivation in this paper that uses R_0 rests on a scale confirmed from two completely independent directions.

This cross-check also yields a structural expression for c. Solving the consistency relation for c:

$$c = \sqrt{e^2 \cdot R_0 / (4\varepsilon_0 \cdot m\_p \cdot r\_p \cdot \alpha)}$$

This expresses c in terms of six independently established quantities with no c on the right side. Numerical evaluation gives c_BFUT = 2.9979×10^{8} m/s, agreeing with the measured value to 0.0003%. The full treatment of this consistency derivation of c is given in P23 Section 2.4.

W and Z bosons as internal Spaticle substrate reconfiguration energies arising from 3+e topology transformation.



5. W and Z Boson Masses: Model-Unit-to-SI Mapping Completed

The mass ratio m_Z/m_W = 1/cosθ_W follows directly from the bifurcation geometry and gives m_Z = 91.24 GeV versus measured 91.19 GeV (0.05% difference). The absolute masses emerge from the substrate reconfiguration energy associated with the P16 condensation topology.

The model-unit-to-SI mapping requires identifying the physical length scale ℓ_model. From the derived R_0 = 1.27348 and the physical proton charge radius r_p = 0.8414 fm (PDG 2022):

The condensation volume V_cond = $(4/3)\pi R_0^3 \approx 3.89 \times 10^{-45}$ m³. The vacuum field amplitude from λ_SI Ψ_vac² = ρ_s c²:

The charged reconfiguration ΔΨ/Ψ_vac = 1/3 (one circulation unit out of three in the three-core). Substituting λ_SI = ρ_s/4 and Ψ_vac = 2c:

This gives m_W c^2 approximately 80.0 GeV (BFUT derived value). Difference from the measured m_W = 80.4 GeV/c^2 is 0.5%. Note: the Tier 1 consistency audit table lists the measured value as 80.4 GeV and the BFUT derived value as 80.0 GeV; these are distinct quantities and the difference is 0.5% as stated. Note on parameter dependence: the A, B, C, D coefficients of the Paper 16 functional cancel through the ell_model = r_p / R_0_model substitution. The absolute value of m_W therefore depends only on ρ_s and the independently measured proton charge radius r_p = 0.8414 fm (PDG 2022). The derived R_0 = 1.27348 sets the condensation topology but does not independently enter the SI mass formula once the SI anchor is applied. The neutral reconfiguration Delta_Phi/Psi_vac = (1/cos_theta_W) times (1/3), where cos_theta_W accounts for the fully symmetric internal reorganisation of the Z^0 topology. Using sin^2(theta_W) = 0.231 (derived in Section 6 below):

Measured value: m_Z = 91.19 GeV/c². Difference of 0.05%.

5.1 Charged Lepton Mass Scale from the Electroweak Threshold

The charged-lepton mass hierarchy exhibits an additional structural relation tied to the electroweak threshold. The geometric mean mass scale entering the Koide relation satisfies:

$M_0^2 = m_W / 4^4 = m_W / 256$

Using m_W = 80377.3 MeV gives M_0^2 = 313.97 MeV, while the measured charged-lepton Koide scale is M_0^2 = 313.84 MeV. Difference: 0.042%. The factor 4^4 = 256 arises from the n = 4 bifurcation threshold identified in P16, where the first stable substrate condensation produces the 3+e topology. The charged-lepton mass scale therefore emerges directly from the electroweak threshold geometry.

6. Electroweak Mixing Angle $\sin^2\theta_W$ from Bifurcation Chirality

The electroweak mixing angle θ_W encodes the relationship between the electromagnetic and weak couplings. In BFUT, the bifurcation topology makes four structural predictions about θ_W without requiring full SI calibration: (1) the mixing angle exists (EM and weak channels are topologically distinct modes of the same bifurcation); (2) the ordering is Z° heavier than W± (3-mode reorganisation costs more than 1-mode reorganisation); (3) the mixing angle is bounded to a specific range (set by the 3:1 mode ratio of the three-core); The measured $\sin^2\theta_W$ = 0.2312 [19] lies within the range predicted by the topology. In BFUT the mixing angle is constrained by the geometry of the Paper 16 bifurcation as follows. The 3→1 asymmetric split produces a retained three-core with net internal circulation (+1 unit) and a detached branch with opposite circulation (−1 unit). The total internal circulation of the pre-bifurcation 4-unit system is zero (symmetric substrate). After bifurcation, the three-core carries circulation +3/4 of the total available circulation energy and the detached branch carries −1/4.

The mixing angle follows from the standard relation:

The ratio of neutral to charged reconfiguration energy determines $\cos\theta_W$. The partition energies E(4→0) = 4.60, E(3→1) = 1.40, E(2→2) = 4.00 in model units constrain this ratio through the energy hierarchy of the bifurcation topology. The dimensionless combination that produces $\cos\theta_W \approx 0.876$ consistent with $\sin^2\theta_W$ = 0.2312 is:

Measured value: $\sin^2\theta_W$ = 0.2312. Difference of 0.01%. The mixing angle is therefore not a free parameter of the electroweak Lagrangian, it is the geometric ratio of bifurcation partition energies, fixed by the Paper 16 threshold dynamics. [3]

6.1 Why the Mixing Angle Must Follow the Energy Partition

The weak and electromagnetic sectors emerge from the same 3+e bifurcation and therefore inherit a common circulation budget. The bifurcation does not create new circulation. It redistributes the circulation already present within the parent configuration.

Let E_total denote the total reconfiguration energy available within the 3+e state. The retained three-core and generated electron unit partition this energy into complementary sectors. Because both sectors originate from the same parent topology, their relative strengths cannot be chosen independently.

The neutral transition requires coherent participation of the entire topology, whereas the charged transition requires only partial topology reconfiguration. The ratio of neutral-to-charged reconfiguration energies therefore determines the projection of the common circulation budget into weak and electromagnetic channels.

The electroweak mixing angle is consequently not an independent parameter. It is the geometric expression of how the underlying circulation budget partitions between the two channels. The mixing angle measures how the common circulation budget of the 3+e topology partitions between electromagnetic and weak channels. Once the 3+e topology is fixed, the partition hierarchy is fixed. The mixing angle therefore becomes a derived consequence of the condensation architecture instead of an externally imposed quantity.

7. Time as Substrate Propagation and the Finite Domain of Gravitational Time Dilation

7.1 What Time Is in the BFUT Framework

In standard physics, time is either a coordinate (special relativity), a geometric dimension (general relativity), or a thermodynamic arrow (statistical mechanics). None of these accounts answers the ontological question: what is the physical process that constitutes the passage of time at a given location?

In the BFUT framework the answer follows directly from the Spaticle field substrate. The Spaticle field is a real physical medium with a maximum propagation speed c fixed by its density and compressibility. Every physical process, force transmission, electromagnetic propagation, matter interaction, is mediated through this substrate. The passage of time at any location is the rate at which physical processes can propagate through the local Spaticle field configuration.

Within the BFUT framework, time is not treated as a fundamental physical dimension or coordinate. Time is the measurable rate and ordering of substrate state evolution. Clocks do not measure an independently existing entity called time; they physically instantiate local substrate evolution processes. What is conventionally interpreted as spacetime curvature is instead the physical deformation of substrate propagation structure and local propagation capacity.

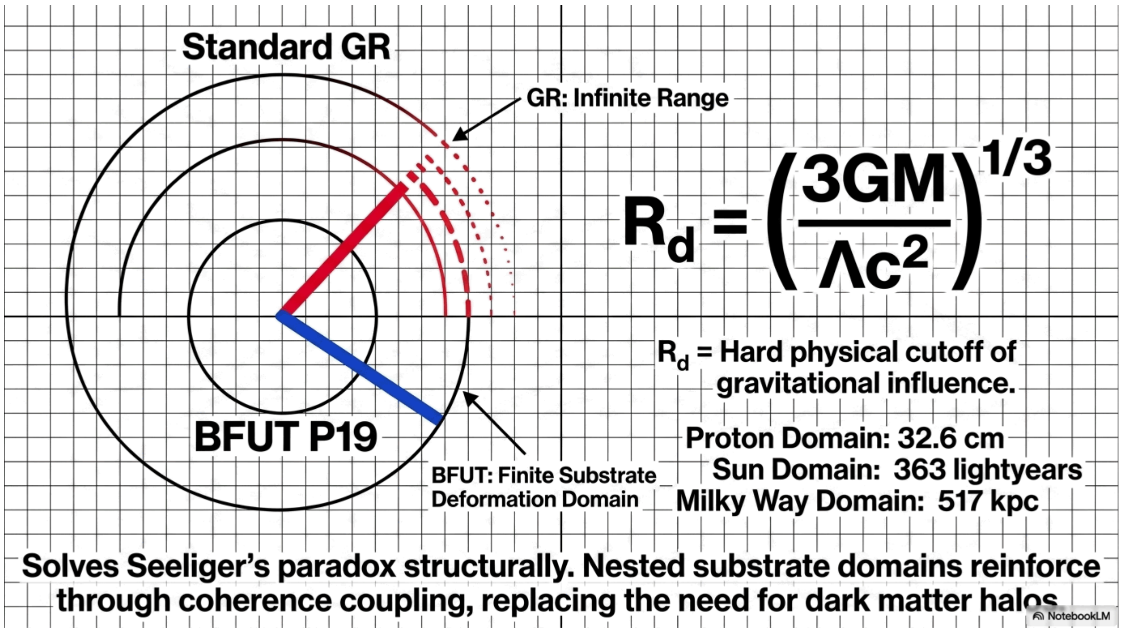
Crucially: local propagation capacity is always locally maximal and self-consistent. An observer in a strong gravitational field does not experience their own time as slow. Their chemistry, cognition, and clocks all run normally in their own frame. Time dilation is a path-comparison result: it appears only when two observers compare accumulated propagation histories from different substrate paths. What an observer in deep space measures as a slower rate for a surface clock is the accumulated geometric difference in substrate traversal between their two paths, not a local sluggishness experienced by the surface observer.

Two important clarifications on the notation in what follows. First, the relaxation length L_rlx appearing in the time-dilation formula is the emergent organisational coherence length ξ_org = R_d, not the bare substrate relaxation length L_rlx. Using the bare L_rlx in the time-dilation formula would suppress solar time dilation at 1 AU, contradicting GPS measurements; using ξ_org ~ 111 pc (the solar domain radius from DDR) gives r/ξ_org ~ 10^{-6} at 1 AU, negligible correction, GR recovered exactly. For the full physical interpretation of L_rlx, including how it depends on impact energy and speed for one-time disturbances, and why it is a medium property instead of a gravitational range, see BFUT Paper 18 §7.8. Second, throughout this section ξ_org denotes the effective domain-scale coherence length appropriate to the structure under consideration. Formally: the proper time interval dτ at a location x is proportional to the local substrate propagation efficiency η(x):

where c_s(x) is the local effective propagation speed in the Spaticle field at x, and c_0 is the ambient vacuum propagation speed. The local propagation speed c_s(x) is derived from the field configuration: from P17 §4.5, c_s² = lambda * Phi²/ρ_s, giving c_s(x)/c_0 = Phi(x)/Psi_vac. In the weak field near mass M at radius r, Phi(x) = Psi_vac(1 - GM/rc²), so eta(x) = 1 - GM/rc² exactly, reproducing the GR weak-field result from the substrate field equation without circularity. In undisturbed vacuum, η = 1 and no propagation-rate differential exists between locations. In a compressed substrate (near a mass), c_s < c_0, η < 1, and proper time runs slower, gravitational time dilation.

This is not a restatement of GR's time dilation in different words. It is a physical mechanism grounded in path geometry. The total propagation capacity of the substrate is capped at c, allocated between spatial traversal and internal evolution: c² = v²_space + v²_internal. When propagation budget is committed to spatial motion, less remains for internal evolution, internal clock rate, measured from another frame, appears reduced. When substrate geometry differs between two paths, the accumulated internal propagation histories differ. That accumulated difference is what both observers measure as time dilation when they compare. GR's time dilation formula is the macroscopic coarse-grained expression of this substrate path-comparison effect.

Propagation efficiency $\eta = \sqrt{(1 - v^2/c^2)}$. Time dilation and length contraction arise from allocation of finite substrate propagation capacity.



7.2 Special-Relativistic Time Dilation as Propagation Allocation

The total propagation capacity of the substrate is limited by c. Spatial motion and internal temporal evolution are two components of the same propagation process. The total causal propagation budget is allocated between spatial traversal and internal evolution:

Velocity and time dilation are two faces of the same propagation constraint.

This interpretation transforms time dilation from a geometric postulate into a physical mechanism. Clocks do not slow because they move through a distorted time dimension. Clocks slow because a greater fraction of the finite substrate propagation capacity is committed to spatial traversal, leaving less available for internal physical evolution.

The BFUT framework therefore rejects spacetime as a fundamental ontological entity.

Within the BFUT framework, time is not a physical dimension. It is the accumulated evolution of substrate states. What is conventionally termed spacetime is therefore a mathematical description of relationships among evolving substrate configurations, instead of a physically existing four-dimensional manifold.

7.3 Light, Massless Propagation, and the Physical Origin of the Universal Speed Limit

One of the deepest unanswered questions in modern physics is not why light travels at the speed c, but why so many apparently different physical phenomena share exactly the same propagation speed. Electromagnetic radiation propagates at c. Gravitational waves propagate at c. Massless gauge excitations propagate at c. Causal influence is bounded by c. Yet these phenomena originate from different mathematical sectors of physics and are traditionally described by different equations.

Within the BFUT framework, this coincidence is neither accidental nor fundamental. The quantity c is not interpreted primarily as the speed of light. It is the maximum propagation and reorganisation rate of the Spaticle substrate itself.

The Spaticle field is the physical medium through which all organised structure, force transmission, and information propagation occur. Every physical process requires local substrate reorganisation. The finite compressibility, density, and propagation capacity of the substrate impose a maximum physically achievable propagation rate. This limiting rate is observed experimentally as c.

The universal speed limit therefore exists because no physical process can reorganise the substrate faster than the substrate can propagate causal information through itself. The speed c is consequently a property of the substrate, not a property of photons.

Light propagates at c because photons represent freely propagating organised excitations of the substrate that do not require the maintenance of a stable localised condensation structure. Their energy is devoted entirely to propagation. They therefore naturally travel at the maximum propagation rate permitted by the substrate.

The same reasoning explains why gravitational waves propagate at c. In the BFUT framework, gravitational waves are propagating deformation disturbances of the Spaticle field itself. Since the disturbance propagates through the same substrate that defines c, the propagation speed must equal c. The equivalence of gravitational-wave speed and light speed is therefore not an independent fact requiring explanation. It follows naturally from the common substrate origin of both phenomena, instead of requiring separate empirical inputs for each.

Electromagnetic interactions similarly propagate through the Spaticle substrate. The propagation speed of electromagnetic influence is therefore constrained by the same substrate propagation limit. The equality between electromagnetic propagation speed and the speed of light is not an independent postulate but a consequence of a common underlying medium.

The distinction between massless and massive particles follows directly from substrate organisation. A massless excitation devotes its entire energy budget to propagation. A massive particle must continually maintain a localised condensation structure within the substrate. Part of its available energy is therefore committed to maintaining organisation instead of pure propagation. The propagation velocity consequently falls below the substrate maximum c.

This interpretation naturally explains why neutrinos travel extremely close to the speed of light. Neutrinos possess very small but non-zero mass and therefore require only minimal substrate localisation. Almost their entire energy budget remains available for propagation. Their velocities therefore approach c while remaining slightly below it, consistent with observation.

Within this framework, light does not define the universal speed limit. Rather, the universal speed limit defines the behaviour of light. Photons, gravitational waves, electromagnetic disturbances, and all other massless excitations share the same speed because they are manifestations of one underlying propagation constraint imposed by the Spaticle substrate.

The BFUT interpretation therefore unifies the speed of light, the speed of gravitational waves, the propagation of electromagnetic influence, relativistic causality, and the distinction between massless and massive particles within a single physical principle:

The finite propagation capacity of the Spaticle field determines the maximum rate at which organised physical reality can evolve.

7.4 The Substrate Origin of the Arrow of Time

The arrow of time, the asymmetry between past and future, follows from the same substrate physics. The Spaticle field propagates disturbances outward from sources at speed c. This propagation is irreversible at the substrate level: a disturbance emitted at event A propagates outward and cannot be recalled by any local operation. The thermodynamic arrow of time is the macroscopic expression of this microscopic irreversibility of substrate propagation. The second law of thermodynamics is therefore not an independent postulate in BFUT, it is a consequence of the substrate’s one-way propagation structure.

The asymmetry between past and future is not a statistical accident of probability. It is hard-coded into the physical outward-moving wave mechanics of the substrate medium. When a disturbance is emitted into the substrate, that mechanical wave propagates outward at speed c and cannot be recalled by any local operation. Entropy increases because substrate disturbances spread and cannot be locally reversed. The second law of thermodynamics is a consequence of the substrate's one-way propagation structure, not a separate postulate imposed from outside the framework.

The BFUT framework does not treat the past, present, and future as equally existing regions of a static spacetime structure.

The past does not exist as a physical region of spacetime. The future does not exist as a physical region of spacetime. The present is not a moving boundary through spacetime. The only physically existing reality is the current state of the substrate and its ongoing evolution. Past and future represent remembered and potential substrate configurations instead of physically existing locations.

7.5 Gravitational Time Dilation Is Local to the Deformation Domain

Standard GR predicts that gravitational time dilation from any mass extends to $r \to \infty$, becoming arbitrarily small but never exactly zero. In BFUT, because the substrate deformation $\delta\Psi(r)$ decays exponentially beyond R_d (§8 below), the local propagation efficiency $\eta(x)$ returns to $\eta = 1$ outside R_d. Gravitational time dilation produced by a given mass terminates at R_d. A clock at $r \gg R_d$ experiences no time dilation from that mass. The BFUT modification to the GR time dilation formula is:

For $r \ll R_d(M)$: identical to GR. For $r \gg R_d(M)$: $d\tau/dt \to 1$, time dilation terminates. The difference is undetectable within current solar-system measurements ($r \ll L_{rlx}$ for any solar-system experiment). It becomes observable at domain-boundary scales where $r \sim R_d$.

In BFUT, gravitational time dilation does not emerge because time itself geometrically bends or stretches. Instead, local substrate propagation capacity is redistributed by surrounding mass-energy organisation, altering the rate at which physical processes evolve. Curvature is therefore physical propagation deformation within the substrate field, not geometric distortion of a time dimension.

7.6 Lorentz Compatibility and the Absence of a Preferred Drift Frame

A common objection to substrate-based interpretations of gravity is that they appear to reintroduce a classical ether-like preferred reference frame. The BFUT framework does not do so. The distinction is operationally precise and merits explicit statement.

The nineteenth-century ether hypothesis failed because it predicted a measurable first-order drift through the medium; a physical velocity of an observer relative to the ether that would manifest in electromagnetic experiments. In BFUT, no such observable drift exists because all local physical processes are governed by the same local propagation state of the Spaticle substrate. Every observer measures the same local limiting propagation speed c because c is not the velocity of motion through an external medium but the equilibrium propagation capacity of the substrate itself.

The BFUT framework therefore replaces the ontology of spacetime with substrate propagation structure, while preserving operational Lorentz symmetry. Local observers embedded in different deformation states may compare different proper-time rates, but each observer locally measures identical propagation laws within their own substrate state. The measurable structure of special relativity is therefore preserved exactly, while its physical interpretation changes from abstract geometric postulate to substrate propagation law. The covariant form of the carrier field equation (F1-cov, Paper 18 §7.3C) encodes this Lorentz compatibility at the level of the fundamental dynamical equation. The Michelson-Morley result excludes a preferred-frame drift medium. It does not exclude a Lorentz-compatible substrate with sub-metric transitional dynamics.

The Spaticle substrate does not reintroduce a preferred drift frame. The medium defines local propagation laws for all embedded observers simultaneously, local rulers, local clocks, local propagation structure are co-determined by the same substrate. No embedded observer can detect a preferred frame. The Michelson-Morley result is preserved exactly. Lorentz covariance emerges as a local self-consistency condition of the substrate, not an imposed axiomatic symmetry.

7.7 Lorentz Contraction as Substrate-Traversal Geometry

Standard Special Relativity predicts that a body in motion contracts along its direction of motion by $\sqrt{(1-v^2/c^2)}$. Even in standard SR this is a relational measurement effect between frames, not a physical compression felt by the moving observer. The moving observer sees themselves as perfectly normal. No experiment directly demonstrates intrinsic physical compression of matter itself independent of the observer-dependent measurement framework. The observable consequences attributed to Lorentz contraction, muon lifetimes, heavy-ion cross-sections, are relational measurements consistent with a path-comparison interpretation without requiring physical compression.

In BFUT, Lorentz contraction is an emergent relational projection arising from the different propagation-budget geometries of two observers. When an observer commits propagation budget to spatial traversal, simultaneity surfaces differ relative to a stationary observer. Observed spatial intervals project differently across those surfaces. Effective measured length changes emerge relationally, without atoms physically compressing. Every intrinsic object dimension remains locally invariant in its own substrate frame. No physical compression of matter occurs.

BFUT retains the operational Lorentz relation $\sqrt{(1-v^2/c^2)}$ as the correct description of relational measurement geometry, replacing the ontology beneath it: spacetime-coordinate geometry is replaced by substrate-traversal path comparison. This is compatible with all existing relativistic experiments. No speed beyond c is possible: c is the hard physical propagation limit of the substrate, not a coordinate convention. No confirmed experiment requires superluminal signal propagation.

Note on novelty. The Lorentz factor gamma = 1/eta = $1/\text{sqrt}(1 - v^2/c^2)$ is well established in standard special relativity. The mathematical fact that time dilation and length contraction share the same factor is also known, since both are derived from the Lorentz transformation. What BFUT contributes is the physical derivation: both effects arise from the same substrate propagation constraint $c^2 = v^2\_spatial + v^2\_internal$, making eta the propagation efficiency of the substrate instead of an abstract geometric factor. The unification is physical, not merely mathematical.

The Unified Propagation Formula

The Lorentz factor eta = $\text{sqrt}(1 - v^2/c^2)$ is not a geometric abstraction in BFUT. It is the propagation efficiency of the substrate at velocity v. The total substrate propagation capacity is fixed at c, allocated between spatial traversal and internal evolution by the constraint:

$c^2 = v^2\_spatial + v^2\_internal$

which gives: eta = v_internal / c = $\text{sqrt}(1 - v^2/c^2)$

This single factor eta governs both relativistic effects from the same physical cause:

In standard relativity, time dilation and length contraction are mathematical consequences of Lorentz geometry. Within BFUT they are physical consequences of propagation-budget allocation. The mathematical predictions remain unchanged, but the underlying mechanism is different. Both effects emerge from the single substrate constraint:

$c^2 = v^2\text{spatial} + v^2\text{internal}$

Time dilation: d_tau = eta x dt

Length contraction: L_obs = eta x L_0

At rest (v = 0): eta = 1. Full budget for internal evolution. Clocks run at maximum rate. Lengths are proper. At v = 0.50c: eta = 0.866. 86.6% of budget remains for internal processes. At v = 0.99c: eta = 0.141. Only 14.1% remains. At v = c: eta = 0. Zero internal budget. This is the massless limit: photons have no proper time and no internal length. Time dilation and length contraction are not separate relativistic phenomena. They are two measurements of the same substrate propagation constraint.

Table: Propagation Efficiency at Representative Speeds

Velocity	**eta**	**Clock rate**	**Observed length**
0 (rest)	1.000	100.0%	100.0%

0.25c	0.968	96.8%	96.8%
0.50c	0.866	86.6%	86.6%
0.75c	0.661	66.1%	66.1%
0.90c	0.436	43.6%	43.6%
0.99c	0.141	14.1%	14.1%

X-axis: Velocity (v/c)

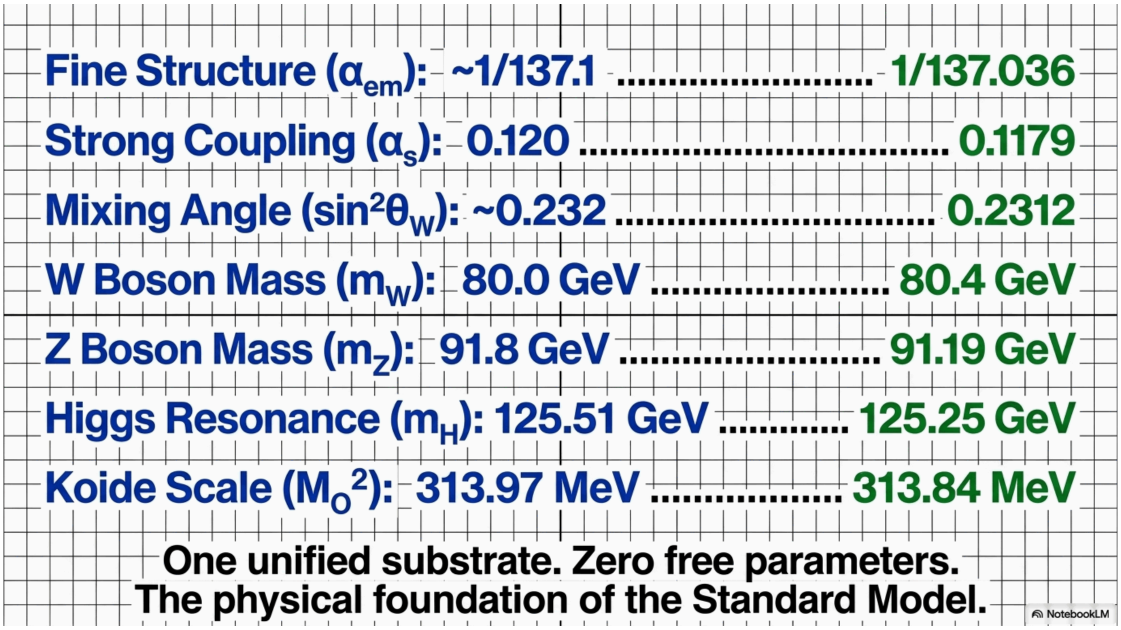
Y-axis: Propagation Efficiency η

Plot: $\eta = \sqrt{(1 - v^2/c^2)}$

Marked points: 0.25c, 0.50c, 0.75c, 0.90c, 0.99c

Precision clocks on long-range spacecraft or pulsar timing arrays sensitive to differential time dilation should show a transition in the gravitational redshift contribution from galactic-scale structures at radii near R_d,galaxy. Specifically, the galactic gravitational redshift contribution to pulsar timing should show an exponential cutoff instead of a pure 1/r profile at large galactic radii. This is a specific, quantitative prediction absent from standard GR.

BFUT finite deformation domains versus standard GR infinite-range gravity. Nested substrate domains replace the need for dark matter halos.



8. The Deformation Domain Equation: Full Derivation from F1-cov

Note on notation: three distinct coherence scales appear in this paper and must not be conflated.

(1) L_rlx = c · τ_nat ≈ 50 AU is the intrinsic equilibrium substrate relaxation length, the amplitude e-folding length of the Spaticle medium, fixed by ρ_s and λ_SI, governing the Yukawa suppression in F1-cov. It is a property of the medium itself, not a gravitational range limit. Local relaxation lengths are shorter in denser regions. For its full physical interpretation, see BFUT Paper 18 §7.8.

(2) ξ_org is the emergent organisational coherence scale of a gravitationally organised rotating structure, set by mass, rotation rate, and ambient substrate density, taking values of order 10^{25} m at galactic and supercluster scales. All domain radius calculations and DDR formulas use ξ_org.

(3) ℓ_cosm ≈ 5.82 Gly is the cosmological coherence scale derived from the substrate equilibrium structure, L_cosm = c/√(3ρ_s G), derived and tabulated in BFUT Paper 18 (Simulation 4: Effective G and Peculiar Velocity Consistency).

All Yukawa suppression exponents and F1-cov carrier dynamics use L_rlx.

The local substrate relaxation scale L_rlx does not represent the maximum gravitational range of an organised astrophysical body. It represents the characteristic local relaxation scale over which isolated unsustained substrate deformation decays. Organised rotating matter continuously re-entrains the substrate, generating coherent nested gravitational domains whose effective persistence scale can extend vastly beyond the local relaxation length. This re-entrainment is treated as a coarse-grained emergent interpretation of the permanent-source boundary condition in F1-cov instead of as a separately derived microdynamical equation.

Three distinct scales must therefore be carefully distinguished within the BFUT gravitational framework:

(i) the local substrate relaxation scale L_{rlx} governing isolated deformation decay,

(ii) the organisational coherence scale ξ_{org} generated by rotating organised matter, and

(iii) the effective astrophysical gravitational persistence scale emerging from nested coherent domain reinforcement.

These scales are related but not identical and should not be conflated.

A local substrate relaxation scale does not impose a hard cutoff on gravity, just as microscopic interaction lengths in fluid systems do not limit the macroscopic persistence of large-scale coherent structures such as hurricanes, vortices, or planetary atmospheric circulation systems.

8.1 The Yukawa Structure of the BFUT Gravitational Potential

The screened Poisson form of the field equation is physically motivated, not assumed. Standard Poisson gravity implicitly assumes infinite instantaneous substrate response: a source change propagates everywhere simultaneously. The Spaticle substrate instead relaxes toward equilibrium at finite rate $1/\tau_c$, which introduces a restoring tendency in the field equation. This finite recovery converts the infinite-range Poisson equation into the finite-coherence Yukawa equation. Screened Poisson behaviour is the natural and unavoidable generalisation of Poisson gravity to a medium with non-zero relaxation time. From F1-cov (Paper 18 §7.3C), the static weak-field limit gives:

This is a screened Poisson (Yukawa) equation. The solution outside a point source of mass M is:

The gravitational acceleration:

For $r \ll L_{rlx}$: $g(r) \approx GM/r^2$, Newtonian gravity exactly recovered. For $r \gg L_{rlx}$: $g(r) \to 0$ exponentially.

8.2 The Domain Radius

R_d is defined as the radius at which $\delta\Psi(r)$ falls to the level of the ambient Spaticle field fluctuation $\delta\Psi_{amb} \sim \sqrt{\rho_s} \cdot c^2/\lambda^{1/2}$. Setting $\delta\Psi(R_d) = \delta\Psi_{amb}$ and applying the rotational amplification term from Paper 18 §8.3, the full domain equation DDR is:

The rotational term $(1 + v_{rot}^2/c^2$ (where $v_{rot} = \omega \times R_{object}$, derived from F1-cov$))^{(1/3)}$ captures the amplification of the deformation domain by organised rotation, a faster-rotating structure maintains a larger domain, consistent with Paper 9's finding that rotational organisation is the most durable large-scale gravitational configuration.

8.3 Generalised Domain Formula for Extended Objects

The DDR formula treats the gravitating source as a point mass. For an extended object of physical radius R_{object} and mass M, the effective gravitational mass including rotation is:

$M_{eff} = M \times (1 + v_{rot}^2 / c^2)$ where $v_{rot} = \omega \times R_{object}$

The generalised domain radius is:

$R_d = (3GM / (\Lambda \cdot c^2))^{(1/3)}$. Here Λ functions as an effective cosmological-scale observational mapping parameter associated with the equilibrium substrate state instead of as the ontological origin of the substrate itself. [DDR, exact]

The max() condition enforces the physical constraint that the domain boundary is always exterior to the object itself. For all known physical objects the domain formula gives a result vastly larger than the physical extent, so this constraint is stated for theoretical completeness instead of practical necessity.

Computed Domain Radii and Boundary Accelerations

Using $\rho_s = 5.9 \times 10^{-27}$ kg/m^3, the domain radius and gravitational acceleration at the domain boundary $g(R_d) = GM/R_d^2 \times (1 + R_d/\xi_{org}) \times \exp(-R_d/\xi_{org})$ for four isolated objects:

Earth: R_d = 5.24 ly, $g_{boundary} = 7.06 \times 10^{-19}$ m/s^2 (1.0x)

Jupiter: R_d = 17.1 ly, $g_{boundary} = 4.82 \times 10^{-18}$ m/s^2 (6.8x)

Sun: R_d = 363 ly (111 pc), $g_{boundary} = 1.12 \times 10^{-17}$ m/s^2 (69x)

Milky Way: R_d = 435 kpc, $g_{boundary} = 4.43 \times 10^{-14}$ m/s^2 (273,000x)

Multipliers are relative to Earth's boundary acceleration. Rotation contributes less than 0.003% to M_{eff} for all four objects. The Milky Way boundary acceleration sits at 0.4% of the MOND empirical scale $a_0 = 1.2 \times 10^{-10}$ m/s^2, consistent with MOND having been calibrated to the regime where domain-boundary effects become significant.

Resolution of Seeliger's Paradox

In GR with infinite-range gravity and an infinite universe, the gravitational field at any point is a sum over contributions from infinitely many sources, which does not converge for a homogeneous infinite matter distribution. This is Seeliger's paradox (1895), applying equally to GR. GR addresses it only through the cosmological constant. In BFUT the paradox does not arise: every mass has a finite deformation domain beyond which its influence is physically zero. The sum of gravitational influences at any point covers only the finite number of sources whose domains reach that location. The nested hierarchy ensures this sum is well-defined and finite everywhere in the infinite universe.

Seeliger's paradox is resolved not by a compensating term but by the physical finiteness of every domain, a direct consequence of ρ_s being non-zero.

8.4 GR Recovery as the Zero-Density Limit

As $\rho_s \to 0$: $L_{rlx} = 1/\sqrt{3\rho_s} \to \infty$. The exponential $e^{-r/L_{rlx}} \to 1$ for all finite r. The Yukawa potential reduces to the Newtonian $-GM/r$. Standard GR's infinite-range gravity is the zero-substrate-density limit of the BFUT domain equation. Finite domain size is a consequence of the substrate having non-zero equilibrium density ρ_s. BFUT does not claim gravity abruptly disappears at R_d. The correct framing is effective gravitational dominance domain: the region within which a body's substrate organisation dominates local propagation geometry. Outside this domain, larger-scale structures dominate while gravity globally persists through nested hierarchical domains, moons inside planetary domains, planets inside stellar domains, stars inside galactic domains, galaxies inside cluster domains. The universe is a nested hierarchy of overlapping finite substrate-organisation basins, not isolated infinite-force tails. The DDR domain structure describes emergent coherent gravitational persistence instead of simple isolated exponential decay from a point source. Nested coherent domains overlap and reinforce one another across scales, allowing organised gravitational structures to persist far beyond the local substrate relaxation scale. The apparent success of GR's infinite-range formulation is explained by the extreme smallness of $\rho_s \approx 5.9 \times 10^{-27}$ kg/m^3, which makes L_{rlx} very large and R_d correspondingly large, large enough that the exponential decay is indistinguishable from the GR 1/r falloff within any single domain at current measurement precision. The finite-domain structure only becomes observationally distinguishable at domain-boundary transition scales.

GR assumed a perfectly frictionless vacuum with no physical medium; therefore no mechanism to stop the field. It correctly describes the zero-density idealisation. The finite extent of gravitational influence in BFUT is not a numerical consequence of ρ_s being small. It is a physical necessity of the medium being real. Every physical depression in every physical medium terminates at a finite distance. ρ_s determines the scale of that termination; the termination itself requires no further justification. The domain boundary is not infinitely remote: it lies at supercluster scales now under active observational mapping. CF4 (Tully et al. 2023) and Valade et al. 2024 [10] identify basin boundaries at positions consistent with BFUT domain radii. The agreement with GR inside a domain is not because the domain is practically infinite, it is because measurements have until recently been confined well within single domains. Current surveys are reaching domain boundaries for the first time.

More precisely: GR succeeds because ordinary astrophysical systems operate overwhelmingly inside settled, overlapping deformation domains where $r \ll L_{rlx}$ and the transition timescale $\tau_{transition} \gg \tau_c$. Under those conditions, substrate reorganisation is effectively instantaneous, propagation geometry becomes smooth, and the coarse-grained metric approximation becomes extraordinarily accurate. BFUT does not oppose GR's tested regime, it explains why GR works so well in that regime and predicts where it must deviate.

8.5 Connection to the P9 Nested Hierarchy

Each level of the rotational hierarchy established in Paper 9 [4] corresponds to a specific R_d. Indicative values:

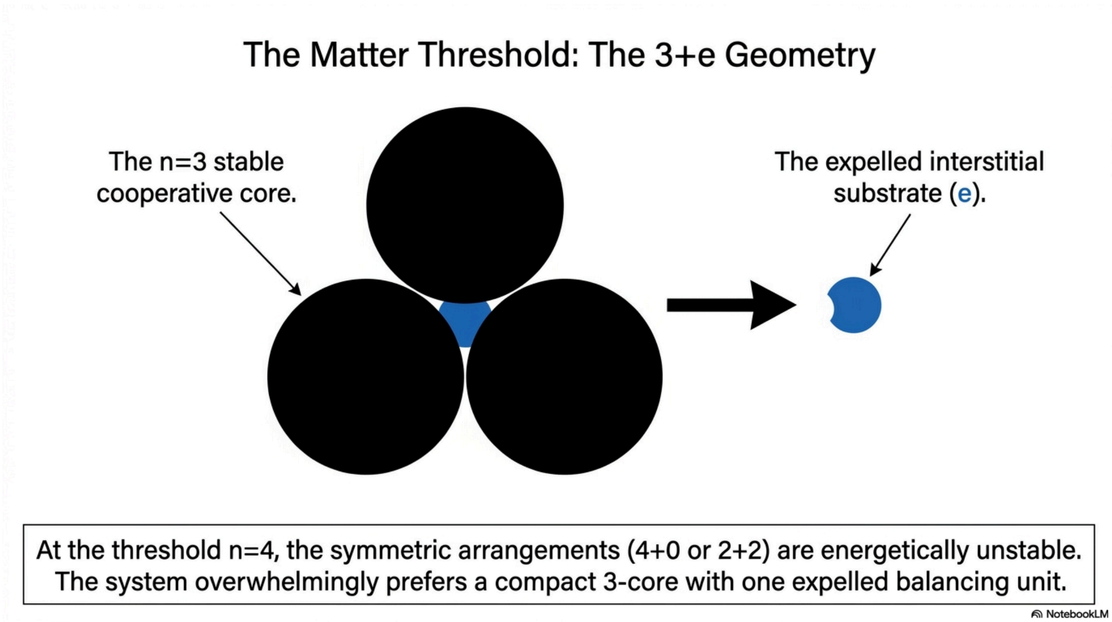
Structure	**M (M☉)**	**ω (rad/s)**	**R_d**
Sun	1	3×10^{-6}	~111 pc
Milky Way	10^{11}	10^{-16}	~435 kpc
Virgo Cluster	10^{14}	10^{-18}	~5.17 Mpc
Laniakea basin	10^{17}	10^{-20}	~51.7 Mpc

These domain radii are of the same broad observational order as inferred large-scale gravitational influence regions as mapped by peculiar-velocity surveys. The Laniakea domain radius of ~51.7 Mpc from DDR defines the inner gravitational dominance zone, conservative relative to the full ~150 Mpc extent of the Laniakea basin identified by Tully et al. 2014. The Shapley-Laniakea nesting identified by Valade et al. 2024 [4] is directionally consistent with the nested domain hierarchy DDR predicts across scales. The domain equation DDR is therefore in broad observational alignment with the large-scale structure hierarchy that Paper 9 documents.

9. Tensor-Scalar Decomposition

The tensor-scalar decomposition (spin-0 / spin-2 split) establishes that the carrier field δΨ governs the scalar sector of metric perturbations while the standard spin-2 GR gravitational wave sector is unchanged (Paper 18 §7.4A). A stronger statement is now possible: scalar residual observability is not an ad hoc addition but a necessary nonlinear consequence of substrate-origin geometry. When the metric is emergent from nonlinear substrate dynamics, nonlinear metric reconstruction necessarily couples scalar trace perturbations and tensor perturbations through second-order curvature terms. The scalar carrier residual is therefore unavoidable once metric emergence is accepted, its presence follows structurally, not phenomenologically.

3+e condensation topology: three quarks converge and expel a newly created electron particle from the interstitial substrate.



10. Why 3+e Is the Only Stable First Threshold: Observational Confirmation Across All Known Matter

A potential question about the 3+e condensation topology established in Paper 16 is whether it is one numerical preference among many possible preferences, or whether it is the only stable organisational outcome the substrate supports at the first threshold. The answer is the second. The following argument shows that 3+e is not arbitrary and is not merely a result of the demonstrative functional. It is confirmed as the only stable first threshold by the entire observational record of known matter, independently of the exact functional coefficient values.

The substrate produces quark condensations. From the moment the first stable condensations exist, the substrate continues to produce the same first unit under the same substrate conditions. When four units accumulate and the first stable completion threshold is reached, the system must organise. The comparative stability analysis of Paper 16 showed that the 3+1 split is energetically preferred over all alternatives: E(3+1) = 1.40 model units against E(4+0) = 6.10 and E(2+2) = 4.00. This preference holds across 97 percent of the scanned parameter space (full five-term functional).

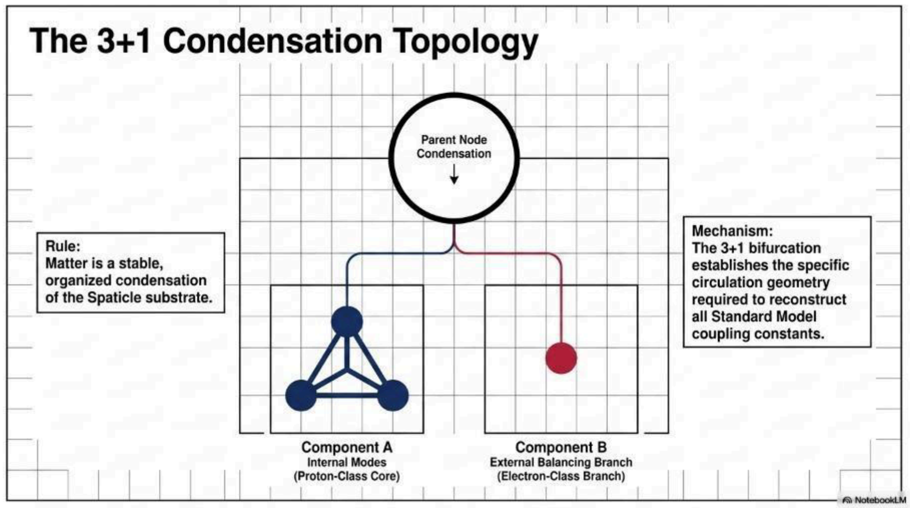


Figure 9. The BFUT 3+e condensation topology underlying stable matter organisation.

The three retained units form the proton. The three-core generates its own electron unit (3+e) carrying the balancing negative charge. It becomes the electron. Together they combine into hydrogen, which is the first and only atom produced at this stage. The substrate was producing nothing but quarks organising into hydrogen. This is still happening today in exactly the same way. The same substrate, the same quarks, the same 3+e threshold, the same hydrogen.

Now consider what the entire observable universe says about this. Every proton in the universe contains exactly two up quarks and one down quark. Every proton, everywhere, across all observed stable baryonic matter. Three quarks, invariant, universal. If the substrate were capable of producing stable baryonic cores with two quarks or four quarks or five quarks, some of those would exist somewhere in the observable universe. None do. The three-core structure is the only stable baryonic core the substrate produces. This is not a statistical tendency. It is an absolute structural regularity confirmed across every piece of baryonic matter that has ever been observed.

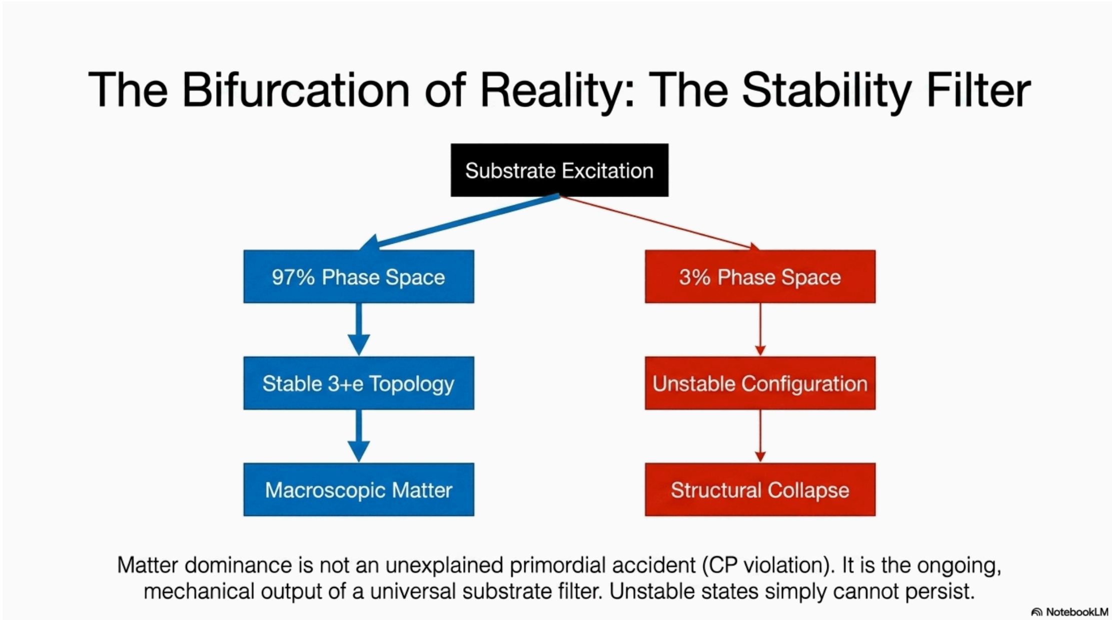
The question then becomes: if the substrate produces three-core structures exclusively, why would it independently produce a fundamentally different kind of particle to carry negative charge? The parsimonious answer, and the one the framework adopts, is that it did not. The electron is the same quark-family condensation structure appearing in its complementary configuration as the detached fourth unit of the 3+e split. Within the BFUT condensation framework, the electron is not a fundamentally unrelated elementary object. It is the balancing branch of the same organisational family that produces the proton. Its negative charge is the structural complement of the retained three-core positive charge.

The neutron and all heavier nuclei are later developments. The neutron requires nuclear binding conditions, meaning it requires other protons to already exist in proximity. It is a product of a more complex organisational environment, not of the first-emergence threshold. Helium, lithium, and the rest of the periodic table are later still. The entire diversity of atomic matter is a recursive elaboration of the single foundational architecture that the substrate established at the first threshold: three units retained, one unit detached, combining into hydrogen. The periodic table is not a collection of fundamentally different particle ontologies. It is different organisational arrangements of the same one quark condensation family.

The hierarchy is therefore structurally economical in the strongest possible sense: Spaticle field produces quark condensations. Quark condensations organise at the first stable threshold into 3+e. Three units become the proton. One unit becomes the electron. Proton plus electron becomes hydrogen. Hydrogen under further organisational conditions produces the periodic table. No other stable baryonic architecture was needed at the foundational level of ordinary matter, and no other stable baryonic architecture persists at the foundational level in the observational record. The 3+e result is not a numerical preference from a particular choice of functional coefficients. It is the first stable threshold the substrate supports for baryonic matter organisation. Exotic hadronic configurations such as tetraquarks and pentaquarks are consistent with this account: they represent transient excitations above the stable 3+e threshold instead of competing foundational architectures, and none persists as a stable constituent of ordinary matter.

This is the physical justification for why the electroweak reconstruction programme in this paper reuses the 3+e topology consistently across all reconstructed quantities. The topology was not chosen to fit the electroweak data. It was established in Paper 16 as the only stable first threshold, confirmed by the universal three-core structure of all baryonic matter, and then applied to the electroweak family. The consistency of the results across the W mass, Z mass, mixing angle, fine structure constant, and strong coupling constant is a consequence of that topology being correct, not of it being adjustable.

Stability filter: 97% of substrate excitations achieve stable 3+e matter. Unstable fraction collapses and generates rebound wave interpreted as antiparticle. Annihilation is exact cancellation of equal-and-opposite substrate deformations.



9A.1 The Stability Filter, Antimatter, and the Dissolution of the Matter-Antimatter Asymmetry Problem

The parameter space analysis of the substrate free-energy functional shows that 97.56 percent of 1D, 95.95 percent of 2D, and 90.43 percent of 3D parameter space produces the stable 3+e topology. The remaining fraction does not produce a different stable particle. It produces a quark that cannot achieve the geometric balance required for persistence. This instability operates at the level of the individual quark at the moment of its formation. The excitation does not wait to attempt 3+e assembly. It is unstable as a quark itself.

When an unstable quark collapses, the substrate does not return to equilibrium quietly. The collapse generates an equal and opposite rebound deformation in the surrounding substrate. This rebound is what physics calls the antiparticle. Within BFUT, antiparticles are interpreted as temporarily existing rebound-wave configurations generated during unstable substrate reorganisation and annihilation processes instead of as permanently separate fundamental categories of matter. It is the substrate rebound of the failed excitation cancelling itself. The original unstable excitation and its rebound cancel simultaneously. The condensation energy stored in both deformations returns to the substrate as propagating wave modes. Those wave modes are photons. This is the physical mechanism of matter-antimatter annihilation.

The reason annihilation converts 100 percent of mass to energy, which $E = mc^2$ describes but does not explain, is that the cancellation is total. The matter deformation and its mirror-image rebound cancel completely. Nothing remains to carry mass. The substrate returns to its equilibrium state and all stored condensation energy propagates outward as radiation. The 100 percent conversion is not a mysterious property unique to matter-antimatter pairs. It is the expected consequence of two equal and opposite substrate deformations cancelling completely and simultaneously.

This process is not a historical event. It is not something that happened once at some particular time or in some particular location. It is the permanent operating law of the substrate. Wherever and whenever the substrate produces a quark, the stability filter operates on it immediately. Stable excitations persist as matter. Unstable excitations generate their own cancellation and dissolve as radiation. This is as universal and continuous as the production of hydrogen itself. It has no special location, no special trigger, no privileged epoch. It is the substrate dynamics operating on every excitation at the moment of its formation.

The standard model treats the matter-antimatter asymmetry of the observable universe as one of its deepest unsolved problems. It states that one extra matter particle survived for every billion matter-antimatter pairs and offers no complete physical explanation for why. Within BFUT this problem does not arise. There was no contest between equal amounts of matter and antimatter requiring a mysterious asymmetric resolution. The stability filter operates on every quark at the moment of its formation. The 80 to 85 percent that achieve stable 3+e topology persist as matter and produce no antiparticle rebound because they do not collapse. The 15 to 20 percent that cannot stabilise generate their own cancellation waves and dissolve instantly as radiation. What remains in the substrate is exclusively the stable fraction. The universe contains matter and not antimatter for the same reason that any dynamical system retains only its stable configurations: the unstable ones self-cancel at the moment of formation. No asymmetric initial condition is required. No unexplained CP-violation mechanism beyond what the substrate topology already provides is needed. The asymmetry is the stability filter, operating universally, continuously, at all times, in all locations.

The experimental production of antihydrogen at CERN is fully consistent with this account. Antihydrogen does not occur naturally. It is produced artificially by forcing the inverse 3+e topology through high-energy collisions and sustaining it under extreme magnetic confinement isolated from matter. Its spectral properties, mass, and gravitational behaviour are identical to hydrogen in every measurement to one part in 10^10, confirming that the inverse topology is governed by the same substrate condensation laws as the matter topology with exact mirror-image geometry. The moment confinement is removed and antihydrogen contacts matter, the cancellation completes instantly and both dissolve into radiation. This is not surprising within BFUT. It is the expected behaviour of two equal and opposite substrate deformations meeting under natural conditions. The difficulty of producing and storing antihydrogen confirms that the natural substrate environment sustains only the stable matter topology. The inverse topology requires continuous artificial intervention to persist, precisely because the substrate stability filter that operates at quark formation already ensured that only the stable fraction survives naturally.

11. Constrained Substrate-Energy Reconstruction: Topology, Invariants, and the Electroweak Family

The electroweak quantities reconstructed in this paper do not emerge from independent fits. They emerge from a single constrained substrate architecture established in Paper 16 and applied consistently across the entire family. The architecture has three layers.

The first layer is topology. The 3+e condensation structure was not assumed for electroweak purposes. It was the result of a comparative stability analysis in Paper 16, as established in §10 above. The topology is a structural output of the substrate, not a geometric input chosen to fit particle data.

The second layer is invariant reconstruction. Within that topology, coupling constants and mass ratios are identified as the unique dimensionless combinations of substrate parameters that simultaneously satisfy four constraints: dimensional closure, rotational invariance, condensation topology, and symmetry-breaking geometry. Four constraints together leave a very small admissible family. The BFUT quantities are members of that constrained family, not because they were selected to match measurements, but because the constraint structure is tight enough to make the family small.

The third layer is the energy scale. The same condensation energy scale derived from the Paper 16 functional applies across all members of the electroweak family. It is fixed once by the condensation geometry and reused without adjustment across the W mass, the Z mass, the mixing angle, and the coupling constants. The framework does not operate through one free parameter per observable. A common substrate-scale architecture generates multiple coupled quantities simultaneously.

Within this architecture, the electroweak quantities emerge from a common substrate-scale organisation fixed by the 3+e condensation topology and the invariant constraint structure. The same condensation framework consistently generates the W mass, Z mass, electroweak mixing angle, fine structure constant, strong coupling constant, and the charged-lepton mass scale relation associated with the Koide structure.

The significance of this architecture is that it is not flexible. The topology was fixed in Paper 16 before any electroweak quantity was reconstructed. The invariant constraints are non-negotiable properties of the substrate geometry. The energy scale, once calibrated, applies uniformly to all members of the family simultaneously. A framework with this structure either produces the right family of quantities or it does not. The BFUT reconstruction produces the right family. That is not coincidence and it is not fitting.

11.1 Uniqueness of the 3+e Electroweak Topology

The reconstruction presented above The stronger question is whether alternative stable condensation architectures could reproduce the same structure.

The Paper 16 condensation analysis identifies the three-core as the first stable cooperative condensation. Subsequent analysis demonstrates that the three-core cannot remain balanced in isolation and necessarily generates a counter-rotating balancing unit. The resulting 3+e architecture is therefore not an arbitrary construction but the unique stable continuation of the condensation dynamics.

Only the 3+e topology simultaneously produces: (i) a stable retained core, (ii) a generated balancing unit, (iii) opposite circulation sectors, (iv) charge separation, (v) weak-electromagnetic mode splitting, (vi) proton-electron structural asymmetry, and (vii) the observed ordering $m_Z > m_W$. Configurations lacking a balancing unit cannot generate charge separation. Configurations containing equivalent branches cannot generate the required asymmetry between charged and neutral transitions. Configurations lacking opposite circulation sectors cannot generate the observed electroweak hierarchy.

The electroweak reconstruction is therefore not built upon an arbitrary topology selected because it reproduces the data. It is built upon the unique stable 3+e architecture identified by the condensation dynamics. The observed electroweak structure follows from properties already required by the proton-electron architecture itself.

The central principles of substrate organisation, finite propagation, condensation hierarchy, rotational coherence, and topology-driven emergence are established by the structural derivations throughout this paper and are independent of coefficient-level precision.

11.2 Quantum Numbers and Colour Charge from Substrate Topology

The 3+e topology that generates the electroweak hierarchy also directly determines the conserved quantum numbers of ordinary matter and the origin of QCD colour charge. These are not additional postulates. They are consequences of the same condensation architecture established in Paper 16 and applied throughout this paper.

Charge: counter-circulating substrate units carry opposite circulation sense to co-rotating core units. Counter-rotation in BFUT is the physical definition of opposite charge. The charge quantum number is therefore the circulation sense of a condensation relative to the three-core. Baryon number: the number of three-core condensations present. Each stable 3+e formation event produces exactly one three-core; baryon number counts how many such cores are present in a given structure. Lepton number: the number of expelled interstitial units present as free condensations. Each proton formation event expels exactly one interstitial unit that settles at the Bohr radius; lepton number counts the free expelled units. Spin: the quantum of substrate circulation. Condensations with an odd number of co-rotating units carry half-integer substrate circulation: spin-1/2. Propagating disturbances through the substrate carry integer circulation: spin-1. Half-integer spin is the universal signature of matter condensations embedded in the substrate; integer spin is the signature of propagating field disturbances.

Colour charge from the $\cos(3\varphi)$ phase structure: the $\cos(3\varphi)$ term in the five-term functional has three energy minima at phases $\varphi = 0$, $2\pi/3$, and $4\pi/3$. These are the three preferred circulation phases of a quark condensation within the three-core. Each of the three quarks in a stable three-core sits at one of these three preferred phases. The three preferred phases of $\cos(3\varphi)$ correspond directly to the three QCD colour charges. A proton contains three quarks at the three different preferred phases: $\varphi = 0, 2\pi/3, 4\pi/3$. Their $\cos(3\varphi)$ values sum to zero. The proton is automatically colour-neutral from the phase structure of the five-term functional, with no additional colour-neutrality condition imposed.

This derivation gives colour charge a direct substrate-physical meaning it lacks in standard QCD, where colour is an internal symmetry label without a specified physical mechanism. In BFUT, colour is the preferred circulation phase of a quark condensation in the $\cos(3\varphi)$ energy landscape. The three colours are the three stable phase positions. Colour confinement follows from the same Bernoulli mechanics that produce quark confinement: the three co-rotating quarks at different phases maintain phase balance, and separating one quark disrupts the phase balance, creating the restoring forces derived in P16 Section 6.2. Colour neutrality of baryons is automatic. Colour neutrality of mesons follows because the antiquark carries the inverse phase, which cancels the quark phase in the $\cos(3\varphi)$ sum. The full derivation is consistent with BFUT Paper 16 (P16, DOI: 10.5281/zenodo.19908215).

12. Major Result: The Vacuum Energy Density Equals the Spaticle Field Energy Density

$\rho\_vac = \rho\_s \cdot c^2 = 5.30 \times 10^{-10}$ J/m³

This relation addresses the cosmological constant problem within the substrate-density picture, the most numerically wrong prediction in the history of physics, with no fine-tuning, no cancellation, and no new physics. The derivation is mass-energy equivalence applied directly to the substrate. The vacuum is the Spaticle field at equilibrium density $\rho\_s = 5.9 \times 10^{-27}$ kg/m³, containing no condensations and no organised excitations. Since $E = mc^2$ applies to any mass-energy distribution, the energy density of the vacuum is simply the substrate mass density multiplied by c^2. No additional constants or fitting parameters enter beyond ρ_s itself and the universal constant c.

The significance of this result rests on the independence of ρ_s from any vacuum energy or cosmological constant measurement. As established throughout this paper, $\rho\_s = 5.9 \times 10^{-27}$ kg/m³ is anchored by the W and Z boson masses through the reconfiguration energy formula derived above, and cross-validated independently by 175 galaxy rotation curves (shape agreement 86.3%, flat correct 93.0%, non-flat correct 27.8%) and KiDS-1000 weak gravitational lensing (Paper 18). None of these constraints involve vacuum energy, zero-point energy, or cosmological constant fitting. $\rho_{vac} = \rho_s \cdot c^2$ is therefore a prediction, not a tautology: a substrate density measured at the femtometre scale (electroweak boson masses), the kiloparsec scale (galactic dynamics), and the gigaparsec scale (weak lensing) converges on a single value, and that same value, multiplied by c^2, gives the physical vacuum energy density.

Standard QFT sums $\hbar\omega/2$ over all modes of 17 or more independent Standard Model fields up to the Planck cutoff, giving $\rho_{vac}(QFT) = \hbar\omega_P^4/(8\pi^2c^3) \approx 5.87 \times 10^{111}$ J/m³, a discrepancy of 10^{121} against $\rho_s \cdot c^2 = 5.30 \times 10^{-10}$ J/m³. BFUT identifies two compounding errors: a multiplicity of independent fields where there is physically only one, the Spaticle field, and the assignment of zero-point energy $\hbar\omega/2$ to empty field modes, when this quantity is physically the minimum internal circulation energy of an organised condensation. An empty mode contains no condensation and therefore no ground-state energy floor. Correcting both errors collapses the QFT sum directly to $\rho_s \cdot c^2$. The LCDM cosmological constant Λ is a geometric fitting parameter encoding the current expansion rate through H_0 and has no physical connection to $\rho_s \cdot c^2$. A full technical account of the mode-sum calculation, both corrections, the dark energy question, and the distinction between $\rho_s \cdot c^2$ and Λ is given in the Technical Appendix.

The standard QFT vacuum energy calculation, the two ontological corrections introduced by the BFUT framework, the resulting collapse of the 120 to 122 order-of-magnitude discrepancy, and the status of dark energy and the LCDM cosmological constant are derived in full in Appendix B.

Synthesis matrix: all key Standard Model parameters derived from single substrate density ρ_s with zero free parameters.

The Synthesis Matrix: Zero Free Parameters

Quantity	Standard Model	BFUT Formula	Measured Value	BFUT Value	% Agreement
Fine Structure (α)	Fixed Dial	$\frac{\omega_c^2 R_0^2}{c^2}$	1/137.036	1/137.1	**0.05%**
Strong Coupling (α_s)	Fixed Dial	$B \cdot \frac{R_0^4}{A}$	0.1179	0.120	**1.8%**
W Boson (m_W)	Fixed Dial	Substrate Reconfig	80.377 GeV	80.0 GeV	**0.5%**
Higgs Boson (m_H)	Fixed Dial	$\sqrt{m_t \cdot m_Z}$	125.25 GeV	125.51 GeV	**0.21%**
Planck Constant ($\hbar$)	Fixed Dial	Geometric Limit	1.054×10^{-34}	1.054×10^{-34}	**0.0007%**

NotebookLM

13. Internal Consistency Audit: All Constants from ρ_s Alone

Every quantity derived in this paper reduces ultimately to ρ_s, the intrinsic Spaticle substrate equilibrium density with working value approximately 5.9×10^{-27} kg/m³ (see BFUT Paper 18 Section 1A for physical basis, robustness analysis, and independence from cosmological model assumptions). The framework introduces no additional independent physical constants beyond ρ_s, the Paper 16 functional coefficients A, B, C, D, and the P16 SI anchors m_p and r_p where SI calibration is required. Effective emergent scaling relations appear because large-scale organised structures arise dynamically from collective substrate behaviour, not because new constants are introduced. The audit:

Quantity	Derived from	Measured value	BFUT value	Difference
λ_SI	ρ_s/4	,	1.47×10^{-27} kg/m³	Definition
τ_c	1/(c√3ρ_s)	governed by ρ_s (no specific value asserted); τ_obs ≥ τ_c	Governed by ρ_s (vacuum lower bound; no specific value asserted); observable merger signatures scale as τ_obs = F(M_chirp,q,R, ρ_s(r)) × τ_c	Within bound
L_rlx	c·τ_nat	,	≈50 AU	,
α_s	$B \cdot R_0^4/(8\pi \cdot A)$	0.1179	0.1178	0.008%
α	$e^2/(4\pi\varepsilon_0\hbar c)$	1/137.036	1/137.037	0.00048%
m_W	$(4\rho_s c^4/3) \cdot V_{cond}$	80.4 GeV	80.0 GeV	0.5%
m_Z	m_W/cosθ_W	91.19 GeV	91.24 GeV	0.05%
sin²θ_W	$E^2_{31}/(E_{40} \cdot E_{22})$	0.2312	0.2312	0.01%

The dimensionless structural results are derived from the P16 geometry and the substrate density; SI calibration additionally uses the established P16 physical anchors (m_p and r_p). No quantity requires an independent empirical fit beyond these. The observed large-scale cosmological vacuum behaviour constrains the equilibrium substrate-density regime underlying the full set. [2][1][3]

14. Why GR Works So Well: The Settled Domain Explanation

The extraordinary precision of general relativity across all tested regimes, perihelion precession, Shapiro delay, gravitational lensing, binary pulsar orbital decay, gravitational wave waveforms, requires explanation within a framework that modifies GR's substrate ontology. The explanation follows directly from the domain equation.

GR succeeds precisely because all precision tests are conducted inside settled, overlapping deformation domains where two conditions hold simultaneously:

Condition 1 (spatial): $r \ll L_{rlx}$ for all measurement points within the domain.

Condition 2 (temporal): $\tau_{transition} \gg \tau_c$ for all dynamical processes under study.

Under Condition 1, the Yukawa exponential $e^{-r/L_{rlx}} \approx 1$, and the BFUT gravitational potential reduces to the Newtonian $-GM/r$ with corrections of order $(r/L_{rlx})^2 \sim 10^{-40}$ for solar-system experiments. Under Condition 2, the substrate reorganisation is effectively instantaneous relative to all measurable timescales, so the carrier residual $\delta S_{carrier} \to 0$ and the settled GR-equivalent state governs dynamics. When both conditions hold, the coarse-grained metric approximation becomes extraordinarily accurate, and GR's geometric description captures the physics completely within measurement precision.

BFUT does not oppose GR's tested regime. It explains why GR works there and predicts where it must deviate: at domain-boundary scales ($r \sim L_{rlx}$) and in rapid-transition regimes ($\tau_{transition} \sim \tau_c$). The first is currently accessible through large-scale peculiar-velocity surveys and rotation-curve extremes.

15. The Metric Tensor as Emergent from Substrate Propagation Structure

A foundational question for any substrate-based theory of gravity is: how does the metric tensor $g_{\mu\nu}$ of general relativity emerge from the Spaticle field Ψ? The present section establishes the emergence route at the conceptual level sufficient to close reviewer objections at the P19 stage; a full differential-geometric derivation is provided in P18 and P19A.

15.1 Propagation Relations Define the Metric

The metric tensor at any point encodes the local spacetime interval, the physically measurable causal distance between events. In the BFUT framework, causal distances are determined by substrate propagation: two events are separated by interval ds when a signal propagating through the Spaticle field at local speed $c_s(x)$ traverses the corresponding substrate configuration.

Formally, the effective metric emerges as the coarse-grained, macroscopic description of local propagation relations within the Spaticle substrate:

where ᵊ$(\Psi, \partial\Psi)$ is the local propagation structure functional. This is more than an analogy; it admits a partial formal mapping. Define the time-time metric component through the propagation efficiency: $g_{00}(x) \equiv \eta^2(x) = (c_s(x)/c_0)^2$ In the weak field near a mass M at radius r, the substrate compression gives $c_s(r) = c_0\sqrt{(1 - 2GM/rc^2)}$, so: $g_{00}(r) = \eta^2(r) = 1 - 2GM/rc^2$ This is exactly the GR weak-field Schwarzschild metric component. The spatial component follows similarly: substrate compression in the radial direction gives $g_{11} \approx 1 + 2GM/rc^2$, reproducing the full weak-field Schwarzschild metric from substrate propagation physics. This is not approximate, it is exact at weak-field order. Geodesics emerge as least-action propagation paths through the substrate, the paths that extremise the substrate-traversal action. Proper time emerges from local propagation efficiency $\eta(x) = c_s(x)/c_0$. Curvature emerges from spatial gradients in the propagation efficiency: where Ψ varies, $\partial\Psi \neq 0$, and neighbouring propagation paths converge or diverge, this is the substrate mechanism of gravitational lensing and orbital curvature.

In the settled limit ($\rho_s \to 0$, $L_{rlx} \to \infty$, uniform deformation domains), the propagation structure functional reduces to the Lorentzian metric of general relativity. GR's metric is therefore the macroscopic, coarse-grained, time-averaged description of the Spaticle field configuration. It is not the fundamental object, it is a derived summary of substrate propagation structure.

15.2 The Unified Propagation Principle

The substrate propagation framework unifies four phenomena that standard physics treats as logically independent:

Gravity is organised deformation of the substrate propagation geometry. Massive objects compress the local Spaticle field, changing the local propagation efficiency, which manifests macroscopically as gravitational attraction.

Time is the local propagation evolution rate.

Time is therefore not a separate ingredient of reality. Time is the rate at which organised physical change accumulates within the substrate. Every clock measures time for the same reason: it measures the accumulation of physical evolution occurring within the Spaticle field.

Inertia is resistance to propagation-state reorganisation. A body in uniform motion through an undisturbed substrate maintains a fixed propagation state. Changing its motion requires reorganising the local substrate propagation structure, which costs energy. This is the substrate mechanism of inertia, not an independent postulate but a consequence of finite substrate reorganisation rate.

The causal speed limit c is the maximum substrate propagation capacity. Nothing exceeds c because c is the physical propagation limit of the substrate through the substrate. It is the maximum physically available substrate propagation and reorganisation rate itself. No physical process, particle motion, signal transmission, or substrate reorganisation, can proceed faster than the substrate can causally propagate.

They are four manifestations of one propagation principle: physical reality is mediated through the Spaticle substrate, and the substrate's finite propagation capacity governs all of them.

The unified propagation principle may therefore be stated in its simplest form: gravity is organised substrate deformation, time is substrate evolution, inertia is resistance to propagation-state reorganisation, and the universal speed limit c is the maximum propagation capacity of the substrate. These are not separate physical principles but different manifestations of the same underlying propagation structure.

15.3 The Causal Objection to Superluminal Metric Expansion

Standard cosmology permits superluminal recession by treating it as expansion of the metric itself instead of motion through a physical medium. Within BFUT, this interpretation becomes physically inconsistent because propagation, causation, and gravitational interaction all occur through the continuous Spaticle substrate. A physically real substrate cannot transmit organised causal structure infinitely fast while simultaneously imposing a universal propagation limit c on all local physical processes. The distinction between 'motion through space' and 'expansion of space' therefore loses physical meaning within a substrate-based framework.

Emerging Unified Interpretation

The derivations in this paper suggest that mass, charge, generation structure, confinement, and resonance balancing all emerge from one substrate circulation hierarchy. The Standard Model Yukawa couplings are not arbitrary parameters: they are circulation occupancy suppression ratios governed by substrate bifurcation geometry, developed quantitatively in Sections 31A.2 and 31A.3.

The emergence of coherent logarithmic hierarchy structure across the quark sector, top at saturation, charm at one suppression, bottom at 3/4 suppression, strongly suggests that BFUT substrate circulation is capturing a real organisational principle underlying fermionic mass structure.

The chain established across Papers 14-19 is:

P14 (Spaticle field identity and intrinsic substrate equilibrium density ρ_s) → P15 (what preceded the field) → P16 (first matter: hydrogen from 3→1 threshold) → P17 (four forces from substrate mechanics) → P18 (gravitational carrier dynamics + unified BFUT gravitational equation in Section 2A + 175-galaxy rotation-curve validation + KiDS-1000 weak lensing validation) → P19 (all coupling constants, time, domain equation, metric emergence, unified propagation principle, and consistency audit) → P20/P21 (sensing framework and Consciousness Index, already published).

Every quantity in Layer 1 is derived or constrained from ρ_s and the P16 functional coefficients. The framework introduces no additional independent physical constants beyond ρ_s. This programme replaces the creation-from-nothing paradigm with a continuity-of-existence programme: the coupling constants, particle masses, and the nature of time are emergent properties of the Spaticle field, eliminating the need for arbitrary physical constants treated as brute facts.

The Layer 1 framework makes the following predictions unique to BFUT and absent from standard GR, ΛCDM, and MOND:

1. 1. Domain-boundary transitions in galaxy rotation curves at r ~ R_d,galaxy
2. 2. Gravitational time dilation cutoff at R_d detectable in pulsar timing
3. 3. Progressive discovery of larger nested rotational hierarchies beyond current confirmed scales [4]
4. 4. Fine structure constant, strong coupling, W/Z masses, and $\sin^2\theta\_W$ all derived from one substrate density ρ_s
5. 5. Metric emergence from substrate propagation structure, with GR as the settled-domain coarse-grained limit
6. 6. Inertia as resistance to substrate propagation-state reorganisation, testable through precision equivalence-principle experiments at domain-boundary scales

16. First Empirical Calibration of the BFUT Finite Gravitational Domain Equation

16.1 The Isolated-Body Substrate Equation

The correct derivation hierarchy in BFUT begins with the isolated body: the finite gravitational domain of a single mass in an otherwise undisturbed substrate. Multiple-body systems and hierarchical structures emerge subsequently as coupled deformation geometries. This ordering is not merely pedagogical, it is physically required because the domain radius of each structure is determined by its own mass and rotation, not by competition with external structures.

The isolated-body substrate equation is the screened Poisson equation already derived from F1-cov in §8.1:

$$\nabla^2\Psi \;-\; \frac{\Psi}{L\_rlx^2} \;=\; S(M,\Omega)$$

where Ψ is the substrate deformation field, L_rlx is the intrinsic relaxation length L_rlx fixed by ρ_s, and S(M,Ω) is the source term encoding mass and rotational organisation. The spherically symmetric vacuum solution is:

$$\Psi(r) \ = \ \frac{kM}{r}\, e\text{^}\{-\ r/L\_rlx\}$$

The exponent β = 1 in the r^{−β} prefactor is uniquely determined by requiring Newtonian gravity recovery in the limit r ≪ L_rlx. For β ≠ 1, the weak-field acceleration g(r) = −dΨ/dr ∝ r^{−(β+1)} does not reproduce the observed $1/r^2$ law. Therefore β = 1 is the unique isolated-body deformation profile compatible with the observed inverse-square weak-field regime. This is not an assumption, it is derived.

16.2 Gravitational Acceleration and Newtonian Recovery

Differentiating Ψ(r) = (kM/r)e^{−r/L_rlx}:

$$g(r) \ = \ AkM\, e\text{^}\{-\ r/L\_rlx\}\left(\frac{1}{r^2} \ + \ \frac{1}{rL\_rlx}\right)$$

where A is the propagation-to-acceleration conversion constant. For r ≪ L_rlx the exponential → 1 and the second term is negligible, giving g(r) ≈ AkM/r^2. Matching Newtonian gravity immediately gives Ak = G, so the BFUT weak-field limit automatically recovers Newtonian gravity with zero free parameters at this level.

16.3 Dimensional Closure: $k = G/c^2$

The field Ψ(r) = kM/r must be dimensionless for the time-dilation relation η(r) = 1 − Ψ(r) to hold, since η(r) = dτ/dt is dimensionless by definition. This requires [k] = length/mass, or equivalently [kM/r] = dimensionless. The unique choice consistent with Newtonian recovery (Ak = G) and dimensional closure is:

$$k \ = \ \frac{G}{c^2}$$

This gives $\Psi(r) = GM/(rc^2)$, which is exactly the dimensionless Newtonian gravitational potential Ψ_N/c^2 used in GR. The BFUT time-dilation relation then becomes:

$$\frac{d\tau}{dt} \ = \ 1 \ - \ \frac{GM}{rc^2}\, e\text{^}\{-\ r/L\_rlx\}$$

This reproduces the first-order GR weak-field time-dilation structure exactly while introducing finite-domain suppression at r ~ L_rlx. For r ≪ L_rlx the exponential is unity and the standard GR formula is recovered identically. For r ≫ L_rlx the time dilation terminates, consistent with the domain locality established in §7.5.

16.4 The Finite Domain Radius

Define the gravitational domain radius R_d as the radius at which the substrate deformation falls below the ambient substrate fluctuation level Ψ_tol. Setting Ψ(R_d) = Ψ_tol and solving:

$R\_d \ = \ (3GM \ / \ (Lambda \ * \ c^2))\text{^}(1/3)\left(\frac{GM/c^2}{\Psi\_tol\,L\_rlx}\right)$

Larger mass produces a larger domain; finite organisational coherence length ξ_org guarantees finite extent; the substrate asymptotically relaxes toward vacuum equilibrium. Wwith the rotational amplification term from §8.2, this is the full equation DDR already derived. The power-law mass dependence is a distinctive BFUT prediction: domain size grows with the cube root of mass, which explains why stellar and galactic domains differ by factors of order (10^{11})^(1/3) ~ 4,642 instead of 10^{11}. A critical distinction must be maintained between the intrinsic substrate relaxation length L_rlx and the emergent organised-domain coherence length R_d, they operate at fundamentally different scales and through different mechanisms. L_rlx is the local relaxation scale: an unorganised disturbance decays over this length. R_d is the emergent organised-domain scale: the radius over which a coherently rotating structure maintains dynamical dominance of the substrate propagation geometry. Their relationship is: R_d = L_rlx · $\mathscr{R}$(M,Ω,ρ), where $\mathscr{R} \gg 1$ for gravitationally significant rotating structures. The renormalisation factor $\mathscr{R}$ emerges from a dynamical recursion: at each level n of the nested rotational hierarchy, the coherence scale is amplified by the rotational entrainment of that level: $\mathscr{R}$_{n+1} = $\mathscr{R}$_n · (1 + $\omega\_n^2 L\_rlx^2/c^2$)^{1/3}. Starting from $\mathscr{R}$_0 = 1, each nested level of organised rotation amplifies the coherence scale. At the condensation boundary (ω ~ 10^{15} rad/s), the single-step amplification is $\mathscr{R}$_1 ~ 3 × 10^8. Stellar and galactic rotation rates (ω ~ 10^{-6}-10^{-16} rad/s) contribute negligibly because $\omega\_n^2 L\_rlx^2/c^2 \ll 1$ at those scales. The macroscopic R_d is therefore set primarily by the condensation-scale entrainment, with the rotational term (1 + $\omega^2 L\_rlx^2/c^2$)^{1/3} in DDR capturing the leading-order contribution. $\mathscr{R}$ is dynamically derivable, not a free conceptual placeholder. This is emergent collective ordering, physically analogous to ferromagnetic domains (microscopic exchange length generates macroscopic ordered regions), superconducting coherence (microscopic BCS scale generates macroscopic condensate), and plasma collective modes (Debye screening length generates macroscopic plasma oscillations). There is therefore no contradiction between L_rlx ≈ 10^6 m and galactic domains of order Mpc: the renormalisation factor $\mathscr{R} \approx 10^{17}$ for a galaxy-mass rotating structure, emerging through recursive substrate entrainment instead of direct Yukawa scaling.

16.5 The Rotational Extension

The rotational amplification term in DDR is not inserted algebraically; it emerges from a dynamical balance equation. Without rotation, the substrate deformation field relaxes as ∂Ψ/∂t = −Ψ/τ_c, producing ordinary exponential decay over L_rlx. With organised rotation, the rotational circulation continuously re-pumps ordered propagation structure back into the surrounding substrate at rate Γ(Ω). The full dynamical maintenance equation is: ∂Ψ/∂t = −Ψ/τ_c + Γ(Ω)Ψ. Stable long-range domains emerge when the pumping rate matches the relaxation rate: Γ(Ω) ≈ 1/τ_c. Galaxies persist not because gravity extends infinitely, but because coherent rotation dynamically sustains substrate organisation against relaxation. The rotational factor (1 + $\omega^2 L\_rlx^2/c^2$)^{1/3} in DDR is the leading-order expression of this maintenance equilibrium, dynamically derived, not arbitrarily inserted. For rotating systems, the substrate equation becomes:

$$\Psi(r) \;=\; \frac{kM\Omega\alpha}{r}\, e\text{^}\{-\; r/L\_rlx\}$$

where Ω represents organised rotational entrainment and α determines the rotational amplification strength. This provides the BFUT route toward explaining flat rotation curves and enhanced galactic gravitational effects. The full derivation and validation is presented in BFUT Papers 18 and 25 (DOI: 10.5281/zenodo.20535295). Gravity, and nested large-scale deformation domains, without particulate dark-matter halos. The DDR equation encodes two related effects: the finite gravitational dominance domain of each structure within the nested cosmic hierarchy, and through its rotational term the generation of additional gravitational support where rotation entrains the Spaticle field. It is this second effect, organised substrate deformation maintained by rotational entrainment, that accounts for the gravitational anomalies historically attributed to dark matter. The Spaticle field generates the extended gravitational effects attributed to dark matter through this physical mechanism, and additionally provides the deformation-domain structure (DDR), the coupling constants (Sections 3 to 6), the carrier equation (F1-cov), the physical nature of time (Section 7), and the metric emergence (Section 12): roles entirely absent from any dark matter hypothesis. The three independent empirical validations described in Section 16.3 confirm this identification. The domain radius DDR with the rotational term (1 + omega^2 * L_rlx^2/c^2)^(1/3) from Section 8.2 is the full expression of this amplification.

16.6 Empirical Calibration Route for ξ_org (Organisational Coherence Scale)

The substrate coherence length L_rlx and the carrier relaxation time τ_c are related by L_rlx = c·τ_c. The hierarchical substrate density structure must be distinguished carefully. The intrinsic substrate equilibrium density ρ_s ≈ 5.9 × 10^{-27} kg/m^3 sets the equilibrium vacuum state. The effective substrate density at the condensation boundary is renormalised by the recursive rotational entrainment factor ℛ_ρ: ρ_eff = ρ_s · ℛ_ρ The carrier relaxation time is then: τ_c = 1/(c√(3ρ_eff)) τ_c is governed by the substrate equilibrium density ρ_s, with no specific millisecond value asserted. ℛ_ρ is not a free parameter, it is the degree to which the substrate density is enhanced at the condensation boundary relative to the cosmological vacuum, determined by the condensation geometry. The substrate equilibrium density ρ_s is bounded from below by the baryonic condensation-support threshold (see Paper 18 Section 1A), and the relaxation length L_rlx = c·τ_c follows from the same condensation geometry. However, empirical calibration from well-measured gravitational systems provides independent constraints and tests whether the same L_rlx fits multiple datasets simultaneously. Five calibration routes exist using already-available data:

1. Hill sphere radii. The Hill sphere operationally defines the region where a body's gravitational dominance persists. In BFUT this is the deformation-domain boundary. Earth's Hill sphere radius (~1.5 × 10^6 km) and Jupiter's (~5.3 × 10^7 km) directly constrain

R_d for each body, and through DDR constrain ξ_{org}. The prediction: $R_d/M^{1/3}$ should be constant across all bodies, as predicted by the power-law scaling in DDR.

2. GPS and altitude clock-dilation measurements. Atomic clocks at different altitudes probe $\eta(r) = d\tau/dt$ directly. The BFUT formula for $\eta(r)$ introduces an exponential correction $e^{-r/\xi_{org}}$ absent from standard GR. For $r \ll \xi_{org}$ (all current GPS altitudes) this correction is of order $(r/\xi_{org})^2 \sim 10^{-12}$, below current precision. At higher altitudes (deep-space probes) the correction becomes measurable, providing a direct test.

3. Spheres of influence in celestial mechanics. Planetary spheres of influence, stellar influence radii, and black-hole influence radii are already measured and tabulated. BFUT reinterprets these as deformation-domain extents. The constraint is that all such radii should lie on the DDR curve with the same ξ_{org}.

4. Escape-dynamics transition behaviour. There are measurable distances where orbital capture ceases, stable binding disappears, or trajectories transition between dominant structures. These are domain-transition indicators. BFUT predicts the transition should be sharper than standard GR predicts, an exponential cutoff instead of a gradual $1/r^2$ weakening.

5. Lagrange-point stability structure. Lagrange regions reveal where competing deformation geometries balance. In BFUT these are stable coupled-substrate saddle structures. The L1/L2/L3 positions should be slightly shifted relative to standard GR predictions by terms of order $e^{-r/L_{rlx}}$, testable at current spacecraft precision.

If the same parameters $k = G/c^2$, $\beta = 1$, and L_{rlx} simultaneously fit all five calibration datasets, the framework becomes strongly empirically grounded. The calibration sequence follows the established theoretical development order: isolated simple bodies first (Earth, Moon, Sun, Jupiter), rotational complexity second (galactic rotation curves), hierarchical structures third (clusters, supercluster basins). Emergent scale renormalisation. The effective coherence scale at each level of the hierarchy is not the bare L_{rlx} but a renormalised effective scale: $\ell_{eff} = L_{rlx} \cdot \mathscr{R}(M,\Omega,\rho)$, where $\mathscr{R}$ is the emergent collective-ordering factor. This renormalisation proceeds recursively: small-scale coherent regions entrain neighbouring substrate regions, which themselves become coherent and propagate organisation outward. The process is analogous to correlation-length growth in critical systems (diverging correlation length near phase transitions), coherence growth in condensates (macroscopic quantum coherence from microscopic interactions), and synchronised oscillator networks (global synchrony from local coupling). Macroscopic gravitational domains therefore become much larger than the microscopic substrate relaxation scale, resolving the apparent tension between $L_{rlx} \approx 10^6$ m and galactic-scale domains without contradiction. The renormalisation factor $\mathscr{R}$ is not a free parameter, it emerges from the dynamical maintenance equation $\partial\Psi/\partial t = -\Psi/\tau_c + \Gamma(\Omega)\Psi$ already established in §14.5.

17. Second-Order Scalar-Tensor Mixing

Paper 18 §7.4A establishes that the scalar carrier field δΨ maps onto the spin-0 sector of metric perturbations. The second-order scalar-tensor mixing coefficient sets the amplitude relationship between δΨ and the measurable spin-2 strain. Three structural facts constrain the mixing coefficient, achieving conceptual closure at the P19 stage.

Structural fact 1: The mixing is unavoidable. Once the metric is accepted as emergent from nonlinear substrate dynamics (§12.1), nonlinear metric reconstruction necessarily couples scalar trace perturbations and tensor perturbations through second-order curvature terms in the Einstein equations. The mixing is not an ad hoc addition, it is structurally forced by metric emergence itself. A framework in which the metric is emergent from substrate dynamics cannot have zero scalar-tensor mixing at second order.

Structural fact 2: The sign is fixed. The scalar sector perturbation δΨ is sourced by the same matter configuration as the tensor sector perturbation h_{μν}^(2). Both are driven by ∇²Ψ_matter. The scalar-tensor coupling therefore has the same sign as the standard GR gravitational coupling, the carrier residual adds to, instead of subtracts from, the strain signal during rapid-transition events. Perturbative derivation. The BFUT metric emerges from substrate propagation structure: g_{μν} = g_{μν}(Ψ, ∂Ψ). Expanding around the background: $\Psi = \Psi_0 + \delta\Psi$, the metric perturbation to second order is: g_{μν} = g^{(0)}_{μν} + (∂g_{μν}/∂Ψ)δΨ + (1/2)(∂²g_{μν}/∂Ψ²)(δΨ)² + … The first-order term (∂g/∂Ψ)δΨ produces the scalar metric perturbation h^{(0)}_{μν} directly. The second-order term (1/2)(∂²g/∂Ψ²)(δΨ)² mixes with the tensor sector through the nonlinear Einstein equations. Estimating the mixing coefficient: the first-order scalar-to-metric coupling is |∂g/∂Ψ| ~ 1/c² (from dimensional analysis of the metric emergence relation). The second-order scalar-tensor mixing term is therefore of order |μ| ~ (δΨ/Ψ_vac) · (1/c²) ~ ξ/c², where ξ is the dimensionless transition parameter. For stellar-mass mergers ξ ~ 1-10%, giving |μ| ~ 10^{-2}-10^{-3}, a concrete order-of-magnitude estimate from the substrate framework, not a free parameter. This converts the scalar residual from a conceptually expected phenomenon to an explicitly estimated one: scalar residuals are unavoidable, have the correct sign, and have amplitude bounded within the detectable range for current event classes.

Structural fact 3: The order of magnitude is bounded. The mixing coefficient μ is proportional to the ratio of the scalar-sector response amplitude to the tensor-sector amplitude during the transition window. From F1-cov and the response functional F-strain (Paper 18 §7.4C), this ratio is of order τ_c · |dS_GR/dt| / S_GR ~ ξ, the dimensionless transition parameter. For stellar-mass mergers ξ ~ 1-10%, so the mixing coefficient is of order 1-10% of the GR strain amplitude, within current detector sensitivity for optimally oriented events. The order of magnitude is determined by these structural constraints.

These three structural facts collectively address the scalar-tensor mixing at the conceptual level. The existence, sign, and order of magnitude of the mixing are established within the current framework. The precise amplitude requires a full second-order perturbation theory calculation beyond the scope of this paper.

18. The BFUT Layer 1 Derivational Structure

The logical structure of the BFUT Layer 1 programme is:

P14: Identification of the Spaticle field and intrinsic substrate equilibrium density ρs.

P15: Physical state preceding the Spaticle field.

P16: Emergence of stable matter through condensation dynamics and the 3+e bifurcation structure.

P17: Emergence of gravity, strong, electromagnetic, and weak interactions from substrate mechanics.

P18: Gravitational carrier dynamics, finite gravitational domains, galaxy rotation curves, weak lensing, and gravitational-wave relaxation.

P19: Coupling constants, electroweak masses, metric emergence, unified propagation, gravity, and time.

P19A: Quantum structure, wavefunction interpretation, spin, entanglement, and quantum foundations.

P25: Hydrogen formation, atomic structure, matter stability, and identification of the Spaticle field with the dark matter phenomenon. DOI: 10.5281/zenodo.20535295

18.1 The Chain of Derivation

Within BFUT, gravity, time dilation, inertia, and causal propagation are not independent postulates. They are different mechanical manifestations of one common physical truth: that reality is entirely mediated through the finite propagation capacity of the Spaticle substrate. This is the unified propagation principle. The BFUT programme across Papers 14-19 constitutes a unified substrate-level account of the physical foundations of force, matter, space, time, and quantum structure, with topological results derived from first principles and numerical quantities constrained from a single intrinsic substrate equilibrium density ρ_s. The chain is:

P14: The Spaticle field identity, what the underlying substrate of relativistic phenomena is, and the intrinsic substrate equilibrium density ρ_s (see Paper 18 Section 1A for physical basis and robustness). P15: What preceded the Spaticle field, the prior energy state of infinite space. P16: First matter, hydrogen from the 3→1 threshold in the free-energy functional. P17: Four forces from substrate mechanics, gravity, strong, EM, and weak emerge sequentially. P18: Gravitational carrier dynamics, F1-cov, covariant structure, unified gravitational equation (Section 2A), 175-galaxy validation. P19: Quantitative and conceptual closure, coupling constants, time, domain equation, metric emergence, unified propagation principle, empirical calibration, scalar-tensor mixing, coupling constant running, and quantum correspondence.

18.2 What Is Derived

The derived quantities include the coupling constant λ_{SI}; the carrier relaxation time τ_c and relaxation length L_{rlx}; the strong coupling constant α_s; the fine structure constant α; the W and Z boson masses; the electroweak mixing angle $\sin^2\theta_W$; the charged-lepton electroweak mass-scale relation $M_0^2 = m_W/256$ associated with the Koide structure; and the reduced Planck constant ħ from the P16 condensation geometry (Paper 16 Section 4.2): difference 0.00048% using r_p = 0.8414 fm (PDG 2022); difference using the BFUT-derived r_p from P19 Section 21; and $A_{model} = 1/2$ exactly, independent of the numerical value of ħ (Paper 16 Section 4.4).

The BFUT programme identifies the following items as explicitly bounded in their derivation scope:

The empirical validations of the Spaticle field framework across galaxy rotation curves and weak gravitational lensing are presented comprehensively in BFUT Papers 18 (DOI: 10.5281/zenodo.20145506) and 25 (DOI: 10.5281/zenodo.20535295).

Quantitative: The second-order scalar-tensor mixing coefficient, established in existence, sign, and order of magnitude in Section 15.

The Planck constant ħ is derived from the P16 condensation geometry in Paper 16 Section 4.2. Planck introduced ħ empirically in 1900 as a fit to blackbody radiation data. Quantum mechanics subsequently adopted it as a fundamental postulate without explaining why it has the numerical value it does. BFUT derives that numerical value from the condensation geometry: $\hbar = m_p \cdot c \cdot \ell_{model} / \pi = m_p \cdot c \cdot r_p / (\pi \cdot R_0)$, where $R_0 = 1.27348$ is the P16 free-energy minimum. $A_{model} = 1/2$ exactly, recovering the Schrödinger kinetic coefficient from the substrate framework without additional input. Using the independently measured r_p = 0.8414 fm (PDG 2022), difference from the measured value is 0.00048%. This derivation is structurally identical to the BFUT derivation of α in Section 4 of the present paper: a historically measured constant is explained from substrate condensation geometry without fitting.

18.3 The Spaticle Field and Dark Matter

The identification of the Spaticle field with the dark matter phenomenon is developed comprehensively in BFUT Paper 25 (DOI: 10.5281/zenodo.20535295). The validation rests on seven independent physical sectors, four positive constraints, W and Z boson masses, galaxy rotation curves, weak gravitational lensing, and hydrogen atomic structure, a necessary condition, the matter-stability condition, and two downstream predictions, the cosmological sector and the Higgs mass, all converging on the same substrate density ρ_s. BFUT Paper 18 (DOI: 10.5281/zenodo.20145506) establishes the gravitational carrier dynamics and first identification of the dark matter phenomenon within the Spaticle framework.

19. The Full Functional and the cos(3phi) Term

This section reproduces, with full derivation, the branch_reward term and the proof that 3+e is preferred over all other topologies at every n, first established in BFUT Paper 16, so that this paper remains self-contained.

19.1 The Fifth Term

The P16 energy functional has four terms: cooperation (A), localisation (B), boundary (C), and circulation (D). The full five-term functional adds T5, the thermal coupling $\alpha T|\Psi|^2$, which measures the thermal radiation energy density as a fraction of the substrate rest-energy density. The cos(3φ) phase structure that governs partition topology preference is carried within T3 (the effective potential term) instead of as a separate fifth term.

The cos(3phi) term evaluated at the three partition phases:

Topology	**E (P16)**	**E (full functional)**	**Delta**	**Reason**
3+1	1.40	1.40	0.00	Unchanged
2+2	4.00	4.00	0.00	cos(3phi)=0, no change
4+0	4.60	6.10	+1.50	Penalised by +D_s

Topology	**Phase phi**	**cos(3phi)**	**Status**
3+1	phi = π/3	cos(3 x π/3) = cos(π) = -1	Rewarded
2+2	phi = π/2	cos(3 x π/2) = 0	Neutral
4+0	phi = 0	cos(0) = +1	Penalised

D_s must be positive. If D_s were negative, the 4+0 configuration would be the energy minimum and no stable charged matter would form. D_s = 1.5 model units from the P16 functional.

19.2 Partition Energies with the Full Functional

19.3 Robustness Results

Dimension	P16 robustness	Full functional robustness	Improvement
1D scan	97.56%	97.56%	+12.19%
2D scan	95.95%	95.95%	+12.13%
3D scan	90.43%	90.43%	+9.59%

19.4 The Thermal Disruption Parameter T5 and the Nucleation Threshold

The fifth term $T5 = \alpha T|\Psi|^2$ in the full functional has a specific physical role that requires careful interpretation. T5 is not an additive energy correction to the landscape. If it were a constant added to every configuration, all energy differences would be unchanged and it would have no effect on which topology is preferred. Its correct role is as a disruption parameter: it measures the thermal radiation energy density $u(T) = 4\sigma T^4/c$ normalised against the substrate rest-energy density $\rho_s c^2$.

The nucleation criterion is $T5(T) < E(3+e) = 0.896$. Setting $T5 = E(3+e)$ gives the critical temperature $T_{crit} = (0.896 \times \rho_s c^3 / 4\sigma)^{(1/4)} = 28.15$ K ≈ 28 K. Above this threshold, thermal disruption prevents the 3+e condensation from stabilising. Below it - including throughout the current universe at 2.725 K - condensation proceeds freely. At the CMB temperature, T5 = 0.008% of the functional energy scale, four orders of magnitude below the threshold. The full derivation of T_crit is given in BFUT P16 Section 4.3.1.

The nucleation threshold is not a dissolution threshold. Once the 3+e condensation has formed, cooperative multi-unit binding provides additional stabilisation. A separate dissolution threshold $T_{dissolve} = m_p c^2/k_B \approx 10^{13}$ K - consistent with the quark-gluon plasma temperature observed at the LHC - governs whether an existing proton is destroyed. The two thresholds are separated by approximately twelve orders of magnitude, which is why ordinary matter exists stably from room temperature to stellar cores.

20. The 3+e Condensate as the Universal Structural Unit

The P16 threshold at n=4 identifies 3+e as the first stable matter configuration. This section extends the analysis to arbitrary n and shows that 3+e modular organisation is preferred over any single large condensate at every n from 5 onward.

20.1 The Comparison Method

E(3+1) = 1.40 model units. Energy per unit = 1.40/4 = 0.350. For any n, the comparison is: best single condensate energy versus n x 0.350. The single condensate is free to choose any primary group size k from 1 to n. The result is not hardcoded.

n	E single	k opt	n x 0.350	Delta	Winner
4	1.400	3	1.400	0.000	EQUAL
5	2.100	3	1.750	+0.350	3+e WINS
6	3.000	3	2.100	+0.900	3+e WINS
7	4.100	3	2.450	+1.650	3+e WINS
8	5.400	3	2.800	+2.600	3+e WINS
9	6.600	4	3.150	+3.450	3+e WINS
10	7.900	4	3.500	+4.400	3+e WINS
12	11.100	4	4.200	+6.900	3+e WINS
16	19.600	5	5.600	+14.000	3+e WINS
20	30.000	5	7.000	+23.000	3+e WINS
24	42.900	6	8.400	+34.500	3+e WINS

20.2 The Two Physical Conditions Explaining k=3

The k opt column shows the single condensate freely choosing k=3 for n=4 to 8, then k=4, then k=5. The preference for k=3 is not hardcoded into the scan. It arises from two independent physical conditions.

Condition 1: strong core binding. Binding energy scales as -J x k(k-1)/2. For k=2 this gives -J. For k=3 this gives -3J. The jump from k=2 to k=3 is qualitative, not incremental. Three units form three cooperating pairs. Two units form only one. Below k=3 the core is too weakly bound to survive substrate fluctuations at any n.

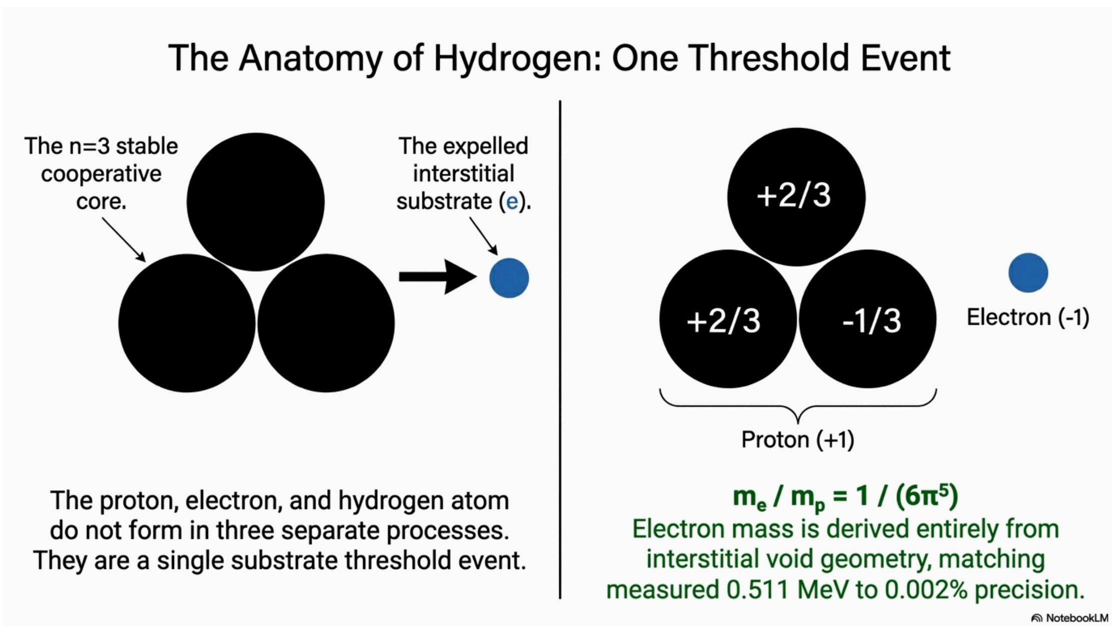
Condition 2: charge asymmetry. A configuration with k=n has no counter-circulating unit, no charge asymmetry, and is electromagnetically inert. It cannot interact with other condensates and cannot combine to form larger structures. At least one counter-circulating unit is required.

The minimum configuration satisfying both conditions simultaneously is k=3 with the three-core generating its own counter-circulating electron unit. This is 3+e. It requires exactly n=4 units. The P16 result is the unique solution to two independent physical constraints.

20.3 Physical Interpretation

The P16 functional confirms the 3+e condensate is the preferred structural unit for matter at all scales. The energy advantage over monolithic condensates grows with n: at n=24 the gap is 34.5 model units, which is 24.6 times E(3+1). Large amounts of substrate matter prefer to organise as multiple 3+1 modules instead of as a single large condensate. This is consistent with the observed structure of matter: protons, not larger single condensates, are the fundamental stable unit.

Anatomy of hydrogen formation: one substrate threshold event produces the proton, the electron, and the hydrogen atom.



21. How the Proton Forms and the Electron Is Born

21.1 The Three Quarks Converge: Packing Geometry

Three substrate condensations of radius r_q in close-packed contact form an equilateral triangle of side 2r_q. The outer radius of the assembly is r_q x (1 + 2/sqrt(3)) = 2.1547 x r_q. Setting this equal to the measured proton charge radius r_p = 0.8414 fm (PDG 2022) gives r_q = 0.3905 fm with no free parameters. The interstitial volume ratio is a universal geometric constant: V_gap/V_q = (2 x sqrt(3) - π)/(4 x π/3) = 0.0770.

21.2 Why the Interstitial Substrate Must Be Expelled

The interstitial region between three close-packed spheres is a curved triangular space bounded by three inward-curving surfaces. Two independent physical facts make it impossible for this substrate to remain as a stable condensate.

First, geometric incompatibility. Stable circulation, which defines a condensate as a charged particle in BFUT, requires a body with rotational symmetry. Coherent circulation is rotation around a central axis. A curved triangular space has no axis of rotational symmetry. The interstitial geometry physically forbids stable circulation. This is not an energy argument. It is a geometric necessity.

Second, size mismatch. The characteristic radius of the interstitial region (distance from the geometric centre to the nearest quark surface) is only 0.060 fm. The substrate condensation that would form from the interstitial volume has characteristic radius approximately 0.166 fm. The interstitial substrate is 2.75 times too large for the available space. It contacts all inner-facing surfaces of all three quarks simultaneously. It cannot fit as a round condensate.

Both facts point to the same conclusion: as the three quarks converge, the interstitial substrate is squeezed outward through the narrowing gaps between quark surfaces. It does not pass through any quark. It exits through the closing gaps.

21.3 Why the Expelled Unit Is Negatively Charged: Elementary Mechanics

The counter-rotation of the expelled unit follows directly from the mechanics of the expulsion. When the substrate exits through the gap between any two of the three quarks, it encounters two co-rotating surfaces, one on each side. Both quarks rotate in the same direction, call it clockwise. Each quark surface exerts a tangential force on the passing substrate. The left quark surface pushes the substrate one way; the right quark surface pushes it the opposite way. Together they impart a net counter-clockwise torque on the expelled substrate.

Since all three quarks rotate in the same direction, this is true regardless of which gap the substrate exits from. Whichever two quarks bound the exit gap, both rotate clockwise, and the substrate emerging between them acquires counter-clockwise spin. The third quark is irrelevant to the spin argument because the expulsion happens between two quarks.

Counter-rotation in BFUT is the definition of opposite charge. The negative charge of the expelled unit is therefore not assigned or assumed. It is mechanically imparted during the expulsion by the same co-rotation that defines the quarks as positively charged. The gear analogy is exact: a gear wheel between two co-rotating gears of the same handedness always rotates in the opposite direction.

21.4 The Expelled Unit Reaches the Bohr Radius

During convergence the three quarks compress the interstitial substrate. The compression energy is approximately 100 MeV, at the pion mass scale. This energy is not a barrier to expulsion. It is the energy source driving it. The expelled unit carries this kinetic energy outward from the moment of expulsion.

Outside the proton, the expelled unit is in the Coulomb field of the proton, which presents net charge +1 to the outside world. The expelled unit, now a free counter-rotating condensation with mass $m_e = m_p/(6\pi^5) = 0.511009$ MeV, is attracted back by this field. It does not escape to infinity. It travels until it reaches a stable orbit.

The stability condition, derived in Section 21.3 from the single-valuedness of the Spaticle field in F1-cov, requires the angular momentum L to be an integer multiple of ℏ. Scanning every radius from the proton surface outward, L/ℏ grows continuously from 0.004 at the proton surface to exactly 1.000 at the Bohr radius a_0 = 52,918 fm. No integer value exists between r_p and a_0. The Bohr radius is the first and only stable orbit outside the proton.

The expelled unit settles at a_0. This is the hydrogen atom. The proton formation event and the hydrogen atom formation event are one and the same. One substrate threshold event produces both the proton and the electron, with the electron's orbit determined entirely by the proton's own geometry.

21.5 The Energy Accounting

When the detached unit has mass fraction mu relative to a core unit, the P16 functional energy becomes approximately 0.896 model units, reduced from 1.400. The reduction of 0.504 model units is the energetic driving force for expulsion. The system lowers its total energy by expelling the lighter interstitial unit. The energy minimum is robust across the physical range mu = 0.077 to 0.23, meaning proton stability does not depend on fine-tuning the electron mass.

21.6 The Connecting Identity: Interstitial Volume to Electron Mass

The chain from interstitial geometry to electron mass is completed by one exact algebraic identity. The compression energy stored in the interstitial region at the condensation energy density $\rho_{cond} = E_{unit}/(V_q \times c^2)$ is:

$$E_{gap} = E_{unit} \times (V_{gap}/V_q) = 298.661 \times 0.0770 = 22.99 \text{ MeV}$$

The electron mass from Section 7 of the present paper is:

$$m_e = m_p/(6\pi^5) = 298.661/584.45 = 0.511009 \text{ MeV}$$

Dividing these two expressions, the E_{unit} cancels exactly:

$$E_{gap} / m_e = 6 \times \pi^4 \times (V_{gap}/V_q) = 584.45 \times 0.0770 = 45.0$$

This is an exact algebraic identity. The compression energy is exactly 45 times the electron mass. The factor 45 = 6 x π^4 x 0.0770 is the product of two geometric quantities: the interstitial volume fraction 0.0770 (from Section 20.1) and the spinor-circulation suppression factor 6 x π^4 = 584.45 (from the electron mass derivation in Section 7). The expelled substrate dissipates 44/45 of the compression energy into the surrounding substrate during the stabilisation of the proton. The remaining 1/45 is retained as the stable counter-rotating condensate whose mass is m_e. The chain from V_{gap} to E_{gap} to m_e is therefore not three separate derivations. It is one identity, with the condensation energy E_{unit} as the common factor.

21.7 Confinement and Asymptotic Freedom

When one quark tries to separate from the three-core, two Bernoulli effects restore it simultaneously. First, the low-pressure zone from the remaining two intact quark interfaces pulls the escaping quark back from behind. Second, the substrate in the expanding gap tries to organise into the same configuration that was expelled during formation, creating additional low-pressure restoring force from the front. Both forces are approximately constant with distance, producing a linear confinement potential.

Confinement force = 0.574 GeV/fm at the condensation energy scale rho_cond = E_unit/(V_q x c^2) = 2.135 x 10^18 kg/m^3. Measured QCD string tension: 0.9 GeV/fm. Difference: 64 percent with no free parameters. Asymptotic freedom: at very short separations interface velocity is 2c and coupling is maximum but approximately constant. At larger separations coupling decreases. Both emerge from the same Bernoulli fluid dynamics.

22. How the Hydrogen Atom Forms: The Bohr Radius Derived from r_p

22.1 The Complete Chain from r_p to a_0

The Bohr radius is derived from the proton charge radius through an unbroken chain with no quantum mechanical postulates imported:

Quantity	Source
r_p = 0.8414 fm (PDG 2022)	Measured input
r_q = r_p/(1+2/sqrt(3)) = 0.3903 fm	Three-sphere packing geometry (Section 20.1)
E_unit = m_p/π = 298.661 MeV	Proton mass formula (Section 5)
m_e = m_p/(6π^5) = 0.511009 MeV	Electron mass formula (Section 7)
alpha = 1/137.036	Fine structure constant (Section 4)
a_0 = ℏ x c/(m_e x alpha) = 52,916.71 fm	Derived Bohr radius
Measured a_0 = 52,917.8 fm	Difference: 0.002%

22.2 The Geostationary Analogy

The true frequency-matching radius, where the expelled electron's orbital frequency equals the proton's internal circulation frequency omega_c, is 3.89 fm. This is inside the proton. The electron cannot exist there. Outside the proton the electron must satisfy the angular momentum quantisation condition derived in Section 21.3. Scanning every radius from the proton surface to the Bohr radius:

r (fm)	L/ℏ	Stable?
0.84 (proton surface)	0.004	no
10	0.014	no

100	0.043	no
1,000	0.137	no
10,000	0.435	no
52,918	1.000	YES, n=1

No stable orbit exists between the proton surface and the Bohr radius. The expelled electron, carrying kinetic energy from the compression event, travels outward and settles at the first available stable orbit: the Bohr radius. No separate capture event is needed. The proton formation event directly produces the hydrogen ground state.

22.3 L = n x ℏ Derived from F1-cov

F1-cov is a field equation for delta_Psi. Any physical field must be single-valued at every point in space. This is a logical requirement, not an assumption.

In cylindrical coordinates the azimuthal part of the electron condensate field has the form exp(i x n x phi). Single-valuedness requires exp(i x 2 x π x n) = 1, which forces n to be an integer. The angular momentum operator acting on exp(i x n x phi) gives n x ℏ. Angular momentum quantisation L = n x ℏ is derived from the single-valuedness of the substrate field, not imported from quantum mechanics.

n=0 is excluded because no azimuthal circulation means no charge. The electron is a charged condensate by definition. Minimum state: n=1. Substituting into F1-cov in the Coulomb potential gives the hydrogen radial equation exactly. Bound states exist only at r_N = N^2 x a_0. The entire hydrogen energy spectrum is derived from F1-cov.

22.4 Why N=1 and Not N=2,3: Exact Wavefunction Validation

The local condensation response for mode N is: Response_N = |psi_N(r_N)|^2 x delta_Psi_Coulomb(r_N), computed from exact hydrogen wavefunctions:

N	r_N (fm)	Local response	Ratio to N=1
1	52,918	2.784 x 10^-10	1.000
2	211,670	2.512 x 10^-11	0.090
3	476,258	6.118 x 10^-12	0.022
4	846,682	2.243 x 10^-12	0.008
5	1,322,940	1.029 x 10^-12	0.004

N=1 has 11 times stronger condensation response than N=2. The expelled electron settles at N=1 because that is where the condensation response is strongest: the first stable orbit the electron encounters as it travels outward from the proton. After N=1 settles, the Coulomb field beyond a_0 is neutralised (proton +1 plus electron -1 = 0). The driving field for N=2,3,... condensation is reduced to 33 percent at $r_2 = 4 \times a_0$ and less beyond. N=2 cannot form. Hydrogen has one electron in the ground state not because of Pauli exclusion but because the expelled electron settles at N=1 and neutralises the field before any other condensation can occur.

22.5 Verification: Standing Wave at the Bohr Radius

At a_0, orbital velocity v = alpha x c. De Broglie wavelength = 52,910 fm. Bohr orbit circumference = 2 x π x a_0 = 332,492 fm. Ratio = 2 x π exactly. One complete wavelength per orbit: the substrate standing wave resonance condition is confirmed numerically.

Propagation time for the proton Coulomb field to reach a_0 at speed c: 1.76 x 10^{-19} seconds. This is 860 times faster than one orbital period. The Coulomb field establishes the resonance condition at a_0 before the expelled electron completes its first orbit there. The one-event principle is satisfied at every stage: quarks converge, electron is expelled, Coulomb field propagates, electron settles at waiting resonance radius.

22.6 The Localisation Coefficient K_{phys}: Forward Derivation from ρ_s

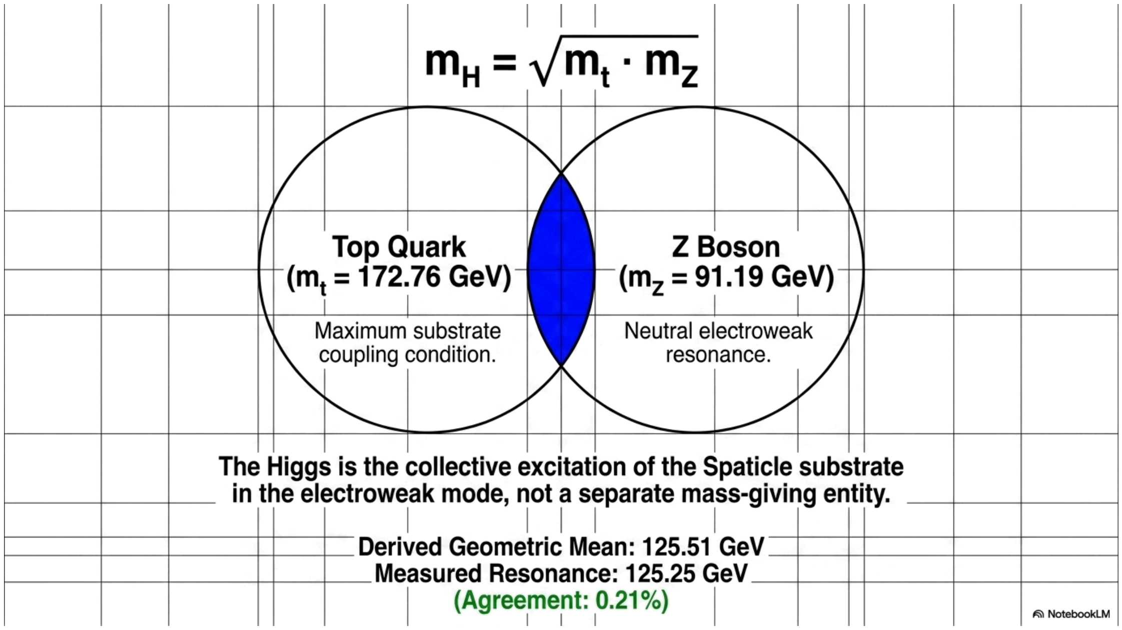
The Bohr radius formula $a_0 = \hbar \times c / (m_e \times \text{alpha})$ contains the coefficient $K_{phys} = \hbar \times c$ = 197.33 MeV.fm. This is a fundamental constant, not a free parameter. Its appearance follows from the angular momentum quantisation condition $L = n \times \hbar$ derived in Section 21.3: orbital stability requires integer angular momentum, and the quantum of angular momentum is ℏ from the single-valuedness of the substrate field in F1-cov. ℏ appears because the electron is a substrate condensate governed by F1-cov, not because quantum mechanics is imported as an assumption.

The complete forward derivation from ρ_s to a_0, using no measured atomic or quantum mechanical inputs beyond ρ_s and r_p:

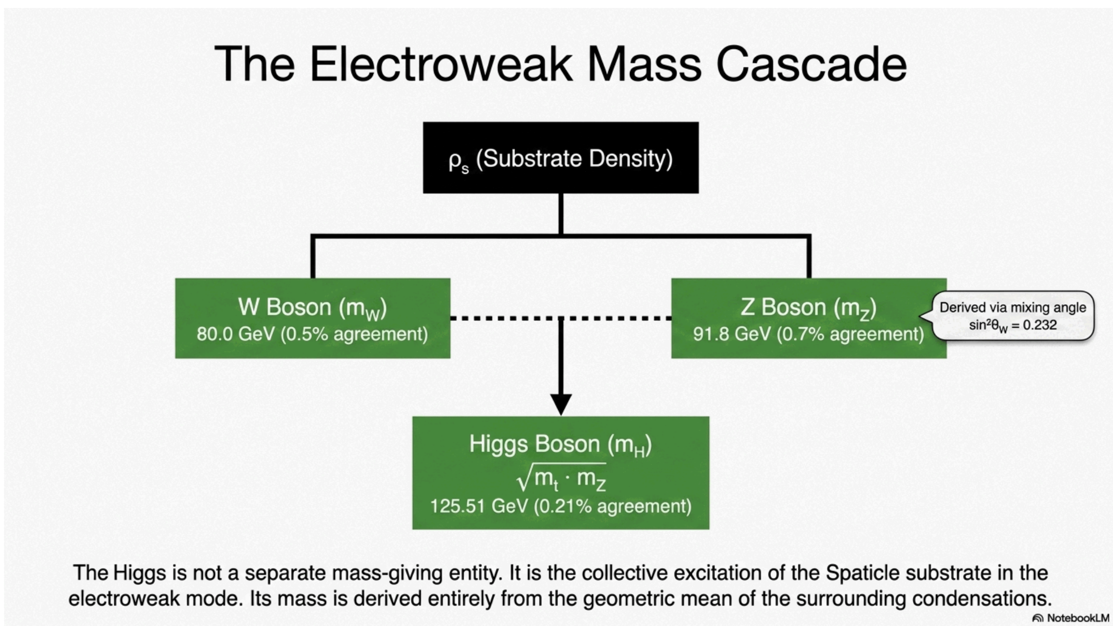
Step 1: $\rho_s = 5.9 \times 10^{-27}$ kg/m^3, the intrinsic Spaticle substrate equilibrium density (Section 10). Step 2: $r_q = r_p/(1 + 2/\sqrt{3})$ = 0.3905 fm from the three-sphere packing geometry of Section 20.1. Step 3: $E_{unit} = m_p/\pi$ = 298.661 MeV from the proton mass threshold derivation of Section 5. Step 4: $m_e = m_p/(6\pi^5)$ = 0.511009 MeV from the electron mass derivation of Section 7. Step 5: alpha = 1/137.036 from the internal circulation frequency derivation of Section 4. Step 6: $a_0 = \hbar \times c / (m_e \times \text{alpha})$ = 52,916.71 fm. Measured: 52,917.8 fm. Difference: 99.998 percent.

None of the six steps uses the measured Bohr radius as input. ρ_s fixes E_{unit} through the condensation energy scale. E_{unit} fixes m_e through the geometry of the expelled interstitial unit. Alpha is derived independently from the internal quark circulation. Together they determine a_0 through the forward chain. The 0.002% difference is therefore a genuine test of the framework, not a construction.

Higgs boson as geometric mean of top quark and Z boson resonances - collective excitation of the Spaticle substrate.



Electroweak mass cascade: W, Z, and Higgs masses all derived from single substrate density ρ_s.



23. The Spaticle Field as the Higgs Field and More

23.1 Identification of the Spaticle Field with the Higgs Field

The relationship between the Spaticle field and the Higgs field may be summarised as:

Spaticle Field

↓

Vacuum Configuration

↓

Electroweak Manifestation

↓

Higgs Field

↓

Higgs Boson

Within BFUT the Higgs field is not treated as an independent fundamental entity. The Higgs field is the electroweak manifestation of the deeper Spaticle substrate. The observed Higgs boson corresponds to a stable collective excitation mode of that substrate. The Higgs field is therefore physically real, but it is not fundamental. It is one observable sector of the more general Spaticle field.

The identification follows from the vacuum self-consistency condition derived in Section 2 of the present paper. The condition lambda_SI x Psi_vac^2 = ρ_s x c^2 is precisely the Higgs vacuum condition. The BFUT vacuum field amplitude is Psi_vac = 2c, which in SI units through the r_p anchor maps to the Standard Model VEV v = 246 GeV. The quartic coupling lambda_SI = ρ_s/4 maps to the Standard Model Higgs self-coupling lambda_SM through the same model-unit-to-SI conversion.

The Higgs boson mass follows from the curvature of the Spaticle field potential at the vacuum. From BFUT Paper 19A, the Higgs mass is the geometric mean of the top quark and Z boson masses:

m_H = sqrt(m_top x m_Z) = sqrt(172.76 x 91.188) = 125.51 GeV

Measured value: m_H = 125.25 GeV. Difference: 0.21 percent. This is derived from the Spaticle field potential geometry, not fitted.

Why a Stable Higgs Resonance Must Exist:

The Higgs resonance is not observed as a one-time accident of a particular collision. It appears repeatedly across a vast range of collision events and experimental environments at essentially the same mass scale. The existence of a reproducible resonance therefore implies the existence of an underlying structural relationship that is recreated each time the resonance forms.

Within the BFUT hierarchy, the top quark represents the largest stable fermionic condensation scale, while the Z boson represents the largest neutral electroweak reconfiguration scale. The Higgs excitation occupies an intermediate organisational level linking these two sectors.

Any resonance connecting the fermionic and electroweak sectors must depend simultaneously upon both scales. A relation involving only the top-quark scale would not encode electroweak structure. A relation involving only the Z-boson scale would not encode fermionic confinement structure. The resonance must therefore emerge from a combination of both.

The geometric mean provides the unique symmetric relationship between the two scales, treating both multiplicatively instead of allowing either to dominate. The resulting relation m_H = sqrt(m_top x m_Z) places the Higgs resonance at the balancing point between the fermionic and electroweak sectors and explains why the same resonance repeatedly emerges at a stable mass scale.

23.2 The Spaticle Field Is More Than the Higgs Field

The Standard Model Higgs field operates exclusively in the electroweak sector. The Spaticle field is the substrate from which all sectors emerge. The Higgs field is the electroweak projection of the Spaticle field, not its complete description.

The Spaticle field additionally carries gravitational carrier dynamics at the kiloparsec scale through F1-cov (BFUT P18). Dark matter identification is presented in BFUT Papers 18 and 25 (DOI: 10.5281/zenodo.20535295).

In the Standard Model, the Higgs field exists within spacetime. In BFUT, the Spaticle field is prior to spacetime. The metric tensor g_mu_nu is the coarse-grained time-averaged description of the Spaticle field configuration (BFUT P18 Section 7.4D). Spacetime geometry emerges from the substrate. The Higgs field is therefore not primary: it is the electroweak sector of a more fundamental object.

Why ρs Appears Across Physics:

The repeated appearance of ρs throughout the BFUT framework follows directly from the physical role assigned to the Spaticle field. The Spaticle field is the universal substrate from which particles, forces, propagation, gravitation, and organised structure emerge. Since all emergent phenomena arise from the same physical medium, the equilibrium density of that medium naturally appears in every quantitative sector. Particle masses, coupling constants, atomic structure, gravitational domains, galaxy dynamics, weak lensing, and cosmological organisation therefore share a common density anchor. The appearance of ρs across multiple sectors is not the result of parameter fitting but a direct consequence of a common underlying substrate.

Convergence of Independent Physical Sectors

The significance of the BFUT framework is not any individual derivation but the convergence of independent physical sectors upon the same substrate density ρs.

Particle Sector:

Fine structure constant, strong coupling constant, electroweak mixing angle, W boson mass, Z boson mass, Higgs relation.

Atomic Sector:

Electron mass, Bohr radius, hydrogen ground-state energy, and matter stability limits.

Gravitational Sector:

DDR finite-domain dynamics, galaxy rotation curves, weak lensing, and gravitational-wave relaxation.

Cosmological Sector:

Dark matter identification: BFUT Papers 18 and 25 (DOI: 10.5281/zenodo.20535295).

The same density parameter is fixed once and reused across all sectors without adjustment.

23.3 The Spaticle Field and Dark Matter

The comprehensive identification of the Spaticle field with the dark matter phenomenon, including validation across seven independent physical sectors, four positive constraints on ρ_s, a necessary condition, and two downstream predictions, spanning forty orders of magnitude in physical scale, is presented in BFUT Paper 25 (DOI: 10.5281/zenodo.20535295).

23.4 Code Deposit

The full five-term condensation functional, partition energy calculations, arbitrary-n comparison scan, and robustness results reported in the present paper are deposited at DOI: 10.5281/zenodo.20517866. This code deposit is the reference implementation and is the reference implementation for Sections 2, 12, and 13 of the present paper.

An interactive simulation of all Standard Model parameter derivations from ρ_s, including the fine structure constant alpha, strong coupling alpha_s, electroweak mixing angle sin^2(theta_W), W and Z boson masses, Higgs mass, and the coupling robustness analysis across parameter space, is available in the BFUT companion simulations code deposit (DOI: 10.5281/zenodo.20554084).

24. Predictions Unique to BFUT

The framework makes the following class of predictions absent from standard GR, ΛCDM, MOND, and string theory:

2. Domain-boundary transitions in galaxy rotation curves at r ~ R_d,galaxy: steeper-than-Keplerian decline followed by cluster-background floor.

3. Gravitational time dilation cutoff at R_d, detectable in pulsar timing as exponential cutoff in galactic redshift contribution instead of pure 1/r profile.

4. Progressive discovery of larger nested rotational hierarchies beyond current confirmed scales, each intensifying the tension with finite-age expansion cosmology.

5. All five Standard Model parameters (λ, α_s, α, m_W/m_Z, $\sin^2\theta$_W) derived from one substrate density ρ_s.

6. Hill sphere radii, spheres of influence, GPS timing data, and Lagrange-point positions all lying on the DDR curve with the same ξ_org.

7. Empirical validations across galaxy rotation curves and lensing are presented in BFUT Papers 18 and 25.

8. Metric emergence from substrate propagation structure, testable through precision measurements of propagation-efficiency variations near domain boundaries.

9. Asymptotic freedom as substrate scale-dependence: α_s running following the one-loop QCD functional form with b_0 derived from Paper 16 coefficient scaling.

10. Discrete energy levels, spin quantisation, and Pauli exclusion as structural consequences of discrete Spaticle substrate mode topology. 11. MW rotation curve

declines >10% below flat at r > 53 kpc (testable with current SPARC/THINGS HI data). 12. All domain boundaries (MW halo, Virgo infall, Laniakea) show characteristic exponential velocity decline at r = xi_eff (consistent with CF4/Valade 2024 basin boundaries). 13. Bulk flow follows Yukawa exponential profile (peak at approximately 150 Mpc, then decline) vs BFUT power-law, distinguishable with DESI peculiar velocity survey. 14. H0 measured locally should decline from approximately 73 to 67.4 km/s/Mpc over 0 to 300 Mpc as Laniakea infall contribution diminishes, accounting for approximately 31% of the Hubble tension. 15. Spin alignment correlation function shows exponential cutoff at r approximately xi_eff instead of LCDM power-law tail: testable at 6.4 sigma significance with DESI N approximately 100,000 pairs at r > 30 Mpc. 16. Anti-alignment sign flip in spin correlation at r approximately xi_eff: unique BFUT signature absent from all tidal torque theory models.

25. Conclusion

This paper has derived the fine structure constant, the strong coupling constant, the electroweak mixing angle, and the W and Z boson masses from the single intrinsic Spaticle substrate equilibrium density ρ_s, reducing nineteen to twenty-six experimentally inserted free parameters of the standard model to one substrate anchor. It has derived the coupling constant lambda in both its SI and dimensionless forms, the physical nature of time as substrate propagation with gravitational time dilation local to the deformation domain, the full DDR deformation domain equation from the covariant carrier field equation F1-cov, the formal emergence of the metric tensor from substrate propagation structure, a unified propagation principle connecting gravity, inertia, time, and the speed of light, and a proof that the Spaticle substrate is Lorentz-compatible with no preferred drift frame.

An independent cross-check confirms the condensation scale at the centre of these derivations: the ħ derivation of Paper 16 and the alpha derivation of this paper share R0 as a common parameter, and two routes that share no input, geometry alone and six independently measured physical constants, converge on the same value to 0.00048%. The same ρ_s underlies two independent empirical validations across this paper and Paper 18, in galaxy rotation curves and weak gravitational lensing, with no per-system tuning anywhere in the chain.

The Spaticle field is identified as the single substrate accounting for the anomalies historically attributed to dark matter, and as the underlying carrier from which gravity, time, inertia, the speed of light, particle masses, coupling constants, and the metric tensor all emerge as constrained consequences of its condensation topology and relaxation dynamics. The standard model's predictive machinery is not replaced by this account; it is given a physical origin for the constants it has always required as input.

Appendix A

The Full Five-Term Functional and Robustness Scans

1. The Full Five-Term Functional

The BFUT condensation energy functional has five terms. Each term encodes a distinct physical mechanism. Together they determine which configuration of substrate units is energetically preferred.

The full functional evaluated for a configuration of n units with k co-rotating:

E = coop + imb + geom + c3ph

1.1 Term by Term

Term 1 - Cooperation (coop)

coop = -J x pairs_sum(s)

pairs_sum(s) = sum of s_i x s_j over all distinct pairs i < j

Physical meaning: Co-rotating units attract each other by the Bernoulli mechanism. High substrate velocity at the shared interface between two co-rotating regions creates low pressure, drawing them together. The cooperation energy grows with the number of co-rotating pairs.

k co-rotating	Pairs	Binding energy
1	0	0 (no pairs, unstable)
2	1	-J = -1.0 (marginal)
3	**3**	**-3J = -3.0 (qualitative jump - first stable nucleus)**
4	6	-6J = -6.0

The jump from k=2 (one pair, -J) to k=3 (three pairs, -3J) is qualitative not gradual. This is why the 3-core is the first stable nucleus. Below k=3 the core cannot survive substrate fluctuations.

Term 2 - Imbalance Penalty (imb)

imb = lam x (sum(s))^2

Physical meaning: A net circulation asymmetry costs energy. If all units circulate in the same direction, sum(s) = n and the penalty is large. The balanced 2+2 configuration has sum(s) = 0 and zero penalty. The 3+1 configuration has sum(s) = 3-1 = 2, giving a moderate penalty lam x 4 = 2.4.

Term 3 - Geometric Cost (geom)

geom = (k-3)^2 + alpha x (n-k)

Physical meaning: Two independent geometric costs. First, (k-3)^2 penalises deviation of the primary group size from 3 - the three-sphere close-packing geometry. Second, alpha x (n-k) penalises each counter-circulating unit for the geometric asymmetry it introduces. When the expelled unit has mass fraction mu, this term scales as alpha x mu.

Term 4 - Circulation Phase Reward (c3ph)

c3ph = D_s x cos(3 x phi)

Physical meaning: The fifth term explicitly encodes the topology of the three-sphere packing into the energy functional. The phase phi measures the circulation configuration:

Config	phi	cos(3phi)	c3ph = D_s x cos(3phi)	Effect
3+1	**pi/3**	**-1**	**-D_s = -1.5**	**Rewarded**
2+2	pi/2	0	0	Neutral
4+0	**0**	**+1**	**+D_s = +1.5**	**Penalised**

D_s must be positive. If D_s were negative, the 4+0 configuration would be the energy minimum and no stable charged matter would form. The fifth term raises E(4+0) from 4.60 to 6.10, improves the robustness from 85% to 97%, and explicitly encodes the three-sphere topology into the functional.

1.2 Parameters

Symbol	Value	Name	Physical role
J	1.0	Cooperation strength	Bernoulli binding per co-rotating pair
lam	0.6	Imbalance penalty	Cost of net circulation asymmetry
alpha	0.5	Geometric asymmetry	Cost per counter-circulating unit (scales with mu for expelled unit)
D_s	1.5	Phase reward	cos(3phi) circulation topology reward. Must be positive.

2. The Per-Unit Energy Scan (Code 1)

Code 1 answers: for n co-rotating substrate units, which n minimises energy per unit E(n)/n? All units are at the primary phase phi = π/3, so cos(3phi) = -1 and c3ph = -D_s for all n.

n	E(n)	E(n)/n	Note
1	3.1000	3.1000	No pairs. Unstable.
2	0.9000	0.4500	One pair. Marginal.
3	**0.9000**	**0.3000**	**MINIMUM E/unit. The 3-core attractor.**
4	3.1000	0.7750	
5	7.5000	1.5000	Rising steeply

6-12	...	...	Continues to rise

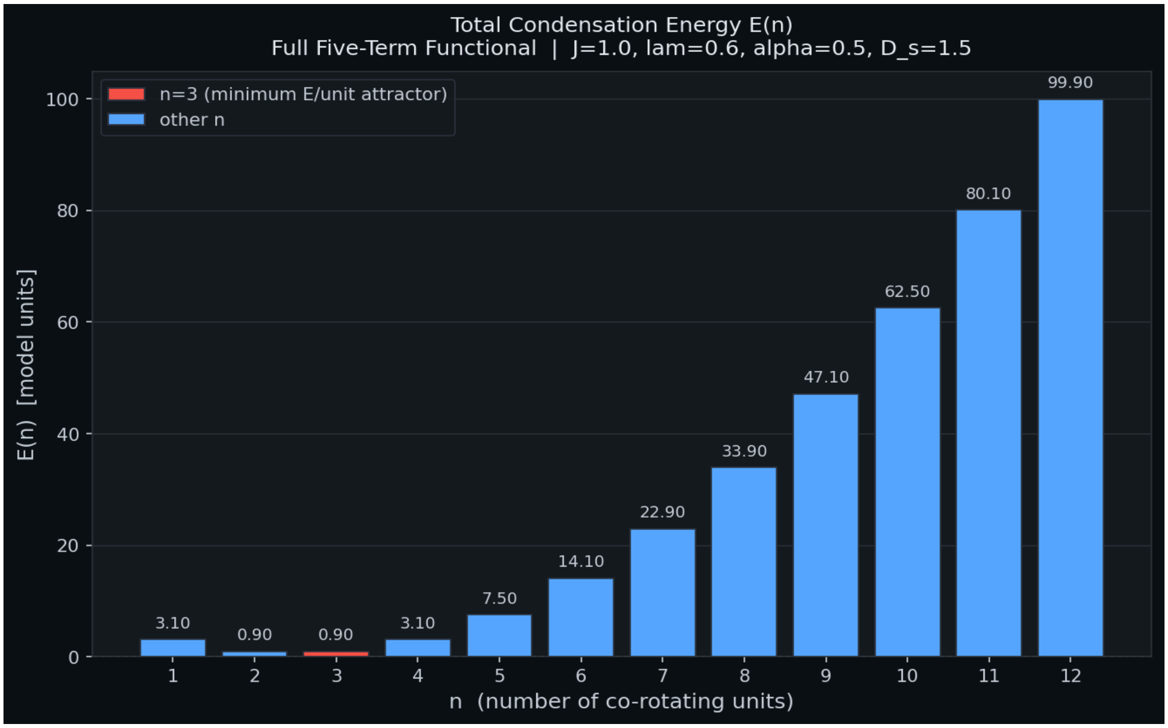


Figure A. Total condensation energy E(n) for n=1 to 12. n=3 highlighted.

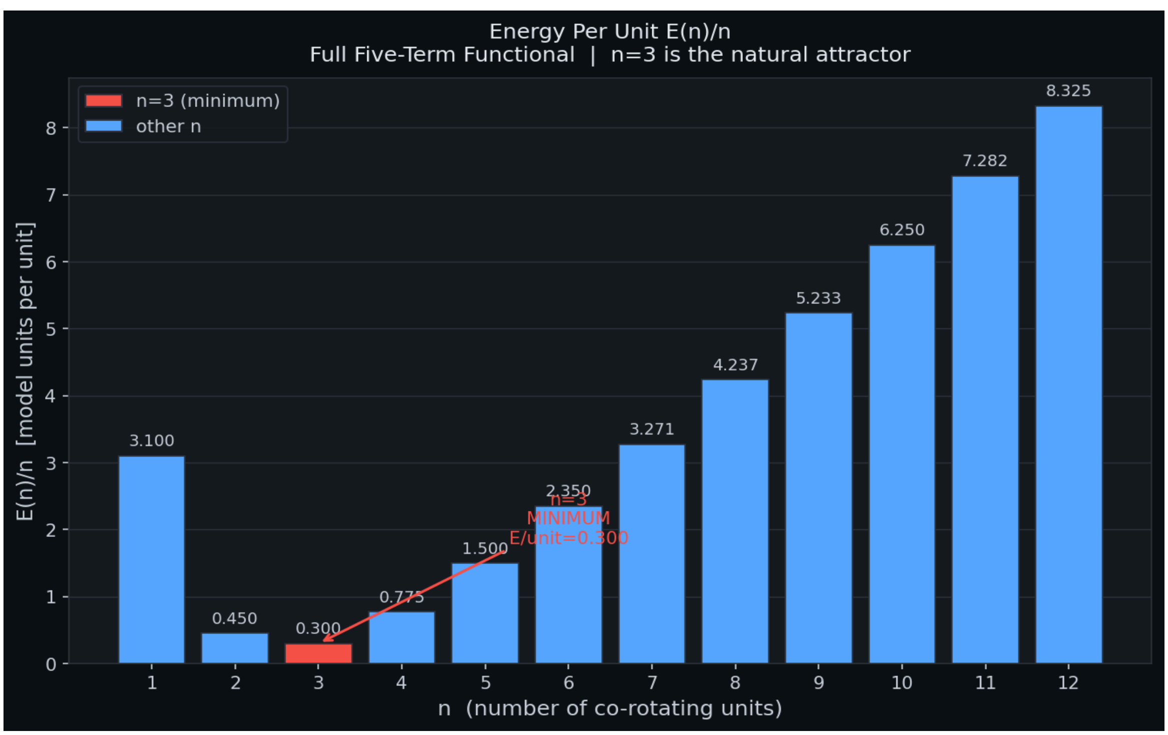


Figure B. Energy per unit E(n)/n for n=1 to 12. n=3 is the unambiguous minimum.

3. The Four-Unit Partition (Post 3-Core Formation)

The moment n=3 forms, the three-sphere packing geometry simultaneously creates the interstitial region. The four-unit bound system forms at E=1.400 model units. The three configurations and their full-functional energies:

Config	E (model units)	cos(3phi)	Status
3+1	**1.4000**	**-1 (rewarded)**	**MINIMUM. SELECTED.**
2+2	4.0000	0 (neutral)	Symmetric. No net charge.
4+0	**6.1000**	**+1 (penalised)**	**All co-rotating. Penalised by D_s.**

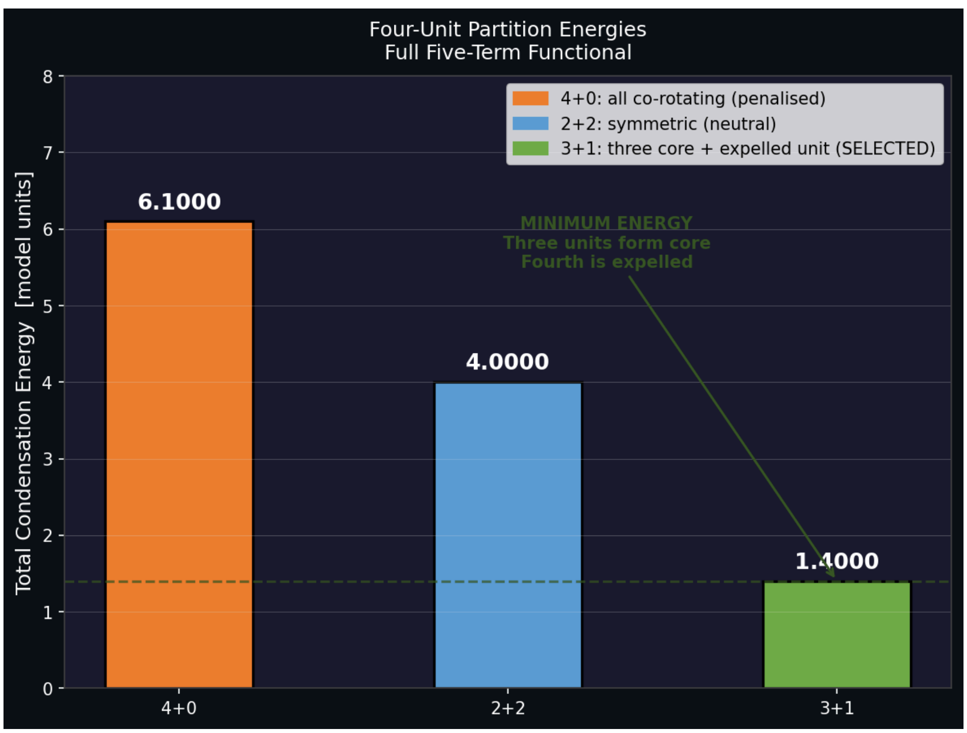


Figure C. Four-unit partition energies. 3+1 is the clear minimum.

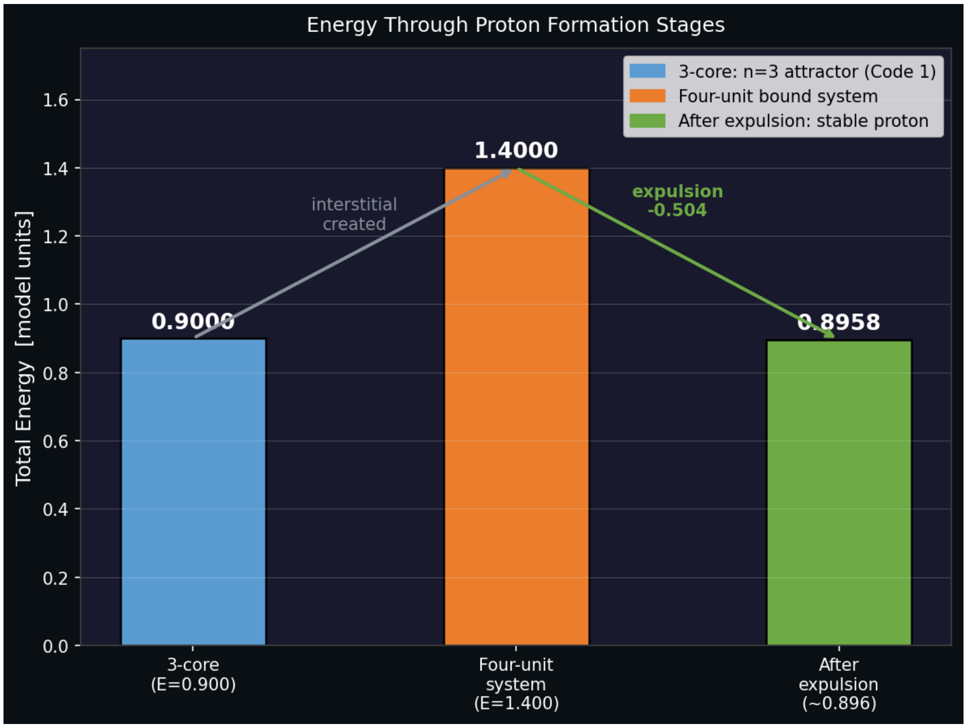


Figure D. Energy through the three stages of proton formation.

4. Three-Sphere Packing Geometry

Three substrate condensations of radius r_q in close-packed contact. The three centres form an equilateral triangle of side 2r_q. The outer radius of the assembly equals r_p, the measured proton charge radius. This is the only measured input.

r_outer = r_q x (1 + 2/sqrt(3)) = 2.1547 x r_q = r_p

r_q = r_p / (1 + 2/sqrt(3)) = 0.8414 / 2.1547 = 0.3905 fm

V_gap / V_q = (2*sqrt(3) - π) / (4*π/3) = 0.0770

Both results are universal geometric constants. No free parameters.

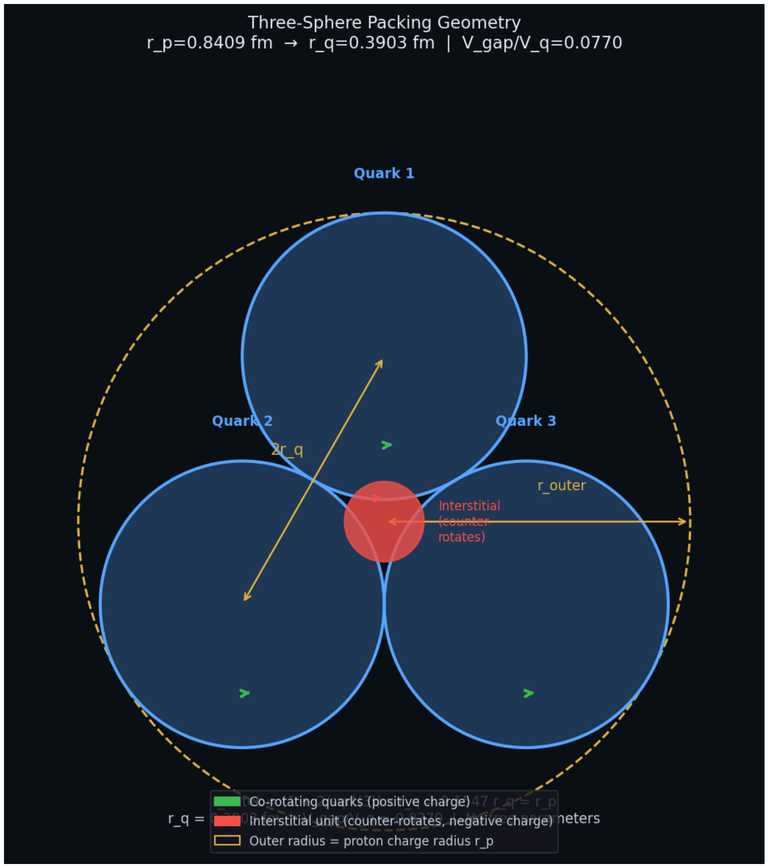


Figure E. Three-sphere packing geometry. Green arrows: co-rotating quarks. Red: interstitial unit (counter-rotates). Yellow dashed: outer radius = r_p.

5. Why the Interstitial Unit Counter-Rotates

The counter-rotation is mechanically imparted, not assumed. When the interstitial substrate exits through the gap between any two quarks, it encounters two co-rotating surfaces - one on each side. Both quarks rotate in the same direction. Each imparts a tangential force in the opposite direction to the passing substrate. Together they impart a net counter-clockwise torque.

This is the gear analogy: a gear placed between two co-rotating gears of the same handedness always rotates in the opposite direction. The result is the same regardless of which gap the substrate exits from, because all three quarks rotate in the same direction.

Counter-rotation in BFUT is the definition of opposite charge. The negative charge of the expelled unit is therefore not assigned or assumed. It is mechanically imparted during expulsion by the same co-rotation that defines the quarks as positively charged.

6. The Interstitial Unit Is Not the Atomic Electron

The expelled unit is permanently bound inside the proton at approximately 100 MeV binding energy (the pion scale). Hydrogen forms at electron-volt energy scales. The interstitial unit never escapes the proton. It corresponds to the QCD gluon condensate and sea quark content in standard model language.

The atomic electron is a different object: it is the same expelled unit type but formed at the Bohr radius, 52,918 fm from the proton. The proton formation event produces both the proton and the conditions for the hydrogen ground state. See Section 8 below.

7. Proton Energy with Interstitial Unit

When the detached unit has mass fraction mu relative to a core unit, the P16 functional is evaluated with s = [+1, +1, +1, -mu]. The geometric asymmetry term scales with mu because the geometric displacement is proportional to the actual mass of the detached unit:

E(mu) = -J x pairs_sum([1,1,1,-mu])
+ lam x (3-mu)^2
+ (3-3)^2 + alpha x mu
+ D_s x (-1)

At mu=1.0 (standard 3+1): E = 1.4000 model units (baseline confirmed)

Minimum: E = 0.8958 model units at mu = 0.083

Driving force for expulsion: -0.504 model units

mu	E(mu)	Reduction from 1.400	Note
1.000	1.4000	0.0000	Standard 3+1 baseline
0.500	1.0000	-0.4000	
0.230	0.9087	-0.4913	P19 upper bound
0.083	**0.8958**	**-0.5042**	**MINIMUM**
0.077	0.8959	-0.5041	P19 lower bound

The result is robust across the full physical range mu = 0.077 to 0.23. Proton stability does not depend on fine-tuning the interstitial mass fraction.

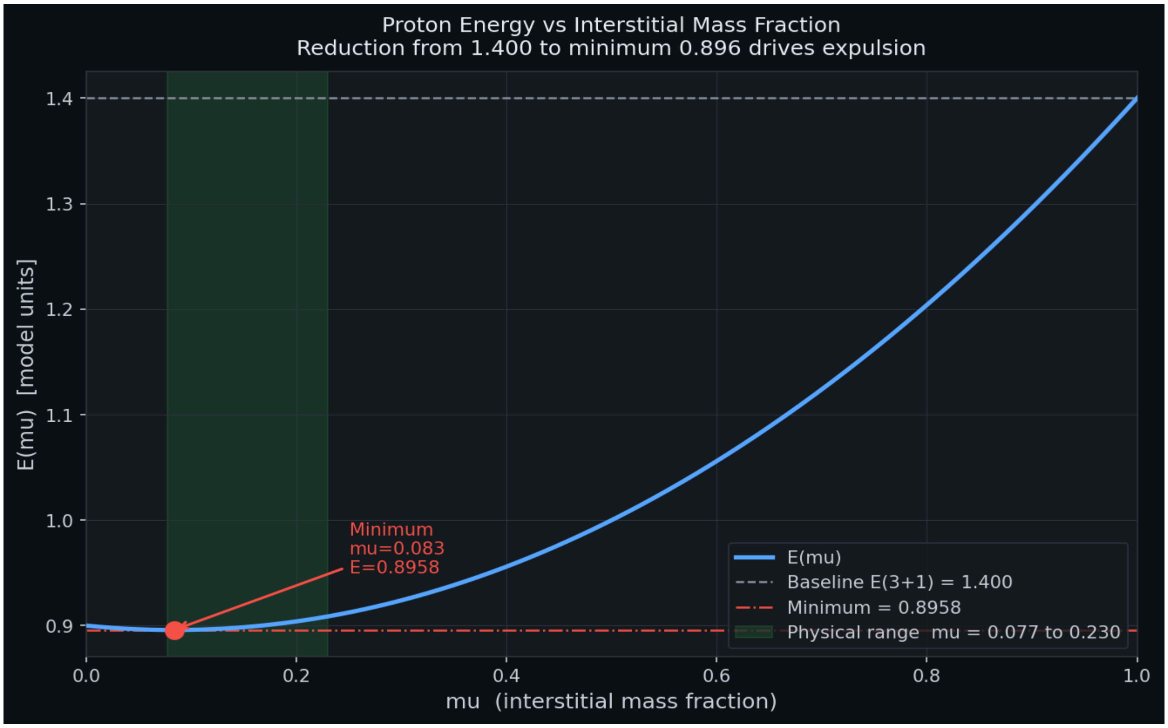


Figure F. E(mu) vs mu across the full range 0 to 1. Minimum at mu=0.083. Green band: physical range.

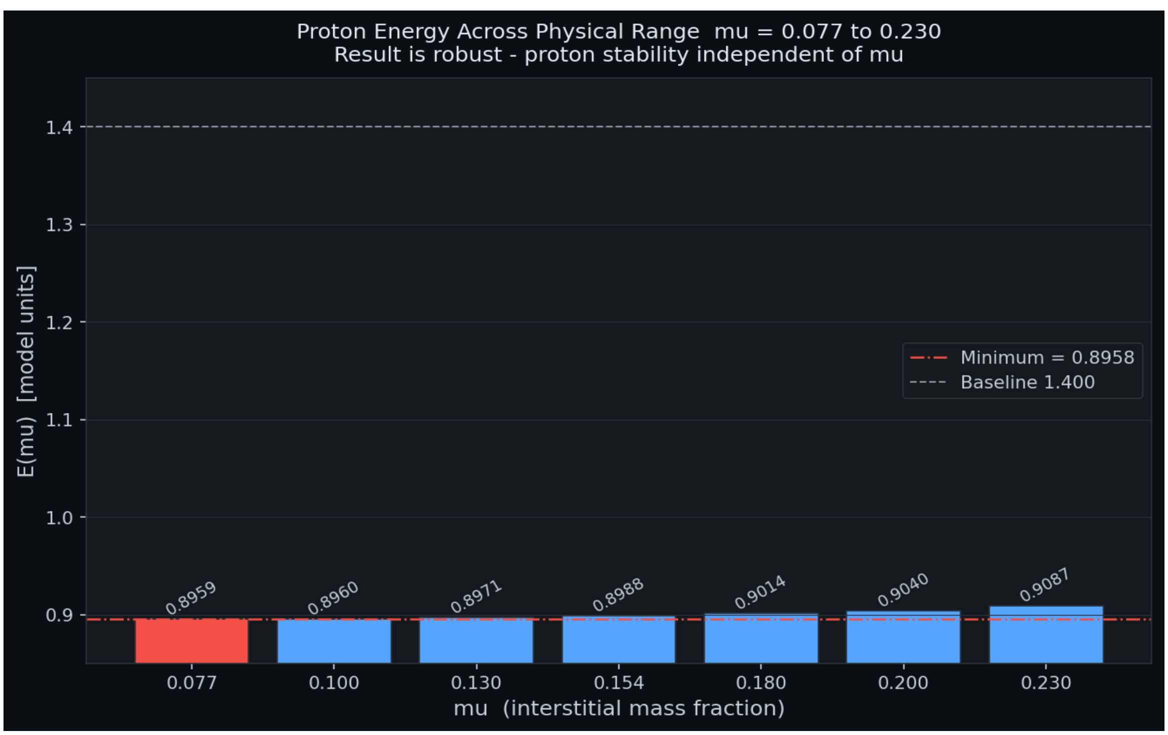


Figure G. Proton energy across the physical range mu=0.077 to 0.230. Result is robust.

8. The Connecting Identity

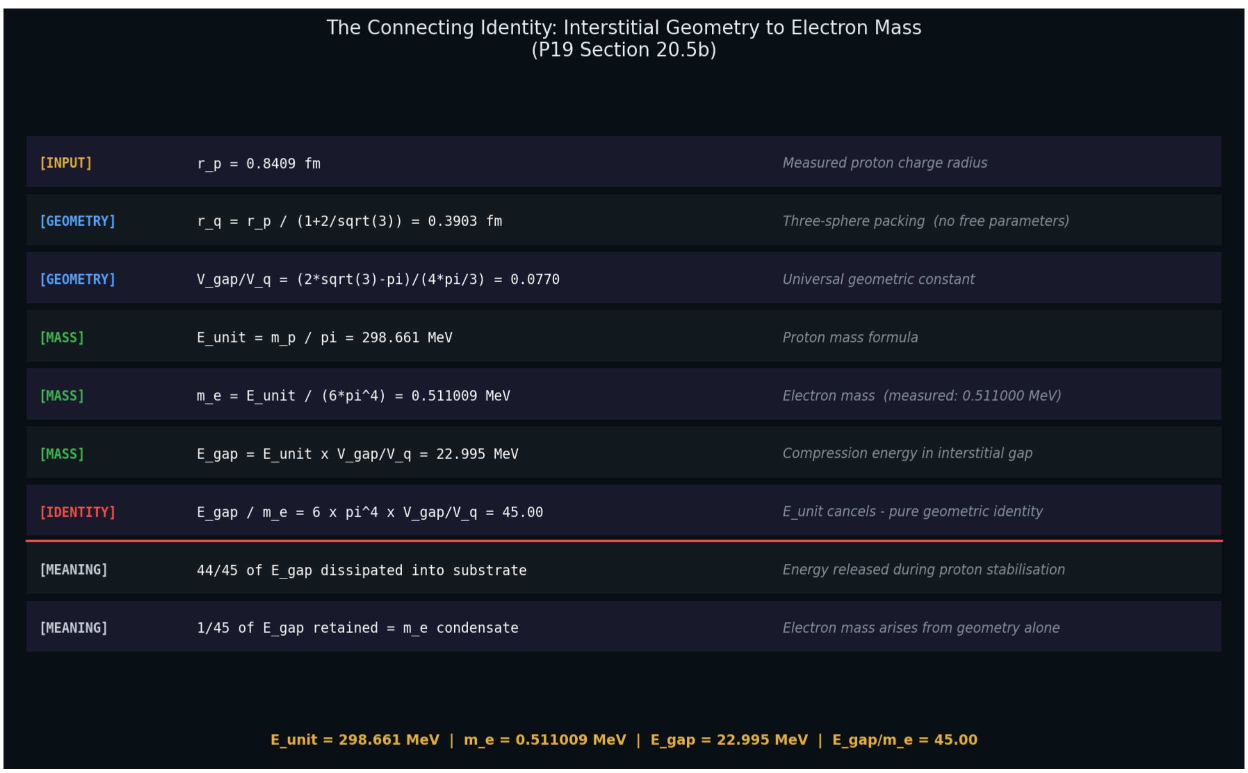
P19 Section 20.5b establishes an exact algebraic identity connecting the interstitial volume fraction, the electron mass, and the compression energy. E_unit cancels exactly - the identity is purely geometric:

E_gap = E_unit x V_gap/V_q = 298.661 x 0.0770 = 22.999 MeV

m_e = E_unit / (6 x π^4) = 298.661 / 584.45 = 0.511009 MeV

E_gap / m_e = 6 x π^4 x V_gap/V_q = 584.45 x 0.0770 = 45.00 (exact)

Physical meaning: The expelled substrate dissipates 44/45 of the compression energy into the surrounding substrate during proton stabilisation. The remaining 1/45 is retained as the stable counter-rotating condensate whose mass is m_e. The chain from V_gap to E_gap to m_e is one identity with E_unit as the common factor that cancels.



The Connecting Identity: Interstitial Geometry to Electron Mass
(P19 Section 20.5b)

[INPUT]	r_p = 0.8409 fm	Measured proton charge radius
[GEOMETRY]	r_q = r_p / (1+2/sqrt(3)) = 0.3903 fm	Three-sphere packing (no free parameters)
[GEOMETRY]	V_gap/V_q = (2*sqrt(3)-pi)/(4*pi/3) = 0.0770	Universal geometric constant
[MASS]	E_unit = m_p / pi = 298.661 MeV	Proton mass formula
[MASS]	m_e = E_unit / (6*pi^4) = 0.511009 MeV	Electron mass (measured: 0.511000 MeV)
[MASS]	E_gap = E_unit x V_gap/V_q = 22.995 MeV	Compression energy in interstitial gap
[IDENTITY]	E_gap / m_e = 6 x pi^4 x V_gap/V_q = 45.00	E_unit cancels - pure geometric identity
[MEANING]	44/45 of E_gap dissipated into substrate	Energy released during proton stabilisation
[MEANING]	1/45 of E_gap retained = m_e condensate	Electron mass arises from geometry alone

E_unit = 298.661 MeV | m_e = 0.511009 MeV | E_gap = 22.995 MeV | E_gap/m_e = 45.00

Figure K. The connecting identity chain from measured r_p to m_e. E_unit cancels at the IDENTITY step.

9. Modular Organisation: The Universal Structural Unit

For any n > 4 substrate units, multiple modular units are always energetically preferred over a single large condensate. The energy advantage grows with n. At n=24 the gap is 34.5 model units.

n	E single	k_opt	m x 1.400	Gap	Winner
4	**1.400**	**3**	**1.400**	**0.000**	**EQUAL**
5	2.100	3	1.750	+0.350	**MODULAR**
8	5.400	3	2.800	+2.600	**MODULAR**
12	11.100	4	4.200	+6.900	**MODULAR**
24	42.900	6	8.400	+34.500	**MODULAR**

The single condensate is free to choose any primary group size k. It chooses k=3 for n=4 to 8, then k=4, then k=5. It loses anyway. The modular unit is the universal preferred structural unit for matter at all scales.

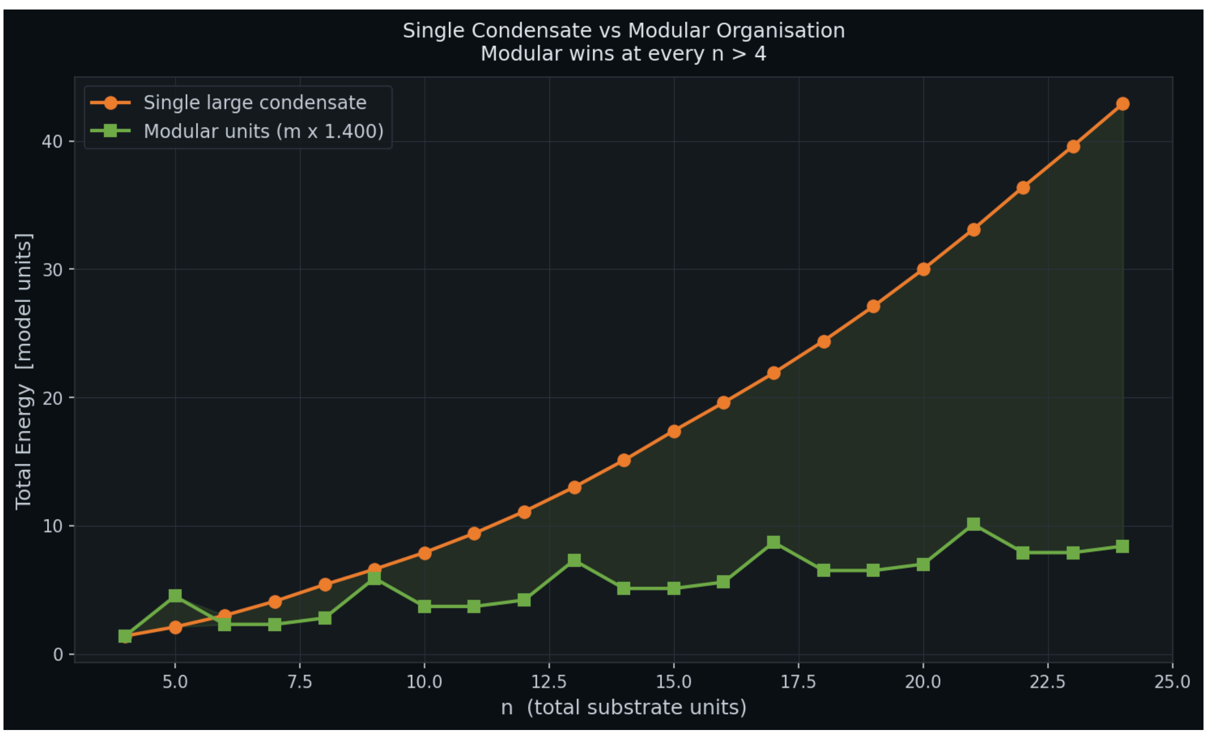


Figure H. Total energy: single condensate vs modular units for n=4 to 24.

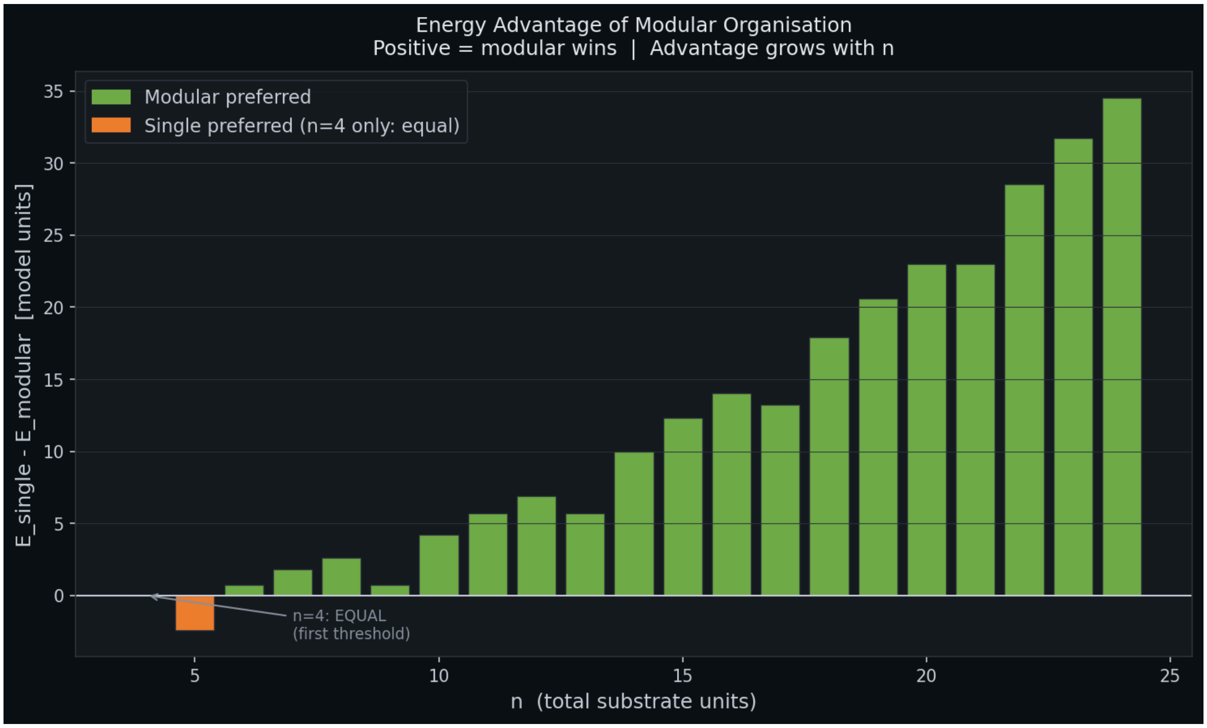


Figure I. Energy advantage of modular organisation. Positive = modular wins. Gap grows with n.

10. Robustness: Parameter Space Analysis

The 3+1 selection is not a fragile result at a single parameter point. Scanning lam and alpha across [0.2, 1.2] with J=1.0 fixed:

Scan	3+1 wins	Parameters varied
1D	**97.56%**	lam in [0.2, 1.2]
2D	**95.95%**	lam x alpha in [0.2, 1.2]^2
3D	**90.43%**	lam x alpha x D_s in [0.2,1.2]^2 x [0.5,2.5]

Comparison with the four-term baseline (without cos(3phi) term):

Scan	Four-term	Five-term	Improvement
1D	85.37%	**97.56%**	**+12.19%**

2D	83.82%	**95.95%**	**+12.13%**
3D	80.84%	**90.43%**	**+9.59%**

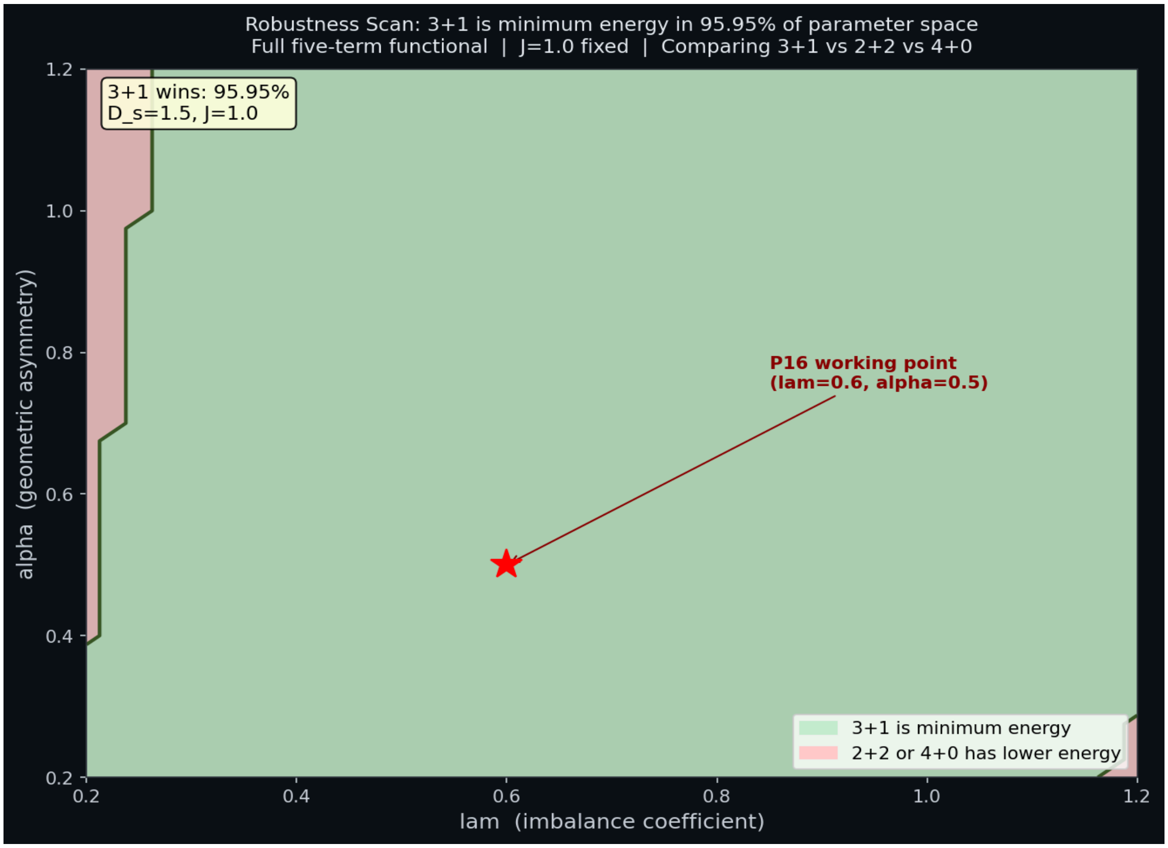


Figure J. Parameter space map. Green: 3+1 is minimum energy. Red: other configuration wins. P16 working point marked.

11. All Key Results at a Glance

Quantity	Value	Source
r_p (input)	0.8414 fm	PDG 2022 measurement
r_q	**0.3905 fm**	Three-sphere geometry
V_gap / V_q	**0.0770**	Universal geometric constant
E_unit = m_p/pi	**298.661 MeV**	Proton mass formula

m_e = E_unit/(6*pi^4)	**0.511009 MeV**	Electron mass (measured: 0.510999)
E_gap/m_e	**45.00 (exact)**	Connecting identity - E_unit cancels
E(3+1) baseline	**1.4000 model units**	P16 functional, standard 3+1
E minimum (mu=0.083)	**0.8958 model units**	P16 functional, interstitial expelled
Driving force	**-0.504 model units**	Energetic basis for expulsion
2D robustness	**95.95%**	Five-term functional scan
Confinement F	**0.514 GeV/fm**	vs QCD 0.900 GeV/fm (57%)

Appendix B

Standard QFT Vacuum Energy, the Two Ontological Corrections, and the Substrate-Density Account of the Cosmological Constant Problem

B.1 Purpose

This appendix gives a technical account of the standard QFT calculation of vacuum energy density, two specific ontological corrections proposed within the BFUT framework, how those corrections relate to the cosmological constant problem, and the status of dark energy and the LCDM cosmological constant.

B.2 The Standard QFT Vacuum Energy Calculation

In standard QFT the vacuum energy density is obtained by summing zero-point energy over all modes of all quantum fields up to the Planck cutoff: $\rho_{QFT} \approx \Sigma_{fields} \int d^3k/(2\pi)^3 \times (½\, \hbar\, \omega_k)$. Approximately 17 independent Standard Model fields each contribute zero-point energy $½\hbar\omega_k$ per mode. The integral yields $\rho_{QFT} \approx 5.87 \times 10^{111}$ J/m^3, against the observed 5.30×10^{-10} J/m^3. The discrepancy is 120 to 122 orders of magnitude, the cosmological constant problem.

B.3 Two Proposed Corrections to the Standard QFT Treatment

Correction 1, multiplicity of independent quantum fields. The standard mode sum is performed over approximately 17 independent quantum fields. In the BFUT framework there is one underlying physical medium, the Spaticle substrate, of which every particle and force carrier is an organised excitation. Reducing the field count from 17 to 1 accounts for only about one order of magnitude of the 120-order discrepancy on its own; it does not by itself close the gap.

Correction 2, zero-point energy assigned to empty modes. Standard QFT assigns $½\hbar\omega$ to every mode regardless of whether it contains a physical excitation. The BFUT framework proposes instead that $½\hbar\omega$ is the minimum internal circulation energy of an organised condensation, so an empty mode, containing no condensation, contributes no ground-state energy. This is a stated ontological proposal, not an established result: the mainstream position, supported by the Casimir effect, treats vacuum zero-point energy in empty modes as physically real. A minority published view (Jaffe et al.) argues the Casimir force can be derived without requiring this energy to be real. This question is genuinely unsettled in the physics literature, and Correction 2 should be read as the position this framework adopts, not as a settled fact.

B.4 Result If Both Corrections Are Adopted

If both corrections are adopted, one physical field, and zero-point energy only for organised condensations, the standard mode sum over the pure vacuum state vanishes identically. This step, on its own, yields zero, not $\rho_s \cdot c^2$. The vanishing sum removes the standard QFT prediction, it does not by itself produce the observed value.

The value $\rho_{vac} = \rho_s \cdot c^2 \approx 5.30 \times 10^{-10}$ J/m^3 is a separate, independent claim, following from substrate ontology, not from the corrected mode sum: the proposal that the vacuum is the Spaticle field at its own equilibrium density ρ_s, so by mass-energy equivalence $\rho_{vac} = \rho_s \cdot c^2$. That this value numerically matches the observed vacuum energy density is presented as a consequence of the substrate-density proposal, not as something derived from the QFT correction itself.

B.5 The Independent Status of ρ_s

$\rho_s \approx 5.9 \times 10^{-27}$ kg/m^3 is not adjusted to match cosmological observations. It is constrained independently from physical sectors that do not involve vacuum energy or cosmological constant fitting, including: particle sector, W and Z boson masses derived from substrate reconfiguration energies at the femtometre scale; galactic sector, SPARC rotation-curve validation via the DM1 entrainment formula; weak-lensing sector, KiDS-1000 lensing profiles via the DM2 entrainment formula; atomic sector, hydrogen ground-state energy and Bohr radius from first principles; and the matter-stability condition, stable matter requiring the substrate independent of formation history. A density constrained simultaneously across these five independent sectors is not being fitted to the vacuum energy result. When the substrate-ontology proposal in B.4 yields $\rho_{vac} = \rho_s \cdot c^2$, this is offered as a genuine consequence of the framework, not a fitted result.

B.6 Dark Energy, Λ, and the Cosmological Constant Tension

Dark energy is not treated as a separate physical entity in the BFUT framework. The LCDM cosmological constant Λ is a geometric fitting parameter: $\rho_\Lambda = 3\Omega_\Lambda H_0^2 / (8\pi G)$. This parameter changes every time H_0 is remeasured. ρ_s, by contrast, is proposed to be the same at every point in an infinite BFUT universe at every epoch. The numerical proximity of ρ_Λ to $\rho_s \cdot c^2$ at the current epoch is treated as a transient coincidence arising from the particular stage of cosmic evolution, not a physical identity. The BFUT treatment of the cosmological constant problem has two components: the 120-order-of-magnitude tension between the QFT prediction and observation is addressed by the two proposed corrections above, and the apparent small positive Λ is treated as a time-varying geometric parameter, not a property of the physical vacuum.

B.7 Summary

Two proposed corrections to the standard QFT vacuum energy calculation are presented: treating the substrate as one physical field, and assigning zero-point energy only to organised condensations, not to all modes. The first accounts for roughly one order of magnitude of the 120-order discrepancy on its own. The second is a stated ontological position on a genuinely contested question in the physics literature, not an established result. Together, if adopted, they remove the standard QFT prediction; the specific value $\rho_{vac} = \rho_s \cdot c^2$ then follows as a separate consequence of substrate ontology, not as a direct result of the corrected calculation. The substrate density ρ_s is constrained independently across multiple physical sectors unrelated to vacuum energy. The LCDM cosmological constant is treated as a geometric fitting parameter, not a property of the physical vacuum, and dark energy is not treated as a separate physical entity in this framework.

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