BFUT P23

Light, Photons, and the Universal Speed Limit: A Physical Derivation of c from Substrate Condensation Dynamics

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Abstract

Standard physics treats the speed of light c as a fundamental constant and photons as massless excitations of the electromagnetic field [16,17]. The reason why c is universally limiting, why massless particles travel at exactly c, why gravitational waves share that same speed, and why massive particles cannot reach it, are treated as consequences of special relativity instead of as phenomena requiring physical explanation.

This paper derives all of these results from the physical properties of the Spaticle substrate established in the BFUT programme. The universal speed limit c is the propagation speed of the Spaticle field itself, determined by the substrate stiffness-to-density ratio: $c_{vss} = \sqrt{(K_s/\rho_s)}$. A photon is a freely propagating organised excitation of the substrate that requires no stable localised condensation structure. All of its energy is available for propagation. It therefore travels at the maximum rate the substrate permits. Gravitational waves are propagating deformation disturbances of the same substrate. They travel at c for the same reason. The equivalence of light speed and gravitational wave speed is not a coincidence requiring a separate explanation. It follows directly from the common substrate origin of both phenomena.

Massive particles travel below c because part of their energy budget is committed to maintaining their internal condensation structure instead of pure propagation. The velocity deficit from c is determined by the ratio of rest energy to total energy. Neutrinos, with their extremely small masses, travel within one part in 10^{-17} of c, consistent with the Supernova 1987A constraint. Photons travel at exactly c because they have no rest energy and therefore no condensation to maintain.

Cosmic redshift is explained by Doppler motion of receding matter and substrate propagation dynamics. The universe is infinite and eternal; no expansion of space is involved. The Doppler effect, aberration, and time dilation all emerge from the finite substrate propagation speed. The paper also derives why the speed limit is absolute: no physical process can reorganise the substrate faster than the substrate propagates causal information. Light does not define the universal speed limit. The universal speed limit defines the behaviour of light.

Keywords: Spaticle field; speed of light; photon; gravitational waves; substrate condensation; neutrino mass; soliton; BFUT; universal speed limit; rest energy; causality; massless excitation

1. Introduction

The speed of light $c = 2.99792458 \times 10^8$ m/s is one of the most precisely measured quantities in physics. The BFUT Spaticle field framework provides a physical substrate in which the universal propagation speed has a definite mechanical origin.

The BFUT Spaticle field framework provides a physical substrate in which these questions have definite answers. The substrate is a real physical medium of density $\rho_s = 7.3 \times 10^{-27}$ kg/m³ permeating all space. It has a finite stiffness K_s determined by its self-interaction structure. Physical processes propagate through this medium at a speed set by these properties. That speed is c. Every physical excitation of the substrate, whether electromagnetic, gravitational, or any other massless disturbance, propagates at this substrate speed. Massive particles, being stable localised condensations embedded in the substrate, cannot travel at the substrate propagation speed because they must carry their condensation structure with them, diverting part of their energy from propagation.

This paper develops this account systematically across the sections below, providing quantitative results and identifying specific testable consequences that distinguish the substrate account from the standard special-relativistic treatment.

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 Scope: Photon Domains and Gravitational Domains

This paper addresses the propagation and coherence of photons, including the conditions under which a photon may maintain an organised soliton character. Section 4 explains why gravitational waves travel at c by the same substrate mechanism as photons: both are excitations of the Spaticle field and both propagate at the substrate maximum reorganisation rate. The finite gravitational deformation domain is a separate result established in BFUT P18 [4]. The domain radius R_d = (3M / 8 pi ρ_s)^(1/3) is the DDR equation established in BFUT P18 [4]. Readers interested in the gravitational domain, gravitational time dilation cutoff, and related gravitational-wave domain results are directed to BFUT P18 (DOI: 10.5281/zenodo.20145506). The present paper is restricted to photon propagation, photon coherence, and the substrate origin of c.

The Big Flare-Up Theory (BFUT) [13] identifies the real physical fabric of space as the Spaticle field, with a specific equilibrium density of $\rho_s = 7.3 \times 10^{-27}$ kg/m³ (BFUT P14; BFUT L1). This established substrate constant underlies the BFUT programme across cosmology, particle physics, gravitation, quantum mechanics, and consciousness. The Spaticle field is a physical medium with measurable properties.

1.2 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	7.3×10^{-27} kg/m³
P23-Specific Symbols		
c	BFUT substrate propagation / numerical consistency result	$\sqrt{(K\_s/\rho_s)} = 2.99792458 \times 10^8$ m/s; independent consistency reconstruction = 2.99791740×10^8 m/s
α	Fine structure constant	1/137.036
e	Elementary charge	1.602×10^{-19} C
m_p	Proton mass	$1.67262192369 \times 10^{-27}$ kg
r_p	Proton charge radius	0.8414 fm = 8.414×10^{-16} m
R_0	Condensation minimum (P16 functional)	1.27348220802151 (dimensionless, derived)
Shared Physical Constants		
G	Gravitational constant	6.674×10^{-11} m³ kg⁻¹ s⁻²
$\hbar$	Reduced Planck constant	1.05457×10^{-34} J·s
K_s	Spaticle substrate stiffness	$K\_s = \rho_s \cdot c^2 = 6.56355667 \times 10^{-10}$ Pa
u_vac	Substrate equilibrium energy density	$u\_vac = \rho_s \cdot c^2 = 6.56355667 \times 10^{-10}$ J/m³
c_s	Local effective substrate propagation speed	c_s = ηc in the local propagation-efficiency relation
λ_{emit}	Emitted photon wavelength	Wavelength at emission
λ_{obs}	Observed photon wavelength	$\lambda_{obs} = \lambda_{emit}(1+z)$
z	Redshift parameter	Dimensionless redshift
ν_{emit}	Emitted photon frequency	Frequency at emission
ν_{obs}	Observed photon frequency	$\nu_{obs}/\nu_{emit} = \sqrt{[(1+\beta)/(1-\beta)]}$ for approach
β	Velocity ratio	β = v/c
m_ν	Neutrino mass	Small non-zero rest mass in the BFUT substrate-ripple description
$\Delta E_{imbalance}$	Residual reaction-energy imbalance	Sets the neutrino mass scale through m_ν ~ ΔEimbalance/c²
$K_{eff}(\omega)$	Frequency-dependent effective substrate stiffness	$K_{eff}(\omega) = K'(\omega) + iK''(\omega)$
$K'(\omega)$	Reactive stiffness component	Real part of $K_{eff}(\omega)$
$K''(\omega)$	Dissipative stiffness component	Imaginary part of $K_{eff}(\omega)$
α_{att}	Energy attenuation coefficient	$E(x) = E_0 e^{(-2\alpha_{att} x)}$
$L_{att}(\omega)$	Energy attenuation length	$L_{att}(\omega) \approx (c/\omega)[K'(\omega)/K''(\omega)]$
u_def	Deformation energy density	E = u_def·A_cs·Δx
A_cs	Disturbance cross-sectional area	Cross-sectional area of a directed propagating disturbance

Δx	Coherent longitudinal extent	Longitudinal extent of a directed coherent disturbance
ε_{att}	Fractional energy transfer per traversed element	$dE/dx = -(\varepsilon_{att}/\Delta x)E$
dV	Traversed volume element	dV = A_cs·dx
τ_{relax}	Internal substrate relaxation time	Relaxation timescale of the internal substrate mode
Δ_K	Substrate stiffness change	Stiffness change associated with internal relaxation
$q(x,t)$	KdV soliton amplitude	Wave-amplitude function used for the KdV soliton illustration

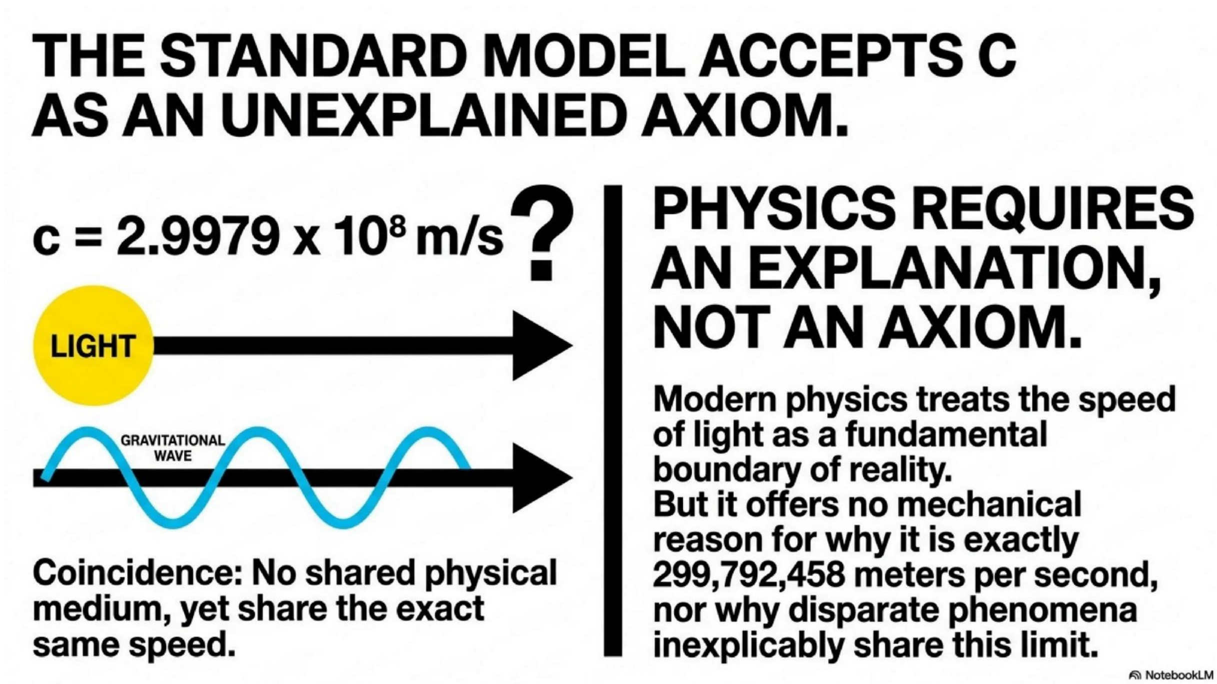

Figure 1: The Standard Model accepts c as an unexplained axiom. Physics requires a mechanical explanation, not a postulate.

2. The Substrate Propagation Speed

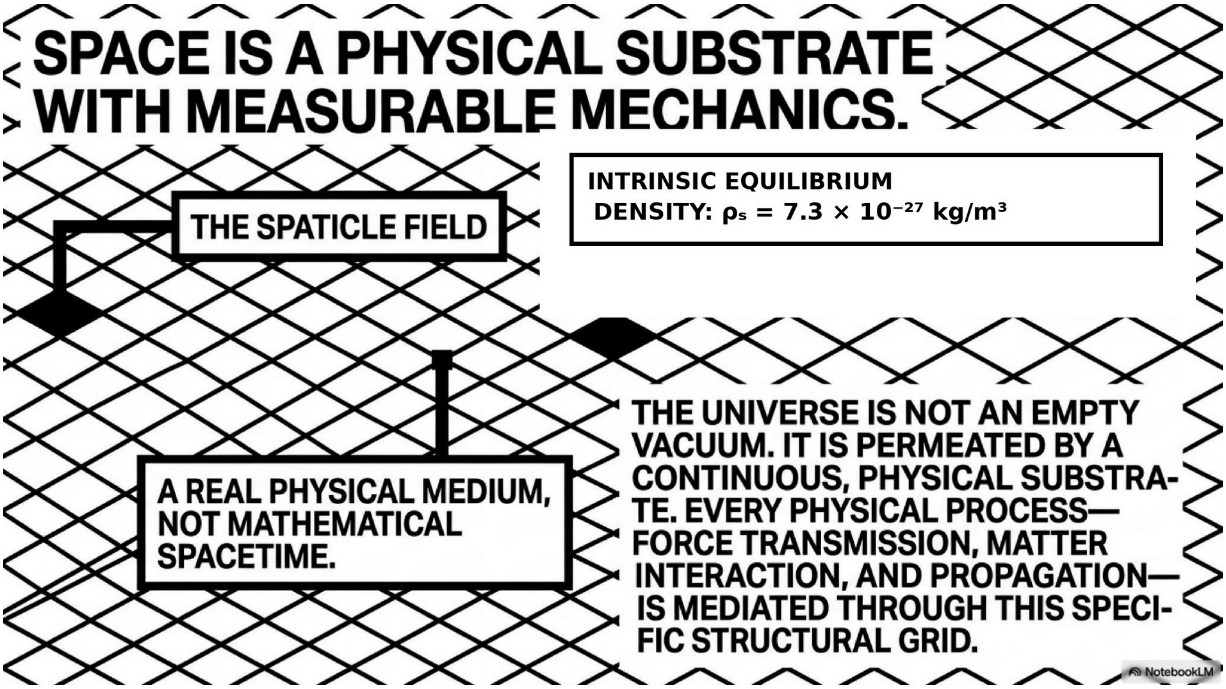

Figure 2: Space is a physical substrate with measurable mechanics. The Spaticle field has intrinsic density $\rho_s = 7.3 \times 10^{-27}$ kg/m³.

2.1 Physical Derivation of c

The Spaticle field is a physical medium characterised by two properties that determine its propagation speed. The first is its density ρ_s, which provides inertial resistance to propagation. The second is its stiffness K_s, which provides the restoring force that drives propagation. For any continuous medium, the propagation speed of disturbances is:

$$c\_vss = \sqrt{(K\_s / \rho_s)}$$

This is the standard relation for appropriate mechanical waves in a continuous medium, such as acoustic waves in air and seismic waves in rock. The Spaticle substrate is the medium in which all physical disturbances propagate. Its propagation speed is the observed speed of light:

$$c\_vss = \sqrt{(K\_s / \rho_s)} \;\Rightarrow\; K\_s = \rho_s \cdot c^2$$

With $\rho_s = 7.3 \times 10^{-27}$ kg/m³:

$$K\_s = \rho_s \cdot c^2 = 6.56355667 \times 10^{-10} \text{ Pa}$$

This stiffness is extraordinarily small compared with ordinary materials, consistent with the substrate being essentially undetectable by ordinary physical probes while still providing the propagation medium for known forces. The substrate density ρ_s was established independently from the baryonic condensation-support threshold and from the gravitational domain structure in BFUT Papers 14 and 18 [1][4]. The relation $\rho_s c^2$ gives the stiffness corresponding to the established substrate density and limiting propagation speed. For context, the bulk modulus of air is approximately 1.4 × 10^5 Pa and of water 2.2 × 10^9 Pa. The Spaticle substrate stiffness is approximately 14 orders of magnitude below the bulk modulus of air.

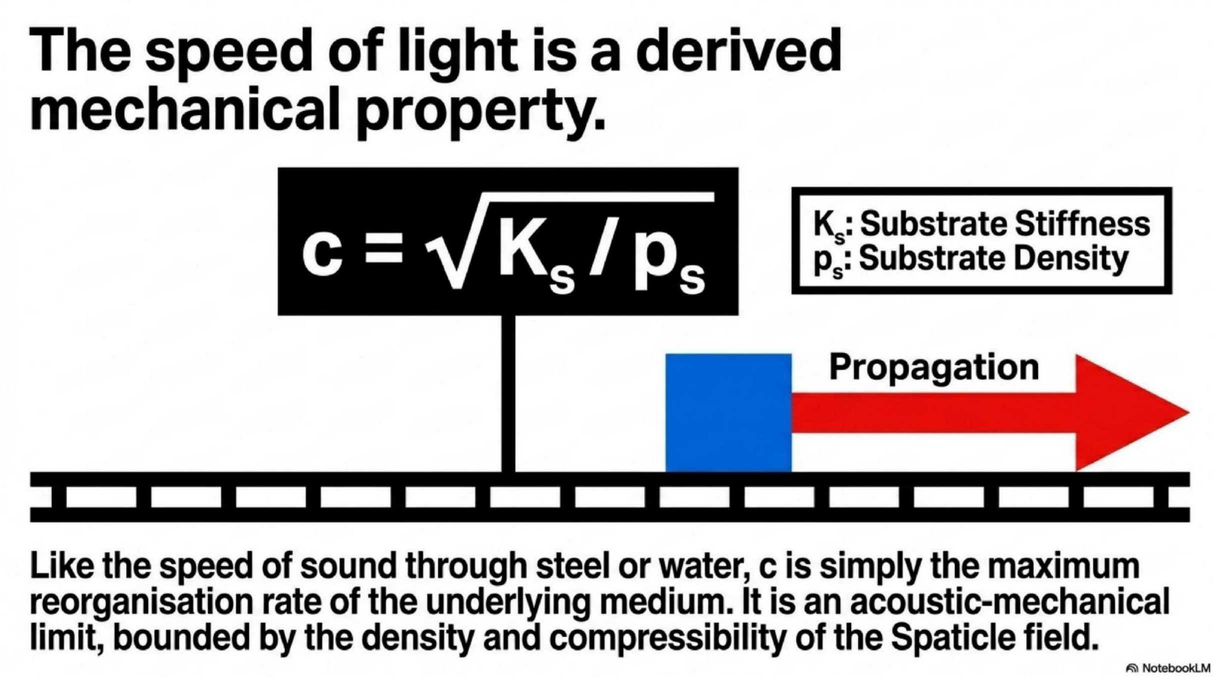

Figure 3: The speed of light is a derived mechanical property: $c\_vss = \sqrt{K\_s / \rho_s}$. It is the maximum reorganisation rate of the Spaticle substrate.

An interactive simulation of the derivation of c as a substrate property, instead of a property specific to light, is available in the BFUT companion simulations code deposit covering Papers P16 through P28 [14]. The simulation, developed for BFUT P22, demonstrates that the same substrate stiffness and density that fix the maximum propagation speed for gravitational and time-dilation phenomena fix the identical speed for photon propagation, since both arise from one medium instead of two independently calibrated limits.

2.2 Why the Speed Limit Is Absolute

This is the standard relation for appropriate mechanical waves in a continuous medium, such as acoustic waves in air and seismic waves in rock. The Spaticle substrate is the medium in which physical disturbances propagate. Its BFUT propagation speed is $c = \sqrt{K\_s / \rho_s}$, which is identified with the observed speed of light c. The relation establishes the physical substrate mechanism. The independent numerical consistency determination of c is given in Section 2.4.

This is the physical basis of the universal speed limit. No process can propagate faster than the substrate can propagate causal information about that process. Any attempt to move a physical object faster than c would require the substrate ahead of the object to be reorganised before the reorganisation signal from the object could arrive. This is a physical impossibility, not merely a mathematical constraint of a coordinate system.

> The substrate density ρ_s is fixed by independent constraints discussed in the BFUT programme. The stiffness $K_s = \rho_s \cdot c^2$ is therefore the stiffness corresponding to the established substrate density and limiting propagation speed. Its role here is to establish the mechanical basis for the propagation limit. The independent numerical consistency determination in Section 2.4 reconstructs c without using c as an input on the right-hand side.

2.3 Relation to the BFUT Substrate Parameters

The substrate density ρ_s is fixed by two independent constraints that give consistent results. The first is the baryonic condensation-support threshold: ρ_s must be sufficient to support stable proton-mass condensations. The second is the cosmological large-scale structure, which constrains the substrate gravitational domain equation DDR. Both give $\rho_s = 7.3 \times 10^{-27}$ kg/m³ [1][4].

The stiffness $K_s = \rho_s \cdot c^2$ is determined by the established substrate density and the limiting propagation speed. The substrate density is fixed by independent physical constraints, and the propagation speed of disturbances in that substrate is c. The broader cross-sector validation of the Spaticle field, including its particle, galactic, cosmological, gravitational-wave, and quantum sectors, is presented in Appendix A.

2.4 Independent Numerical Consistency Determination of c

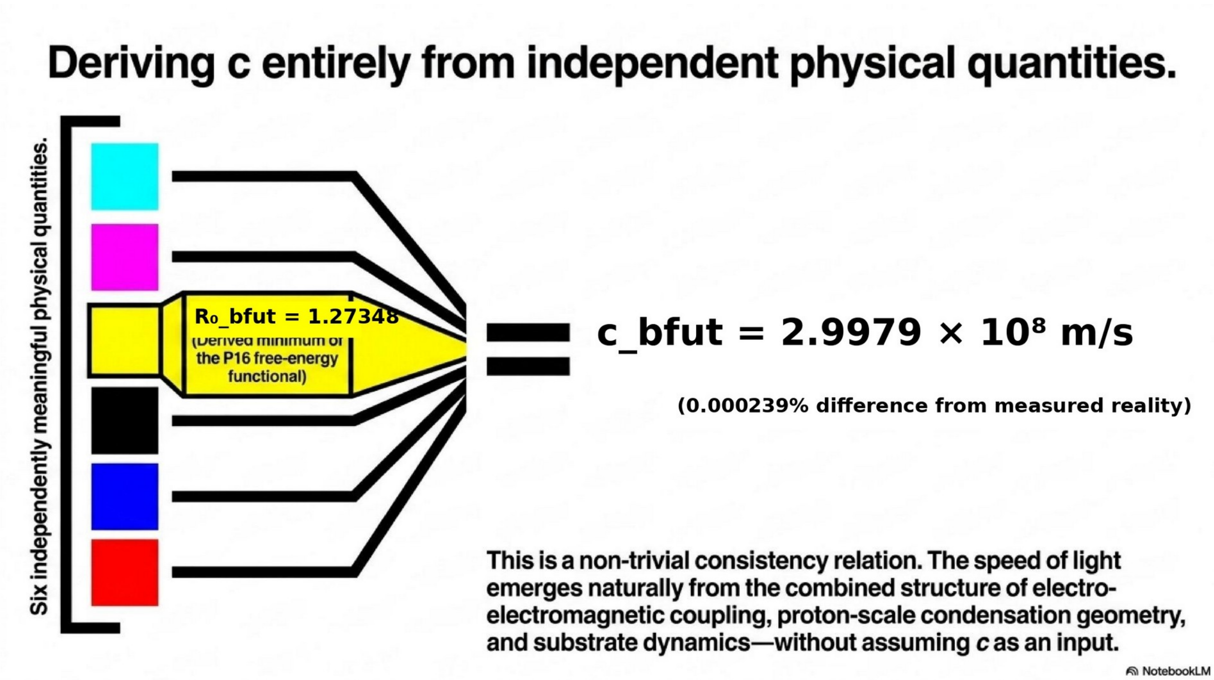

Figure 4: c is independently reconstructed from six physical quantities. The calculated value matches the defined SI value of c to 0.000239%.

The significance of this result is not that it derives c from nothing. Its significance is that it establishes a non-trivial consistency relation between six independently meaningful physical quantities. Each quantity participating in the expression carries independent physical meaning and observational support throughout the BFUT programme:

Section 2.1 derives c as the substrate propagation speed $c\_vss = \sqrt{K\_s/\rho_s}$. This section establishes an independent consistency relation that expresses c in terms of quantities each derived or measured independently within the BFUT programme, without using c as an input on the right-hand side.

The BFUT derivation of ħ_vss in P16 Section 5.2, developed further in P27 [15], gives:

$$\hbar\_vss = mp \cdot c \cdot rp / (\pi \cdot R_0)$$

The standard electromagnetic definition of the fine structure constant is:

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

Substituting the BFUT expression for ħ into the definition of α and solving for c:

$$c^2 = e^2 \cdot R_0 / (4\varepsilon_0 \cdot mp \cdot rp \cdot \alpha)$$

$$c\_vss = \sqrt{e^2 \cdot R_0 / (4\varepsilon_0 \cdot m_p \cdot r_p \cdot \alpha)}$$

Substituting all values: $e = 1.602 \times 10^{-19}$ C, $R_0 = 1.27348220802151$ (derived P16 functional minimum), $\varepsilon_0 = 8.854 \times 10^{-12}$ F/m, $mp = 1.6726 \times 10^{-27}$ kg, $rp = 0.8414$ fm (CODATA 2018), $\alpha = 1/137.036$:

$$c = 2.99791740 \times 10^8 \text{ m/s}$$

Defined SI: $c = 2.99792458 \times 10^8$ m/s. Difference: 0.000239%.

$R_0 = 1.27348220802151$ is the derived dimensionless minimum of the P16 free-energy functional $E(R) = A/R^2 + B \cdot R^2 + C \cdot R + D/R$, with all four coefficients derived from first principles. It emerges from the condensation geometry without any reference to c or ħ. It appears throughout the condensation hierarchy of P16 through P19A.

$\alpha = 1/137.036$ is the standard measured fine-structure constant used in the numerical consistency relation. BFUT P19 also reports a BFUT-derived value $\alpha\_vss \approx 1/137.1$. The independent measured value provides the external comparison used in the c consistency calculation.

e, ε_0, m_p, and r_p are independently measured properties of matter and the electromagnetic substrate. None of their experimental determinations requires c to be known in advance.

The resulting value of c is not obtained through parameter fitting. The six quantities on the right-hand side were fixed by independent physical constraints before this relation was examined. The measured value of c is reproduced as a constrained consistency result from electromagnetic coupling, proton-scale condensation geometry, and substrate dynamics.

This also gives the expression a physical reading. The BFUT consistency relation $c^2 = e^2R_0/(4\varepsilon_0 m_p r_p \alpha)$ can be written as:

$$\mathbf{c^2 = (e^2/4\varepsilon_0)\cdot(R_0/m_p r_p)\cdot(1/\alpha)}$$

The first factor $e^2/(4\varepsilon_0)$ is the electromagnetic coupling energy at unit distance. The second factor $R_0/(m\_pr\_p)$ is the condensation geometry divided by the inertial scale. The third factor $1/\alpha$ is the electromagnetic dilution factor. The speed of light squared is the product of the electromagnetic coupling strength, the condensation geometric ratio, and the inverse fine structure constant. This is considerably richer in physical content than the relation $c = 1/\sqrt{(\varepsilon_0\mu_0)}$, which in modern SI is largely a definition.

The relation is obtained from the derived $R_0 = 1.27348220802151$ and $r_p = 0.8414$ fm (CODATA 2018), giving a 0.000239% deviation from the defined SI value of c.

Unifying the phenomena of massless propagation

Standard Model (Coincidence)	BFUT (Unification)
Why do light and gravity waves share speed c?	
An unexplained mathematical coincidence.	Both are waves propagating through the exact same physical substrate.
What exactly is c?	
An axiomatic mathematical limit of spacetime.	The maximum mechanical reorganization rate of the Spaticle field.
Why can't mass reach c?	
Requires infinite kinetic energy.	Mass permanently consumes part of the substrate's propagation capacity.

NotebookLM

Figure 5: Unifying massless propagation: Light and gravitational waves share speed c because both are disturbances in the same physical substrate.

3. What a Photon Is

3.1 Photons as Massless Substrate Propagation Excitations

In the Standard Model, photons are massless gauge bosons mediating the electromagnetic interaction, described as excitations of the quantised electromagnetic field. The physical nature of the electromagnetic field itself is not specified. It exists in spacetime, it has energy and momentum, and its excitations are photons. Why photons are massless, why they travel at c, and what the electromagnetic field physically is are left unaddressed.

In the BFUT framework, the electromagnetic interaction is the propagation channel associated with the charge asymmetry of stable substrate condensations [3]. The photon is a propagating organised excitation of the Spaticle substrate that carries energy but has no stable localised condensation structure. It is a disturbance propagating through the medium, not a structure embedded in the medium.

The crucial distinction is this. A massive particle such as a proton is a stable condensation: a region of the substrate organised into a persistent structure that maintains its identity as it moves. Part of the proton's energy is committed to maintaining this internal organisation. The remainder is available for translational propagation. Because some energy is always committed to maintenance, the proton can never reach the substrate propagation limit c.

A photon has no internal organisation to maintain. It is an organised propagating excitation with no rest energy. Its entire energy is available for propagation. It therefore propagates at the full substrate propagation speed c.

3.2 The Energy-Momentum Relation from Substrate Physics

For a substrate excitation with no rest structure, the energy-momentum relation is:

$$E = pc$$

where p is the propagation momentum and c is the substrate propagation speed. This gives the photon its characteristic dispersion relation. For a massive condensation of rest mass m, part of the energy is the condensation rest energy mc^2. The total energy-momentum relation becomes:

$$E^2 = (pc)^2 + (mc^2)^2$$

This is the standard relativistic energy-momentum relation, here derived from the physical distinction between substrate condensation energy and propagation energy. The rest energy mc^2 is not a mysterious intrinsic energy. It is the energy committed to maintaining the condensation structure.

3.3 Photon Polarisation as Substrate Circulation Orientation

Photon polarisation, the transverse oscillation direction of the electromagnetic wave, corresponds in the substrate account to the orientation of the transverse substrate deformation in the propagating excitation. A linearly polarised photon is a substrate excitation whose transverse deformation oscillates in a fixed plane. A circularly polarised photon is a substrate excitation whose transverse deformation rotates in the propagation plane.

The two polarisation states of the photon correspond to the two helicity states of the transverse substrate deformation: clockwise and anticlockwise rotation of the deformation vector in the plane perpendicular to propagation. The spin-1 character of the photon is consistent with the photon being a propagating disturbance instead of an embedded condensation. In the BFUT spin-statistics account established in P19A, condensations embedded in the substrate require 720° rotation to restore their configuration, giving half-integer spin. A propagating disturbance that is not embedded in the substrate but moves through it has no topological obstruction requiring 720° periodicity: a 360° rotation of the deformation pattern restores the original configuration, giving integer spin. The photon spin-1 character therefore follows from the same substrate topology argument that gives condensations spin-1/2, applied to the propagating instead of embedded case.

3.4 Bound and Free Electromagnetic Excitations: Electric Fields, Magnetic Fields, and Photons as States of the Same Substrate

The BFUT framework removes the conventional separation between electromagnetic fields and photons. Electric fields, magnetic fields, and photons are not fundamentally different entities. They are different dynamical states of the same underlying phenomenon: organised wave structures of the Spaticle substrate. The distinction that matters is not between real photons and virtual photons. It is between bound electromagnetic waves and free electromagnetic waves.

A free electromagnetic wave is a propagating organised substrate excitation that has detached from its source and propagates through the Spaticle field at c. This is what BFUT identifies as a photon. A bound electromagnetic wave is an organised substrate excitation that remains attached to the source structure that generated it. It does not propagate away. Instead it forms a stable standing-wave or circulating-wave configuration in the surrounding substrate. Electric fields and magnetic fields are bound electromagnetic wave configurations of this second type.

This interpretation removes the need for virtual photons. QED introduces virtual photons as mathematical carriers of static electromagnetic interactions - entities that do not satisfy the photon energy-momentum relation $E = pc$, are not directly observable, and exist only as internal elements of perturbative calculations [18, 19, 20]. No such invisible mediators are needed in BFUT. The source establishes a stable deformation pattern in the surrounding substrate. A second object entering that region responds directly to the local substrate geometry. The field is not a messenger service. It is a configuration of the medium.

3.4.1 Electric Fields as Bound Radial Substrate Waves

A charged particle establishes a radial organisation of the surrounding substrate. This organisation is a bound electromagnetic wave pattern anchored to the charge asymmetry of the condensation. The electric field is a static solution of the substrate dynamics, not a propagating photon population. No continuous emission or absorption process is required to sustain it. The field exists as long as the charge asymmetry that generates it exists, drawing no power from the source to maintain itself.

This is precisely analogous to gravitational deformation in BFUT. A mass establishes a deformation profile in the Spaticle field. A second mass entering that region experiences a force because it responds to the local deformation gradient. No stream of gravitons maintains the field. In the same way, a charged structure establishes an electromagnetic deformation pattern, and a second charged structure responds to that pattern without any mediating particle exchange being required.

3.4.2 Magnetic Fields as Bound Circulating Substrate Waves

A magnetic field corresponds to a circulating bound wave of the Spaticle substrate. The current or spin alignment structure of the source organises the surrounding substrate into a stable looping wave pattern. The configuration loops back upon itself because it is bound instead of freely propagating. Standard electromagnetism describes magnetic field lines as closed loops that emerge from one pole and return through the other - this is exactly the geometry of a bound circulating substrate wave. The field possesses energy but does not transport that energy away from the source.

The source does not continuously expend energy to maintain the field. The field energy resides in the organised substrate configuration itself, analogous to a compressed spring. Energy was required to create the deformation. Once created, the deformation persists in the absence of dissipative processes. The source is not pumping energy into the field moment by moment. It established the configuration and the configuration persists.

3.4.3 Photons as Detached Substrate Waves

A photon arises when an electromagnetic substrate excitation detaches from its source. When an accelerating charge or changing current produces a disturbance that is no longer bound to the originating structure, the organised wave propagates freely through the medium. The distinction between a magnetic field and a photon is not a distinction of substance. Both are electromagnetic wave structures of the Spaticle field. One remains bound. The other propagates freely through the medium.

3.4.4 Unified Electromagnetic Classification

Within BFUT, electromagnetic phenomena are classified as follows. The underlying physical substrate and governing dynamics are the same in every case. The apparent diversity of electromagnetic phenomena arises from different boundary conditions and stability states of organised wave structures within the Spaticle field.

State	Type	BFUT Description	Standard Model Equivalent
1	Static bound solution	Radial substrate deformation anchored to charge; no propagation	Electric field (Coulomb)
2	Circulating bound solution	Looping substrate deformation sustained by current or spin alignment; no propagation	Magnetic field
3	Quantised propagating free solution	Detached substrate excitation propagating at c	Photon (real)
4	Classical propagating free solution	Macroscopic ensemble of quantised free excitations	Electromagnetic radiation

3.4.5 Field Collapse as a Falsifiable Prediction: The Jacuzzi Test

The bound/free distinction produces a specific, testable prediction about what happens when an electromagnetic source is switched off.

Consider a Jacuzzi. The pump creates a sustained circulation pattern in the water. The waves are a consequence of the pump running, but the waves are not the pump. When the pump is switched off, the waves do not reverse and flow back into the pipes. They propagate outward into the surrounding water, travel a short distance, lose coherence, and their energy dissipates into the ambient thermal state of the water. The pipes receive nothing back. The pump receives nothing back. The wave energy returns to the medium.

A magnetic field behaves identically in the BFUT account. The sustained current in an electromagnet creates a bound circulating substrate wave. The wave is not the current - it is the substrate's response to the current. The field energy was transferred from the source to the substrate during field formation, when the current was established; this is the energy cost of creating the bound configuration, paid once, not continuously. When the current is switched off abruptly, the bound substrate configuration is no longer sustained. It does not collapse inward toward the magnet. It releases outward, propagating as a brief free pulse that dissolves back into the ambient substrate after a finite distance. The magnet receives no energy back. No inward-propagating wave exists. The field energy returns to the substrate locally and outwardly, not to the source.

A similar analogy: a tuning fork held in air creates a near-field bound acoustic pressure pattern immediately around it. When the fork is damped, that near-field pattern does not collapse back into the fork. It radiates outward as a brief decaying pulse. The fork receives nothing back. The energy goes into the surrounding medium.

Bound field release and loss of soliton coherence are related substrate reorganisations viewed at different scales: both can occur when a configuration crosses a stability boundary, releasing stored organisation into the surrounding medium as source support is removed or as geometric dilution reduces the amplitude below a sustaining threshold. Electromagnetism, on this account, is a single wave phenomenon of the Spaticle substrate, distinguished by boundary conditions: anchored and static, anchored and circulating, or detached and propagating.

The prediction is this: in a perfectly isolated electromagnet switched off by breaking the current abruptly, the stored magnetic field energy appears as an outward-propagating electromagnetic pulse - detectable at increasing distances from the magnet at times d/c - and no inward-propagating signal exists. Detectors placed between the magnet and the field boundary register the pulse moving outward, not inward. The magnet registers no return of energy from the field. This is consistent with what electrical engineers observe as the inductor voltage spike - energy leaving through the circuit outward, never returning to the magnet coil - and gives that well-known phenomenon a precise physical account in terms of bound substrate wave release.

4. Why Gravitational Waves Travel at c

4.1 The Problem in Standard Physics

In general relativity, the equivalence of gravitational wave speed and light speed is built into the theory: both propagate on the light cone of the spacetime metric. But the physical reason why a ripple in spacetime geometry propagates at the same speed as an electromagnetic wave is not given a deeper explanation. It requires that gravity and electromagnetism, which are fundamentally different in GR, happen to share the same propagation speed. This is confirmed experimentally to extraordinary precision but explained only by mathematical consistency, not by physical mechanism.

4.2 The Substrate Account

In BFUT, both light and gravitational waves are propagating disturbances of the Spaticle substrate. Light is a transverse electromagnetic disturbance. Gravitational waves are longitudinal or quadrupolar deformation disturbances, arising from accelerating mass distributions that generate time-varying substrate deformation patterns. Both propagate through the same physical medium.

Because both are substrate disturbances propagating through the same medium of density ρ_s and stiffness K_s, both propagate at the same speed:

$$c\_light = c\_GW = \sqrt{(K\_s / \rho_s)} = c$$

> Gravitational waves and light share the same propagation speed not because of a mathematical coincidence in GR but because both are disturbances in the same physical medium. The Spaticle substrate is the common physical carrier of both electromagnetic and gravitational propagation. One medium, one propagation speed.

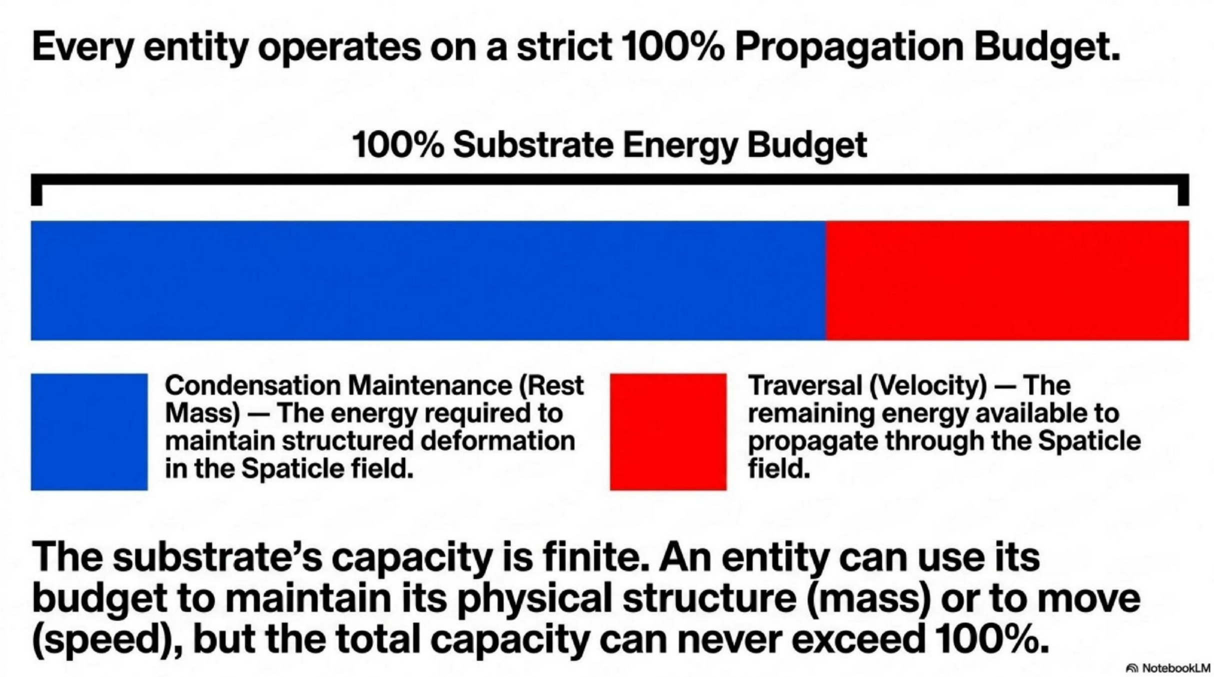

Figure 6: Every entity operates on a strict 100% Propagation Budget. Mass permanently consumes part of the budget for condensation maintenance.

5. Why Massive Particles Cannot Reach c

5.1 The Condensation Maintenance Cost

A massive particle is a stable localised condensation of the Spaticle substrate. It has an internal structure that must be continuously maintained as the condensation moves through the substrate. This maintenance requires ongoing substrate interaction: the condensation must continuously reorganise the substrate around it as it propagates.

The energy available for translational propagation is the total energy minus the rest energy. The rest energy mc^2 is the energy committed to maintaining the condensation structure. At velocity v, the total energy is:

$$E = \gamma mc^2, \quad \gamma = 1/\sqrt{(1 - v^2/c^2)}$$

The propagation momentum is $p = \gamma mv$, and the velocity is:

$$v/c = pc / E = pc / \sqrt{((pc)^2 + (mc^2)^2)}$$

As $p \to \infty$, $v/c \to 1$ but never reaches 1 because $mc^2 \neq 0$. The rest energy is the irreducible energy cost of maintaining the condensation. To reach c, the condensation would need to dissolve its internal structure entirely, converting all rest energy to propagation energy. But a dissolved condensation is no longer the particle. It becomes a massless excitation.

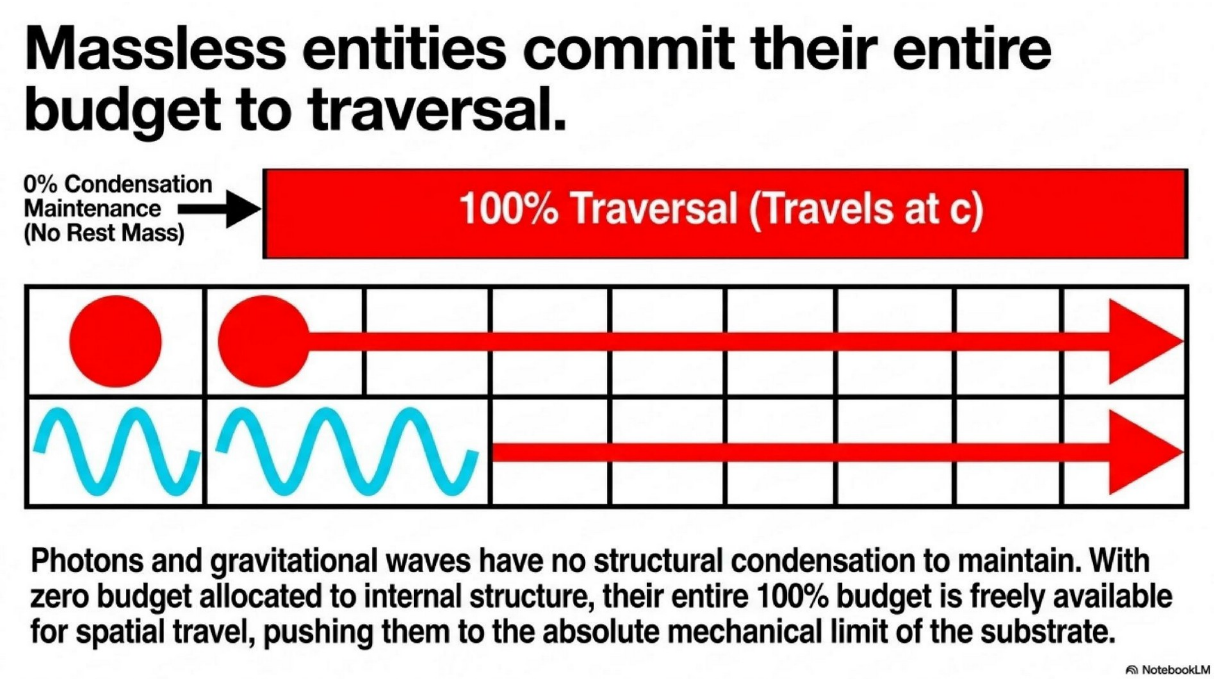

Figure 7: Massless entities commit their entire budget to traversal and travel at exactly c. Photons and gravitational waves have no condensation to maintain.

5.2 Physical Interpretation

The Lorentz factor $\gamma = 1/\sqrt{(1 - v^2/c^2)}$ has a direct substrate interpretation. As a condensation accelerates, it encounters increasing substrate resistance to its motion. The substrate ahead of the condensation must be reorganised to accommodate the condensation's approach. As $v \to c$, the condensation approaches its own substrate reorganisation front. The energy required to push the condensation to the next increment of speed diverges because the condensation is trying to outrun the substrate reorganisation signal that must precede it.

This is not merely a mathematical feature of Lorentz transformations. It is a physical consequence of the substrate structure: a condensation cannot outrun the substrate's ability to reorganise in response to its presence.

5.3 Rest Mass as Condensation Energy

The rest energy $E_0 = mc^2$ is the energy of the substrate condensation at rest: the energy that maintains the condensation's internal circulation structure against the substrate's ambient state. This is not a mysterious intrinsic energy. It is the energy stored in the organised deformation of the substrate that constitutes the particle.

The factor c^2 connecting mass and energy is the substrate propagation speed squared. It enters because the condensation energy involves the BFUT substrate stiffness $K_s = \rho_s c^2$ and the energy density of the deformation structure is naturally expressed in units involving c^2. The relation $E_0 = mc^2$ is therefore not surprising from the substrate perspective: it is the energy of a substrate deformation of characteristic amplitude (related to the condensation radius) in a medium of stiffness $K_s = \rho_s c^2$.

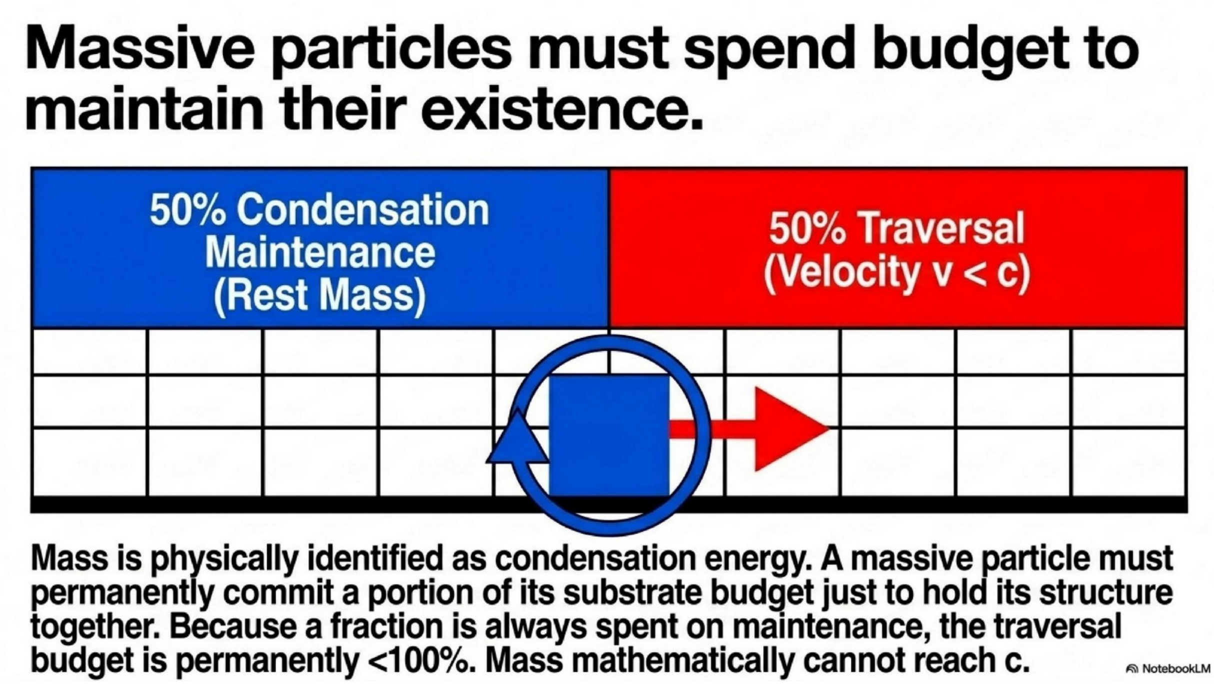

Figure 8: Massive particles must spend budget to maintain their existence. A fraction of their propagation capacity is permanently committed to condensation maintenance.

6. Neutrinos: Nearly Massless Substrate Ripples

6.1 Physical Nature of Neutrinos in BFUT

Neutrinos present a special case. They are produced in violent substrate reactions: nuclear beta decay, stellar collapse, particle annihilation. In the BFUT framework, these events involve rapid reorganisation of the substrate condensation structure. The reorganisation is not perfectly contained. Some substrate deformation escapes the reaction site as a propagating ripple.

These ripples carry energy and momentum but have very small mass. Unlike photons, which are pure propagation excitations with no condensation structure, neutrinos carry a trace condensation component: the residue of the substrate imbalance produced by the reaction. This gives them a tiny but non-zero rest mass. Dimensionally, the neutrino mass scale is set by the reaction energy imbalance ΔEimbalance divided by c^2: $m\_\nu \sim \Delta E_{imbalance} / c^2$. The beta decay Q-value is 0.782 MeV, while the neutrino mass corresponds to the residual substrate imbalance not absorbed into the condensation products. This residual is suppressed by multiple powers of the fine-structure constant α relative to the Q-value, placing it in the sub-eV range consistent with the cosmological and direct experimental bounds cited in References [10] and [11]. The neutral-fermion mass mechanism is developed in BFUT P19A.

This picture is consistent with the known properties of neutrinos: produced only in weak interaction processes involving structural substrate reorganisation; no electromagnetic coupling (they carry no charge asymmetry); three flavours corresponding to the three lepton generation scales; extremely small masses; and speed extremely close to c.

6.2 Neutrino Speed: Quantitative

For a neutrino of mass m_ν and energy E, the speed deficit from c is:

$$1 - v\_\nu/c \approx (m\_\nu\, c^2)^2 / (2E^2)$$

For SN1987A neutrinos with typical energy E ≈ 10 MeV and m_ν ≈ 0.04 eV (one third of the cosmological sum bound):

$$1 - v\_\nu/c \approx (0.04\ \text{eV})^2 / (2 \times (10 \times 10^6\ \text{eV})^2) \approx 8 \times 10^{-18}$$

This is far below the SN1987A observational constraint of $|v - c|/c < 2 \times 10^{-9}$ (derived from the few-hour arrival window over the 168,000 light-year distance). The neutrino speed is consistent with the substrate account.

> Neutrinos are substrate ripples from energetic reactions. Their tiny mass reflects a residual condensation component produced by the structural imbalance of their generating reaction. For the representative parameters used here, they travel within 8×10^{-18} of c. Photons travel at exactly c because they have no condensation component.

6.3 Three Neutrino Flavours

The three neutrino flavours (electron neutrino, muon neutrino, tau neutrino) in the BFUT account correspond to substrate ripples produced in association with the three charged lepton generation reactions. The electron neutrino is the substrate imbalance ripple from beta decay reactions involving the first-generation lepton sector. The muon neutrino and tau neutrino are associated with the second and third generation reactions respectively.

Neutrino oscillation, the observed conversion between flavour states, reflects the fact that the three flavour ripples are not eigenstates of the free-propagation Hamiltonian. The propagation eigenstates are substrate deformation modes with definite mass. The three flavour ripples are coherent superpositions of these propagation eigenstates. As they propagate, the phase relationships between the superposed modes evolve, producing the oscillation pattern.

This is the standard quantum mechanical account of oscillation, here given a substrate physical interpretation: the three propagation mass eigenstates are three slightly different substrate ripple modes, and flavour is the basis in which they are produced and detected.

7. Cosmic Redshift: The BFUT Account

7.1 Standard Account and Its Limitation

In standard cosmology, cosmic redshift is attributed to the expansion of spacetime. A photon emitted with wavelength λemit is received with wavelength λobs = λemit(1 + z), where z is the redshift parameter. BFUT describes the observed redshift through Doppler motion of matter together with substrate propagation dynamics.

BFUT describes an infinite and eternal universe with fixed intrinsic equilibrium density $\rho_s = 7.3 \times 10^{-27}$ kg/m³. This density is a physical constant that remains fixed across the BFUT framework. The proton mass, electron mass, Planck constant, carrier relaxation time τc, and gravitational domain radius R_d are therefore defined within a fixed-density substrate framework.

7.2 BFUT Account: Redshift from Doppler Motion and Gravitational Sorting

In BFUT, the observed systematic redshift of distant galaxies has two physical sources, both arising from the dynamics of matter in an infinite eternal universe under the BFUT gravitational framework.

Source 1 - Doppler motion. In an infinite universe, matter organises gravitationally into structures at all scales. On the largest scales, BFUT Paper 9 [7] establishes that the universe exhibits a large-scale rotation and gravitational vortex hierarchy. Matter moves within this structure. Galaxies receding from the observer produce a Doppler redshift that increases with the line-of-sight recession velocity. The observed Hubble relation - apparent recession velocity proportional to distance - is consistent with a gravitational sorting process in which matter at greater distances has had more time or more gravitational impetus to reach higher velocities. It does not require space itself to be expanding.

In this formulation, a change in the locally measured wavelength does not imply an unexplained loss of photon energy: the local wavelength and frequency must remain related to the retained photon energy through the local propagation relation.

Source 2 - Photon propagation through the substrate. A photon is a propagating soliton deformation of the Spaticle substrate, as established in Sections 2 through 6 of this paper. Its wavelength is the spatial period of this deformation pattern. As the photon propagates through the substrate over cosmological distances, it traverses regions of varying local substrate density associated with large-scale gravitational structure. These density variations alter the local propagation characteristics of the substrate and contribute to the observed wavelength at reception. This is a physical mechanism - substrate deformation dynamics - instead of a geometric postulate about expanding space.

7.3 Why No Expansion Parameter Is Needed

The standard account introduces an expansion parameter a(t) and derives the Hubble parameter from a Friedmann equation. BFUT has no expansion parameter and no Friedmann equation. The Friedmann equation is derived from the FLRW metric, which assumes a homogeneous isotropic expanding spacetime. BFUT does not accept the FLRW metric as describing physical reality. The universe is not homogeneous at the scales where FLRW is applied - it is structured, rotating, and gravitationally organised at every scale (BFUT P9 [7]).

BFUT treats the substrate density ρ_s as the intrinsic equilibrium density of the physical medium, distinct from the cosmological constant Λ. The apparent accelerated expansion associated with Λ is addressed within the BFUT matter-dynamics and infinite-universe framework. The full BFUT treatment of cosmic redshift, the Hubble relation, and the CMB temperature is developed in BFUT Papers 7 and 7A [8][9].

The full BFUT treatment of cosmic redshift, the Hubble relation, and the CMB temperature as dynamic thermal equilibrium is developed in BFUT Papers 7 and 7A [8][9]. The present paper is concerned with photon propagation physics. The redshift account above is included for completeness and to prevent any misreading of the soliton propagation results of Sections 4 through 6 as implying an expanding substrate.

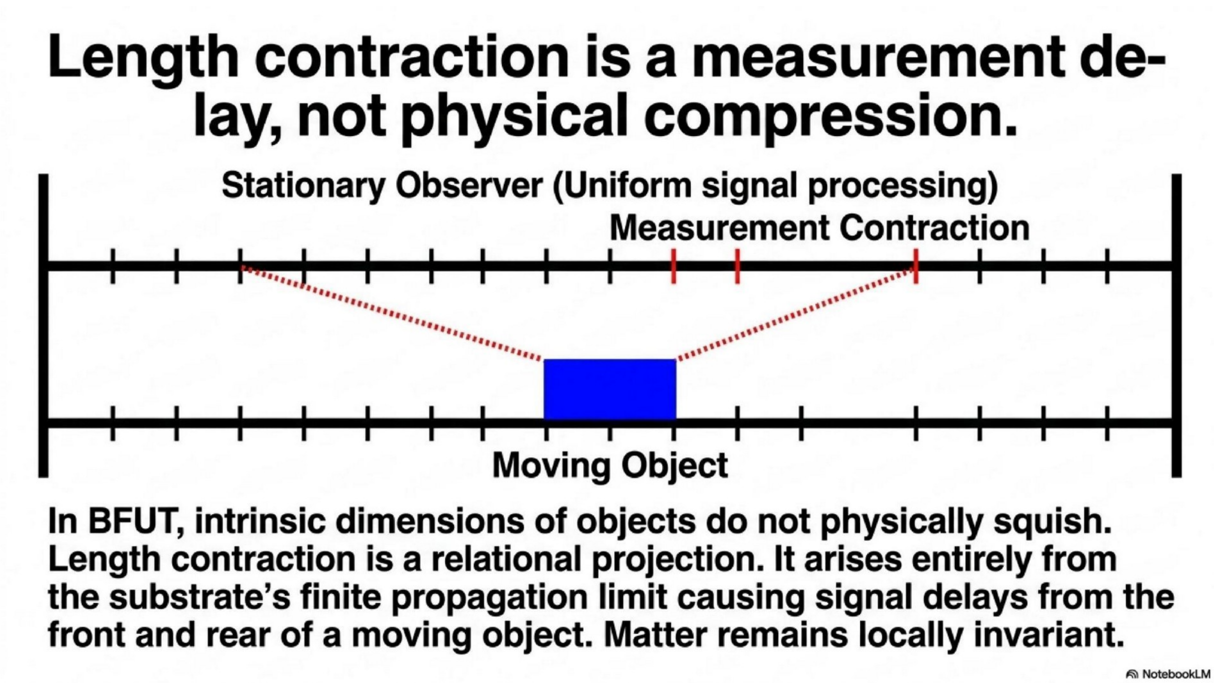

Figure 9: Length contraction is a measurement delay caused by finite substrate propagation, not physical compression of matter.

8. Time, Light Cones, and Causality from Substrate Physics

8.1 Time as Substrate Propagation Budget

BFUT Papers 19 and 22 [5][12] established that time is not an independent dimension of a spacetime manifold but a measure of the substrate's propagation budget: the accumulated capacity of the substrate to propagate causal information. The flow of time at a given location reflects the rate at which the substrate there can process and propagate physical changes.

The connection to light is direct. The light cone of standard relativity is the region of spacetime that can be causally connected to a given event. In the substrate account, the light cone is the region of substrate that can receive causal information from that event: the region within which the substrate reorganisation signal from the event can arrive within a given elapsed substrate time. The light cone is defined by the substrate propagation speed c.

Events outside the light cone are causally disconnected not because of an abstract geometric property of spacetime but because the substrate reorganisation signal from one event cannot reach the substrate region of the other event within the relevant time interval.

8.2 The Doppler Effect from Substrate Physics

The Doppler effect, the change in observed frequency of light from a moving source, follows directly from the finite substrate propagation speed. A source moving toward the observer at speed v emits successive wavefronts that are closer together in the substrate than a stationary source would produce, because the source moves toward the previously emitted wavefront. The observed wavelength is shortened. For recession, the wavefronts are farther apart.

The relativistic Doppler formula:

$$\nu\_obs / \nu\_emit = \sqrt{(1 + \beta)/(1 - \beta)} \quad \text{for approach,} \quad \beta = v/c$$

follows from the substrate propagation geometry combined with the time dilation of the moving source. Time dilation itself, the slowing of the rate of change for a moving condensation, follows from the substrate propagation limit: a condensation moving at speed v through the substrate has less substrate propagation budget available for internal processes, because part of the budget is committed to translational motion.

8.3 Length Contraction as Substrate Measurement Effect

Length contraction in special relativity is sometimes described as a physical compression of moving objects. The BFUT account is more precise. Length contraction is a consequence of how measurements of length are made using substrate propagation signals. To measure the length of a moving object, the observer must simultaneously establish the positions of both ends. But simultaneity is defined using substrate propagation, and the substrate propagation signal from the front of the object and the rear of the object take different times to reach the observer.

Length contraction in BFUT is a measurement relation arising from finite substrate propagation and the synchronization procedure used to determine the positions of a moving object's endpoints. Muon lifetime measurements, particle storage-ring experiments, and GPS corrections are reproduced by the same propagation-budget structure.

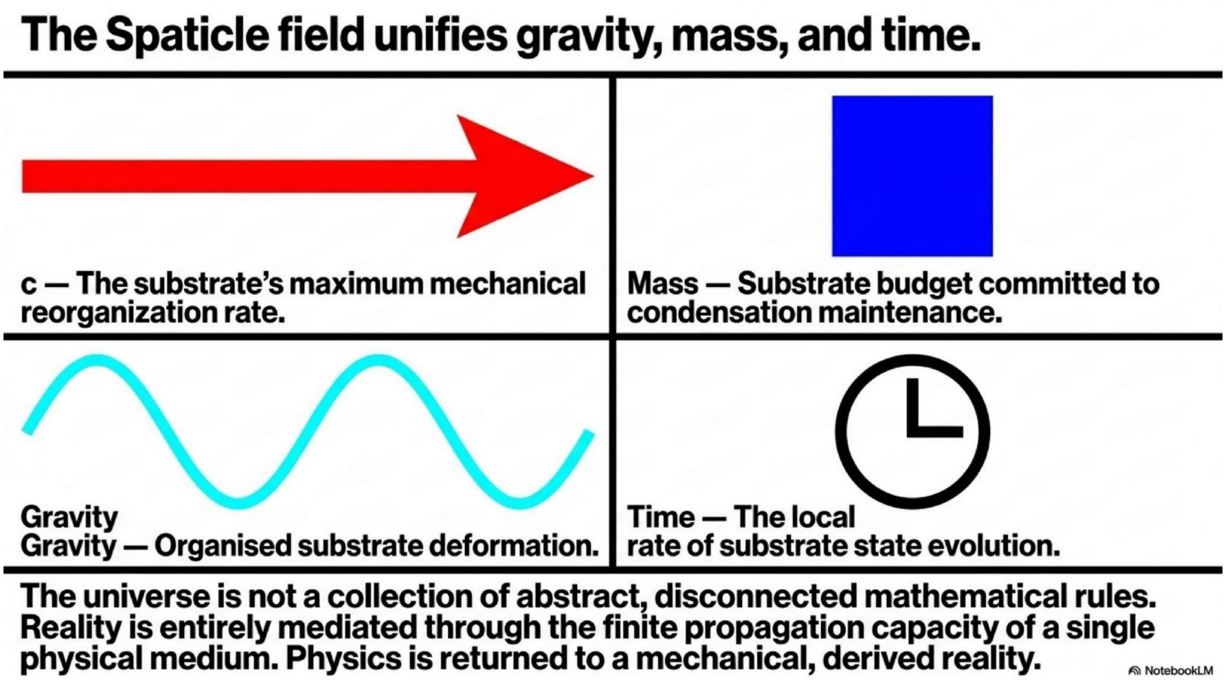

Figure 10: The Spaticle field unifies gravity, mass, and time through a single physical mechanism: finite propagation capacity of one medium.

9. Comparative Summary

Phenomenon	Standard Account	BFUT Substrate Account
Speed of light c	Postulated as universal constant; reason unspecified	Substrate propagation speed: $c_{vss} = \sqrt{K_s/\rho_s}$, derived from substrate stiffness and density
Why c is universal limit	Consequence of Lorentz invariance; no deeper explanation	No process can reorganise the substrate faster than the substrate propagates causal influence
Why photons travel at c	Massless, so no rest frame; travels at c by definition	No condensation to maintain; entire energy budget available for propagation through the substrate
Why massive particles cannot reach c	Mass implies nonzero rest energy; infinite energy needed	Condensation maintenance diverts energy from propagation; condensation cannot outrun the substrate
Why GW and light share c	Both propagate on null geodesic_s; mathematical coincidence in GR	Both are substrate disturbances in the same medium; one propagation speed because one medium
Neutrino speed (< c)	Massive particles travel below c; no physical picture	Substrate ripple with residual condensation; speed deficit = $(m_\nu c^2)^2/(2E^2) \sim 8\text{x}10^{-18}$ for SN1987A

Cosmic redshift	Spacetime metric expansion; geometric. Disputed: the dark-energy/acceleration evidence underlying this claim is consistent with observer bulk flow alone (P4 [21]); the 3.9-sigma dipole signal vanishes when bulk flow is set to zero.	Doppler motion of matter under BFUT gravitational dynamics; photon propagates through a static, non-expanding substrate. Because the substrate does not stretch, the photon's energy is fixed at emission and does not change during transit.
Rest energy mc^2	Intrinsic energy; $E=mc^2$ postulated	Energy of substrate condensation maintaining its internal organisation in a medium of density ρ_s
Photon polarisation	Transverse EM field oscillation direction	Orientation of transverse substrate deformation in the propagating excitation

10. Predictions Distinguishing BFUT from Standard Treatment

10.1 Gravitational Wave Propagation at Very Long Wavelengths

The BFUT substrate account requires gravitational waves to propagate at the same limiting speed c as photons because both are disturbances of the same substrate. The local relaxation scale L_{rlx} is a constitutive scale of the carrier response, not a gravitational range or a second propagation limit. At wavelengths approaching a relevant substrate relaxation scale, frequency-dependent response or attenuation could in principle occur, but any such effect would remain subject to the universal causal limit c.

The gravitational-wave propagation analysis identifies the carrier relaxation spectrum and its coupling to the gravitational-wave mode as the physical quantities governing frequency-dependent response. The corresponding response is represented through the substrate's internal relaxation structure and provides a basis for observational testing.

Photons, gravitational waves, and time share a single physical origin in BFUT. Photons and gravitational waves are organised propagating disturbances of the same Spaticle substrate, and both are massless: no rest-mass condensation diverts any part of their propagation budget into internal maintenance, so the entirety of their propagation capability is available for travel, and both propagate at c, the substrate's maximum reorganisation rate. Gravity itself, as a static field, is the substrate deformation produced by mass-energy directly [4]; a gravitational wave is a propagating disturbance of that same deformation, and like the photon it carries no rest mass and travels at c.

Time accumulates by the same mechanism, and the same single quantity governs both propagation and time:

$\eta = d\tau/dt = c\_s/c$

where η is the local substrate propagation efficiency, $d\tau$ is local proper time, dt is coordinate time in an undisturbed substrate region, c_s is the local effective propagation speed, and c is the vacuum propagation speed. A clock measures the amount of physical substrate evolution occurring within its own structure, so the fraction by which clock rates change is identical to the fraction by which local propagation capability changes [5].

Relativistic time dilation follows from a propagation budget shared between spatial motion and internal evolution:

$$c^2 = v_{spatial}^2 + v_{internal}^2$$

giving $\eta = \sqrt{1 - v^2/c^2}$, the Lorentz factor, derived here as a substrate propagation-budget result instead of a geometric postulate [5]. Gravitational time dilation follows from the same mechanism, since mass-energy deformation of the substrate reduces local propagation efficiency η, lowering local clock rates and local propagation speeds together, by the same factor [5, 4]. Causality is a direct consequence of the same finite propagation capability: no causal influence propagates faster than the substrate's maximum reorganisation rate c_0 [5].

Appendix A

Spaticle Field Cross-Sector Validation and the QFT Vacuum Energy Reconciliation

A.1 The Spaticle Field and Its Independent Constraints

The Spaticle field at intrinsic equilibrium density ρ_s is the single physical substrate underlying this paper's derivation of c, the photon, and the soliton mechanism. $\rho_s = 7.3 \times 10^{-27}$ kg/m³ is an established substrate constant constrained across the BFUT programme.

- Particle sector: W and Z boson masses derived from substrate reconfiguration energies at the femtometre scale (BFUT P19).

- Galactic sector: DME on 175 SPARC galaxies (BFUT P18). Shape agreement 92.0%, flat classification 98.8%, median outer relative residual 0.100. a_s from ρ_s.

- Weak-lensing sector: the same DME equation and the same a_s on KiDS-1000 isolated-lens stacks (BFUT P18).

- Atomic sector: hydrogen ground-state energy and Bohr radius recovered from first principles with no fitting to measured hydrogen structure (BFUT P25).

- Matter-stability sector: stable matter requires the substrate at every formation pathway, independent of formation history, a necessary condition, not a numerical fit (BFUT P25).

A density constrained simultaneously across particle, galactic, weak-lensing, atomic, and matter-stability observations is not a free parameter available to this paper. It is an emergent substrate constant inherited from the rest of the BFUT programme.

A.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:

$$\text{rhoQFT} \sim \text{Sumfields Integral } d^3k/(2\ \text{pi})^3 \cdot (1/2\ \hbar\ \text{omegak})$$

Approximately 17 independent Standard Model fields each contribute zero-point energy (1/2)h-bar-omega$_k$ per mode. The integral yields rho$_{QFT}$ ~ $5.87 \cdot 10^{111}$ J/m^3, against the observed $5.30 \cdot 10^{-10}$ J/m^3. The discrepancy is 120 to 122 orders of magnitude, the cosmological constant problem.

A.3 The Two Errors in the Standard QFT Treatment

Error 1, multiplicity of independent quantum fields. The 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, including the photon treated in this paper, is an organised excitation.

Error 2, zero-point energy assigned to empty modes. QFT assigns (1/2)h-bar-omega to every mode regardless of whether it contains a physical excitation. In the BFUT ontology, (1/2)h-bar-omega is the minimum internal circulation energy of an organised condensation. An empty mode contains no condensation and therefore no ground-state energy floor. Empty modes contribute zero.

A.4 Result After Correction

When both errors are corrected, one field and zero-point energy only for organised condensations, the mode sum over the pure vacuum state vanishes identically. What remains is the background equilibrium energy density of the physical medium:

$$u\_vac = \rho_s \cdot c^2 = 6.56355667 \times 10^{-10}\ \text{J/m}^3$$

The same substrate density ρ_s and the same speed of light c derived in the main body of this paper combine directly to give the substrate equilibrium energy density u_vac.

A.5 Dark Energy and the Cosmological Constant

Dark energy is not a separate physical entity in the BFUT framework. The LCDM cosmological constant Lambda is a geometric fitting parameter:

$$\mathrm{rho}_{\mathrm{Lambda}} = 3\ \mathrm{Omega}_{\mathrm{Lambda}}\ H_0^2\ /\ (8\ \mathrm{pi}\ G)$$

The cosmological parameter $\rho_\Lambda = 3\Omega_\Lambda H_0^2/(8\pi G)$ describes the Λ-based cosmological framework. ρ_s is the intrinsic equilibrium density of the Spaticle substrate and remains fixed throughout the infinite BFUT universe. The numerical relationship between these quantities is addressed by the BFUT cosmological framework.

A.6 Summary

The BFUT vacuum-energy treatment identifies one physical substrate field and assigns ground-state energy to organised condensations. The pure substrate equilibrium contributes $u_{vac} = \rho_s c^2$. The same ρ_s and c established across this appendix and the main body combine directly to give this substrate equilibrium energy density.

Appendix B.

The Soliton: How Nonlinear Waves Maintain Coherence

The soliton is a general phenomenon of nonlinear dispersive media, with a well-established physical and mathematical basis. This appendix establishes that basis, its historical development, and its occurrence across physical systems. It then examines how a three-dimensional organised propagating disturbance could lose soliton coherence in an unbounded medium such as the Spaticle field. The specific numerical thresholds for photon behaviour in the Spaticle field are not independently verified and are not asserted here.

B.1 The First Observation

On the afternoon of 1 August 1834, a Scottish engineer named John Scott Russell was watching a horse-drawn barge on the Union Canal near Edinburgh. The barge stopped suddenly. The mass of water the barge had been pushing forward did not stop. It detached from the barge, formed a single rounded heap of water, and continued down the canal at roughly fourteen kilometres per hour, maintaining its shape and height without any visible flattening or spreading for a distance of nearly three kilometres, until Russell lost sight of it around a bend.

Russell called it the Wave of Translation. He followed it on horseback. He was sufficiently astonished that he spent the next decade studying the phenomenon in laboratory wave tanks, generating it repeatedly by dropping weights into water. He published his findings in 1844 [1]. He had discovered what is now called a soliton.

The scientific establishment did not believe him. The leading hydrodynamicists of the day, Airy and Stokes, argued on theoretical grounds that such a wave was impossible. A solitary wave of translation, they said, must either steepen and break like an ocean wave approaching shore, or flatten and spread like a ripple from a stone. It could not maintain its shape. Russell was ignored for decades.

Russell was right and the theorists were wrong.

B.2 Why Ordinary Waves Die

To understand why a soliton is remarkable, it is necessary to understand why ordinary waves do not maintain their shape.

When a stone is dropped into a still pond, the disturbance is a pulse containing many frequencies. The pond is a dispersive medium: different frequencies travel at different speeds. The short wavelengths travel faster than the long wavelengths in shallow water, or the other way around in deep water depending on the regime. The pulse therefore spreads: the fast frequencies race ahead, the slow frequencies lag behind. After sufficient distance the original compact pulse has smeared into a long oscillating train of diminishing amplitude. This is dispersion.

Simultaneously, in three dimensions, the energy spreads outward as a sphere. The energy per unit area decreases as 1/r squared. The wave height decreases as 1/r. This is geometric spreading. It is purely a consequence of the three-dimensional geometry of space and has nothing to do with the properties of the medium.

Dispersion and geometric spreading together guarantee that ordinary waves die. They flatten, smear, and eventually become indistinguishable from the random thermal motion of the water molecules.

B.3 The Nonlinear Compensation

A soliton arises when the medium has a nonlinear response that exactly counteracts dispersion.

In water, the nonlinearity is this: a taller wave travels faster than a shorter wave of the same frequency. This is because the wave speed in shallow water depends on the total water depth, and a tall wave locally increases the effective depth. The crest of the wave moves faster than the trough. In an ordinary steep wave this causes the front face to steepen until the wave breaks. But if the wave is already a smooth single hump of exactly the right shape, the nonlinear speeding-up of the crest exactly compensates for the tendency of dispersion to spread the crest energy away from the peak. The hump locks its shape.

The mathematical condition for this balance was derived in 1895 by Korteweg and de Vries [2]. The wave equation they wrote, now called the KdV equation, has exact solutions of the form:

$$u(x,t) = (c/2)\,\mathrm{sech}^2[\ \sqrt{(c/12)}\ (x - ct)\ ]$$

where c is the wave speed. This solution travels at speed c without any change of shape. It is the mathematical soliton. The amplitude determines the speed: a taller soliton is faster. Two solitons of different heights that collide pass through each other and emerge unchanged, each at its original height and speed, with only a small phase shift as the record of their meeting [3].

B.4 The Canal and the Soliton - Why Russell's Wave Survived

Russell's Wave of Translation survived for three kilometres for the following reasons.

First, the canal is effectively one-dimensional. A narrow channel confines the wave to travel in one direction. There is no sideways spreading. Geometric dilution in one dimension gives amplitude falling as $1/\sqrt{r}$ instead of $1/r$. This is far slower. Over three kilometres the amplitude would fall only modestly from $1/\sqrt{r}$ spreading.

Second, the barge produced a disturbance of approximately the right amplitude and shape to lock into the soliton solution of the KdV equation for the canal dimensions. It was not a designed experiment. It was accidental. But the physics selected the soliton solution from the available conditions.

Third, the canal water has very low viscosity at canal scales. The energy loss from viscosity over three kilometres at canal depths is small. The soliton maintained enough amplitude to remain above the dissipation threshold for the length of Russell's observation.

B.5 Solitons in Other Physical Systems

The soliton turned out not to be a curiosity of canal hydrodynamics. It is a general phenomenon of nonlinear dispersive wave equations.

Optical fibres [4]: pulses of light in optical fibres are subject to dispersion that would broaden and destroy the signal over long distances. But at the right power level, the Kerr nonlinearity of the fibre glass, in which the refractive index increases slightly with light intensity, exactly compensates for the dispersion. The pulse becomes a soliton and travels without broadening. Optical soliton communication was demonstrated experimentally in the 1980s and is used in long-distance fibre-optic cables today.

Bose-Einstein condensates [5]: at temperatures near absolute zero, a cloud of atoms in a magnetic trap can form a quantum soliton. The matter wave of the condensate obeys the Gross-Pitaevskii equation, which has the same mathematical structure as the nonlinear Schrödinger equation. Solitons have been observed propagating through condensates without spreading.

Plasma physics [6]: ion-acoustic solitons propagate through plasmas. The balance between nonlinear wave steepening and dispersive spreading in a plasma produces solitary waves that travel without distortion through the ionosphere.

Biological systems [7]: soliton models have been proposed for nerve impulse propagation along axons, where the nonlinear compression of the axon membrane may produce a solitary acoustic wave accompanying the electrical signal. This remains an active area of research.

Particle physics [8]: certain quantum field theories have soliton solutions that correspond to stable particles. The Skyrme model treats the proton and neutron as topological solitons of a pion field. This is a formal ancestor of the BFUT account of the proton as a soliton of the Spaticle field.

B.6 The Three-Dimensional Soliton and Its Dissolution

Russell's soliton survived because the canal was effectively one-dimensional, the disturbance matched the nonlinear KdV balance, and dissipative losses were small over the observed distance. The KdV equation is a one-dimensional model. BFUT's proposed photon-coherence mechanism is expressed through the T4 nonlinearity: a self-trapped disturbance can maintain coherence while its amplitude remains within the regime supported by the nonlinear response. A transition out of that regime produces dissolution into an ordinary linear wave, with the energy redistributed into the background substrate.

A separate general mechanism follows from internal substrate relaxation. For a purely elastic substrate, with stiffness K_s = $\rho_s \cdot c^2$ fixed by density and limiting propagation speed, the wave's mechanical energy is conserved by the ideal equation of motion. An internal substrate degree of freedom introduces an additional channel through which deformation energy can be transferred into internal modes.

If the substrate contains an internal state driven by deformation and responding with a finite delay, its effective stiffness becomes frequency-dependent and complex, $K_{eff}(\omega) = K_{'}(\omega) + iK''(\omega)$, where $K''(\omega)$ represents irreversible transfer into the internal mode. This produces exponential attenuation, $E(x) = E_0 e$^($-2\alpha_{att}$ x), with an energy attenuation length $L_{att}(\omega) \approx (c/\omega)[K_{'}(\omega)/K''(\omega)]$.

This mechanism is local and does not depend on spherical spreading. For a directed disturbance of cross-sectional area A_cs and coherent longitudinal extent Δx, the deformation energy is E = u_def·A_cs·Δx. If a fraction εatt of the energy in each newly traversed element dV = A_cs·dx is transferred irreversibly to internal modes, the cross-sectional area cancels exactly, giving dE/dx = −(εatt/Δx)E and E(x) = E_0e^(−εatt x/Δx).

The soliton and internal-relaxation descriptions identify the physical quantities governing coherent propagation and attenuation: the nonlinear T4 response, the substrate relaxation time τ_{relax}, the stiffness change Δ_K, and the microscopic condensation-mode spectrum. These quantities determine the frequency dependence of coherent propagation in the substrate.

Observational constraints on photon and gravitational-wave propagation provide bounds on additional attenuation and dispersion. Fermi-LAT observations constrain energy- and distance-dependent photon attenuation from photon-photon pair production with the extragalactic background light [9]. The cited gravitational-wave amplitude-birefringence analysis provides a corresponding constraint on the attenuation parameter κ [10]. These measurements define the observational range within which any substrate propagation contribution must lie.

The BFUT propagation framework therefore connects coherent-range behaviour to the substrate's internal eigenmode spectrum and to its coupling with the transverse propagating mode. The resulting frequency-dependent response is governed by the microscopic substrate dynamics.

References (Appendix B)

[1] Russell, J. S. (1844). Report on Waves. Report of the 14th Meeting of the British Association for the Advancement of Science. York, pp. 311-390.

[2] Korteweg, D. J., & de Vries, G. (1895). On the change of form of long waves advancing in a rectangular canal, and on a new type of long stationary waves. Philosophical Magazine, 39(240), 422-443.

[3] Zabusky, N. J., & Kruskal, M. D. (1965). Interaction of solitons in a collisionless plasma and the recurrence of initial states. Physical Review Letters, 15(6), 240-243.

[4] Hasegawa, A., & Tappert, F. (1973). Transmission of stationary nonlinear optical pulses in dispersive dielectric fibers. Applied Physics Letters, 23(3), 142-144.

[5] Strecker, K. E., Partridge, G. B., Truscott, A. G., & Hulet, R. G. (2002). Formation and propagation of matter-wave soliton trains. Nature, 417, 150-153.

[6] Ikezi, H., Taylor, R. J., & Baker, D. R. (1970). Formation and interaction of ion-acoustic solitions. Physical Review Letters, 25(1), 11-14.

[7] Heimburg, T., & Jackson, A. D. (2005). On soliton propagation in biomembranes and nerves. Proceedings of the National Academy of Sciences, 102(28), 9790-9795.

[8] Skyrme, T. H. R. (1961). A non-linear field theory. Proceedings of the Royal Society A, 260(1300), 127-138.

[9] Fermi-LAT Collaboration. (2026). A New Measurement of the Extragalactic Background Light using 15 yr of Fermi-Large Area Telescope Data. arXiv:2604.09139.

[10] Ng, T. C. K., Isi, M., Wong, K. W. K., & Farr, W. M. (2023). Constraining gravitational wave amplitude birefringence with GWTC-3. Physical Review D, 108, 084068.

References

[1] Sharma, V. S. (2026). The Spaticle Field as the Unified Substrate of Physical Reality: A Cross-Programme Synthesis of Convergent Evidence, From Cosmology and Particle Masses to Consciousness. BFUT P14. Zenodo. DOI: 10.5281/zenodo.19394064

[2] Sharma, V. S. (2026). The Origin of Matter, Antimatter, and Fundamental Forces: How Protons, Electrons, and Hydrogen Formed. BFUT P16. Zenodo. DOI: 10.5281/zenodo.19908215

[3] Sharma, V. S. (2026). The Emergence of Forces and Fundamental Senses: How the Spaticle Field Gave Rise to Gravity and All Other Forces. BFUT P17. Zenodo. DOI: 10.5281/zenodo.19976408

[4] Sharma, V. S. (2026). Beyond General Relativity: A Unified Gravitation Equation Across Quantum, Classical, Galactic, and Rapid-Transition Regimes. BFUT P18. Zenodo. DOI: 10.5281/zenodo.20145506

[5] Sharma, V. S. (2026). Unification of Particle Physics: Deriving Fine Structure and Coupling Constants, W, Z, and Higgs Boson Masses, Redefining and Unifying Gravity and Time. BFUT P19. Zenodo. DOI: 10.5281/zenodo.20145567

[6] Sharma, V. S. (2026). Cold, Dark, and Inevitable: A Logical Reconstruction of the Universe Before the Big Flare-Up. BFUT P8. Zenodo. DOI: 10.5281/zenodo.19323579

[7] Sharma, V. S. (2026). Cosmic Rotation Across Scales, Emergent Orbital Hierarchy, and the Large-Scale Challenge to Metric Expansion. BFUT P9. Zenodo. DOI: 10.5281/zenodo.19341549

[8] Bionta, R. M., et al. (1987). Observation of a neutrino burst in coincidence with supernova SN1987A in the Large Magellanic Cloud. Physical Review Letters, 58, 1494.

[9] Hirata, K., et al. (1987). Observation in the Kamiokande-II detector of the neutrino burst from supernova SN1987A. Physical Review Letters, 58, 1490.

[10] KATRIN Collaboration (2022). Direct neutrino-mass measurement with sub-electronvolt sensitivity. Nature Physics, 18, 160-166. DOI: 10.1038/s41567-021-01463-1

[11] Planck Collaboration (2018). Planck 2018 results VI: Cosmological parameters. Astronomy and Astrophysics, 641, A6. DOI: 10.1051/0004-6361/201833910

[12] Sharma, V. S. (2026). Time: Identifying the Cause and Effects and Unifying General and Special Relativity. BFUT P22. Zenodo. DOI: 10.5281/zenodo.20556908

[13] Sharma, V. S. (2026). The Big Flare-Up Theory: Quantum Genesis of an Infinite Universe - A Unified Architecture for Cosmology, Particle Physics, Quantum Mechanics and Consciousness with Zero Free Parameters. BFUT L1. Zenodo. DOI: 10.5281/zenodo.19149785

[14] Sharma, V. S. (2026). The Big Flare-Up Theory: Companion Simulations. Zenodo. DOI: 10.5281/zenodo.20554084

[15] Sharma, V. S. (2026). The Planck Constant: A First-Principles Derivation of ħ and How It Reshapes the Interpretation of Quantum Mechanics. BFUT P27. Zenodo. DOI: 10.5281/zenodo.20620283

[16] Tu, L.-C., Luo, J., and Gillies, G. T. (2005). The mass of the photon. Reports on Progress in Physics, 68(1), 77-130. DOI: 10.1088/0034-4885/68/1/R02

[17] Goldhaber, A. S., and Nieto, M. M. (2010). Photon and graviton mass limits. Reviews of Modern Physics, 82(1), 939-979. DOI: 10.1103/RevModPhys.82.939

[18] Particle Data Group (2022). Review of Particle Physics. Progress of Theoretical and Experimental Physics, 2022, 083C01. (Photon mass upper limit: $1.07 \cdot 10^{-27}$ eV/c^2)

[19] Inomata, K., et al. (2016). Single microwave-photon detector using an artificial Lambda-type three-level system. Nature Communications, 7, 12303. DOI: 10.1038/ncomms12303

[20] Opremcak, A., et al. (2018). Measurement of a superconducting qubit with a microwave photon counter. Science, 361(6408), 1239-1242. DOI: 10.1126/science.aat4625

[21] Sharma, V. S. (2026). Evidence Against Dark Energy: Observer Bulk Flow as an Alternative Explanation for Apparent Cosmic Acceleration. Zenodo. DOI: 10.5281/zenodo.19228065