

Pilot Investigation of Space-Time Dynamics as a Probe of Low-Frequency Universal Modulation

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ABSTRACT

This work proposes a structural–informational model of space–time in which a global low-frequency background oscillation (~ 0.06 Hz) plays a fundamental role in the dynamics and stability of physical systems across all scales. Based on pendulum experiments and a re-examination of Brownian motion, it is argued that purely stochastic molecular impacts are insufficient to explain sustained particle motion. Instead, both macroscopic oscillators (such as Foucault and torsion pendula) and microscopic particles are interpreted as responding to a universal space–time pulsation. The model further reveals a structural correspondence between this space–time pulsation and the cosmic microwave background, suggesting a common underlying physical origin. Within the proposed framework, gravity emerges from a fundamental vacuum pressure acting on a cellular background structure of space–time, while Newton’s gravitational constant is interpreted as an effective parameter arising from the balance between this pressure and a newly introduced surface mass–energy density (SMED). Modified de Broglie relations explicitly incorporate background space–time cells, providing a unified description of orbital dynamics for both micro- and macro-objects. Elementary particles are interpreted as localized soliton-like excitations of space–time energy, with proton structure described by a Gaussian standing-wave configuration whose internal nodal patterns are associated with quark confinement. Mass generation is treated as a geometric–energetic property of space–time rather than as a consequence of interaction with a scalar Higgs field. The approach links gravitation, electromagnetism, and strong interactions to a single underlying physical mechanism associated with vacuum pressure and predicts that dark matter may correspond to stabilized background space–time cells. Overall, the results suggest that matter, fields, and interactions arise from a common structural dynamic of space–time, accessible in principle through low-frequency oscillatory phenomena.

Keywords: space–time pulsation; fundamental vacuum pressure; structural–informational model; soliton particle dynamics

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1. INTRODUCTION

In the present work, pendulum systems are treated not as primary objects of study but as sensitive probes of the underlying dynamics of space–time. Their behavior is interpreted as a macroscopic response to a universal low-frequency modulation governing physical systems across all scales. The standard interpretation of Brownian motion attributes irregular particle trajectories to random molecular

impacts arising from thermal agitation (Einstein, 1905). While successful in describing ensemble diffusion statistics, this approach does not explicitly identify a persistent physical source of kinetic energy acting on an isolated particle. From a mathematical perspective, Brownian motion is represented by a Wiener process with continuous yet nowhere differentiable trajectories, implying the absence of a well-defined instantaneous velocity (Genthon, 2021).

These features suggest that purely stochastic molecular impacts may be insufficient to fully account for sustained particle motion.

Within the structural–informational model adopted here; Brownian motion is interpreted as the collision-smeared manifestation of an underlying coherent oscillatory process associated with space–time dynamics. The cornerstone of the model is the postulated existence of a universal low-frequency pulsation of the Universe with a characteristic frequency of approximately 0.06 Hz. This background oscillation provides a continuous physical modulation capable of inducing coherent motion of isolated particles, which experimentally appears as chaotic Brownian trajectories when coherence is disrupted by collisions.

The same background oscillation is proposed to govern macroscopic mechanical systems. In particular, the equations describing the transverse motion of the Foucault pendulum can be formally transformed into those of a Brownian particle through the introduction of viscous damping and finite mass. This correspondence indicates that both microscopic and macroscopic systems respond to a common background modulation of space–time.

The existence of such a background oscillation suggests a deeper unification of fundamental interactions. Within the present framework, the hypothesized “superforce” [Davies \(1984\)](#) is identified with the fundamental vacuum pressure of space–time. In the present framework, this superforce is identified with the fundamental pressure of space–time. Gravitation emerges as a structural effect produced by this pressure acting on curved space–time, while a new parameter the surface mass–energy density (SMED) links volumetric mass to effective surface deformation. Newton’s gravitational constant is therefore interpreted as an effective parameter arising from the balance between vacuum pressure and SMED, rather than as a fundamental constant.

Space–time is assumed to possess a cellular structure, with background cells governing gravitational phenomena and larger normal cells responsible for electromagnetic interactions. Orbital motion of both microscopic particles and astronomical bodies obeys the same dynamical equations, indicating a universal response of matter to waves of space–time ([Zhussupov, 2015](#)). Modified de Broglie relations incorporating background cells reveal a direct connection between gravitation and quantum wave behavior.

Within this framework, elementary particles are interpreted as localized standing-wave excitations of space–time energy stabilized by curvature and vacuum pressure. The proton is modeled as a Gaussian soliton with an internal nodal structure, providing a geometric interpretation of quark confinement. Mass is treated as a structural property of space–time rather than as a consequence of interaction with a scalar Higgs field, consistent with classical and hydrodynamic formulations of gravitation and quantum mechanics ([Birkhoff, 1923](#)), [Madelung \(1927\)](#).

At larger scales, the background pulsation of space–time is shown to influence high-energy astrophysical processes, including ultra-high-energy cosmic ray transport and pulsar electrodynamics ([Goldreich & Julian, 1969](#); [Greisen, 1966](#); [Zatsepin & Kuz'min, 1966](#); [Hillas, 1984](#); [Melrose & Yuen,](#)

[2016](#)). Observational constraints further support the presence of an extended energetic medium permeating space ([Planck Collaboration, 2015](#); [Hajra et al., 2024](#)). Stabilized background space–time cells are proposed to constitute dark matter, interacting gravitationally while remaining electromagnetically inert.

Taken together, these results indicate that space–time is not a passive geometric background but an active physical medium endowed with intrinsic structure, energy density, and information content. The present article combines theoretical development with experimental motivation derived from pendulum dynamics to demonstrate that low-frequency space–time pulsation represents a physically testable organizing principle capable of unifying classical mechanics, gravitation, quantum theory, and cosmology within a single structural–informational framework. The present study is based on the following key hypotheses:

1. Existence of a universal low-frequency space–time pulsation. Space–time possesses an intrinsic global oscillation with a characteristic frequency of approximately 0.06 Hz, acting as a continuous physical driver of motion and stability across microscopic and macroscopic scales.
2. Structural origin of Brownian and pendulum dynamics. Brownian motion and the transverse dynamics of pendulum systems represent different observational manifestations of the same underlying space–time oscillation, with stochasticity arising from environmental decoherence rather than from the absence of deterministic dynamics.
3. Fundamental pressure and structural mass–energy coupling. Gravitation, inertia, and particle mass emerge from the interaction between vacuum pressure and the cellular structure of space–time, characterized by the SMED, rendering Newton’s gravitational constant an effective rather than fundamental parameter.

STRUCTURAL–INFORMATIONAL MODEL AND THE PHYSICAL ORIGIN OF BROWNIAN MOTION

The standard interpretation of Brownian motion invokes random molecular impacts as the origin of the observed irregular trajectories of suspended particles ([Einstein, 1905](#)). According to this view, thermal agitation of the surrounding medium generates instantaneous asymmetries of momentum transfer that displace the particle in random directions. Although this explanation is deeply rooted in the molecular–kinetic theory, it leaves open certain conceptual questions when examined from the standpoint of single-particle energetics. A suspended Brownian particle of radius 1–5 μm is many orders of magnitude heavier than a water molecule. In order to impart a measurable displacement, numerous molecular impacts must act in a coordinated manner from one side of the particle.

However, from the standpoint of probability theory, the relative frequency of impacts from opposite directions must converge to 1:1 as the number of collisions increases. Thus, the probability of a persistent imbalance in momentum transfer decreases rather than increases with time. Consequently, purely random and uncorrelated molecular impacts do not

readily account for sustained directional displacement of a micron-sized particle. This difficulty remains implicit in classical treatments. Einstein's diffusion relation for many suspended particles (Eq.1),

$$D = \frac{RT}{6\pi\eta r N_A} \quad (1)$$

links the diffusion coefficient to osmotic pressure and to the dynamic viscosity η of the fluid. However, osmotic pressure does not constitute a source of kinetic energy for a single Brownian particle. It describes an ensemble property, not a microscopic force that acts individually on isolated particles. Therefore, Einstein's formula explains the statistics of diffusion but does not identify the physical engine that produces motion at the level of a single particle.

The diffusion coefficient (Eq.1) reflects the behavior of many suspended particles, which, in their motion, cross a certain geometric area of space per unit time. This area is inversely proportional to the radius of a Brownian particle. In his calculations Einstein assumed a particle radius of $1 \mu\text{m}$, and considered water at a temperature of 17°C (290K), for which the dynamic viscosity η is approximately $1.1 \times 10^{-3} \text{ Pa}\cdot\text{s}$.

If, instead of a flux of many particles, we consider a single Brownian particle, then the "front" of this flux becomes equal to the cross-sectional area of that one particle. In this case, the unit of time in Eq.1 belongs to a single particle and can be interpreted as the characteristic cycle of its motion in the fluid. According to Eq.2, this characteristic time is equal to the period of oscillation of the presumed background gravitational waves of space-time, approximately 16 s,

$$t = \frac{6\pi r A \eta N_A}{RT} = \frac{6\pi^2 r^3 \eta N_A}{RT} \quad (2)$$

where r is the radius of the Brownian particle, N_A is the Avogadro constant. For a single, sufficiently isolated particle, the characteristic time scale associated with the geometric cross section used in Einstein's derivation coincides with the $\approx 16 \text{ s}$ period appearing naturally in our model of background space-time pulsation.

Thus Eqs.1 and 2 can be interpreted as providing indirect support for the possible presence of periodic background waves affecting the particle's motion. Under these conditions an isolated particle would be expected to undergo approximately harmonic oscillations with a frequency of approximately 0.06 Hz. In practice, this periodicity can be distorted by additional forces, including the Coriolis term arising from Earth's rotation.

This reconsideration changes the physical interpretation of Brownian motion. From a probabilistic viewpoint, purely random local impacts cannot explain why a particle continuously acquires kinetic energy in a particular direction. From a mathematical viewpoint, the Wiener process a continuous but nowhere differentiable trajectory does not possess a well-defined instantaneous velocity, a point emphasized in detail by Arthur Genthon (Genthon, 2021). Thus, the classical and mathematical descriptions both leave open the question of the origin of motion.

In the structural-informational model, a consistent candidate for the physical driver of Brownian motion is proposed to be the background pulsation of space-time. A Brownian particle, being a macroscopic object relative to molecules, possesses a very large effective quantum number.

According to the large-quantum-number equation developed earlier, an isolated particle subjected to a background oscillation of frequency 0.06 Hz would be expected to follow a circular trajectory of radius roughly 3 cm. In real fluids many such particles interact and collide, destroying the coherence of this circular drift. The result is the irregular, chaotic trajectory conventionally associated with Brownian motion. In this view, Brownian motion is not produced solely by molecular impulses but can be interpreted as the collision-smeared manifestation of an underlying deterministic oscillation of space-time.

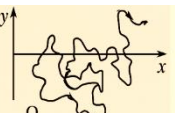
A deeper connection between macroscopic and microscopic dynamics arises from a formal transformation of the transverse equations of the Foucault pendulum into the equations of motion of a Brownian particle. This transformation suggests that both systems respond to the same low-frequency space-time pulsation. In linear approximation the horizontal dynamics of the Foucault pendulum are given as the following equations:

$$\begin{aligned} \ddot{x} + \omega_0^2 x &= 2\Omega \dot{y} + F_{ext}(t), \\ \ddot{y} + \omega_0^2 y &= -2\Omega \dot{x} + F_{ext}(t), \end{aligned} \quad \omega \approx 0.06 \text{ Hz}$$


where $x(t), y(t)$ are horizontal coordinates; $\dot{x}, \dot{y}$ are velocities; $\ddot{x}, \ddot{y}$ are accelerations; $\omega_0 = g/L$ is the natural frequency of a pendulum of length L ; Ω is Earth's angular rotation rate; $F_{ext}(t)$ is an external driving force representing background space-time pulsation; on the figure is the trajectory of pendulum's bob as respond to the low-frequency oscillation of space-time. For a Brownian particle the natural frequency vanishes: $\omega_0 = 0$,

- viscous damping appears with coefficient γ ,
- the particle's finite mass m must be included,
- the driving term becomes the background pulsation $F_{bg}(t)$.

Thus, the transformed equations can be written in the analogous form:

$$\begin{aligned} m\ddot{x} + \gamma\dot{x} &= 2m\Omega \dot{y} + F_{bg}(t), \\ m\ddot{y} + \gamma\dot{y} &= -2m\Omega \dot{x} + F_{bg}(t), \end{aligned} \quad \omega \approx 0.06 \text{ Hz}$$


where on the figure is a schematic Brownian-like trajectory. The system responds to the low-frequency oscillation of space-time; damping and collisions convert the circular drift into Brownian motion.

These equations describe a damped two-dimensional oscillator in a rotating frame, driven by the same low-frequency background pulsation as the pendulum. An isolated particle would, in this idealized limit, be expected to follow a circular path of radius several centimeters, representing a microscopic analogue of the Foucault precession. Collisions between many

particles erase this coherent drift and generate the apparent randomness of Brownian motion.

SUPERFORCE AND FUNDAMENTAL INTERACTIONS

The product of the squared background-structure wavelength (5.0326×10^9 m) and the fundamental pressure of space–time yields a value of 1.2091×10^{44} N, which numerically coincides with the definition of the Planck force expressed as c^4/G . This coincidence suggests that the Planck force may be interpreted not merely as an abstract dimensional construct but as a realized action of vacuum pressure applied to an elementary area determined by the background-structure wavelength. In this interpretation, gravity and the other fundamental interactions are viewed as manifestations of a unified mechanism rooted in the pressure of space–time.

Such an approach echoes Paul Davies' idea in *Superforce*, where all fundamental interactions arise from a single underlying physical principle (Davies, 1984). It is often argued that the Planck force sets the order of the maximum possible force between two bodies; this is consistent with the present interpretation. The “superforce” may thus be understood as the total dynamic pressure exerted by background gravitational waves of space–time. The diversity of its manifestations is illustrated by Eq.3, which shows that it is linked not only with the Planck unit of force, but with all fundamental constants. It participates in the formation of electric charge, mass, particle velocities, vacuum permittivity and permeability, and ultimately the fundamental pressure (P) itself:

$$F_s = \frac{c2\pi r_f P V_b}{\omega V_b} = \frac{m_e c^3 r_f}{16\pi^3 \epsilon_0 \omega V_b} = \frac{m_e c^5 \mu_0 r_f}{16\pi^3 \omega V_b} = \frac{e^2 c}{2\epsilon_0 \alpha \omega V_b} = \frac{e^2 c^3 \mu_0}{2\alpha \omega V_b} = \frac{c^4}{G} = \frac{hc^2}{\omega V_b} \quad (3)$$

where r_f is the intrinsic radius of the photon, V_b is the volume of a hydrogen atom within the first Bohr orbit, V_b is the cell volume of the background structure of space–time ($V_b \approx 8.26 \times 10^{-60}$ m³), ω is the background gravitational wave frequency. Thus, as Davies anticipated, the superforce may be regarded as capable of contributing to the observable forms of the fundamental interactions, including gravity. The nature of gravitational attraction between massive particles and objects arises from the fundamental pressure, the surface energy density, and the dynamics of the background structure of space–time. Gravity manifests between two massive objects as the acceleration produced by the fundamental pressure acting on the enlarged area of curved space–time. This area increases due to masses $M_1 M_2$, which tends to stretch (or expand) the surface of the space–time medium $\Delta S = M/D$, where D is the surface density of space–time. This surface density is equal to the ratio of the Plank constant to the volume of the background cells of space–time and speed of light $D = h/cV_b$. The fundamental pressure resists this deformation and through its relation to surface density accelerates the particles and bodies $a = P/D$.

Since space–time seeks to minimize its curved surface, gravitating objects redistribute themselves so that they occupy the minimum possible area. Compactly shifted configurations

minimize this area; hence, objects spontaneously move closer together due to gravitational force F_G (Eq.4).

$$F_G = \frac{M_1 M_2 P}{R^2 D^2} \quad (4)$$

where R is the separation between the massive particles or bodies. Because G is expressed through P and D ($G = P/D^2$) in this framework, the gravitational constant is interpreted not as a fundamental quantity but as a parameter emerging from the properties of a self-consistent background. This shifts the interpretation of gravity from that of a primary interaction to a phenomenon arising from the structural energetics of the vacuum medium (Fig.1).

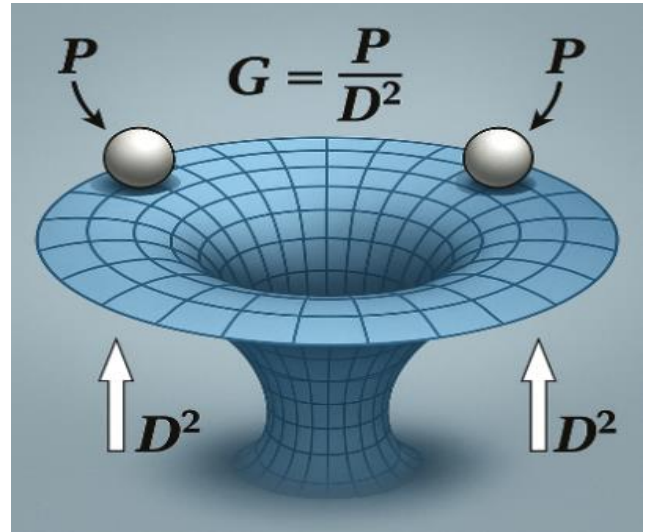


Figure 1 Gravitational constant arising from background pressure P and surface density D of space–time. Visualization generated using AI-based graphic synthesis tools.

The curvature of space–time (its surface density D) produced by uniform background pressure P yields the gravitational constant G , demonstrating that gravity emerges from the energetic structure of the vacuum. Therefore, the structural–informational model predicts the nature of gravity as the action of the postulated fundamental pressure and the induced curvature of the space–time structure governed by its the surface density.

We interpret the relationship between gravity and the fundamental pressure as a manifestation of structural symmetry in space–time. Both phenomena operate at the most fundamental level of matter and jointly determine the curvature of the space–time fabric. The fundamental pressure tends to induce local curvature, increasing the effective area of energetic influence whenever two or more massive objects are present.

Gravity, in contrast, acts as a global compensating mechanism: it reduces excessive local stress created by this pressure and redistributes the load across the space–time fabric as uniformly as possible. In this sense, gravity may be viewed not as an independent force, but as a dynamic consequence of a structural symmetry that balances local and global deformations of space–time. This symmetry is captured by Eq.5.

$$D = \sqrt{\frac{P}{G}} \quad (5)$$

We interpret the quantity D in this equation as a new fundamental parameter, the Surface Mass–Energy Density (SMED), which links the volumetric mass of particles and macroscopic bodies to the effective surface area associated with distortions of the space–time background. This interpretation suggests a natural division of roles:

- fundamental pressure P reflects the tendency of the Universe's structural background to maintain dynamic stability through local curvature,
- gravity G arises as the global redistribution of this curvature, minimizing the total deformation of space–time.

Conceptually, the symmetry between P and G becomes intuitive if both are viewed as manifestations of the same underlying property of space–time. SMED — D (dimension kg/m^2) serves as an effective surface density of mass–energy stored in the space–time fabric, determining how much curvature any local region can sustain. Fundamental pressure generates curvature locally, acting outward from regions of high mass–energy. Gravity spreads this curvature across the entire structure to achieve global balance. Thus, the pair (P, G) can be regarded as forming a unified structural symmetry:

P corresponds to a local curvature-generating operator, whereas G represents a nonlocal curvature-redistribution operator acting on the global geometric structure.

In this framework, SMED becomes the parameter that encodes how the structural-informational background of space–time stores, transmits, and balances mass–energy through curvature. The normal cellular structure of space–time is

associated with particles and macroscopic objects and, with respect to the background cellular structure, is secondary. It consists of larger cells ($V_n > V_b$) and is responsible for the phenomenon of electromagnetism, whereas the background structure governs gravitation. The normal structure is emergent and arises under the combined action of gravity and fundamental pressure when particles and objects are embedded into the background structure of space–time (Eq.5, Eq.9) see (Zhussupov, 2026).

The quantum number of particles and objects, as shown above, is measured in the cells of the normal structure. Within the structural-informational model, the boundary between the behavior of micro- and macro-objects is essentially reduced. For example, the orbital motion of electrons in atoms and the orbital motion of planets in the Solar System are described by the same equations and are directly related to the structure of space–time. As demonstrated in previous work (Zhussupov, 2015), such behavior can be interpreted as being associated with gravitational waves of space–time. In the structure of space–time, in the Solar System, and in the dynamics of particles and macroscopic bodies, a universal harmony is observed, expressed as a unified response to the pulsation of the Universe (Eq.6).

$$\omega_R = \frac{4\pi G M_\odot m V_n}{h R \pi r^3} \quad (6)$$

where $M_\odot$ is the mass of the Sun, m is the mass of the particle or object, R is the Earth–Sun distance, and r is the intrinsic radius of the particle or object. As an example, Tab.1 presents the calculation of the correspondence between Eq.6 and a variety of objects.

Table 1. Data for the calculation of the frequency ω_R according to Eq.6. (Constants G, h , were used in the calculations; the volume of the normal-structure cell is $V_n = 4.74 \times 10^{-49} \text{ m}^3$.)

Name of object	m (kg)	r (m)	ω_R (Hz)
Planets: Earth	5.9722×10^{24}	6 378 169	0.0585
Venus	4.867×10^{24}	6 051 800	0.0558
Mars	6.39×10^{23}	3 389 500	0.0417
Jupiter	1.8986×10^{27}	66 854 000	0.0161
Mercury	3.3×10^{23}	2 440 000	0.0577
Moon	7.36×10^{22}	1 737 400	0.0357
Foucault's pendulum in Paris	28	0.08	0.1389
Brownian particle	5.236×10^{-12}	5×10^{-6}	0.0106
Hydrogen atom	1.67×10^{-27}	5.29×10^{-11}	0.0287

The Tab.1 contains reconnaissance-level estimates of the longitudinal oscillation frequencies of various objects. Deviations of some objects from the universal pulsation frequency of the Universe are attributed to neglected precession effects and possibly to material composition. In general, Eq.6 demonstrates that the structure of space–time plays a crucial if not the dominant role in the formation and static stability of physical objects.

In dynamics, the participation of the space–time structure manifests itself in the formation of de Broglie waves. In the modified de Broglie equation (Eq.2) (Zhussupov, 2026), it was

shown that the wavelength depends on the number of normal space–time cells. With the inclusion of **SMED**, the direct involvement of background cells becomes explicit: the wavelength now depends on their number as well (Eq.7).

$$\lambda = \frac{NcV_b D}{p} = \frac{NcV_b}{Mv} \sqrt{\frac{P}{G}} \quad (7)$$

where D is the surface density (SMED), p is momentum $= Mv$, V_b the volume of the background-structure cell is $V_b = 8.26 \times 10^{-60} \text{ m}^3$.

In this equation, the connection between de Broglie waves and gravitation becomes evident. It is universal and promising for high-precision calculations of wavelengths (orbits) for both micro- and macro-objects. As a test, one can verify that an electron on the first Bohr orbit of the hydrogen atom ($N=1$) is bound to the nucleus by the same gravitational constant as, for example, the Earth is bound to the Sun (for the Earth, according to Eq.7, $N=2.523346 \times 10^{74}$) (Zhussupov, 2026). The volume of the background cells reflects the geometry of space-time and has been determined experimentally. All other parameters of this equation are fundamental, which enables the derivation of a universal formula for the gravitational constant (Eq.8).

$$G = P \left(\frac{NcV_b}{Mv\lambda} \right)^2 \quad (8)$$

This result challenges the widespread view that Newton's law of universal gravitation does not operate in the micro world. It is also remarkable that, for calculating the orbital radius, knowledge of the mass of only one gravitating object is sufficient. The gravitational constant obtained for the electron on the first Bohr orbit (when $N = 1$) is numerically equal to $G = 6.68115 \times 10^{-11} \text{ m}^3 \text{ kg}^{-1} \text{ s}^{-2}$, differing from the CODATA value by only one-tenth of a percent. If the experimentally determined value of the background-cell volume is confirmed, the numerical value of the gravitational constant currently known only to about the fourth significant digit could in principle be refined within this framework.

Equation (8) shows that gravity is linked not only to **SMED**, but also to the volumetric energy density of space-time, PV_b . The motion of particles and objects is governed by the gradients of this energy density, which physically represent gravitational fields. The volumetric energy density of space-time, gravitation, and SMED are coupled through these gradients in the form

$$\Delta NPV_b = \nabla Y_1, \quad \Delta \lambda Mv \frac{GD}{c} = \nabla Y_2, \quad \frac{\nabla Y_1}{\nabla Y_2} \rightarrow 1$$

Locally, gravity reduces to the force interaction of space-time cells with particles and objects. This mechanism may be interpreted as follows. The mass, velocity, or curvature of the object's trajectory create an excess volume of background-structure cells ΔNV_b , which gives rise to a gradient of the volumetric energy density of space-time ∇Y_1 . This gradient, in turn, generates a gradient of the ponderomotive moment of force ∇Y_2 , which displaces the particle or object toward a state of equilibrium energy density.

From the standpoint of the quantitative assessment of space-time cells, gravity possesses a quantum nature, while in all other respects it is consistent with the theory of relativity. The background structure of space-time responsible for gravitation represents a higher-order structure that can locally transform into the normal structure.

It forms a continuous medium that accommodates all observable particles and macroscopic objects. This very medium is responsible for the formation of matter and physical fields, acting as the matrix of fundamental interactions

gravitation, electromagnetism, and the strong and weak interactions of matter.

The background cells of space-time are microscopic, yet they are coupled to gigantic cosmological-scale waves oscillating with a frequency of approximately 0.06 Hz.

The nature of these oscillations is determined by the intrinsic dynamics of space-time, in which the background cells oscillate in the form of transverse waves. From the characteristic size of the background cells, the wavelength of these transverse waves is $2\pi R_b$, where R_b is the radius of a background cells determined from its volume V_b . The same volume, multiplied by the fundamental pressure and divided by the square of the speed of light, yields the mass of a background space-time cell $m_b \approx 4.394 \times 10^{-52} \text{ kg}$ (Eq.9):

$$m_b = \frac{PV_b}{c^2} \quad (9)$$

This mass, together with the speed of light an intrinsic and invariant component of the space-time structure generates the background waves of space-time (Eq.10).

$$\omega = \frac{mc^2}{h} \quad (10)$$

Here, the estimated numerical value of the frequency is 0.0596 Hz, which, at the speed of light, corresponds to a wavelength $\lambda \approx 5.0297 \times 10^9 \text{ m}$. A conceptual diagram of the formation of longitudinal background waves of space-time is shown in Fig.2.

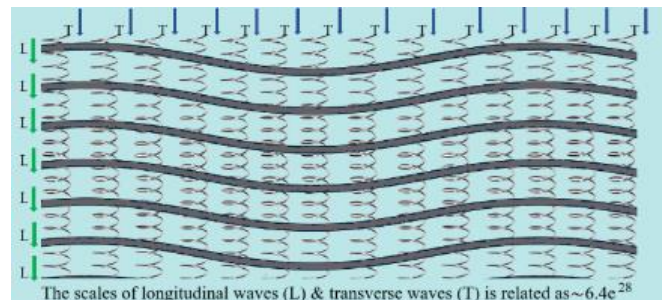


Figure 2. Schematic representation of the formation of longitudinal space-time waves with the participation of transverse oscillations of the background space-time cells at different scales. Here, L denotes longitudinal space-time waves, and T denotes transverse waves of the background cells.

In the classical picture, a photon may be regarded as a hypothetical carrier of gravitational modulation. If the photon is treated not as a high-frequency quantum of light but as a low-frequency information carrier in a gravitational field, then such long-wavelength "photons" could, in principle, produce an excitation effect in a pendulum. For this purpose, space-time must be represented as a continuous field or as a photon ocean, analogous to Dirac's electron sea. In this interpretation, the self-oscillations of a pendulum observed in experiments can be viewed as a weak excitation induced by fluctuations of the photon ocean.

This excitation corresponds to a low-frequency mode and manifests itself as sustained oscillations of particles and macroscopic objects in the absence of visible energy sources.

Such excitation is likely not associated with ordinary fluctuations of the relic radiation type, but rather with topological waves in a gravitational-type field. Thus, particles and objects oscillating under conditions of isolation from turbulent and mechanical disturbances may experience stable excitation through interaction with an extended photon-field mode whose wavelength is on the order of millions of kilometers.

According to de Broglie's hypothesis, a photon as a wave may be regarded as a particle possessing momentum and an effective mass m_γ . This mass is interpreted as a frequency characteristic of a topologically bound vortex arising as a result of stable transitions of photon cells. It is connected with the characteristic frequency ω of the vortex state through an analogue of the relativistic relation $E = \hbar\omega = m_\gamma c^2 \Rightarrow \omega = m_\gamma c^2 / \hbar$. Thus, a "mass vortex" represents a stable vibration of the photon field with its own intrinsic frequency of collective, self-consistent excitation.

From this definition emerges the idea of the sedimentation-like nature of the mass of particles and objects, by analogy with the process of material deposition under mechanical vibrations. Such a mechanism is based on the transfer of vibrational energy to relatively heavy particles of matter, which leads to their acceleration and penetration into denser layers. Numerous examples of sedimentation mechanisms are known from vibration-induced compaction of concrete to the absorption of vibrating objects by quicksand. The physical principle of this phenomenon is well described in the literature, where it is also noted that higher frequencies cause the particles to sink faster (Khabazi et al., 2016).

The postulated photon field (or photon ocean) is universal and can participate not only in gravitational processes but also in electromagnetism. In particular, the electric charge e (most naturally expressed in the CGS system) is determined by the intrinsic radius of the photon r_f , the fundamental pressure, and the volume of the hydrogen atom with the Bohr radius V_B (Eq.11).

$$q = \sqrt{\alpha r_f P V_B} \quad (11)$$

where α is the fine-structure constant. By converting the electric charge q into the SI system ($e = q\sqrt{4\pi\epsilon_0}$), one may proceed to a description of electromagnetic interactions within the framework of unified fundamental interactions. The presence of the intrinsic photon radius in this equation further supports the genetic connection between the electron and the photon discussed above. According to Eq.12, strong interactions, in the same way as gravitational and electromagnetic interactions, depend on the energy density, the fundamental pressure, and the structure of space-time:

$$m_p = \frac{DV_b}{\lambda_c} = \frac{V_b}{\lambda_c} \sqrt{\frac{P}{G}} \quad (12)$$

where V_b is the volume of a background space-time cell, D is **SMED**, λ_c is the Compton wavelength of the proton, and G is the gravitational constant. In this equation, the mass of the proton is expressed with high accuracy through the geometry

of space-time, the Compton wavelength, and the fundamental pressure. This expression shows that the proton mass arises as a structural effect, reflecting a balance between gravity, energy, and the geometry of space-time, while the proton itself may be interpreted as nothing more than a Compton wave. For the corresponding Compton wavelength, Eq.12 also describes the masses of other particles.

This approach may be regarded as an alternative geometric interpretation of the Higgs mass-generation mechanism of the Standard Model. In the structural-informational model of space-time, the mass of elementary particles is interpreted not as being generated by interaction with a scalar Higgs field, but as arising as a structural effect of space-time geometry and its energy density. As shown above, within the space-time structure, mass is associated with a quantum number.

As expressed by Eq.12, the proton mass is determined by the volume of the background cell. This demonstrates that the proton mass can be viewed as emerging as a geometric-energetic invariant of space-time itself, rather than as a consequence of spontaneous symmetry breaking in a scalar field. Within this framework:

- particles are interpreted as localized wave states of space-time energy, stabilized by curvature;
- mass represents a stationary vibrational mode of the background structure, rather than a fundamental intrinsic property;
- the Compton wavelength defines the geometric scale of mass localization;
- the **energy equivalent of mass** reflects the structural balance between curvature, pressure, and energy density of space-time.

Thus, the postulated Higgs field of the Standard Model is reinterpreted within this framework as a manifestation of a universal structural mechanism of mass formation, in which mass originates from the self-consistent curvature and energy density of the cellular space-time medium.

This postulate provides a unified geometrical interpretation of mass that applies equally to elementary particles, composite particles, and macroscopic objects, and naturally integrates mass into the same framework that governs gravity, electromagnetism, and strong interactions through the geometry and topology of space-time

Within the structural-informational model, all interactions occur in a unified field of fundamental pressure, encoded in the geometry (defects, topology) and in the logical state of space-time. This logic unifies field and geometry into a single structure that serves simultaneously as a carrier of information and a carrier of energy. In this framework, the field is not superimposed on geometry, but emerges from it. The postulated parameters of space-time ultra-high energy and mass density, super-strong interaction, and cellular structure differ significantly from those assumed in the Standard Model framework.

They depart from conventional descriptions of the structure, dynamics, and physicochemical properties of matter. From the standpoint of the Standard Model, under such conditions corpuscular particles would not ordinarily be expected to

remain stable, since the embedding medium would be physically impenetrable for them.

In the structural–informational model, matter and all observable particles and objects are described as waves of energy embodied in information. In such a medium, the composition, structure, and dynamics of particles and objects are interpreted in terms of their wave nature, and upon annihilation only information in the form of energy remains. The existence of matter and particles is associated with the energy density sustained by the curvature of space–time itself. Particles and macroscopic objects can be modeled as localized energy distributions, the density of which is maintained by the curvature of space–time.

The relation between energy density and curvature can be described by a standing wave equation with a Gaussian envelope. For example, the proton is represented as a localized soliton stabilized by the background energy density of space–time. Its localized Gaussian wave function is given by Eq.13:

$$\Psi(r) = A \cos(kr) \exp\left(-\frac{r^2}{2\Sigma^2}\right) \quad (13)$$

where A is the background amplitude or normalization constant depending on the chosen dimensionality and physical interpretation, k is the wavenumber (spatial “frequency” with dimension m^{-1}), r is the spatial coordinate or radius in meters, and Σ is the width of the Gaussian envelope (with dimension of meters).

In this model, the processes of particle and object creation and annihilation are interpreted exclusively as transformations and structural reorganizations of energy. This postulate can be regarded as a fundamental link between the space–time structure and physical objects. This interpretation is compatible with the Schwarzschild metric (Karl Schwarzschild, 1916) and the Birkhoff theorem (Birkhoff 1923), according to which a gravitational source forms a curvature field through its own energy (Birkhoff, 1923). The Schwarzschild metric has the form (Eq.14).

$$ds^2 = \left(1 - \frac{2GM}{c^2 r}\right) c^2 dt^2 - \left(1 - \frac{2GM}{c^2 r}\right)^{-1} dr^2 - r^2 d\Omega^2 \quad (14)$$

Here, r is the radial coordinate in the spherically symmetric case, and M is the equivalent mass of the particle or object responsible for the local curvature of space–time and determining the gravitational radius $r_s = 2GM/c^2$.

If a one-dimensional formulation with a wave function $\Psi(x)$ is considered for convenience, then instead of the radial coordinate r , the linear coordinate x, y, z is used. In this approximation, the energy density is expressed as (Eq.15).

$$\rho(x) = |\Psi(x)|^2 = A^2 \cos^2(kx) \exp\left(-\frac{x^2 + y^2 + z^2}{\Sigma^2}\right) \quad (15)$$

where the cosine modulation is chosen along the x -axis. Here, the localized mutual influence of the space–time geometry and the energy density associated with the Schwarzschild mass becomes apparent. In other words, the Schwarzschild metric can be interpreted not only as describing a gravitational field,

but also as being consistent with the wave nature of energy density and, consequently, of matter and particles. The particle mass is identified with the integral of the energy density, where the mass density is given by (Eq.16):

$$M = \int |\Psi(r)|^2 dV = A^2 \int \cos^2(kx) \exp\left(-\frac{x^2 + y^2 + z^2}{\Sigma^2}\right) dx dy dz \quad (16)$$

For the chosen functional form (cosine modulation along x and a spherical Gaussian), the integral can be evaluated analytically,

$$\begin{aligned} & \iiint_{-\infty}^{\infty} \cos^2(kx) \exp\left(-\frac{x^2 + y^2 + z^2}{\Sigma^2}\right) dx dy dz \\ &= \frac{\pi^{3/2} \Sigma^3}{2} (1 + e^{-(k\Sigma)^2}) \end{aligned}$$

and after integration the equivalent proton mass is obtained (Eq.17):

$$M = A^2 \frac{\pi^{3/2} \Sigma^3}{2} (1 + e^{-(k\Sigma)^2}) \quad (17)$$

At this stage, the physical meaning and quantitative value of the normalization constant A must be specified. For this purpose, the localized energy-density distribution $\rho(r)$ of the modeled proton is plotted graphically (Fig.3). It takes the form of a Gaussian-modulated wave function, in which standing waves are confined within a Gaussian envelope of radius Σ (Eq.18):

$$\rho(r) \propto |\Psi(r)|^2 = A^2 \cos^2(k_0 r) \exp\left(-\frac{r^2}{\Sigma^2}\right) \quad (18)$$

This equation describes the spatial distribution of a standing wave confined inside a Gaussian envelope. In the Gaussian-modulated wave function, the standing waves form the internal structure, while the Gaussian envelope limits their spatial extent.

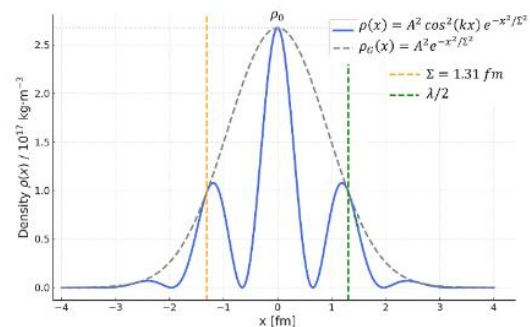


Figure 3 Proton density profile: Gaussian vs. cosine-modulated.

The figure shows how the cosine modulation forms standing-wave nodes inside the Gaussian “shell”, producing a structure with a maximum density at the center and side peaks. For parameters $\Sigma = 1.31\text{fm}$ and $\lambda/2 = 1.31\text{ fm}$ (the Compton

wavelength of the proton), the peak density corresponds to the nuclear matter density. This establishes the physical meaning of the normalization constant A as the parameter that sets the maximum mass density at the center of the wave packet. The numerical value of this density, $\rho_0 \approx 2.5 \times 10^{17} \text{ kg/m}^3$, corresponds to the typical density of nuclear matter, which is nearly universal for all atomic nuclei and equals the ratio of their mass to volume.

Thus, the wave model with a Gaussian envelope and cosine modulation is not only formally normalized to the proton mass, but also reproduces the correct physical nuclear density, as if the proton were indeed a “localized packet” of nuclear matter. With the introduction of the parameter A^2 , the numerical evaluation of the integral mass in Eq.17 yields the true proton mass. As a result, $\rho(r)$ describes a spherical standing wave, determined by k_0 , inside a Gaussian envelope of width Σ , which defines the boundaries of the proton as a localized real particle.

Here, the cosine modulation $\cos(k_0 r)$ endows the proton with a “granular” internal structure, similar to standing waves in a localized volume (Fig.4).

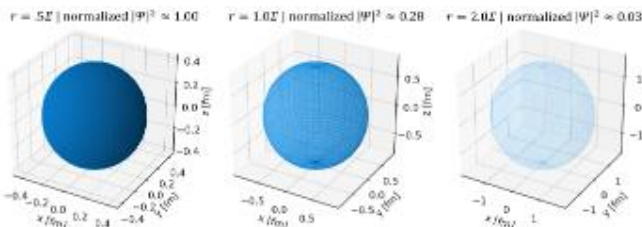


Figure 4. Proton as a Gaussian soliton with cosine modulation: 3D visualization of spherical shells of a Gaussian soliton (proton) at fixed radius r .

The opacity of the shells is proportional to the normalized density $\rho(r)$. The inner shells (e.g., $r < \Sigma$) appear denser, whereas the outer shells ($r > \Sigma$) are more transparent, reflecting the decrease of mass density with distance. Thus, the connection between the Schwarzschild metric and the Gaussian soliton makes it possible to interpret the proton, and probably some other particles, as a fundamental wave object unifying the geometric description of gravity with the energy density of space–time. However, the Gaussian-modulated wave function by itself does not ensure the stability of the soliton. The Gaussian envelope $\exp(-r^2/\Sigma^2)$ reflects the spatial localization of the soliton, while the cosine modulation $\cos(kr)$ introduces an internal oscillatory structure with nodes and antinodes. This nodal structure can be represented as the product of a pure Gaussian wave packet and a cosine factor: $\psi(r) = Ae^{-r^2/\Sigma^2} \cos(kr)$.

The nodes correspond to alternating sign regions that generate strong gradients of phase and density. As a consequence, the associated probability current j drives mass–energy outward, effectively leading to its delocalization.

The quantum Schrödinger equation allows for forced localization of mass–energy through a bosonic self-interaction term $g|\Psi|^2$, where the nonlinear coupling constant is $g = 4\pi\hbar^2 a_s/m$, with a_s being the s -wave scattering length and m the boson mass. However, even for optimized values of the nonlinear interaction strength g , the nodal configuration

enhances instability and leads to the spreading of the soliton, as shown in Fig.5.

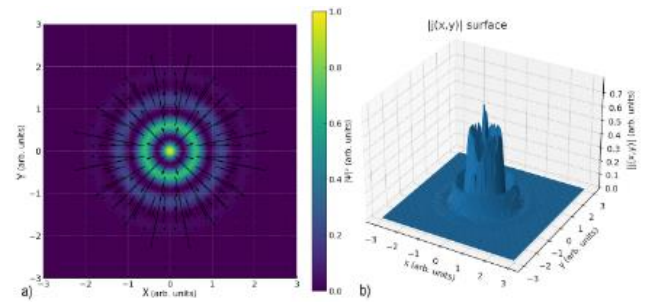


Figure 5. (a) Gaussian–cosine density with radial phase: the nodal structure enhances the outward “pumping” of mass, and the wave packet spreads. Heat map: density distribution; arrows indicate the probability current j . (b) 3D surface of the modulus $|\Psi|$.

Thus, cosine-modulated nodal states of the wave packet amplify the leakage of mass and energy, generating instability. In contrast, a purely Gaussian profile provides a smooth, monotonically decreasing density distribution. In this case, the nonlinear self-interaction term in the basic equation acts as a focusing contribution that compensates the linear dispersion. As a result, the energy density ρ remains localized and self-consistently enhances the confinement against dispersion, leading to a stable soliton-like wave state.

To estimate the density of such energy which is clearly insufficient by itself to counteract the pressure generated by the Gaussian $\times$ cosine nodal structure the hydrodynamic form of the nonlinear Schrödinger equation, introduced by Erwin Madelung (1927), is employed (Madelung, 1927).

In the Madelung representation of the nonlinear Schrödinger equation, two scalar pressure contributions appear. The gradient term gives rise to the so-called quantum pressure. Starting from the Bohm (1952) quantum potential Q , which acts as a force per unit mass, it can be rewritten as the gradient of an effective pressure per unit density. The characteristic pressure scale is determined by the localization length Σ . For a Gaussian profile $\rho(r) \propto e^{-r^2/\Sigma^2}$, the Bohm quantum potential at the center is $Q(0) \sim 3\hbar^2/(2m\Sigma^2)$. The corresponding characteristic energy density (or pressure) is obtained by dividing by the characteristic localization volume $\sim \Sigma^3$ (Eq.19).

$$E_{Gauss(0)} = \frac{3\hbar^2}{2m\Sigma^5} \quad (19)$$

For a Gaussian soliton localized in space with a profile width Σ equal to the proton charge radius ($\approx 0.84 \text{ fm}$), the numerical value of the energy density is $\rho_E \approx 2.38 \times 10^{34} \text{ J/m}^3$.

This value is obtained directly from the three-dimensional Madelung–Bohm formalism without any phenomenological reduction of numerical coefficients. Thus, Eq.19 provides a strictly derived three-dimensional quantum energy-density scale associated with the Gaussian localization length Σ .

The cosine modulation in Eq.18 adds an additional oscillatory contribution to the Bohm potential and to the probability current, which enhances the outward flux and destabilizes the soliton; in contrast, the Gaussian result in Eq.19 represents the

fundamental lower scale set purely by spatial localization of the wave packet.

This result is fully consistent with the geometric mass relation derived earlier (Eq.12), in which the proton mass is expressed with high accuracy through the geometry of space–time, the Compton wavelength, and the fundamental pressure.

This demonstrates that the proton mass arises as a structural effect reflecting a balance between gravity, energy, and the geometry of space–time, while the proton itself may be interpreted as a localized Compton wave. At the same time, Eq.19 provides the local quantum energy density of the proton arising from three-dimensional Gaussian localization (Balbus & Hawley, 1991).

The fact that both Eq.12 and Eq.19 independently describe the proton energy scale at the same geometric radius $R = \Sigma = 0.84$ fm indicates that the geometric and quantum-hydrodynamic descriptions are mutually consistent. This matching strongly suggests that the proton mass and its internal energy density are jointly fixed by the geometry of space–time and by the fundamental pressure, rather than being independent empirical inputs. The quantum energy density associated with the Gaussian localization length Σ generates a centripetal

(focusing) Bohm force directed toward the center of the wave packet. This force counteracts linear dispersion and provides the fundamental stabilizing mechanism of Gaussian self-localization. In contrast, the additional cosine modulation introduces nodal regions with strong phase gradients, which generate local centrifugal (defocusing) probability currents and thus promote delocalization. Therefore, the Gaussian envelope is responsible for centripetal confinement, while the nodal modulation produces the destabilizing centrifugal contribution. The numerical value of ρ obtained in Eq.19 at $\Sigma = 0.84$ fm is independently confirmed by the physical calculation of the proton energy density (Eq.20),

$$U_P = \frac{3hc}{8\pi^2 R^4} \quad (20)$$

where R is the curvature radius of space-time cells or the intrinsic particle radius. This energy density differs from the fundamental pressure in that it has a local character and depends on the curvature of space–time produced by different particles and objects (Tab.2).

Table 2. Dependence of particle energy parameters on the structure of space–time. Here U_P is the energy density calculated using Eq.20, and N is the number of space–time cells within the particle volume.

Name	$R (\lambda_c/2\pi)$, m	U_P , J/m ³	En.charg, eV	En. mass, eV	N of cells
Proton	8.4184×10^{-16}	1.5027×10^{34}	1 710 481	234 397 742	5 244
Proton	2.1031×10^{-16}	3.8583×10^{36}	6 846 896	938 272 048	81.755
Neutron	2.1002×10^{-16}	3.8795×10^{36}	6 856 335	939 565 532	81.417
Electron	3.8616×10^{-13}	3.39425×10^{23}	3 728.9	510 994	5.061×10^{11}
Electron	2.818×10^{-15}	1.96968×10^{32}	510 994	70 024 746	196 673
Charmonium	4.8456×10^{-18}	1.36902×10^{39}	29 716 538	4.07224×10^9	1
Hydrogen	5.2918×10^{-11}	9.625×10^{14}	27.211	3 728.9	1.302×10^{18}

The numerical value of the Gaussian-soliton energy density exceeds the tabulated proton value by a factor of 3/2. This difference can be attributed to the potential degrees of freedom of the soliton, by analogy with the internal energy of an ideal gas. At the proton Compton radius, the energy density increases by nearly two orders of magnitude and significantly exceeds the tensile internal pressure of the soliton. As a result, the stable proton state is created precisely by the balance between internal oscillations and the external vacuum pressure. The proton does not disperse but remains a *self-confined* object with finite energy and mass. Within this interpretation, the proton represents a standing wave inside a Gaussian envelope stabilized by the pressure of space–time matter. Thus, the proton, as a stable particle, is a geometrically structured soliton whose localized (non-dispersive) configuration preserves its integrity due to a deterministic external space–time potential.

The proposed model of the proton as a Gaussian soliton may contribute to revealing the physical nature of quark confinement. This soliton is modulated by an internal standing wave. The modulation generates nodes and antinodes inside the Gaussian envelope. These localized structures can be genetically associated with quarks. The key point is that the

nodes cannot exist outside the Gaussian envelope: once the soliton is destroyed, the supporting structure disappears and the nodes vanish as well. This provides a natural explanation for quark confinement observed in real collider experiments, where quarks are identified through localized peaks of energy density inside the proton.

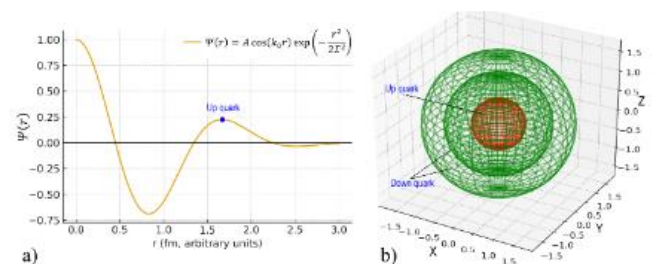


Figure 6. (a) Gaussian soliton with three internal nodes in the quark interpretation; (b) 3D visualization of the proton with quark regions.

When the proton disintegrates, the nodal structure instantaneously disappears, and only hadrons remain as redistributed energy states. Thus, quarks are interpreted not as free fundamental particles, but as manifestations of the internal nodal structure of the proton soliton (Fig.6). In Fig.12(a), the

proton is phenomenologically interpreted as a Gaussian soliton with three internal nodes (quarks). The Gaussian envelope ensures mass confinement, while the cosine modulation generates the nodal structure. On the curve, the nodes correspond to the zeros of the wave function and are responsible for confinement: in these regions the quantum pressure changes sign and a “structural trap” arises in which the excitation is confined. The antinodes (the amplitudes between the nodes) can be interpreted as “localized objects,” i.e., analogs of quarks. In this picture, the proton appears as a soliton in which three internal nodes give rise to three energy localization regions, interpreted as three quarks (two down and one up).

Fig.12(b) shows a three-dimensional visualization of the proton as a Gaussian soliton with internal standing-wave nodes. The wireframes can be interpreted as the boundaries of the antinode and nodal zones in the proton wave function. Each such surface corresponds to a region where the phase changes sign or where the density ρ exhibits sharp oscillations. These are probable “structural layers” inside the proton associated with internal standing oscillations nodal shells of the soliton. Inside these zones, the antinodes of the energy density are concentrated, which are interpreted as probabilistic “quark clouds.” The spherical wireframes reflect the lines of nodal oscillations that physically keep the quarks confined. This visualization explains why quarks occupy different radial levels and cannot leave the proton: confinement occurs because they are retained as nodal structures.

As a result, an effective image of a wire-frame (quark) skeleton of the proton formed by the lines of nodal oscillations of the soliton emerges. The strength of this representation lies in the fact that it demonstrates not only the cause of confinement, but also that quarks constructively form a closed internal framework of the proton. The modeled proton structure is a soliton in which the internal nodal (quark) structure is bound by the force of the local energy density of space–time. In such a construction, there is no need to introduce gluons as independent corpuscular particles. Their role can be interpreted as being played by the local pressure of space–time associated with the curvature of the soliton surface. Reinterpreting gluons in this geometric manner significantly simplifies the conceptual structure of nuclear physics.

If quarks are not real particles but rather manifestations of the internal modes of a soliton-like distribution of energy density, while the role of gluons is performed by the geometry of space–time, the proton may be reconsidered not as a composite particle in the conventional sense, but as a structurally organized mono-object. When irradiated in a collider, the proton receives an external impulse and becomes excited, decomposing into a spectrum of soliton-like waves. These excited modes may appear phenomenologically as a “sea of quarks and gluons,” whereas in this interpretation they represent fragments of the internal wave structure of the proton manifested in an unstable regime.

In quantum chromodynamics (QCD), confinement is understood as a consequence of non-Abelian gauge dynamics. The color field between quarks does not spread out as an inverse-square Coulomb field, but instead forms narrow flux tubes whose energy grows approximately linearly with

separation. As a result, the energy required to isolate a single quark diverges, and only color-neutral bound states (hadrons) are physically observable. In this framework, confinement is a dynamical field-theoretic effect mediated by gluons as independent gauge bosons.

Thus, while QCD explains confinement through the dynamics of interacting gauge fields in an underlying quantum vacuum, the present approach proposes that confinement may also be interpreted as a structural property of a localized wave configuration. The proton is treated as a single coherent Gaussian soliton modulated by an internal standing wave. The nodal structure of this standing wave generates discrete regions of energy localization (antinodes) separated by nodal surfaces where the Bohm quantum pressure changes sign. These nodal surfaces act as geometric confinement boundaries. In this view, quark-like degrees of freedom appear as internal modes of a single soliton and cannot exist outside it, because the nodal pattern itself ceases to exist once the soliton loses its integrity.

Importantly, these two descriptions need not be regarded as mutually exclusive but may be viewed as complementary levels of description. From a hierarchical perspective, QCD may represent an effective field-theoretic description of confinement at the level of interacting currents and gauge symmetries, while the soliton model may describe a deeper geometric layer in which confinement is already encoded in the geometry of localized energy density. In this sense, gluons can be interpreted not as independent fundamental carriers of a separate force, but as effective excitations of the underlying geometric and hydrodynamic degrees of freedom of the soliton-like proton structure.

Another conceptual distinction concerns ontology. In QCD, quarks and gluons are taken as fundamental microscopic entities, even though they are never observed as free asymptotic states. In the present model, quarks are interpreted not as independently existing particles, but as emergent internal modes of a single coherent object. They acquire operational meaning only through their effects on the internal energy-density distribution of the soliton and through their manifestations in high-energy scattering processes.

From this standpoint, the proton is not a composite system in the usual particle sense, but a geometrically structured mono-object whose apparent substructure reflects a standing-wave pattern of localized space–time energy. High-energy collisions do not liberate pre-existing point-like constituents, but rather excite and fragment the internal wave organization of the soliton into unstable modes that are subsequently detected as hadronic jets and resonances.

Conceptually, therefore, QCD and the geometric soliton model represent two complementary layers of description. QCD successfully accounts for the phenomenology of strong interactions in terms of gauge fields and color charges. The soliton approach, on the other hand, suggests that this phenomenology may admit a deeper geometric origin, in which confinement and partonic structure arise from the self-organized localization of energy in space–time itself. In this sense, gauge-field confinement may be understood as an effective manifestation of a more fundamental geometric

confinement encoded in the structure of the proton as a localized standing-wave soliton.

Within the structural-informational model, all fundamental interactions are formulated, at a deeper structural level, in terms of classical mechanics defined on a discretely structured space-time background. On this basis, a conceptual unification of quantum mechanics and general relativity is proposed within the framework of the model. This provides a key argument in favor of revealing the physical nature of gravity, for which both a quantum and a fundamental level are identified, and whose background manifestation is interpreted as being experimentally detectable in the form of low-frequency gravitational waves.

The structure of space-time, together with the transformation of background cells into normal ones and the associated energy density, is proposed to account for the electromagnetic interaction. In this framework, all fundamental interactions are interpreted as manifestations of a single universal principle of a superforce, reflecting the self-consistent dynamics of space-time itself.

The structural correspondence between the low-frequency pulsation of space-time and the observed cosmic microwave background demonstrates that the proposed framework extends beyond laboratory-scale probes and particle-level considerations. The emergence of a cosmological equilibrium scale from the same underlying dynamics indicates that space-time structure, energy, and information are intrinsically linked across all physical scales. This motivates a broader discussion of the role of structure and information in shaping cosmological behavior, which is addressed in the following section.

STRUCTURAL LINK BETWEEN LOW-FREQUENCY SPACE-TIME PULSATION AND THE COSMIC MICROWAVE BACKGROUND RADIATION

Within the structural-informational model, elementary particles are interpreted as stable geometric configurations embedded in a discretely structured space-time. In this framework, the electron represents the minimal self-consistent configuration capable of existing independently of external binding potentials. Its stability arises from a balance between its rest energy and the work performed by the fundamental structural pressure of space-time acting on a curved trajectory.

$$E_{\text{str}} = m_e c^2 - PV$$

where $m_e c^2 = 8.187 \times 10^{-14}$ J is the electron rest energy, P is the fundamental structural pressure of space-time, and V is a characteristic volume determined by the geometry of the electron's closed trajectory $V = \pi r_c^2 2\pi R_B$, where $r_c = 2.818 \times 10^{-15}$ m, R_B is the radius of first Bohr orbit.

This volume is approximated by the product of the classical electron radius, which sets the transverse curvature scale, and an effective curvature radius of the trajectory in space-time. For the electron, the work performed by the vacuum pressure is found to be of the same order as the residual structural energy, indicating a self-consistent energetic configuration and $E_{\text{str}} = 4.223 \times 10^{-14}$ J.

The rest mass of an electron is naturally associated with a characteristic low-frequency modulation of space-time. Using the reduced Planck constant $\hbar$ and fundamental electrodynamic parameters of the vacuum, in particular the vacuum impedance Z_0 , an angular frequency scale can be constructed as

$$\omega = \frac{m_e}{\hbar Z_0^2}$$

which yields a characteristic frequency of 0.0609 Hz. This value lies within about 2 % of the previously identified universal low-frequency background pulsation of space-time (~ 0.06 Hz).

The small deviation may be interpreted as a weak feedback effect: the electron does not generate the background pulsation, but locally polarizes the vacuum structure and slightly modifies the effective frequency of the ambient modulation. Thus, the electron acts as an active structural element embedded in, and responding to, the universal dynamics of space-time.

The connection between the low-frequency pulsation and observable cosmological scales becomes apparent when the structural energy balance is reformulated in terms of discrete space-time cells. The residual structural energy corresponds to the collective contribution of a large number of normal space-time cells participating in the electron's Compton configuration. Estimating this number $N = E_{\text{str}}/\hbar\omega$ yields $\approx 1.05 \times 10^{21}$ cells, whose total volume is fixed by the known cell volume of the normal space-time structure $V_n \approx 4.75 \times 10^{-49}$ m³. When this volume is interpreted as being distributed along an extended wave-like configuration with a transverse scale set by the electron's Compton radius R_C , an effective wavelength of order 10^{-3} m naturally emerges ($\lambda = V_n N / \pi R_C^2$).

This length scale coincides with the millimeter range characteristic of the maximum of the cosmic microwave background (CMB) spectrum. Interpreting the effective wavelength through Wien's displacement law yields a corresponding temperature of approximately 2.72 K, in striking agreement with the observed temperature of the CMB. Importantly, this scale is not introduced ad hoc, but arises within the internal logic of the model as a structural consequence of the electron's mass, the discrete geometry of space-time, and the universal low-frequency pulsation.

A crucial feature of this correspondence is its selectivity. The effective wavelength scales with particle mass through the number of involved space-time cells and the associated geometric parameters. For heavier leptons, such as the muon, the resulting wavelength is shifted far outside the millimeter range, while for hadrons, such as the proton, the characteristic scale corresponds to much higher frequencies.

Consequently, the emergence of a wavelength consistent with the observed CMB temperature is specific to the electron and does not occur for particles of substantially different mass. This selectivity provides a natural criterion of falsifiability for the model.

Within this interpretation, the cosmic microwave background need not be regarded exclusively as a relic of a primordial explosive event. Instead, it may also be interpreted as a structural equilibrium scale of the vacuum, arising from the

self-consistent coupling between the universal low-frequency modulation of space–time, the discrete cellular structure of the vacuum, and the minimal stable particle configuration represented by the electron.

The CMB thus can be viewed as a macroscopic manifestation of the same underlying space–time dynamics that govern microscopic particle stability.

This structural correspondence establishes a direct conceptual bridge between laboratory-scale phenomena, particle physics, and cosmological observations. The low-frequency pulsation of space–time, inferred from pendulum dynamics and particle-scale considerations, is proposed to reproduce one of the most robust observational features of modern cosmology.

In this sense, the cosmic microwave background may be interpreted as an observational imprint of universal space–time dynamics rather than as an independent cosmological input.

STRUCTURE, INFORMATION, AND COSMOLOGY

In structural–informational model, structure determines localization, while information governs the action of matter. The only parameter that defines the local geometry of space–time is the mass M in the Schwarzschild metric, which describes the gravitational field of a spherically symmetric object. This mass is directly related to the Schwarzschild radius through the well-known relation (Eq.21).

$$Rs = \frac{2GM}{c^2} \quad (21)$$

where G is Newton’s gravitational constant and c is the speed of light. This radius characterizes any mass, not only that of a black hole. However, the Schwarzschild radius acquires a special functional meaning if, instead of G , one introduces an alternative gravitational coefficient Γ (Eq.22).

$$\Gamma = \frac{\pi r^2 c^3}{h} \quad (22)$$

where r is the Compton radius of the particle. Unlike Newton’s constant, the coefficient Γ is individual for each particle or object and depends explicitly on its characteristic radius. When the radius equals the Planck length multiplied by $\sqrt{2}$, the coefficient Γ becomes numerically identical to the universal Newtonian constant G . Substituting Γ into Eq.21 leads to remarkable results: for the proton mass, the Schwarzschild radius becomes equal to the proton Compton radius; for the electron mass, it becomes equal to the electron Compton radius. This equivalence implies that the proton, electron, and possibly other corpuscular particles can be formally associated with properties analogous to those of black holes.

Their physical essence may therefore be interpreted as being bounded by effective geometric horizons defined by their observable radii. A hydrogen atom composed of a proton and an electron and, by extension, all atoms with electron shells, may thus be viewed within this framework as structurally bounded informational units.

When such particles combine into more complex structure’s molecules, crystals, or living matter their collective geometric boundary is displaced, while the internal informational

integrity is preserved. Consequently, within this framework, space–time together with elementary particles, macroscopic bodies, and living organisms can be described as forming a unified structural–informational system. The emergent properties of matter within this system arise under the direct structural control of space–time itself. The postulated low-frequency pulsation of the Universe generates a powerful local structural potential that induces a metamorphism of space–time and leads to the formation of a background cellular structure. This potential is associated with the curvature of space–time produced by background gravitational waves arising from the pulsation with wavelength $\lambda = c/\omega$.

The radius of the resulting curvature is inversely proportional to this wavelength and defines the characteristic radius of a background space–time cell (Eq.23).

$$r_b = \sqrt[3]{\frac{3hc}{4\pi\lambda P}} \quad (23)$$

Since this radius is approximately $r_b \approx 1.254 \times 10^{-20}$ m, it generates an extremely high local structural potential $U(r_b) = hc/2\pi r_b \approx 15 - 18.5$ TeV. This energy scale lies well above the electroweak scale and within the characteristic range of many dark-sector models. This fact provides a probable physical basis for interpreting the background cellular structure of space–time as a candidate for dark matter.

In this approach, dark matter is not necessarily required to consist of additional unknown particles, but may be interpreted as a structural form of vacuum energy stored in the stabilized background cells of space–time, which interact gravitationally while remaining electromagnetically inert. This interpretation offers a natural explanation for the non-luminous and non-baryonic character of dark matter, as well as its predominantly gravitational manifestation on galactic and cosmological scales. The fundamental pressure, acting in association with the global pulsation of the Universe, naturally leads to the emergence of Planck-scale quantities (Eq.24).

$$P = \frac{m_P \omega^2}{l_P} \quad (24)$$

where m_P and l_P denote the Planck mass and the Planck length, respectively.

Thus, from the Planck mass, Planck length, and low-frequency background oscillation $\omega (\sim 0.06$ Hz), one obtains a fundamental pressure of approximately 4.8×10^{24} Pa. This pressure can be regarded as defining the energetic scale of the structural background of space–time. It provides the dynamical basis for curvature formation, gravitational interaction, and the stability of localized particle configurations. Within this framework, the fundamental pressure is proposed to underlie the entire spectrum of interactions, from microscopic soliton stabilization to macroscopic gravitational attraction.

The Planck units therefore acquire a structural interpretation: they are not merely dimensional constructs, but may be interpreted as reflecting intrinsic parameters of the discrete space–time background. In this sense, the Planck scale can be

viewed not only as a limit of applicability of classical gravity and quantum field theory, but also as a structural reference scale for the organization of space–time itself. The combination of Planck mass, Planck length, and background-cell geometry thus suggests a unified energetic hierarchy linking particle physics and cosmology.

Treating space–time as organized matter implies that it possesses internal structure, energy density, and intrinsic dynamical degrees of freedom. This conceptual shift makes it possible to describe the coupled evolution of particles and the background medium in the language of phase diagrams.

In contrast to conventional applications of phase space, here the phase portrait characterizes not only material trajectories but the structural state of space–time itself.

In this sense, the global low-frequency modulation (~ 0.06 Hz) may be interpreted as a dynamical trajectory in the phase space of the vacuum structure. For the construction of the phase diagrams, a system of nine equations of classical physics was formulated (Eq.25). These equations, together with the corresponding curve designations, are presented in Fig.7.

$$\left\{ \begin{array}{ll} E_P = PV & (a) \\ E_h = \frac{hc}{2\pi r} & (b) \\ E_L = \frac{4\pi\sigma PV^2}{hc} & (c) \\ E_G = \frac{Mm_e c^4}{4\pi^2 P r^3} & (d) \\ E_Q = \frac{q^2}{r} & (e) \\ E_T = \frac{8\pi r^2 \sigma}{3} & (f) \\ E_A = \frac{2\sigma h^2 c^2}{3\pi P^2 V^2} & (g) \\ E_S = \frac{h^2 c^2 r}{3\pi P V^2} & (h) \\ E_E = \frac{2h P r^2}{3m_e c} & (i) \end{array} \right. \quad (25)$$


Figure 7. System of equations (25), where the colored curves denote the corresponding phases in the phase diagrams shown in Figs. 14–15. The curve labels correspond to the following physical quantities: (25a) energy density; (25b) photon horizon; (25c) Laplace energy; (25d) gravitational energy; (25e) electric charge horizon; (25f) surface energy; (25g) kinetic energy; (25h) Schwarzschild energy; (25i) cyclotron energy.

This system is designed to calculate the energetic equivalent of the local mass of particles and macroscopic objects as a function of the energy density and curvature of space–time. In particular, Equation 25a, where P denotes the fundamental pressure (energy density), determines the energy E as a function of the volume in which an active space–time cell is localized.

Such a cell may be associated with either a particle or a macroscopic object. Equation 25b, where r represents the

radius of space–time curvature or the intrinsic radius of a particle, yields the energy associated with the photon energy scale. In Eqs.25c, 25f, and 25g, a previously unknown quantity σ appears, which is interpreted as the surface tension of space and time.

This conjectured parameter finds a natural interpretation within the hydrodynamic representation of the wave equation developed by Madelung and Bohm. The analogy between electromagnetic waves and hydrodynamics allows one to attribute additional fluid-like properties to space–time. For example, the quasi-spherical electronic shell of the hydrogen atom with the Bohr radius R_B can be regarded as being contracted by the surface tension of space–time.

The surface of the hydrogen atom cannot be regarded as ideally smooth, since the electron, in addition to its orbital motion, follows a wave-like trajectory governed by the fine-structure constant $R_B = \hbar/(am_e c)$. To estimate the surface tension, one may employ the Laplace formula of Pierre–Simon Laplace (1806). With a correction for the fine-structure constant, the surface tension of space–time can be written as $\sigma = PR/2\alpha$.

If the Laplace pressure is taken equal to the fundamental pressure, and the hydrogen atom with radius $R = R_B$ is used as a reference scale for estimating the surface tension of space–time, then this surface tension will be equal to $\sigma = 1.73279 \times 10^{16}$ N/m. The validity of this value can be tested using the classical electron radius R_c , assuming it to depend on the Laplace pressure.

Then the intrinsic surface energy of the electron in the plane of the fundamental pressure is $E_\sigma = 2\sigma 4\pi R_c^2/3$, which numerically yields $E_\sigma \approx 7.19$ MeV. This value — that is, the “surface” energy at the scale $R_c \in R_B R_c^2/\alpha = \bar{\lambda}_c^3$, where λ_c being the reduced Compton wavelength of the electron numerically coincides with the volumetric work of the fundamental pressure $E_\sigma = P 4\pi \bar{\lambda}_c^3/3$. In terms of the traditional fundamental constants, this energy takes the form (Eq.26):

$$E_\sigma = \frac{m_e c^2 \bar{\lambda}_c^3}{4\pi \epsilon_0 (2\pi R_B)^3} = \frac{m_e c^2 \alpha^3}{32\pi^4 \epsilon_0} \quad (26)$$

The described energy level (~ 7.2 MeV) corresponds to ultra-relativistic electrons, which are formed in the outer radiation belt of the Earth during periods of enhanced geocosmic activity. Their acceleration occurs locally in the magnetosphere due to resonant interaction with plasma waves (chorus, hiss, etc.) excited by disturbances of the solar wind (Hajra et al., 2024).

These observations indicate that, in the terrestrial environment, the energy level of approximately 7 MeV acts as a characteristic upper limit or barrier for the penetration and acceleration of electrons. This value may therefore reflect a property of the medium itself rather than an intrinsic fundamental constant of the electron.

Within the framework of the structural–informational model, this level can be interpreted as being controlled by an effective “surface tension” of space–time.

Verification of this hypothesis requires comparative analyses in other planetary magnetospheres; however, no systematic

studies in this specific context have yet been reported. Nevertheless, the proposed value of the surface tension parameter is incorporated into the calculations and demonstrates internal consistency with the fundamental quantities represented on the phase diagrams.

In the system of equations (25), Eq.(25d) describes the gravitational interaction energy of the electron with a local mass. In this formulation, the energy is calculated not using the Newtonian gravitational constant but the gravitational coefficient introduced in Eq.(22). Equation (25e) represents the analogue of Eq.(25b) expressed in the CGS system. Equation (25h) corresponds to the mass–energy induced by the influence of the medium in a Schwarzschild-type metric. Equation (25i) describes the energy associated with the quantum of action, where the relevant ratio $f_c = Pr^2/m_e c = E/\hbar$ is interpreted as the cyclotron frequency.

As a whole, the system of equations provides a framework for investigating the structure of space–time and its interaction with particles and macroscopic objects in terms of phase diagrams. The principal feature of this approach is that the physical system is treated as inseparable from the matter of space–time itself.

Space–time is regarded as the embedding medium for particles and objects, which controls their physical and chemical properties. This corresponds to a form of structural control in which the geometry and energy density of space–time act as governing parameters.

The space–time medium possesses its own intrinsic structure, which is transformed upon the incorporation of particles and objects. This is represented graphically by two phase diagrams: one shows the intrinsic structure of space–time, and the other shows the structure containing a proton. The phase diagrams are shown in the original form generated by the computational program.

On these graphs, the X-axis corresponds to the radius of space–time curvature, while the Y-axis represents energy in eV on a logarithmic scale. Fig.8 displays the intrinsic structure of space–time in the absence of particles and objects.

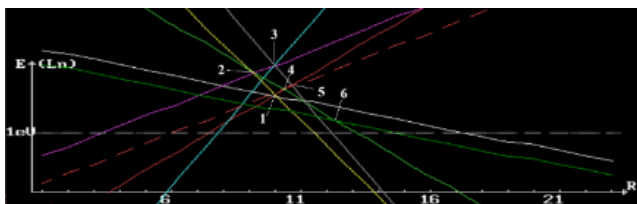


Figure 8. Phase diagram of the structure of space–time. R is the radius of curvature. E is the energy level on a logarithmic scale. The horizontal dashed line marks the level of 1 eV. The numbered arrows indicate the nodes of intersection of different phases.

The diagram shows several phase lines (color-coded in Fig.7), whose most significant intersections are marked by numbers. Intersection 1 occurs at a curvature radius of approximately $R \approx 2 \times 10^{-13}$ m and at a potential energy level of approximately $E \approx 990$ keV.

This value is nearly twice the rest-energy equivalent of the electron mass, suggesting that a normal space–time cell may provide a structural condition compatible with electron

stability. At Intersection 2, the gravitational, surface, and Schwarzschild energy lines intersect.

The curvature radius at this point is $R = 2.77 \times 10^{-14}$ m, while the potential energy level is $E = 19.2$ GeV. According to the literature, this energy range is frequently employed in nuclear physics experiments for proton scattering. The nature of the intersecting phase lines suggests the possibility of a structural phase transition at this point. Intersection 3 corresponds to a potential energy level of $E = 36$ GeV. Thus, the structure of space–time appears to establish a sufficiently high potential barrier for the stable existence of particles and objects under normal conditions.

The remaining two nodes of the phase diagram may indicate further modes of structural control exerted by space–time over particles. At Intersection 4, the curvature radius is exactly equal to the reduced Compton wavelength of the electron, while the corresponding energy level $E = 7.189$ MeV matches the energy scale of the alpha particle. Intersection 5 appears on all phase diagrams independently of the curvature radius at an energy level of $E = 32.8$ MeV. In nuclear physics, this value corresponds to the symmetry energy of nuclear matter, which characterizes the equilibrium of nuclear systems.

This value serves as a reference scale, determined from a wide range of theoretical calculations and experimental studies of nuclear structure. Revealing a possible connection between the symmetry energy and the structure of space–time may provide new insights into both evolution and the physical properties of matter. Finally, at Intersection 6 (with a correction factor involving π), the curvature radius is equal to the radius of the electron orbit in the first Bohr orbit, while the corresponding energy level equals the Hartree energy. This result indicates a structural compatibility between the hydrogen atom and the cellular organization of space–time.

The incorporation of a proton locally modifies both the energy density and the structure of space–time. Space–time responds to the size (radius) of embedded objects through variations in its geometry and energy density.

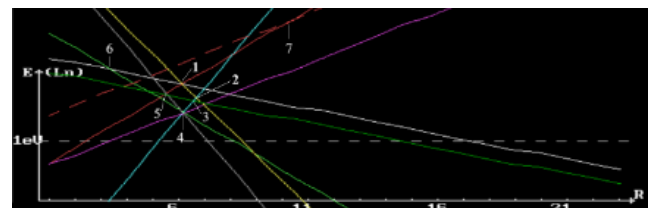


Figure 9. Phase diagram of the structure of space–time containing a proton.

Owing to its Compton radius, the proton is localized by the space–time medium by a pressure of the order of $P \approx 3.858 \times 10^{36}$ J/m³ (Tab.2). The phase diagram shown in Fig.9 is constructed by incorporating this pressure into the system of equations.

The fundamental node of the diagram associated with the proton mass corresponds to the intersection of the energy–density and Schwarzschild lines (Node 1), linked to the photon horizon. At this point, the energy level is $E = 938$ MeV, and the curvature radius is $R \approx 0.21$ fm.

At Node 2, corresponding to the intersection of the Laplace and Schwarzschild lines, the energy level is $E \approx 9.7$ MeV at a curvature radius $R \approx 0.525$ fm. The energy $E \approx 9.7$ MeV is well known in nuclear physics, where it is widely used in accelerators for the high-precision study of proton, neutron, and Compton scattering.

At this energy, a pure elastic-scattering regime with dominant S-waves is achieved. Such a regime is known to be particularly sensitive to the parameters of nuclear interactions. It can be shown that the radius $R \approx 0.525$ fm is consistent with the criterion for the formation of a “pure” S-wave regime. The general criterion for a pure S-wave regime is the condition $kR \ll 1$, under which the contribution of P-waves becomes negligible. In low-energy pp - scattering on a fixed target, the smallness parameter of partial waves is given by

$$kR = \frac{R}{\hbar c} \sqrt{2\mu c^2 T_{lab}}$$

where R is the effective thickness of the proton interaction “surface layer”, which in the present structural–informational model is identified with the local radius of curvature of space–time at the proton phase boundary (Fig.15, Node 2), $\mu \approx m_p/2$ is the reduced mass of the proton system, and T_{lab} is the kinetic energy of the incident particle measured in the laboratory frame.

The general criterion for the dominance of the pure S-wave regime is $kR \ll 1$, under which the contributions of P- and D-waves are strongly suppressed. For the phase-diagram values $R \approx 0.525$ fm, $T_{lab} \approx 9.7$ MeV, one obtains $kR \approx 0.18$, which corresponds to the commonly adopted threshold for S-wave dominance in nuclear scattering experiments.

In this expression, the characteristic energy scale $\hbar c/R$ represents the quantum–geometric energy of localization at the proton boundary and, within the present model, is interpreted as the energy associated with the photon horizon (Eq.25b, Fig.7). Thus, the S-wave scattering regime of protons appears to be closely related to the local geometric and energetic structure of space–time.

The energy level $E \approx 9.7$ MeV is numerically close to the commonly quoted upper bound for down-quark current masses. In this connection, a genetic relation between the phase-diagram nodes and the soliton structure of the proton becomes plausible. This refers to the possible existence of eutectic points of the up- and down-quark states on the phase diagram. Within the present phase-diagram representation, the up quark may be associated with Node 3, where the Laplace and electric-charge horizon lines intersect.

At this point, the energy level is $E = 3.285$ MeV, which is close to its commonly accepted upper bound (the bare mass of the up quark is not precisely defined and is usually quoted in the range 1.8–3.0 MeV). On the phase diagram, the up-quark node lies on the electric-charge horizon, which corresponds to its positive charge (+2/3).

This representation suggests that quarks, within the present structural–informational framework, can be interpreted not merely as point-like entities but as manifestations of specific structural domains in the phase space of space–time. Such interpretation is consistent with the previously stated

hypothesis of a geometric component in the mechanism of confinement. The geometric unity of the phase space may therefore play a fundamental role in the emergence of quark confinement.

Within the structural–informational framework, quark masses may be associated with discrete energy nodes of the space–time phase structure, while color confinement may be interpreted as arising from the topological closure of the proton phase domain. Gluons acquire, in this representation, the physical meaning of carriers of curvature and energy-density gradients of the background cellular medium.

The QCD string tension can be viewed as a projection of the fundamental surface tension of space–time onto color degrees of freedom. Asymptotic freedom may reflect the weakening of geometric gradients at small curvature scales, whereas confinement corresponds to their growth near the phase boundary of the proton soliton.

Thus, within the present model, QCD may be regarded as an effective gauge-field description of an underlying structural–informational dynamics of space–time. The confinement of quarks, the generation of effective quark masses, the formation of gluon flux tubes, and the asymptotic freedom regime all emerge here as secondary manifestations of the geometric and energetic phase structure of the proton embedded in the cellular medium of space–time. This establishes a direct conceptual bridge between quantum chromodynamics and the structural–informational model, within which the following structural correspondences are proposed:

- QCD color charge corresponds to geometric phase labeling of space–time cells,
- gluons correspond to curvature–energy density carriers,
- quark confinement corresponds to the topological closure of the proton phase domain,
- and hadronization corresponds to the restructuring of the phase domain under critical curvature gradients.

Node 4, where the Laplace, surface-energy, and kinetic-energy lines intersect, represents the opposite pole of the base Node 1 on the phase diagram. In the vicinity of this intersection, the gravitational line passes and intersects the surface-energy line at an energy level of approximately $E \approx 45$ keV. At the polar point of the phase diagram, the energy level is $E \approx 40$ keV. According to the literature, this energy range is also widely used in various experimental applications. It is identified as the Coulomb (lepton–nucleus) scale, which arises in the electric field near the nuclei of atoms with a medium and higher number of electrons.

The electrons of the inner atomic shells are bound to the proton by an electric field that can be accurately calculated within the framework of quantum electrodynamics (Morgner et al., 2023).

For the K-shell, this field reaches extremely high values exceeding $E > 10^{13}$ Vm⁻¹, which, when expressed as an equivalent energy density, exceeds the fundamental pressure by approximately two orders of magnitude. The phase diagram (Fig.15) demonstrates that, for a proton embedded into the structure of space–time, conditions for atomic formation naturally arise.

The subsequent Node 5 on the diagram coincides with the energy level of nuclear-matter symmetry within the structure of space–time (32.8 MeV). The smallest curvature radius on the diagram, $R=1.598668 \times 10^{-18}$ m, corresponds to the intersection of the gravitational line and the photon-horizon line (Node 6). This radius is numerically close to the reduced Compton wavelength of the Higgs boson and is associated with a nearby energy level which, according to Eq.25d, is $E \approx 123.43$ GeV, at the energy density $U_p = 3.858 \times 10^{36}$ J/m³ (Tab.2). Since the Higgs boson is experimentally observed in proton–proton collisions, the proximity of Node 6 to the gravitational line may indicate a nontrivial geometric contribution within the present framework. The physical nature of the Higgs boson has not yet been fully clarified; here a geometric interpretation is proposed, which is consistent with its experimentally measured mass.

Within this interpretation, the Higgs-boson production process may be schematically represented as $p + p \rightarrow H + g$, where g denotes a ‘gluon’. It follows that the Higgs boson may be viewed as a resonant response of the space–time medium to high-energy proton–proton collisions, during which the local curvature and energy density are significantly modified.

This process is interpreted as a local geometric deformation of the background space–time cells, while the two proton “support cells” provide the missing contribution to the resonance mass, $\Delta m \approx 1.8765$ GeV. As a result, the total mass reaches the observed value $m \approx 125.2$ GeV. Thus, within the structural–informational framework, the Higgs boson may be interpreted as a resonant geometric state of space–time cells excited during proton–proton collisions, complementing the conventional scalar-field description with a geometric–energetic perspective.

The description of the phase diagram in Fig.9 is completed by Node 7, where the energy-density line intersects the cyclotron-frequency line. The curvature radius at this point is equal to the reduced Compton wavelength of the electron, while the corresponding energy level reaches an extremely high value, $E \approx 5.8 \times 10^{18}$ eV.

This energy may be interpreted as a structural limit for the geometric stability of the proton phase embedded in the vacuum medium. The phase boundary identified in this way for the proton may indicate a possible structural connection between space–time and ultra-high-energy cosmic rays (UHECRs). In nature, energies of this order ($\geq 10^{18}$ eV) are characteristic of the luminosity of UHECR (Lemoine, 2013). The physical origin of this phenomenon remains an open problem in modern astrophysics, as there is still no universally accepted model for the specific acceleration sources of protons and the radiation-formation mechanism.

The phase diagram shows that the energy density of space–time increases approximately in proportion to the radius of curvature.

For the proton, the minimum of this energy density $U_p \approx 3.9 \times 10^{36}$ Jm^{−3} is located at Node 1 on the photon-horizon line. The cyclotron-frequency line also increases with increasing radius but with a less steep slope.

At Node 7, the cyclotron frequency of the space–time structure (the internal frequency of the phase/geometric regime) appearing in Eq.25i is described by the relation $f_{int} =$

$2U_p r^2 / 3m_e c$ which indicates that the elasticity scale of the medium is set by the electron, with the reduced Compton radius $r = \lambda_{c,e} / 2\pi$. This elasticity ensures the stability of the proton mass–energy through oscillatory support. A probable astrophysical source of ultra-high-energy cosmic rays is neutron stars, which typically possess extremely strong magnetic fields (magnetars and pulsars).

Protons in these stars are produced through neutron decay and are subsequently exposed to magnetic induction of order $B \sim 10^{11}$ T. The levels of magnetic pressure in magnetar fields are approximately of the same order as the energy density of space–time for the proton, but are lower than it. Within the present geometric–phase framework, such pressure gradients may be interpreted as contributing to the acceleration and expulsion of protons beyond the stellar surface.

This process is further facilitated by the fact that the energy density of the proton is lower than that of the neutron (Tab.2). From the viewpoint of classical electromagnetism, this dynamic is interpreted as the inductive acceleration of protons by the magnetic field of a neutron star under the action of the Lorentz force. In the geometric–phase description, electromagnetic acceleration is interpreted as emerging from the underlying space–time relations of the proton. In a magnetic field, together with the magnetic induction B , the proton acquires an intrinsic gyromagnetic (cyclotron) frequency $f_c = eB/m_p$, or, in the relativistic limit, $f_c(\gamma) = eB/\gamma m_p$, where γ is the Lorentz factor.

This frequency, and correspondingly the proton energy, is approximately 14 orders of magnitude lower than the phase frequency of space–time at Node 7, (f_{int}/f_c) .

If the internal phase frequency of space–time acts as a carrier, then the proton cyclotron frequency can be regarded as a modulator which, through phase locking, extracts a constant power component from the carrier, producing a secular growth of proton energy. Resonant acceleration may occur when the internal phase frequency of the medium, multiplied by an integer factor n , coincides with the proton cyclotron frequency: $f_{int}/n \approx f_c$. Here n is a discrete modal (topological) index that specifies the harmonic order of the frequency matching and tends toward its minimum value ($n \approx 1 - 10$).

As a result, the carrier frequency f_{int} becomes synchronized with the modulator f_c through an integer resonance order n , and an efficient energy pumping into the proton is switched on. A rotating magnetar acting as a unipolar inductor, according to the model of Peter Goldreich and William Julian (Goldreich & Julian, 1969), generates induction electric fields along open magnetic field lines, creating enormous potentials at the polar caps and surrounding the star with plasma co-rotating with it. Due to this rotation, the star forms an electric field with potential Φ , which is associated with particle acceleration (Eq.27):

$$\Phi \approx \frac{\Omega^2 B R^3}{2c} \approx 6.6e^{12} B_{12} P_s^{-2} \quad (27)$$

where Ω is the angular velocity of rotation of the star, R is the neutron-star radius (≈ 12 km), B is the magnetic induction, $B_{12} \equiv B/(10^{12} \text{ Gauss})$, P is the rotation period in seconds.

In a magnetic field, a longitudinal electric field $E_{\parallel}$ is required to increase the kinetic energy of a charged particle. The rotational energy of the magnetar is transported by this field and then transferred to the particles, which acquire a radial velocity component along the magnetic field lines. Consequently, it is not the mechanical rotation of the magnetar itself that directly supplies energy to the particles, but rather the electric field $E_{\parallel}$ that performs the work.

For newborn millisecond magnetars and pulsars, the estimated total potential drop along open magnetic-field lines reach $\Delta\Phi \sim 10^{20} - 10^{21}$ V, so that a single pass along such a line is sufficient for a charged particle (a proton) to acquire a kinetic energy of the order of 10^{20} eV.

This represents a classical self-acceleration channel, in the sense that the medium accompanying the compact star itself creates the conditions required for the formation of ultra-high-energy cosmic rays (UHECR). A quantitative estimate of the longitudinal electric field in the region of the light cylinder, whose radius is $R_L = c/\Omega \approx 4.77e^4$ m, for a stellar rotation period $P = 1$ ms, gives $E_{\parallel} \sim \Delta\Phi_{pc}/R_L \approx 1.38e^{17}$ Vm $^{-1}$.

The energy of UHECR has an upper limit at which the energy gain from the longitudinal electric field $E_{\parallel}$ is exactly compensated by the losses due to curvature radiation (also known as Joseph–Larmor radiation) P_{curv} during motion along curved magnetic-field lines of radius ρ . The radiated power is described by the author's Eq.28:

$$P_{curv} = \frac{2}{3} \frac{Z^2 e^2 c \gamma^4}{4\pi\epsilon_0 \rho^2} \quad (28)$$

where γ is the Lorentz factor and Z is the charge number of the particle. Above the limiting value γ_{max} , further acceleration becomes impossible, since the energy supplied by the field is instantaneously converted into radiation. The Lorentz factor of a UHECR proton is given by $\gamma = E_R/(m_p c^2)$.

There exist two independent estimates of the maximum Lorentz factor γ_{max} :

one based on the energy gain from the longitudinal electric field $E_{\parallel}$, and the other based on its relation to the critical (Schwinger) field $E_S = \frac{m_e^2 c^3}{e\hbar} \approx 1.3234e^{18}$ Vm $^{-1}$. If γ_{max} is determined with the required accuracy from the observed UHECR energy scale $E_R \sim 10^{20}$ eV, which corresponds to $\gamma_{max} \approx 10^{11+0.2}$ for protons, then the only remaining unknown parameter in the radiation–acceleration balance is the trajectory curvature radius ρ_c entering the author's Eq.29.

$$\rho_c = \gamma_{max}^2 \sqrt{\frac{e}{6\pi\epsilon_0 E_{\parallel}}} = \bar{\lambda}_C \gamma_{max}^2 \sqrt{\frac{2\alpha E_S}{3E_{\parallel}}} \quad (29)$$

where $\bar{\lambda}_C$ is the reduced Compton wavelength of the electron, α is the fine-structure constant, and E_S is the Julian–Schwinger critical field.

By estimating $\gamma_{max} \sim 10^{11+0.2}$, one assumes that the calculated energy represents the upper limit for protons, while the rare sporadic cosmic rays with even higher energies are attributed to heavy nuclei, such as iron.

The obtained curvature radius coincides, within rounding accuracy, with the amplitude of the postulated background gravitational waves of space–time.

For the corresponding wavelength $\lambda = 2\pi\rho_c$ and the speed of light, this yields a frequency $f \approx 0.06$ Hz. This result suggests that the structure of space–time may participate in the formation and long-distance transport of UHECR. The curvature radius of proton trajectories resonantly matched to the amplitude of a background gravitational mode in this process.

This postulate provides a new perspective on one of the central theoretical problems of cosmic-ray astrophysics the interaction of UHECR with the cosmic microwave background (CMB). The classical calculations of Kenneth Greisen, Georgiy Zatsepin, and Vadim Kuz'min (the GZK effect) show that protons with energies above $\sim 5 \times 10^{19}$ eV rapidly lose energy through photo-pion production on the CMB over distances of $\sim 50 - 100$ Mpc (Greisen, 1966), while below this threshold Bethe–Heitler $e^{\pm}$ pair production causes gradual losses (Bethe & Heitler, 1934).

Within the present phase-gated transport model, the interaction cross sections are not modified. Instead, a weak but recurrent phase-synchronized energy replenishment is postulated, acting in small packets at each step of length ρ_c , synchronized with a background space–time wave of frequency $f \approx 0.06$ Hz.

Such a phase-locked transport mechanism is hypothesized to partially compensate, on average, radiative and photonic losses over large cosmological distances. As a result, the proposed mechanism may extend the admissible search range for extragalactic UHECR sources beyond the conventional megaparsec limitations.

The criterion of Michael Hillas (Hillas, 1984) makes it possible to estimate the distance from the observer to the radiation source. For this purpose, it is necessary to know the magnetic field strength B in which the accelerating particle moves.

Then the distance r_L traveled by the particle must correspond to the size of the acceleration region containing this magnetic field $r_L \sim E_{max}/(2cZeB)$, where E_{max} is the maximum energy acquired by a particle, or by an UHECR. In principle, space–time itself may possess an intrinsic constant magnetic field associated with its structure and energy density, in particular with the fundamental pressure (Eq.30).

$$B = \frac{P_4 \pi R_b^2}{3ec} \quad (30)$$

For the radius of the background space–time cells ($R_b = 1.254 \times 10^{-20}$ m), the magnetic field strength of this field is $B \approx 6.556 \times 10^{-5}$ T. At present, this field may be regarded only as a natural magnetic scale of the space–time cell model. Phenomenologically, it should be noted that this value lies near the upper limit of the typical range of the Earth's magnetic field at its surface.

On the surfaces of the Moon, Mars, and Venus the magnetic field strength is significantly lower, which may be explained by the absence of an active core. If one assumes that the field B (Eq.30) has a universal character, then for $E_R \sim 10^{20}$ eV it can provide a curvature radius $r_L =$

$E_R/(eBc) \approx 0.165$ pc. Cosmological estimates place the upper limit of extragalactic magnetic fields at no more than a few nanogauss ($\sim 10^{-13}$ T) (Planck Collaboration, 2015).

In such a weak field, the acceleration of a proton to UHECR energies must occur along trajectories with extremely large curvature radii practically along straight lines (Fig.10).

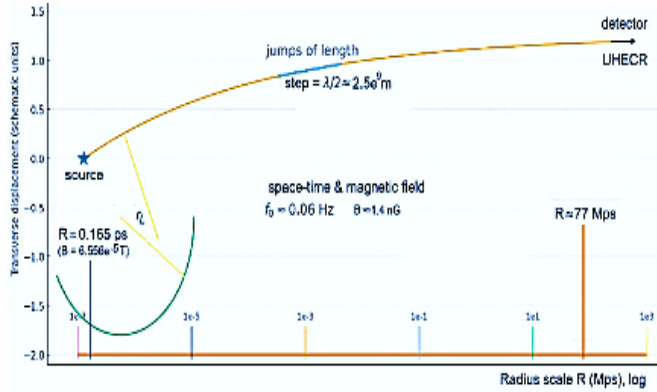


Figure 10. Phase-gated transport of UHECR along a curved field line; $\lambda/2$ denotes the step length (blue segments), r_L is the local radius of curvature, and R is the macroscopic trajectory radius (Hillas scale).

For example, if we consider the Great Attractor, in the region of which active galactic nuclei with jets are located, the curvature radius of the outgoing cosmic-ray trajectories may be taken equal to the distance to this object ($r_L \approx 77$ Mpc or 2.376×10^{24} m). According to the GZK limit, UHECR energy at such a distance through the intergalactic medium should be lost.

On average, per 1 pc the losses amount to approximately 1.3×10^{12} eV/pc, inferred from the ratio of 10^{20} eV to the total distance. According to the postulate proposed here, these losses must be fully compensated by the background space-time waves. For this purpose, the background longitudinal wave ($\lambda \approx 5.03 \times 10^9$ m, $f_0 \approx 0.06$ Hz) provides a discrete transport channel with periodic replenishment of UHECR energy through small but regular energy portions ΔE .

The replenishment step is equal to half the wavelength ($\lambda/2 \approx 2.5 \times 10^9$ m), and the energy increment ΔE (based on the energy loss per 1 pc and the number of half-waves $q = 1\text{pc}/(\lambda/2)$ at each step) should be approximately $\Delta E \approx 105$ keV. Thus, the energy along the path is $\varepsilon \approx 4.2 \times 10^{-5}$ eV/m. This energy makes it possible to estimate the magnetic field strength accompanying UHECR propagation: $B \approx 1.4 \times 10^{-13}$ T (≈ 1.4 nG), which is numerically comparable to the typical level of extragalactic magnetic fields. Thus, the proposed background gravitational waves of space-time may exist and participate, together with the magnetic field of the medium, in the transport of UHECR from regions that are otherwise forbidden by the GZK limit. The numerical estimates presented here are internally consistent and dimensionally compatible within rounding accuracy.

The background-wave energy transfer model reproduces both the Hillas curvature scale and the observed nanogauss level of extragalactic magnetic fields.

Donald Melrose and Rai Yuen (Melrose & Yuen, 2016) point to the necessity of involving hypothetical large-amplitude

longitudinal oscillations in the electrodynamics of pulsars. Although the characteristic frequencies they consider are many orders of magnitude higher than 0.06 Hz, the longitudinal mode of the proposed background waves may act as an external low-frequency modulation.

This modulation can be viewed as a slow phase regulator (gating) that synchronizes and feeds the high-frequency large-amplitude longitudinal oscillations, but does not replace them dynamically. Within the present framework, background space-time waves are assumed to influence the formation of the magnetosphere and the dynamical evolution of pulsars.

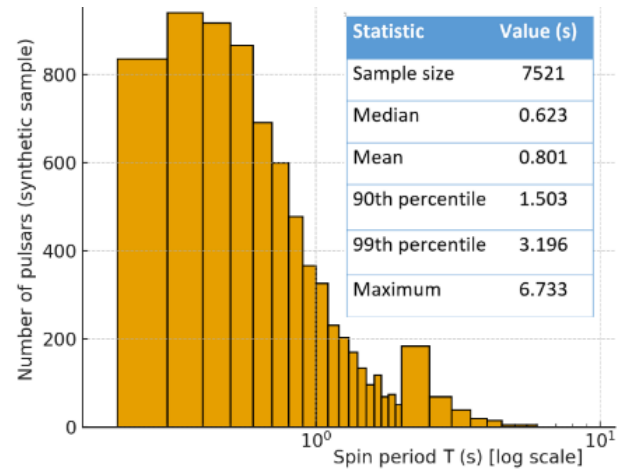


Figure 11. Distribution of pulsar periods ($T > 0.2$ s).

A very characteristic feature of pulsars and magnetars is their high spin rate, with rotation periods T ranging from several tens of seconds down to milliseconds. The rotation period of a neutron star is a key parameter that determines the light-cylinder radius R_{LC} , the Goldreich–Julian charge density ρ_{GJ} , and also the nature of the interaction between the star and the accreting matter. Statistics for 7521 pulsars with rotation periods $T > 0.2$ s show that 99% of their periods do not exceed ≈ 3 s (Fig.11).

Above this value, a quantitative decline is observed, which then turns into a rise for pulsars with periods $T > 3$ s, whose distribution maximum occurs near ≈ 7 s. This “secondary maximum” may indicate the existence of a ‘mature’ group of pulsars that have completed the spin-down process and reside in a state of relative dynamical equilibrium.

Within the overall population there are individual objects with periods exceeding several tens of seconds, but they are extremely rare. Their slow rotation is likely related to the loss of angular momentum through electromagnetic radiation and interaction with the surrounding environment.

In analysing the period statistics, one should bear in mind that a pulsar can emit radiation into two beams (a main and an intermediate cone) during a single revolution, and an observer may detect two pulses per rotation. In such a case, when interpreting the distribution, one can assume that the observed maximum should correspond to a period more consistent with the postulated background waves. At the stage of accretion, the torque on the star in a simplified model is described by Eq.31 (Melrose & Yuen, 2016).

$$N \approx \dot{M} \sqrt{GM r_m} (1 - \omega_s) \quad (31)$$

where $\dot{M}$ is the accretion rate [kg/s], M is the mass of a star, r_m is the magnetospheric radius and $\omega_s = \Omega_*/\Omega_K(r_m)$ is the fastness parameter.

The fastness parameter represents the ratio between the angular velocity of the neutron star Ω_* and the Keplerian angular velocity at the magnetospheric radius $\Omega_K(r_m)$. If $\omega_s < 1$ the inner disc edge rotates faster than the star and the star spins up. If $\omega_s > 1$ the torque becomes negative and the system enters a spin-down (propeller) regime; the star rotates faster than the disc, and by breaking it transfers angular momentum to the disc.

At $\omega_s \approx 1$, the stellar angular velocity becomes equal to the Keplerian angular velocity at the magnetospheric radius r_m , which corresponds to the corotation equilibrium. In this case the net torque vanishes ($N = 0$), and the system lies at the boundary between the spin-up and spin-down regimes.

The Coriolis force $F_{Cor} = 2\Omega \times v$ enters directly into the equations of motion of the disc, determining the epicyclic frequencies and stability. It plays a central role in the magnetorotational instability, which provides the outward transport of angular momentum and inward mass accretion (Frank et al., 1992).

In the vicinity of the magnetospheric radius, Coriolis dynamics together with magnetic stresses set the conditions for instabilities that excite large-scale vortices and modulate the inflow of matter onto the stellar surface. The mechanism of twisting the accretion disc and spinning the pulsar may be interpreted as a manifestation of a thermodynamically asymmetric interaction between Coriolis dynamics and gravitational infall.

Nonlinear processes lead to accretion gating: transitions between accretor and propeller regimes, which may be regulated by space-time modulations. In particular, the proposed low-frequency background waves at $f \sim 0.06$ Hz, when commensurate with the characteristic transport times near r_m , can resonantly accelerate or decelerate the stellar rotation.

Preliminary experiments with the rotational pendulum suggest that, when the Coriolis force is balanced by the twist of the suspending thread, the pendulum can perform periodic oscillations with a frequency close to the proposed background one.

By analogy, a pulsar may hypothetically synchronize with the oscillations of the space-time waves. Fig.12 shows the dependence of the torque N including the fastness parameter. The red dashed line corresponds to the critical value of ω_s at which the torque changes sign. The orange trajectory represents sinusoidal modulation of N at a frequency of 0.06 Hz; the model indicates that part of the cycle may fall into the region of negative torque, which is equivalent to engaging a “brake”.

Thus, Coriolis dynamics (from classical to relativistic) together with the structured space-time medium may represent an integral component of the accretion mechanism, capable of contributing to both spin-down and spin-up episodes in pulsars. In this model, space-time is treated as a medium whose curvature and energy density may significantly

influence ultra-dense relativistic objects. Neutron stars may therefore serve as potential astrophysical indicators of the underlying structure and dynamics of space-time.

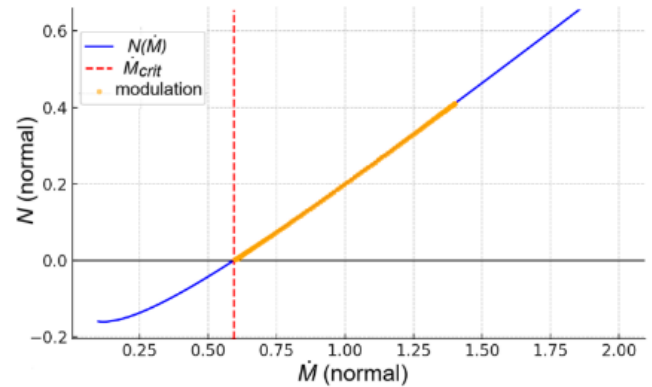


Figure 12. Modulation of the accretion torque by longitudinal waves at 0.06 Hz.

In particular, the proposed interpretation of their rotational evolution may provide indirect phenomenological support for the existence of low-frequency background gravitational modes.

RESULTS

Low-frequency ponderomotive oscillations of various particles and macroscopic objects, with a characteristic frequency of approximately 0.06 Hz, have been experimentally detected and theoretically analyzed. These oscillations are interpreted as a mechanical response to the periodic pulsation of the embedding medium of these particles and objects namely the matter of space-time itself, interpreted at the cosmological scale. This frequency is considered as a phase characteristic capable of modulating the dynamics of both microscopic particles and macroscopic objects (Eq.32).

$$\omega = \frac{Gh}{V_b c^2} \quad (32)$$

here, V_b is the volume of a cell of the background structure of space-time. This formula consists of two parts: the first G/c^2 is equal to the ratio of the radius to the mass of the Universe (R_U/M_U), and the second $h\omega/V_b$ corresponds to the fundamental pressure of the Universe (P). It provides a possible structural explanation for the emergence of a global pulsation mode.

The matter of space-time possesses an energy density whose existence probability follows from the experimentally established additivity property of the de Broglie equation. This property involves the postulated large quantum number N , equal to the number of space-time cells within one cubic meter. The expression GM/c^2 describes the curvature of space produced by mass (the gravitational radius) and connects mass and length through the geometry of space-time.

This is a fundamental scale linking matter and the metric field. The condition $GM_U/R_U c^2 \sim 1$ may be interpreted as describing a gravitationally critical state, where the curvature generated by its mass is compensated by the propagation speed

of interactions the speed of light. The square of the speed of light introduces a quadratic scaling between curvature and energy density, implying nonlinear feedback. Within the proposed structural–informational model, as in the equations of general relativity, c^2 acts as the coupling coefficient between the space–time metric and the energy density. One may say that the speed of light sets an invariant curvature, and its square provides the system with a second order of stability self-consistency, as in nonlinear systems where feedback sustains oscillations (Fig.13).

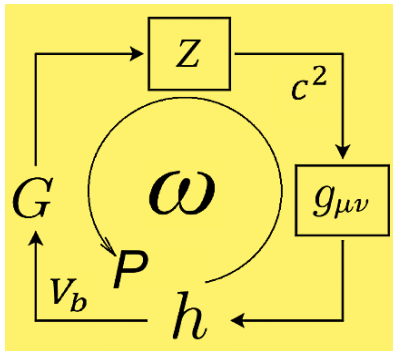


Figure 13. Feedback loop of cosmological self-consistency.

Here, G is the gravitational coupling (“synthesizer” of space–time cells), Z is the self-consistency coefficient, c^2 represents the invariant background of the Universe associated with the squared speed of light and acting as a nonlinear regulator, $g_{\mu\nu}$ is the metric of a space–time cell where nonlinearity manifests itself, and h is the quantum of action defining discreteness and V_b is the volume of the background space–time cell in which the nonlinear energy localization occurs..

The inner loop $\omega \leftrightarrow P$ describes the autogenous oscillatory coupling between the pulsation frequency of the Universe and the fundamental vacuum pressure. The diagram represents a conceptual closed nonlinear feedback loop that may underlie the global self-consistent pulsation of space–time.

The entire diagram shows that the oscillations arise naturally as a result of a structural–informational feedback between gravitation, quantization, and the invariance of light speed. The square of the speed of light plays the role of a “damping regulator”, maintaining the system in a regime of nonlinear resonance without destroying it similarly to how a damper maintains equilibrium in a Foucault pendulum under active excitation.

This special mechanism of nonlinear damping is capable of sustaining oscillations of constant amplitude, as a result of which the Universe may be modeled as a nonlinear self-oscillatory system, similar to a Van der Pol oscillator. Thus, the periodic pulsation of the Universe is a condition of its self-consistency as a closed object, analogous to a gravitationally closed system with a limiting energy density.

In this work, we have developed a structural–informational model of space–time, in which physical interactions arise from the internal organization and dynamical state of a two-level space–time lattice. The background lattice determines the metric configuration and gravitational behavior, while the normal lattice, formed in the presence of matter, determines electromagnetic interactions.

These two structural scales are linked by a condition of energetic stability, leading to the appearance of the golden ratio as a possible equilibrium relation between the characteristic radii.

PROPOSED DISCOVERY

The results obtained in the present work justify the formulation of a new physical statement concerning the dynamics and fundamental structure of space–time. The experimentally detected and theoretically substantiated low frequency component with a characteristic value of approximately 0.06 Hz is interpreted not as a secondary mechanical effect, but as an intrinsic dynamical property of space–time itself. The detected global low-frequency mode exhibits a dimensional correspondence with the millimeter-scale maximum of the cosmic microwave background spectrum (~ 2.72 K).

This structural agreement suggests that the laboratory-scale manifestation of the ~ 0.06 Hz modulation and the cosmological microwave background represent complementary expressions of a common equilibrium property of the vacuum architecture. The cross-scale invariance of this frequency, observed in both microscopic stochastic systems and macroscopic mechanical oscillators, demonstrates that the phenomenon is independent of system-specific resonances. Its stability, energetic consistency, and reproducibility indicate that it reflects a background structural property rather than a local perturbative process.

Space–time is proposed to represent a two-level structural lattice: a background lattice governing the metric and gravitational properties of matter, and a normal lattice formed in the presence of substance (particles and macroscopic objects) and governing their electromagnetic interactions. The dynamics of the relationship between space–time and substance are regulated by a quantum number defined as the number of normal lattice cells participating in fundamental interactions.

To clarify the structural interpretation, it is necessary to distinguish between two fundamentally different quantum numbers beyond the atomic model of Bohr. The first type arises from the de Broglie relation and characterizes the dynamical wave behavior of matter: $N_{dyn} = mv\lambda/h$, where m is mass of particle or object, v is its velocity, λ is the de Broglie wavelength and h is Planck’s constant. This quantum number governs the propagation of matter waves and is directly linked to relativistic energy momentum relations.

The second type corresponds to the interaction with the intrinsic background mode detected in the present work: $N_{str} = A/\hbar\omega$, where A represents the work performed by space–time on the system, $\hbar$ is Dirac’s constant and ω is the frequency of the global space–time modulation. Unlike the dynamical quantum number, which describes motion, the structural quantum number measures the degree of coupling between a physical system and the architecture of space–time itself.

Both quantities indicate that the effective quantum number of a system is determined by the ratio between its characteristic energy (or structural work) and a fundamental governing frequency. This relation expresses a universal geometry–

energy–frequency principle underlying both dynamical wave processes and structural vacuum coherence.

Formula of the proposed discovery

Space–time possesses an intrinsic global low-frequency pulsation mode with a characteristic frequency of approximately 0.06 Hz. Against the background of this mode emerges a two-level structural organization of physical reality governed by a universal geometry–energy–frequency relation. The pulsation of space–time, treated as a closed physical system, constitutes a mechanical source of ponderomotive excitation for macroscopic and microscopic objects embedded within the space–time continuum. This work establishes a new foundational structural principle for the interpretation of vacuum dynamics, coherence, and the emergence of classical and quantum domains, thereby introducing a new organizing principle in fundamental physics.

CONCLUSION

The present work reports the experimental detection and theoretical substantiation of a global low-frequency mode of space–time characterized by a stable frequency of approximately 0.06 Hz. The observed ponderomotive oscillations in mechanical systems are interpreted as the direct mechanical manifestation of a periodic modulation of the embedding medium the structured vacuum of space–time.

A structural–informational model of space–time has been developed in which the vacuum is treated as an active physical medium composed of background cells characterized by energy density, fundamental pressure, and metric structure. Within this framework, space–time is not merely a passive geometric arena but a dynamically organized physical medium participating in the generation of mass, inertia, gravitation, and electromagnetic phenomena.

A central result of this work is the introduction of a large quantum number describing macroscopic coupling between localized systems and the cellular structure of space–time. This concept establishes a concrete conceptual bridge between quantum mechanics and general relativity, indicating that both may represent limiting regimes of a deeper structural–informational dynamics. The pendulum experiments demonstrate that under specific dynamical conditions the work

of non-inertial forces becomes commensurate with kinetic and potential energies, revealing a direct energetic interaction between local mechanical motion and global background modulation. Regimes with effectively vanishing Lagrangian correspond to conditions of dynamical self-consistency between local motion and global metric structure.

Within this framework, particle mass is interpreted as a structural property of space–time associated with localized stationary configurations of the background medium. Proton confinement arises naturally from geometric closure within the phase domain of the cellular vacuum. Gravitation and fundamental pressure are identified as complementary manifestations of a unified self-consistency mechanism governing curvature and energetic stability. On astrophysical scales, the structural–informational model provides a coherent geometric–phase interpretation of ultra-high-energy cosmic rays, pulsar dynamics, and magnetar energetics, linking these phenomena to the intrinsic energy density and structural organization of the vacuum medium. The structural correspondence between the detected low-frequency modulation and cosmological scales, including the millimeter maximum of the cosmic microwave background, indicates the presence of an underlying equilibrium mechanism in the large-scale organization of space–time.

Taken together, the results presented in this work constitute evidence for a previously unidentified structural property of space–time a global low frequency pulsation of the metric medium. This proposed discovery supports the interpretation of the vacuum not as an empty geometric background, but as an active physical substrate underlying matter and interaction. The structural–informational framework developed here provides a unified geometric basis linking classical mechanics, gravitation, quantum phenomena, and cosmology within a coherent dynamical description of the Universe.

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