Can Dimensional Anisotropy Satisfy Mach's Principle? A Topological Approach to Variable Dimensions of Space using the Borsuk-Ulam Theorem

Eva Deli[1]

1 University of Debrecen

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Abstract

In general relativity, Einstein's equations relate the geometry of space-time to the distribution of matter. Nevertheless, the equations are in contradiction with quantum mechanics and even possibly our experience of physical reality. We propose a thought experiment to investigate a compact wave function (WF) insulated by an information-blocking horizon. The WF can produce entanglement independent of distance but interaction with the horizon evolves the quantum state (frequency) of the WF and the topology (curvature) of the horizon in an orthogonal relationship. Their mutual evolution satisfies the Borsuk-Ulam Theorem and the Page and Wootters mechanism of static time. Therefore, the field curvature measures the particle's evolution as time. Because increasing field strength accumulates pressure, whereas negative curvature creates a vacuum, their opposing dynamics give rise to poles with dimensionality transformations; pressure culminates in two-dimensional black hole horizons (infinite time), whereas vacuum gives rise to four-dimensional cosmic voids (time zero). The orthogonality of the field and the compact WF is global self-regulation that evolves and fine-tunes the cosmos' parameters. The four-dimensional cosmic voids can produce accelerating expansion without dark energy on the one hand and pressure gives the impression of dark matter on the other. The verifiable and elegant hypothesis satisfies Mach's principle.

Eva Deli

University of Debrecen, Department of Anatomy, Histology, and Embryology

eva.kdeli@gmail.com

ORCID: 0000-0003-1126-1970

James F. Peters

james.peters3@umanitoba.ca

University of Manitoba, Department of Electrical and Computer Engineering and

Department of Mathematics, Faculty of Arts and Sciences, Adıyaman University

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Preliminaries

There is a difference in Newton's bucket's water surface when the water is at rest and when the bucket rotates along a curved surface relative to the stars [1]. Nevertheless, in Newtonian physics, the intrinsic state of a particle, i.e., its mass, has no immediate connection with its extrinsic state in space and time, i.e., its locus and velocity. Hence, the universe's distant matter content cannot cause inertia, provided *a priori* independence of the particle's position (x) and momentum (p).

The idea of absolute space was questioned by Mach, who sought to define inertia as a dynamical quantity determined by the global distribution of matter [2][3]. He proposed that inertial forces result from a body's motion relative to the bulk of matter in the universe. Mach's profound insight into Newtonian mechanics' shortcomings inspired Einstein to develop general relativity (GR). For example, gauge symmetries are indifferent to the location; a global symmetry holds as a local symmetry. As a result, the frame of reference does not correspond to a directly observable physical object and can be moved around without changing the physical situation. Nevertheless, Einstein had to postulate "boundary conditions" at infinity.

A path integral of the gravitational action can be used to derive the Wheeler–DeWitt equation, which defines the WF, containing information about the geometry and matter content. Although the physical states do not evolve in time [4], decoherence with a clock operator leads to the emergence of time. Therefore, attaching a spatial field to the WF with which it interacts creates an evolving clock universe, tracking the discrete frequency evolution of the WF.

The resulting system, which satisfies the Wheeler–DeWitt equation[5], acts like Maxwell's demon. Maxwell's demon is an imaginary creature that can lower entropy by allowing faster particles into another compartment, creating differences in energy distribution. Similarly, the clock universe will necessarily evolve into polar states because the ancillary system creates irreversibility, stabilizing curvature [6][7]. The global state of the system evolves different parameters of temperature, pressure, matter and energy density, and even dimensionality.

In the present work, we will investigate the evolution of spatial topology in a model WF connected to a clock system. The Borsuk-Ulam theorem (BUT) can explain how entanglement generates spatial anisotropy, with implications for entropy, inertia, and Mach's principle. We close with a discussion and summary.

The wave function

The Page and Wootters mechanism (PaW) presents a static universe without time evolution (i.e., the Hamiltonian of the theory does not generate time translations of the physical states for an external time) [8][4][9]. The PaW intuitively satisfies energy conservation [8][10], and a recent experiment validated its fundamentals[11][12][9].

The WF represents compact dimensions (i.e., wrapped up or curled onto themselves as in Calabi-Yau spaces). Setting the horizon at infinity imposes discrete frequencies but permits non-locality, entanglement independent of the spatial coordinate [13] (Fig1. top). Although entanglement is reversible, it causes local instability[14] (Fig2), which triggers interaction. An interaction term in the Hamiltonian couples a clock spatial field to WF [15][16], tracking its evolution. In other words, the clock system must periodically interact with the system whose evolution it tracks.

Interaction with the spatial field (SF) triggers WF decoherence. Because interaction must satisfy conservation principles [17] (Fig1. bottom), increasing WF frequencies must be accompanied by decreasing field strength (negative field curvature) and vice-versa. Rather than a one-dimensional manifold moving in time (world sheet), the spatial curvature evolution represents the tick-tack of the particle's WF, which generates local pressure differences.

The interaction of insulated systems is an orthogonal transformation, which inversely modifies their energy states, pressures, and volumes. For example, increasing frequencies are concomitant with positive curvature (pressure), whereas slower frequencies parallel negative curvature (vacuum). Therefore, interaction increases curvature locally while keeping the global information-energy relationship constant (Fig2).

Thus, quantum mechanics' axiomatic formalization supports global conservation laws[14]; the equivalence of entanglement and superposition [13] or the double-slit experiment (Table I).

Table I. The orthogonality of space. Qualitative differences between compact dimensions and space permit the cosmos' self-regulation. However, global self-regulation, which fine-tunes the cosmos' parameters, requires the orthogonality of space and compact dimensions.

Compact dimensions	Clock system (gravity field)
Discrete WF	Topological manifold
Non-locality, insulated from gravity	locality (forms pressure and curvature)
Entanglement is reversible	Interaction is irreversible (stable topology)
Constant frequencies increase entropy	Tolman density gradient
Evolution via the Schrödinger equation	The Schrödinger equation describes the global evolution
Measurement causes decoherence, changing the WF frequency	Measurement updates the field curvature
Discrete energy level	Dimensional anisotropy

Topological considerations

Topological spaces are central unifying notions in mathematics and physics, such as gravity. Although the cosmic microwave background (CMB) represents slight density variations and smooth distribution of a nearly spatially flat early universe [18][19][20], the current web-like cosmic structure consists of gravitational nodes dispersed in empty space (Fig3). How could a nearly spatially flat universe evolve a cellular structure dominated by emptiness?

Because phase change often makes reactions possible in physics, chemistry, and biology, the existence of the horizon precipitates cosmic evolution. Therefore, compact dimension formation (time zero) is a phase change that solidifies space into the gravity field—the compact dimensions' energy requiring birth guarantees identical, homogeneous initial conditions throughout space [21]. More precisely, the CMB shows the newborn cosmos' first interaction.

If the global structure of the cosmos (as suggested by GR) were dominated by gravity, then empty space would occupy corners between globular galactic accumulations. In reality, the opposite happens; voids squeeze galactic structures in a nearly spherically symmetric galaxy outflow, pushing against massive objects, and spiking temperature and pressure [18]. Galaxy movement is channeled into diverging velocity flows, like watersheds [20], forming not blobs but walls, knots, and filaments (relative to the universe's overall expansion) [22][23]. The interior void flow fields expand as vacuums spur accelerating expansion.

Recent void analysis shows a hierarchical, nonlinear mass distribution mechanism where the void size parallels galaxy mass distributions [24]. The larger supervoids are located in the lowest density regions and remain well-insulated from gravitational structures (Fig4, orange regions). The hierarchical cosmic density organization displays smooth transitions ranging from vacuum -2.3, –1.1, –0.7, 0.2 and progressing through increasingly dense 1.00, 1.25, 1.50, 1.75, 2.00, and 2.25 [23]. Void density is less than one-tenth or even smaller than the average cosmic density[25][23] with expansion due to tens of millions to hundreds of millions of light-years diameter cosmic voids [26][27][28].

The detailed calculations for the field curvature changes during density transitions will be the subject of future work.

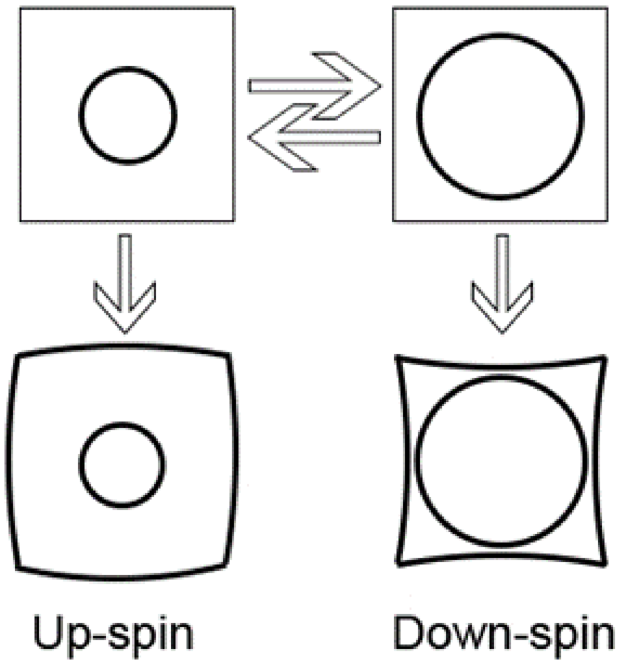


Fig1. An ancillary clock system in two dimensions. Top: Compact dimensions (indicated by circles) are insulated from space by an information-blocking horizon, allowing non-locality, such as entanglement. Bottom: Interaction between the spatial field and the compact dimensions permanently separates the energy function into daughter particles, changing the pressure and volume, which modifies field curvature.

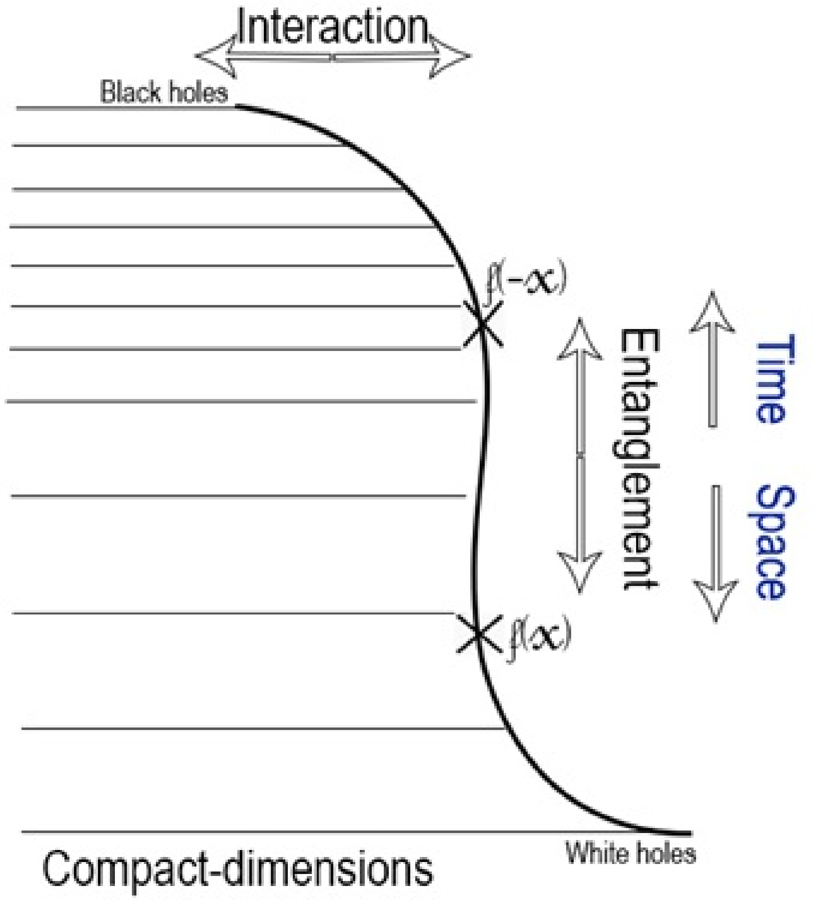


Fig2. The proposed view of 'space-time'. The compact dimensions (horizontal lines) are isolated by an information-blocking horizon, limiting particle frequencies to discrete energy levels. Entanglement between f(x) and f(−x) can be mapped to the equator. Entanglement triggers interaction with the spatial field (right curved line), forming a clock system that tracks the evolution of discrete compact frequencies via smooth topology between black holes (top) and cosmic voids (bottom). The field strength increases toward the top. In black holes, time = ∞, space = 0; in cosmic voids, space = ∞, time = 0.

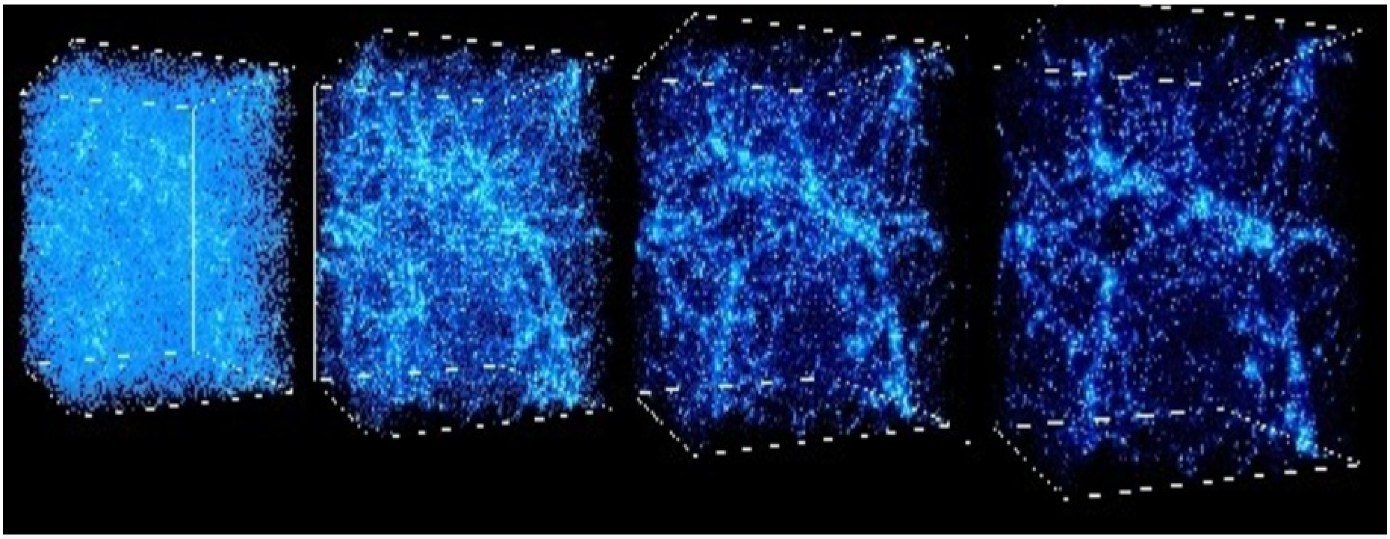


Fig3. Computer simulation of the cosmic web evolution over time. Evolution from left to right shows the gradually increasing curvature differences. Thin filaments connect dense, galaxy cluster-filled regions around nearly empty voids. Picture credit: Andrey Kravtsov (The University of Chicago) and Anatoly Klypin (New Mexico State University) at the National Center for Supercomputer Applications.

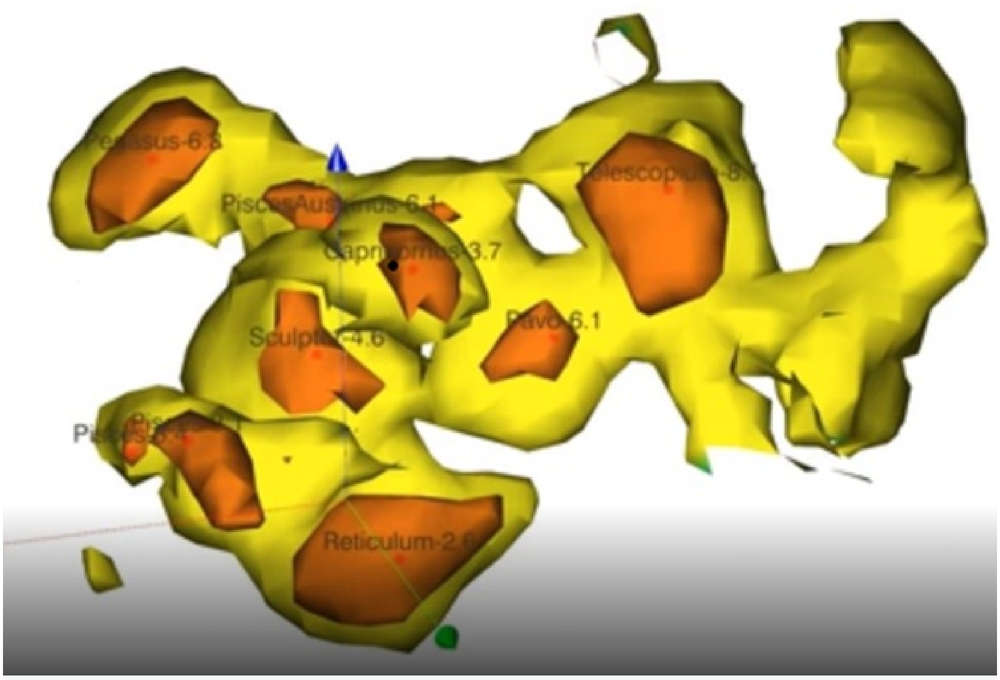


Fig4. The density map of the Local Void. The central void density is –1.1 (orange) and –0.7 (yellow) elsewhere (the negative sign indicates under-density). The central location of the coldest regions within voids stabilizes them—image from Tully et al., 2019.

The Borsuk-Ulam Theorem (BUT)

In 1961 Rolf Landauer predicted the minimum amount of heat needed to erase a classical bit $E = k_B\ T\ ln\ 2$[29], where k_B is the Boltzmann constant and T is the temperature of a "reservoir" with which the bit exchanges heat. Because E/T is constant (on a constant temperature), interaction modifies the local volume (pressure), which evolves the large-scale structure. Entanglement updates the particles' energy state [9]. The antipodal volume transformations of sister particles update the field curvature [30].

The Borsuk-Ulam Theorem (BUT) states that if an n-sphere is mapped continuously into an n-dimensional Euclidean space R^n, there is at least one pair of antipodal points on S^n which map onto the same point of R^n [31][9]. Correspondence can be found between a pair of antipodal points, and they can be represented in terms of one point. The analog of this mapping process is the drawing together separate antipodal free particles whose entangled states are correlated in a quantum mechanics view of BUT. This correlation of entangled states can be explained mathematically in terms of the descriptive proximity of a pair of antipodal particles [32][33]. In other words, thanks to a pair of companionable feature vectors that describe antipodal particles, the particles have a nonempty descriptive intersection [34]. That is, let pA, pB be a pair of antipodal particles and let be $\Phi(pA), \Phi(pB)$ descriptions of the particles defined by

$$\Phi(pA) = x \in pA : \Phi(x),\ \text{a description of } x \text{ in } pA,$$
$$\Phi(pB) = \left\{x' \in pB : \Phi\left(x'\right),\ \text{a description of } x' \text{ in } pB\right\}.$$

For example, $\Phi(pA)$ is a set of descriptions of the parts of pA, represented by a feature vector that describes pA with its n parts, namely, $\overrightarrow{\left(\Phi\left(x_1\right), \Phi\left(x_2\right), \ldots, \Phi\left(x_n\right)\right)}$. In the case where a pair of antipodal particles have companionable descriptions, the descriptive intersection $pA_{\Phi}pB$ is nonempty, i.e., $pA_{\Phi}pB = \{y \in pA \cup pB : \Phi(y) \in \Phi(pA)$ and $\Phi(y) \in \Phi(pB)\} \neq \varnothing$

That is, there is at least one component y in the union pA, pB that has a description $\Phi(y)$ that is common to the descriptions of $\Phi(pA)$ and $\Phi(pB)$, i.e., $\Phi(y) \in \Phi(pA)$ and $\Phi(y) \in \Phi(pB)$. In effect, particles whose states have companionable descriptions can be mapped to a higher state in terms of their descriptive intersection.

From a compactified dimensions perspective, a higher-dimension feature vector that describes a physical structure can be shrunk to a lower-dimensional structure by convolving (rolling together) the features in a description into a more concise feature vector [35]. According to BUT, the pressure of positive curvature correlates with a negative curvature vacuum. This convolution can be represented topologically by a collection of contraction maps from surface points (each with its own feature vector) to a fixed point, such as a surface centroid with a single feature vector with a reduced number of features.

For example, the points on an edge attached between the boundaries of a ribbon *rBE* can be mapped to a fixed point *p* in the intersection of *p* with the ribbon boundary body of the closure cl of ribbon cycle*cycB* as shown in Fig5, using mapping *f* defined by $f(p \in pq) = pq \cap dby(cl(cycB)) = p$ [36], see [37] for further details and mathematical treatment.

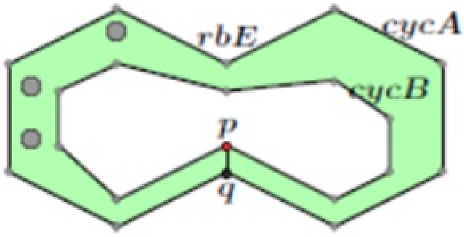


Fig5. Mapping an edge pq to a fixed point p on a ribbon boundary

The notation n within S_n stands for an n-sphere [38], an n-dimensional, circular structure embedded in an n+1 space[39]. For example, a 2-sphere (S_2) is the 2-dimensional surface of a 3-dimensional space. Antipodal points are, e.g., the poles of a sphere [34]. The mapping $f: S^n \to S^n$ is smooth, provided *f* is a 1-1, continuous, differentiable mapping from the manifold S^n (domain of Euclidean space) into itself in which the inverse mapping$f^{-1}: S^n \to S^n$ is also continuously differentiable [40].

$$degf = X^x \in f^{-1} sig(det\, dxf). \qquad (1)$$

The cosmological standard model assumes that the universe is isotropic around all observers. However, applying conservation principles with BUT show that antipodal changes, separated in space or time, map into one. This spatial and temporal separation results in dimensional anisotropy. Antipodal changes might originate in entanglement and the quantization of particles in quantum mechanics [41][13].

A system consisting of only one particle type evolves into a two-type particle system with attraction and repulsion forces having equal fractions [42][43]. Antipodal transformations, the emergence of attraction and repulsion forces can map into Euclidean space; the lack of volume within positive curvature is compensated for excess volume within negative curvature regions (Fig2 and Fig6). For example, the asymmetric tails of star clusters are consistent with the anisotropic geometry of space [44].

According to BUT, any two-dimensional black hole boundary (see, e.g., Fig2) must have at least one antipodal, i.e., a four-dimensional point corresponding to it. Rather than treating the causes of the two regimes independently (dark energy and dark matter), PaW offers a unique cause arising from the same fundamental physical process [45]. Next, we discuss the emergence and nature of dimensional anisotropy.

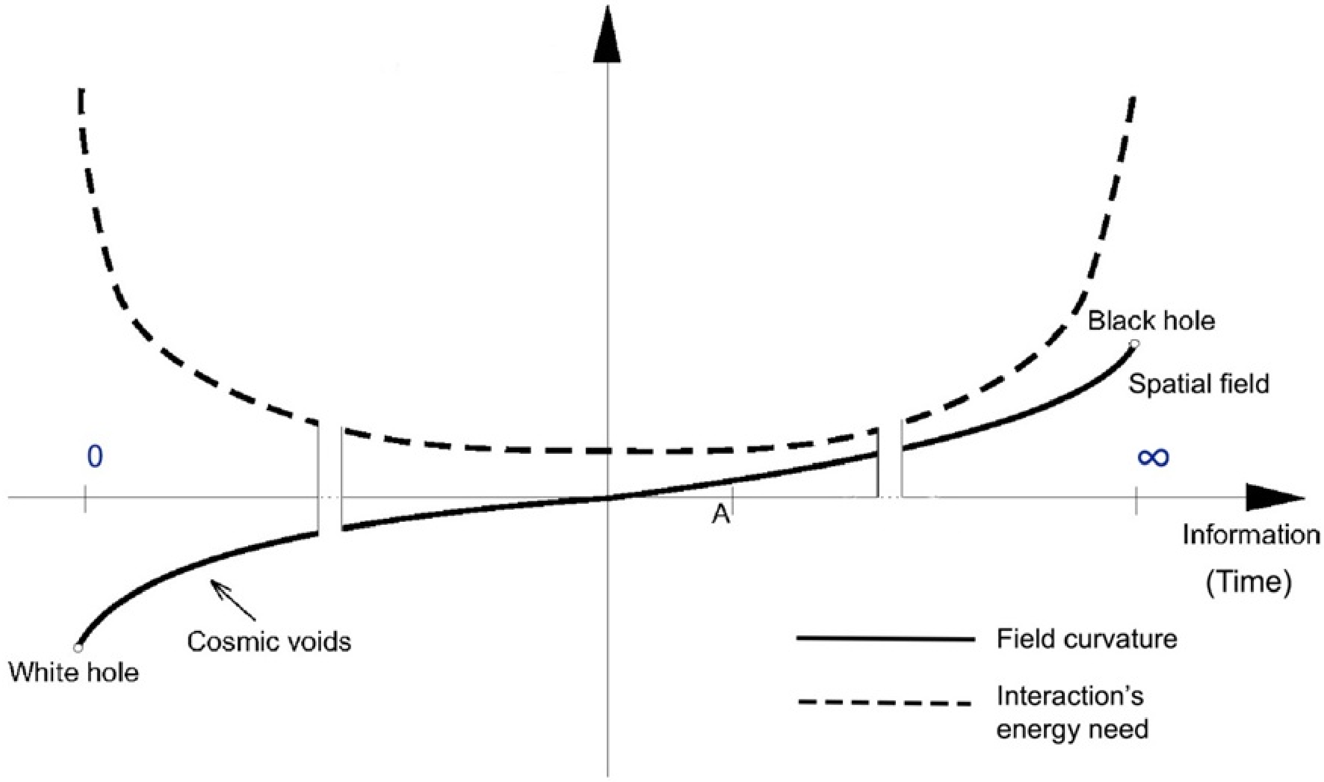


Fig6. The energy-information changes in the universe. The x-axis represents the information accumulation or age (from 0 to ∞). The continuous line is the degree of compactification (dimensionality is four on the left and changes to two on the right). The dotted line is the Lorentz contraction, indicating the energy change of interaction. A is the gravity on an Earth-like planet.

Dimensional anisotropy

Time is often represented by a temperature-dependent entropy generation and entropy rate[46][47]. Moreover, t evolution of time intervals (t = 1 / υ) shows a frequency (υ) dependence [48][49].

$$Ds^2 = dr^2 + (cdt)^2 \qquad (2)$$

From the trigonometric identity:

$$1 = \cos^2\psi + \sin^2\psi \qquad (3)$$

$$\sin\psi = \frac{cdt}{ds} \qquad (4)$$

If time measures the curvature change, then change (i.e., time) is fastest in the Euclidean field and slows with the curving field. Therefore, the orthogonal transformation between the compact dimensions and the field can slow the clocks but form either acceleration or gravity. Therefore, gravity and acceleration might have a trigonometric origin (Fig2; Fig6). Moreover, the field curvature change is the derivative of the inverse sine function of the quantum frequency (E/h):

$$\frac{d}{d\psi}\sin^{-1}\psi = \frac{1}{(1-\psi^2)} \qquad (5)$$

Therefore, the Lorentz transformation can be interpreted as the curvature change per unit of energy input (Fig6). The changing curvature ultimately culminates in phase change via dimensionality transformations. Black hole physics is a subject of a lot of debate [50], but the AdS/CFT conjecture[51] and the firewall hypothesis [52] support lesser dimensionality horizons.

Landauer's principle supports our experience that information accumulation causes black holes' high temperatures[29]. Likewise, negative temperatures [53][54][55][56][57][58] suggest a possible relationship between vacuum energy and temperature [59]. In addition, PaW and BUT shows that any two-dimensional boundary (e.g., Fig3) has at least one antipodal point pair, i.e., four-dimensional space.

Current literature vigorously debates the existence and nature of white holes[45][60][61][62][63]. In contrast to black holes' extreme pressures and temperatures, white holes represent the lowest density and temperature space. Furthermore, voids [64][65][66][67][68] are insulated from gravitational influences [53][54] (Fig4, orange regions). In contrast to gravitational lensing, cosmic voids would disperse passing light rays. Therefore, the cosmological constant might be a dimensionality function [55], causing accelerating expansion without dark energy and dark matter[45].

Energy input, such as an increase in temperature, increases entropy and pressure (Fig2)[56][57][58]. In an ideal gas, entropy S can change as a function of temperature: $\Delta S = nC_v ln\frac{T}{T_\circ}$, or volume $\Delta S = nRln\frac{V}{V_\circ}$, where n is the number of moles, R is the ideal gas constant. Entropy, an elusive concept, is often associated with a thermal disorder [69] caused by gravitational effects. Nevertheless, entropic effects were found in order-increasing gravity-free simulations [70][71].

Although pressure creates gravity and vacuum expands the degrees of freedom (order or work potential), both generate entropy. Therefore, cosmological entropy is related to geometry, with the highest entropy at the poles. The substantial field strength leads to the spectacular destructive power of collisions and explosions [72][73]. Moreover, the expansion acts as dark energy, whereas dimensionality loss gives the semblance of dark matter.

The cosmological constant problem is the discrepancy between the theoretical vacuum energy density and its empirically measured value [74]. Systems with a bounded energy spectrum display negative absolute temperature and negative pressure akin to dark energy [21][75][59]. Entanglement populates expanding vacuum with pairs of particles lost in black holes[28] Although particle-antiparticle pairs annihilate each other in three-dimensional space, they remain viable in four-dimensions [60][76]. The combined effect is that cosmic voids produce energy rich space which drives an accelerting expansion.

Antipodal dynamics, such as simultaneous heating and cooling, produce thermal convection cells, and the surface tension in expanding hot gas forms foam [77]. Compression (as in black holes) expands time to infinity, whereas expansion rewinds time to zero. Likewise, the zero-point energy in cosmic voids gives rise to cosmic expansion [78][76][79][55]. For example, the Sloan Digital Sky Survey found vast cosmic voids [20][80], such as the long, fully connected supervoid Eridanus [65], originating in the CMB cold spot[66].

The spatial field operates as a clock, tracking the WF evolution[16][15]. Time progression from time zero in the white holes to time infinity in the black holes correlates with gravity as black hole horizons' immense field strength slow expansion [81]. The cosmos dimensionality alternation between two and four dimensions acts as a harmonic oscillator.

The cosmos as a harmonic oscillator

Applying the Fourier transform to the time-independent Schrödinger equation naturally leads to an oscillatory solution. The peaks in the probability density function can be interpreted as the spectrum of the system.

The Hamiltonian of the system:

$$\hat{H} = -\frac{\hbar^2}{2m}\frac{\partial 2}{\partial x2} + V(x) \qquad (6)$$

where m is the particle mass, the first term is the kinetic energy operator and V(x) is the potential energy.

The time-independent Schrödinger equation:

$$-\frac{\hbar^2}{2m}\frac{d^2\psi(x)}{dx^2} + V(x)\psi(x) = E\psi(x) \qquad (7)$$

where ħ is Planck's constant divided by 2π, and ψ is called the WF of the system.

The poles form either a node or an antinode (voids) of the universe's WF (Fig2), causing a power-law scaling relation between the void size and the corresponding cluster mass [67][82][68]. The scatter in the scaling relation is more significant at low redshifts and small voids, indicating that larger voids are more insulated from environmental influences (Fig4).

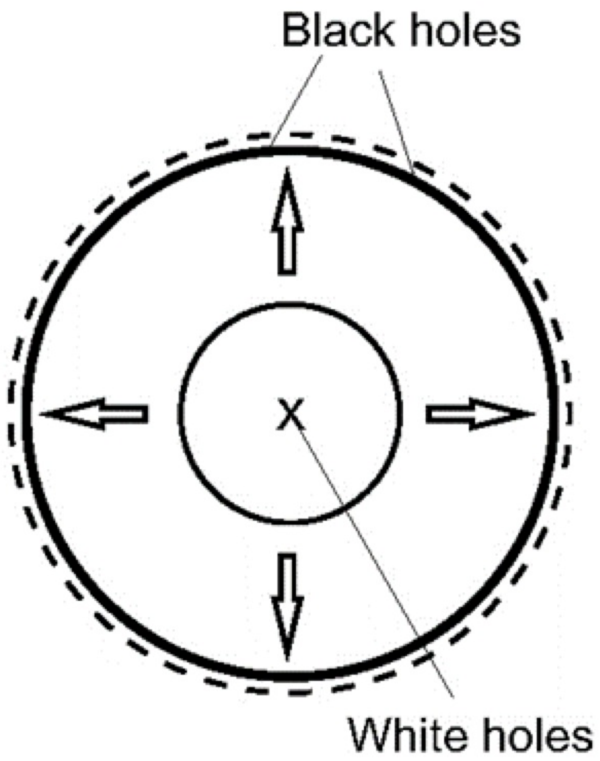
The AdS/CFT correspondence, a holographic mapping, asserts that a lower-dimensional non-gravitational theory can fully describe a higher-dimensional gravitational one [83][41][51]. In our derivation, galaxies and clusters separate high-dimensional voids from the low-dimensional horizon. Furthermore, when using the CFT side (as opposed to the more usual AdS side) to analyze black holes as a starting point, Almheiri, Marolf, Polchinski, and Sully (AMPS, 2012) found information conservation (i.e., black hole formation and evaporation process are unitary), the firewall hypothesis [52][59].

Life in the universe is very sensitive to the values of fundamental physical constants, leading to the so-called fine-tuning problem. However, in our model, the WF maintains constant spatial curvature, but entanglement increases curvature differences [13]. The two contrasting effects result in a global self-regulation that constantly fine-tunes the cosmic parameters and promotes a fractal topology with enormous complexity [84][30][42]. For example, the orthogonal transformation between the compact dimensions and the spatial field leads to wave-particle duality or uncertainty. Furthermore, augh gravity is Lorentz invariant [85][86], the particles' dimensional anisotropy turns gravity into a bipolar force, causing the Tolman temperature gradient [87][88].

Inertia

Brans showed that if one adopts the modern geometric interpretation of GR, then the inertial mass of a free test particle cannot change in a gravitational field [2][3]. However, in the Machian view, the global mass distribution must determine the inertial frame of reference, the inertial mass, and acceleration [87]. Although particles appear constant, their vibrations are related to the field strength (curvature or metric). Therefore, an object's position corresponds to a freely hanging plumb (Fig7).

Deviations in the angle of that plumb (location of the object) change the equilibrium of the whole universe and lead to inertia. Inertia is proportional to the object's mass and the field strength (i.e., topological distance from the black hole) represented by the metric $g(v, w)$. Congruent with the intuitive expectation that the inertial mass is related to the global topology [89], a test particle mass increases in the vicinity of a large mass, such as a black hole[52]. Therefore, inertia reflects the whole universe's field structure and global dynamics, as Mach had insisted.



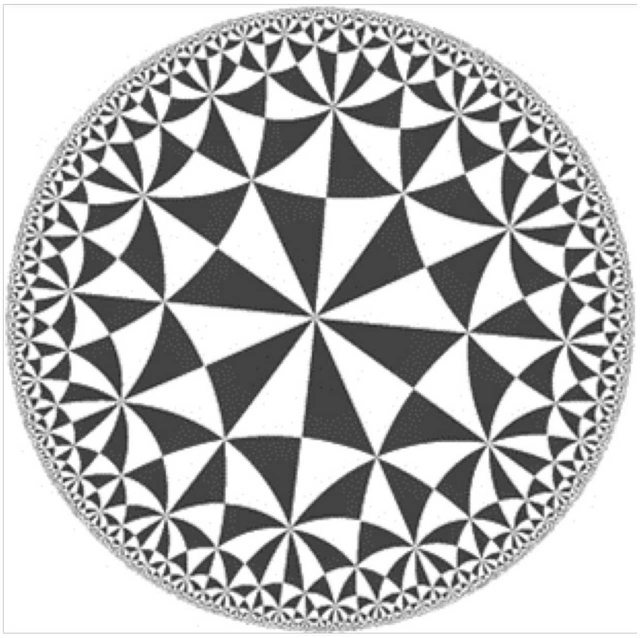


Fig7. Left: The global topological map of the universe Right: The hyperbolic plane with its inherent self-symmetries satisfying the AdS/CFT conjecture (Wikimedia Commons: Tom Ruen). The immense field strength of the cosmos' outer boundary slows expansion. The vacuum energy of white holes is a negative pressure that expands space into the fourth dimension (hyperbolic geometry). The poles' opposing dynamics (2 and 4 dimensions) enforce constant interactions on the dynamic and unstable three-dimensional regions (marked by white arrows), causing complexity and biological evolution.

Discussion and Summary

We insulated a compact WF with an information-blocking horizon to form a spatial field, thereby introducing an energy requirement for their interaction. The energy requirement of interaction stabilizes the spatial curvature and satisfies conservation principles. The insulated quantum waves form discrete energy levels, but the field curvature is a smooth surface. Therefore, the PaW mechanism originates in the microstructure of space and gives rise to a quaternion cosmic structure.

The poles' dimensional anisotropy produces an accelerating universe without exotic particles or forces. Dimensionality modifications cause the Tolman temperature gradient and the destructive power of explosions and collisions. As massive objects form gravitational lensing, cosmic voids cause the divergence of light rays. On temperatures close to absolute zero, particle production [28] can drive cosmic expansion [45][28]. Therefore, Einstein's gravitational theory might be a limiting case of a more general theory with space as a dynamic variable [38].

Time is defined by entropy generation and the entropy rate. However, the directionality of time might originate in the irreversibility of interaction [46]. The Lorentz transformation also indicates that entropy increase can occur through different mechanisms. For example, gravity creates disorder, but acceleration is an order forming via the degrees of freedom. The latter can explain negative temperatures' antigravity-like effects. Gravity-free systems' work potential may give Maxwell's demon the last laugh [90].

The universe's antipodal sinks and sources satisfy Mach's principle and explain three puzzles in physics: 1) the behavior of cold vacuum in the lab, 2) the expansion of space, and order increasing entropic effects (increasing degree of freedom), and 3) the accelerating expansion and power-law scaling relation between the void size and the corresponding cluster mass [67].

The WF's and spatial topology's orthogonal interdependence is a global self-regulation that continuously fine-tunes the universe's parameters. It can help understand the cosmological constant and the coincidence problem (matter density depends on dimensionality). The three-dimensional Euclidean space represents a dynamic birthplace for the formation of stars, planets, and biological evolution.

Physics' solid foundation should not be changed at a whim. Nevertheless, the persistent questions at the core of relativity (dark matter and dark energy), cosmology (the horizon problem and inflation), and quantum mechanics urge us to reconsider fundamental questions at the heart of physics. The above considerations represent only baby steps, but point to numerous agreements with large-scale observations of quantum mechanics, relativity, and accelerating expansion. Further studies, such as computer simulations and negative temperature experiments in a microgravity environment can verify its points.

Declarations

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