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On the limits of knowledge and the evolution of the physical laws in non-Euclidean universes

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The anthropic principle suggests that the universe's fundamental constants are precisely fine-tuned to allow for life. However, by incorporating a dynamic physical perspective of nature, such as the multiscale thermodynamic principle known as *Principium Luxuriæ*, it is found that fundamental constants and forces of the universe may evolve over time in a non-Euclidean universe. If the universe has this geometry, it would have profound implications, which are discussed in this paper. For example, that the conditions conducive to life are not static and finely tuned but rather transient, undermining the need for a fine-tuned universe. Given that multiscale thermodynamics requires external forces, it's plausible that the universe's expansion could be linked to the existence of other phenomena such as other universes acting as external forces, each with their own evolving laws of physics. This suggests that life might be a transient and coincidental occurrence across multiple universes, if they exist. Additionally, the ever-evolving physical laws limit our ability to fully comprehend the universe at any given time. As we inevitably overlook certain aspects of reality, physical systems cannot be fully explained by the sum of their parts. Consequently, emergent phenomena like consciousness could not be studied from a self-referential perspective, as there will always be elements beyond our understanding.

I. INTRODUCTION

Since the dawn of civilization, humanity has gazed at the night sky and pondered the existence of the universe. Why is the cosmos as it is? Why do the laws of nature permit life? The anthropic principle, a concept that has captivated philosophers and scientists alike, posits an intriguing answer: Our universe appears to be fine-tuned to allow for conscious observers like ourselves [1–3]. A contrasting perspective that challenges this fine-tuned view is offered by the multiverse hypothesis. This implies that our universe is only one of countless others, each with distinct physical constants. In this framework, our universe's capacity to support life is seen as a matter of chance rather than deliberate design [4, 5]. Beyond the debate over cosmic fine-tuning, fundamental constants, the numerical values governing interactions between particles and forces, play a pivotal role in shaping the universe. These constants not only define the properties of matter and energy, but also influence the large-scale structure of the universe [6], giving rise to phenomena such as fractals [7–12], hierarchies and emergent properties [13–23]. Even consciousness, as an emergent property of complex systems [24], could be intrinsically linked to these constants.

A promising tool for understanding the relationship between fundamental constants, the fractal dimension of universe D, and emergent systems is multiscale thermodynamics [25, 26]. This theory proposes that complex systems can be described in terms of multiple scales, from the microscopic to the cosmological, based on the fractal dimension. Moreover, it suggests that the evolution of these systems is driven by energy and matter flows across these different scales. Evidence suggests that the fractal dimension of the universe is not static but evolves over time as it has different values in different epochs [27–29]. Therefore, it is natural to ask whether fundamental constants and the emergent properties of complex systems are related through this changing theoretical framework [30–32]. Consequently, the potential for long-term variability in these constants merits serious consideration within the context of the anthropic principle. Moreover, critical realism, with its focus on complexity and epistemological limitations, provides a suitable theoretical lens through which to examine these concepts. In the domain of complex systems, critical realism asserts that the whole is more than the mere aggregation of its parts, thus challenging reductionist accounts [33]. By acknowledging that our theories are always incomplete models of reality, critical realism invites us to consider the possibility of levels of reality beyond our current understanding [34]. If we apply this perspective to fundamental constants, we can ask whether our current understand-

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ings are complete or if, like the fractal dimension, these constants might be subject to change throughout the history of the universe. This dynamic view of the universe presents profound philosophical implications. Could we be witnessing a constantly transforming universe where the laws of physics are not immutable but evolve along with it? What does this imply for our understanding of the nature of reality? To address these questions, this paper will explore this possibility in depth. Given its interdisciplinary nature, this work is divided into two parts. In the first part is primarily physics-oriented and comprises sections II and III. These sections will delve into the connection between fundamental constants, the fractal dimension of the universe as understood through multiscale thermodynamics, and the resulting physical implications. The second part aims to invite a broader audience to comprehend the implications of the preceding sections. This is comprised of Section IV, which will explore a series of philosophical consequences, encompassing the anthropic principle and critical realism, and contrasting ideas. Section V will discuss this perspective from a broader philosophical standpoint, while the conclusions will be presented in Section VI.

II. PHYSICAL CONSTANTS AND FRACTAL DIMENSION

Current galactic structures can be described as fractals with dimensions around 2.2 or varying between 1 and 1.2, averaging 1.2 [27, 29]. It should be noted that, according to Ref. [35], the fractal dimension of a given system can be related with other dimension by adding an integer constant. For instance, if D is 1.41, its two-dimensional approximation would be 2.41. By expressing the Golden Ratio in terms of fractal dimension D (see Equation A5 in Appendix A and Figure 1 for mathematical development), the observed D of galactic structures can be derived, thus revealing a deeper connection between the two quantities. Given D's temporal evolution from high values close to the big bang time ($D > 2.6$) [28, 36, 37], φ is expected to evolve similarly. As depicted in Figure 2a, the value of φ decreased from values near 4 at the time of the Big Bang to its present value of around 1.6. Viewing φ as a ratio a/b, its change can be attributed to variations in a and b. In a rectangular representation, where a and b describes the rectangle sides, the evolution would involve a contracting and b expanding until they equalize, transforming the rectangle into a square (Figure 2b). In the context of multiscale thermodynamics, D is understood as an energy dissipation balance, with lower values indicating more efficient large-scale (dS) and higher values for smaller-scale (dS_0) dissipation [26, 38]. Equation A10 in Appendix A shows that φ is a function of dS and dS_0, implying that all structures characterized by φ are essentially physical systems formed by dissipating energy. Consequently, the convergence of a and b implies a system exhibiting a more substantial macroscopic energy dissipation.

Appendix A demonstrates that π can be expressed in terms of φ, with π increasing as φ decreases during cosmic expansion. Although π is conventionally understood as a constant and is thus immutable by definition, it is conceivable that it could assume different values within a non-Euclidean geometric framework (e.g., Ref. [39]). As some authors have explored such geometries in the context of cosmological studies (e.g., [40–42]), the following analyses will proceed under the assumption of a universe governed by non-Euclidean conditions.

Figure 3 illustrates these parameter changes and the rate of change of π. Figure 4a schematically illustrates π's deviation from the classical ratio of circumference to diameter. Unlike the convergent nature of φ, π exhibits a growing circumference relative to diameter. Figures 4b and 4c explore potential causes for this discrepancy, suggesting non-planar geometries for both circumference and diameter. Essentially, π reflects the extent to which these geometric elements deviate from a two-dimensional plane.

III. EFFECTS IN SOME PHYSICAL CONSTANTS

The change of π impacts fundamental non-Euclidean physics due to π's presence in key equations. For instance, the vacuum magnetic permeability μ_0 is proportional to π [43], suggesting a rising μ_0 over cosmic time (Figure 5a, blue curve) and weaker past magnetic fields [44]. This affect permittivity ε_0, decreasing over time (Figure 5a, red curve), suggesting a more electrically active early universe. The change in c potentially influence current light measurements and frequency (Figure 5b). Consequently, light would have traversed greater distances in shorter time frames, causing distant objects to appear nearer. This variation in frequency implies an approximate 1000 nm wavelength shift, corresponding to a redshift of around 1.6. This has been observed in galaxy clusters under a constant c [45]. Note that D can be interpreted as a time marker, with $D = 3$ corresponding to 27 billion years ago and $D = 2$ to 6.8 billion years in the future, aligning with recent estimates, such as Ref. [46]'s 26.7-billion-year age of the universe and reinforcing the potential of D as a cosmological clock (Figure 5). Since the gravitational constant G_E is a function of π (Equation B3 13 in Appendix B), the gravitational force is thereby influenced. This relationship implies that gravity during the Big Bang was approximately 10% weaker than its current state (black curve in Figure 5c). The strength of electromagnetic forces, characterized by the fine-structure constant α, which is also π-dependent (Equation B4 in Appendix B and Ref. [47]), is also predicted to increase over time (see Figure 5c, blue curve). Given that α can also be linked to the Golden Ratio [48], any variation in φ would consequently affect α, further supporting the hypothesis of α's

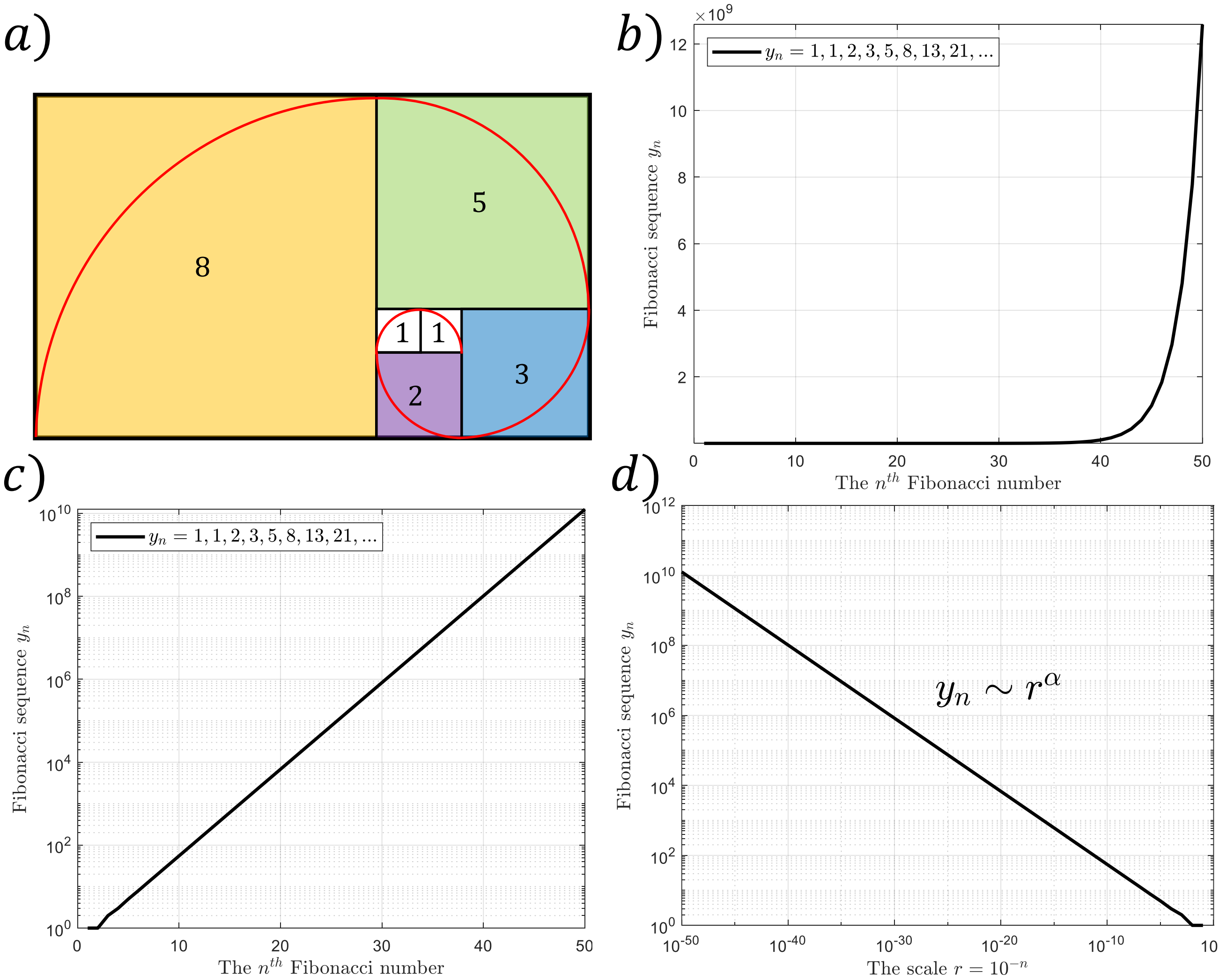

FIG. 1. a) shows the representation of the Fibonacci sequence, where the red curve corresponds to the Fibonacci spiral. b), c), and d) depict different graphical representations of the Fibonacci sequence. Figure 1b displays the sequence based on the Fibonacci numbers, while Figure 1c presents the same data with the vertical axis expressed logarithmically. In Figure 1d, the effect of the variable change described by Equation A2 is demonstrated. This last figure illustrates that the Fibonacci sequence can be expressed as a power law.

non-constancy.

IV. PHILOSOPHICAL CONSEQUENCES

This section outlines the potential consequences and paradigm shifts arising from a non-Euclidean universe with mutable laws. Such implications may extend to profound aspects of physics, mathematics, and critical realism.

A. Principium Luxuriæ vs the Anthropic Principle?

The anthropic principle argues that the universe's constants, crucial for life, appear "fine-tuned" because even slight changes in fundamental forces might render life impossible [49–51]. Some authors regard fine-tuning too precise, implying that life seems improbable by chance alone [52]. Besides, there is no explanation why life arrived much later than the universe's birth, requiring a pre-existing Earth and the formation of complex molecules for life's building blocks. This principle also assumes a fixed set of universal parameters. These analyses and definitions, however, are predicated on a Euclidean framework. Equations B3 and B4 show that the issue of universal constants is significantly altered

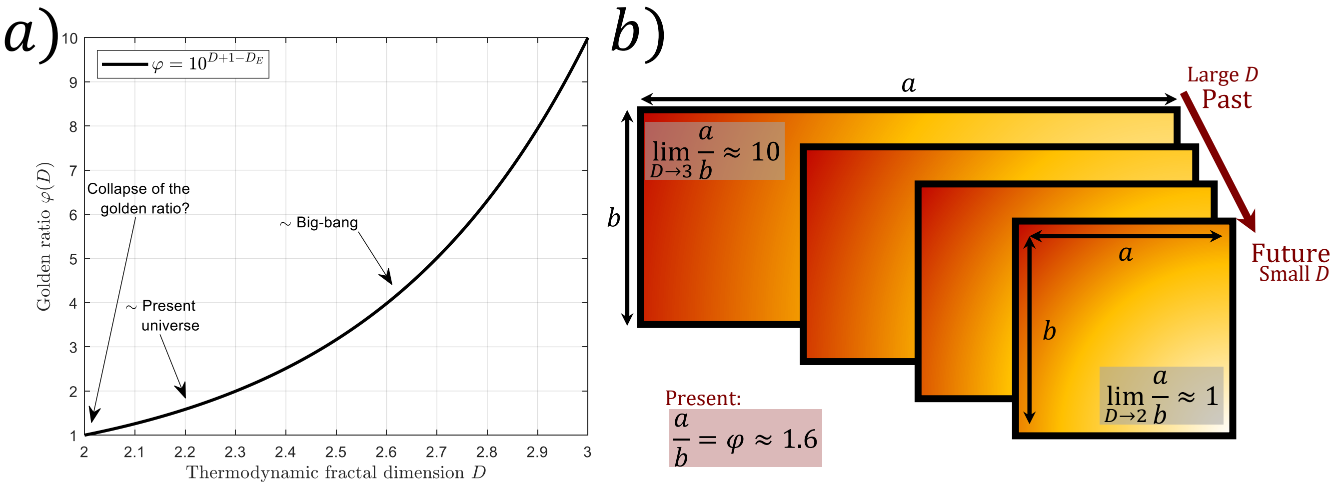

FIG. 2. a) The evolution of the golden ratio value as a function of thermodynamic fractal dimension is shown. As it has been suggested that D may change as the universe progresses, it is shown that the golden ratio decreases. The figure shows the current value of φ and what it could have had at the beginning of the universe. b) A schematic representation of the change in the golden ratio over time can be made by considering the interpretation given by the ratio between the sides a and b of a rectangle. As D decreases, the ratio a/b tends to one, so the sides of the rectangle tend to be similar (a square).

in a non-Euclidean universe, where they behave as time-varying parameters. This raises the possibility of early eras where fundamental forces were too weak for life, potentially hinting at a dynamic universe with evolving parameters. In particular, Equation B4 suggests that a weaker electron charge (smaller fine-structure 'constant' α) would have resulted in weaker electric forces, hindering the formation of complex molecules essential for life [43]. Similarly, a weaker gravitational force (Equation B3) would have impeded the formation of planets and stars. Notably, neither complex molecules nor planets are observed in the early universe. This aligns with the "Principium Luxuriæ" hypothesis, which posits that fundamental forces might have strengthened over time, potentially due to evolving constants. This concept of non-constant forces resonates with longstanding theoretical explorations by Refs. [53–55]. The anthropic principle, sometimes used to argue for a fine-tuned universe by a higher power [56], faces challenges. The controversial multiverse hypothesis suggests numerous universes with varying constants, potentially explaining the seemingly arbitrary values we observe [4, 5]. This allows life-supporting conditions in some universes, while others remain sterile [57]. The alternative to multiverse theory is simply accepting the universe "is what it is," which is seen as unscientific [58]. If the universe's constants changed over vast timescales, the need for anthropic explanations like the multiverse or fine-tuning would diminish. These concepts attempt to explain the "special" values of the constants that allow life. With evolving constants, there's no need for a preordained or statistically necessary value for life to arise. Life simply appears under temporarily favorable conditions within a constantly changing universe. In essence, the constants are not "fine-tuned" for life; they merely evolve, and life emerges under compatible conditions. While fine-tuning arguments with a multiverse can be dismissed, the concept of multiple universes remains open. The Principium Luxuriæ suggests fractal dimensions, like mass distribution, require an external force [26]. This external force could be interaction with other universes, potentially explaining the universe's expansion [59] or changing forces [60]. The latter aligns with the idea of an open universe interacting with others, solving the non-conservation issue proposed by the Principium Luxuriæ. This logic suggests a two-way street: our universe might influence others, causing their internal forces to evolve due to inter-universe interactions. Consequently, other universes might also lack fine-tuned constants for life. This scenario surpasses the anthropic principle's simplicity. In this framework, none of the universes are preordained for life; instead, they arise from complex interactions without necessarily favoring their existence. Evolving parameters could impact the future. Increased electromagnetic and gravitational forces might concentrate matter, eventually leading to the collapse of complex molecules and potentially life as we know it.

B. Scientific Realism and Gödel's theorem

Scientific realism posits that existence is absolute and independent of our observations and theories. This implies that nature possesses immutable rules, while our ability to access them limits our knowledge (e.g., Ref. [61]). However, if the universe alters its laws of nature (as shown in this work), our objective knowledge shifts in accordance with the changing reality. This analogy

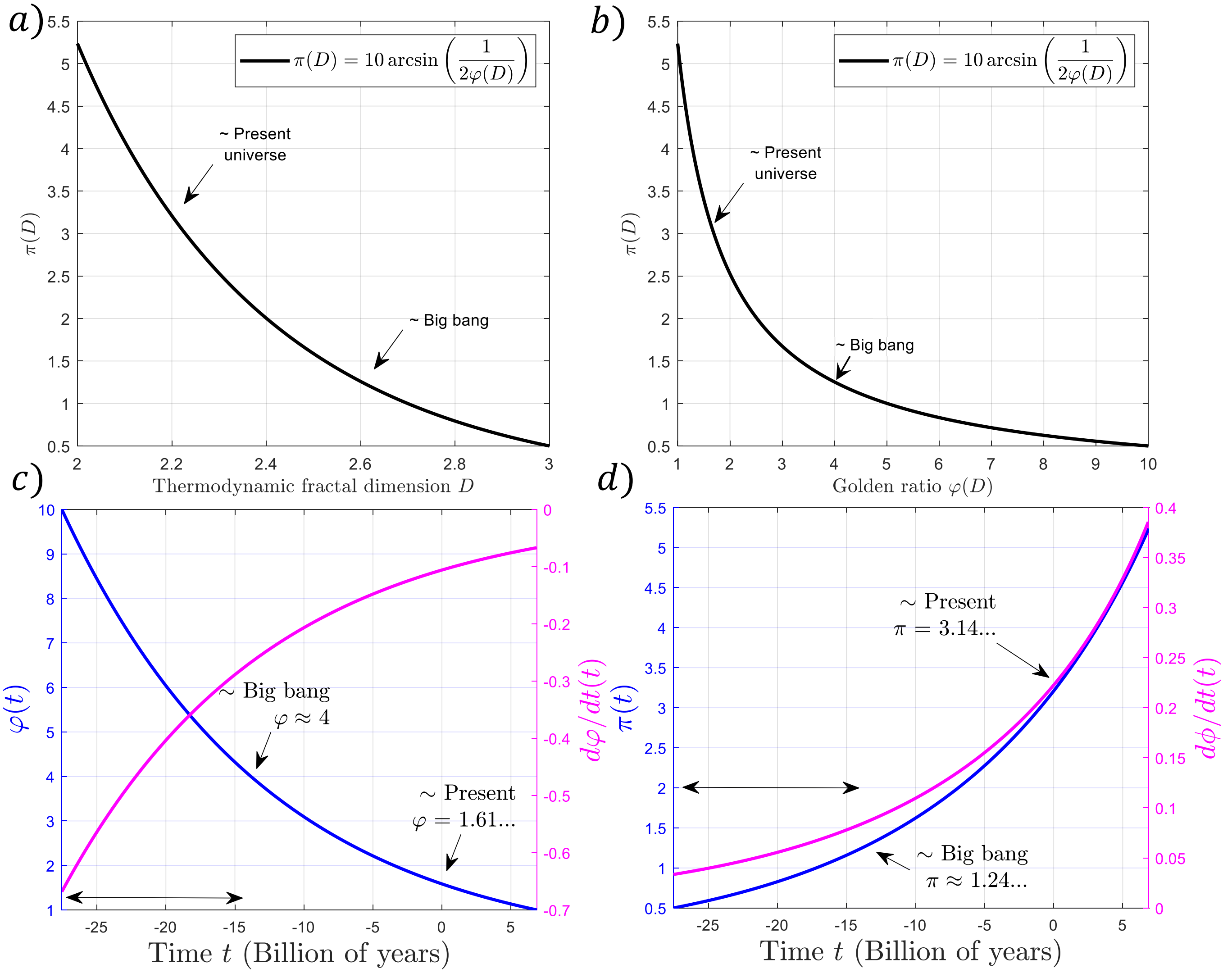

FIG. 3. Figures a and b show the change of π as a function of the thermodynamic fractal dimension and the golden ratio, respectively. If we consider that the increase in D is associated with a reversal in time, we can find how φ and π change over time as shown in panels c and d, respectively. That is, φ decreases while π increases.

resembles the notion that a river is not the same upon each observation (Heraclitus' River), as its constituent particles have already moved away from the measurement point (e.g., Ref. [62]). In essence, what we currently perceive as reality will cease to be in the future, rendering absolute knowledge forever beyond our grasp. This has profound implications for scientific advancement. For instance, scientific realism advocates scientific progress, asserting that we are constantly approaching the truth, with each experiment or result enhancing our understanding of nature (e.g., Ref. [63]). If the universe alters fundamental principles of reality, it is likely that, in the long run, what we term progress will conflict with prior knowledge, as current knowledge describes a reality different from that of the past universe. This can be represented as follows: Let the evolving state of knowledge at time t be denoted by $K(t)$, while the reality itself is represented by the set R_0. Note that the concept of K, as used in this context, represents the maximum attainable knowledge of nature, not a reflection of our technological capabilities. In other words, K signifies the extent of knowledge that the universe itself permits us to acquire. It is expected that our knowledge will always be a sub representation of the immutable reality, hence the relationship between K and R_0 can be expressed as:

$$K(t) \subseteq R_0 \tag{1}$$

Where R_0 is constant. On the other hand, the advance of scientific progress over time can be expressed in the form:

$$\lim_{t\to\infty} K(t) = R_0 \tag{2}$$

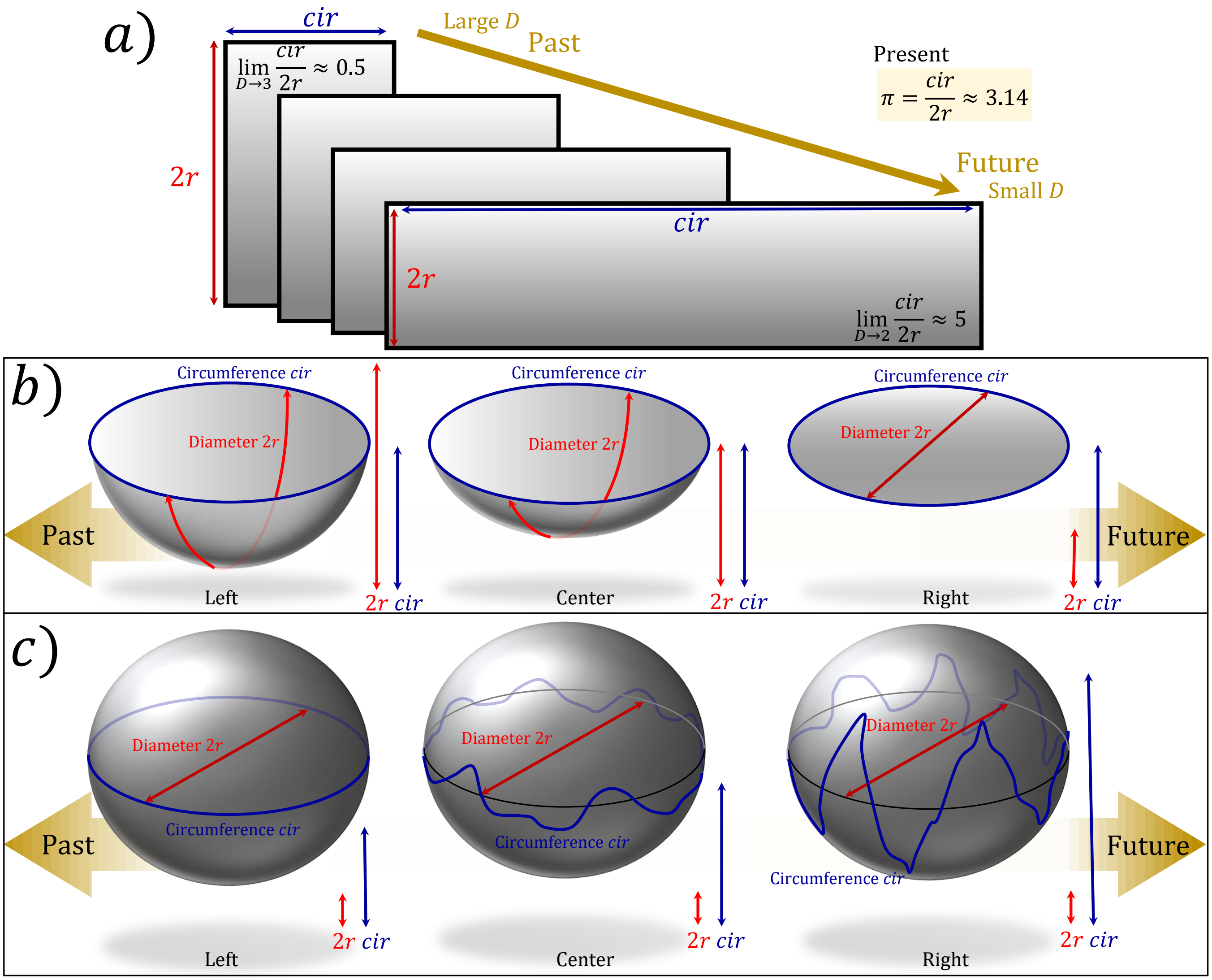

FIG. 4. Representation of the change of π as a change in the ratio between the circumference cir and diameter $2r$. a) Representation of the change of π using the sides of a rectangle, as in Figure 2b. When D tends to 3 (past), the ratio tends to 0.5, while when D tends to 2 (future), the ratio tends to 5. b) Representation of the change of π considering that the diameter (double red arrows) could be greater that the circumference because it is not in the same plane as the circumference (blue). c) Representation where the circumference (blue) is the one that leaves the plane where the diameter (double red arrow) is located, allowing the circumference to be larger as the time progresses.

The presented Equation 2 implies that over a sufficiently extended period, we could attain complete and accurate knowledge of reality. However, it is crucial to consider the inherent distinction between knowledge as an internal state of the mind and reality as an external entity. This distinction suggests that Equation 2 should be viewed as an approximation rather than an absolute equality. Furthermore, Equations 1 and 2 assume that R_0, the set representing the true reality, remains constant. However, if the laws of nature are subject to change, influenced by evolving constants, then R_0 should be redefined as $R(t)$, a time-dependent set. Consequently, Equation 1 would only hold true for a specific moment in time, t_0. That is:

$$K(t_0) \subseteq R(t_0) = R_0 \tag{3}$$

This would mean that it cannot be said that our knowledge was always a sub representation of reality. This means that there could be a time t_1 in which the expression:

$$K(t_1) \nsubseteq R \tag{4}$$

Be valid. In other words, if reality is entirely measurable, it implies the existence of potential forms of knowledge that cannot be verified (since they lie outside the realm of the real and measurable). However, within a given

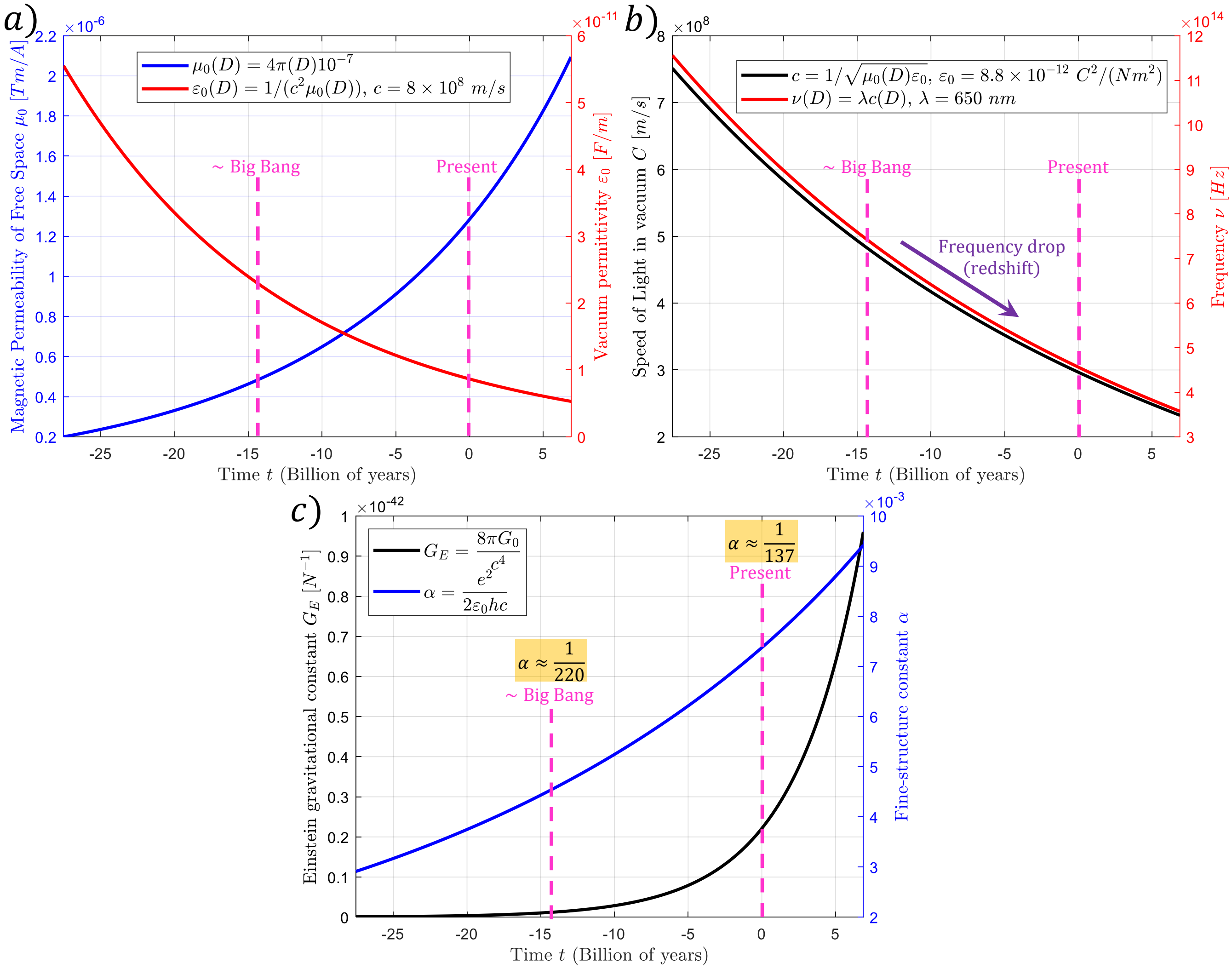

FIG. 5. a) The blue curve shows the change in the vacuum magnetic permeability, assuming that π can change. It is shown that this increases over time. Since the electrical permittivity ε_0 depends on μ_0, an increase in μ_0 implies that ε_0 could decrease (red curve). b) The black curve shows how the speed of light would evolve if the permittivity ε_0 is considered constant, as it does not depend directly on π. In this case, the speed of light would decrease over time. An interesting implication of this is to consider the wavelengths λ (in this case red, 650 nm) and how they vary as time evolves. It is shown that there would be a redshift as the frequency would also decrease over time. c) Two examples of physical constants that explicitly depend on the speed of light are the gravitational constant G_E (black curve) and the fine structure constant α (blue curve). Both increase as the universe evolves.

system, K could be true despite not being real or measurable. This suggests that as the laws of nature change, there may exist true knowledge that was measurable in the past but may cease to be measurable or demonstrable within our current or future understanding. This parallels Gödel's incompleteness theorems, which establish that there are truths in certain systems that cannot be proven [64, 65]. In this sense, Gödel's description could be analogous to the logic of a state of knowledge within a universe with changing laws. Equation 4 could also mean that our senses are not good mechanisms for collecting information and interpreting the environment, or they are unreliable mechanisms. In this situation of errors of interpretation, one could reach erroneous conclusions, such as assuming that R and the laws of nature are constant over time. The situation described by Equation 4 can be applied on a smaller scale to the case of the first human hunter-gatherers who, upon perceiving an unstable and unpredictable world (equivalent to saying that their reality R mutates), decided to generate fictional stories that are not measurable as part of their knowledge K (e.g., Ref. [66]). Nowadays, we could say that, since the things that happen around us also have a certain amount of uncertainty or unexpected change (or a changing R), then it is normal to generate or ascribe to fictitious knowledge. On the other hand, Equation 2 would be valid

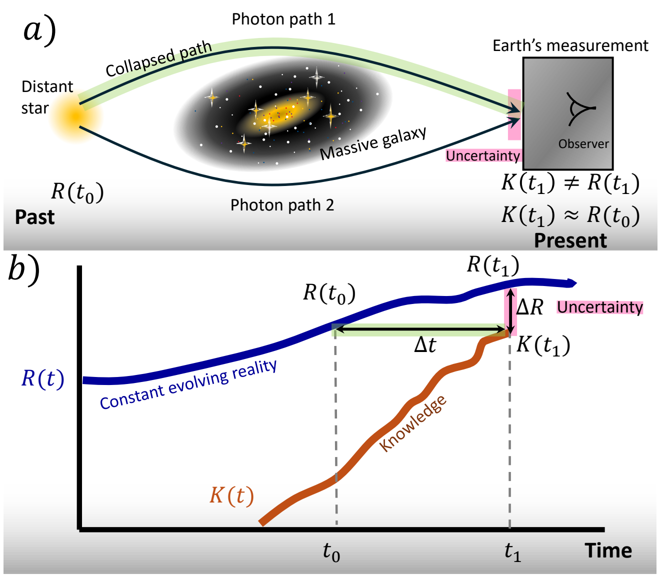

FIG. 6. a) this diagram illustrates the Participatory Anthropic Principle scenario involving two photons emitted from a distant star, each following distinct paths (curved black arrows). If a galaxy's gravitational influence can bend the light's trajectory, the paths could converge at a specific point, potentially on Earth where an observer (gray rectangle) is present. The act of measurement would select one path (highlighted in green), implying that the light from path two never originated, which, according to Wheeler, would signify an influence on the past. b) diagram that illustrates the evolution of reality R (blue curve) governed by changing physical laws and the evolution of our knowledge K (red curve) over time. According to Equation 7, our knowledge K about reality R at a given instant t_1 is always limited by an uncertainty ΔR (transparent magenta double arrow). This implies that knowledge at time t_1 can be associated with a prior reality $R(t_0)$.

only for an R' that represents an outdated reality of the form $R' = R(t')$, where $R(t')$ represents a reality from some previous or posterior moment t'. Considering this, Equation 2 becomes:

$$\lim_{t\to\infty} K(t) = R' = R(t') \tag{5}$$

Since reality R' can evolve independently of t, it can be said that the state of knowledge K may not converge to reality R. This case can be expressed as:

$$\lim_{t\to\infty} K(t) \neq R \tag{6}$$

Equation 6 suggests that the pursuit of complete comprehension of reality may be an inherently unattainable long-term goal. As the laws of nature evolve and the value of R expands, potentially encompassing elements outside the current domain of knowledge, reality itself may expand in a manner that outpaces our ability to fully grasp it, maintaining a perpetual gap between our knowledge and reality.

C. Wheeler's Participatory Anthropic principle and the past

The Participatory Anthropic Principle proposed by Wheeler draws upon an interpretation of quantum mechanics, particularly the wave function collapse, which describes the probability of encountering different states representing a particle-scale system [67–69]. These quantum states can coexist until they collapse, or are selected into one, through a measurement process. Here, Wheeler extended this concept to the universe as a whole. Building upon the double-slit experiment with extra glass, he proposed that the universe itself could be in a superposition of quantum states until it is observed or interacted with by conscious beings (e.g. Ref. [70]). This implies that the very existence of the universe might depend on the presence of observers or that the universe is self-created. This suggests that present-day observers could influence the past [71]. To understand this, consider the case of light propagation from a distant star. Two light beams propagating in different directions can be bent due to the presence of a massive object, such as a galaxy generating a gravitational lens, and converge at a later point like the Earth (see the curved arrows in the schematic Figure 6a) [72, 73]. This means that two photons can take different paths before reaching the Earth, forming an interference pattern similar to a wave.

According to the double-slit experiment, when one proceeds to measure where the photon originates (observer in Figure 6a), it behaves as a particle, defining a single path taken (highlighted green curved upper arrow in Figure 6a) [74]. According to the Participatory Anthropic Principle perspective, measuring the traveling photon on Earth automatically defines the path the photon had to take millions of years ago in the past, suggesting an influence of the present on the past. Nevertheless, Equations 4 and 6 suggest a different scenario. If the fundamental rules of nature are not static but undergo constant transformation over time, the notion of attaining absolute understanding of reality becomes elusive. This inherent uncertainty, denoted by ΔR, is not merely a theoretical construct but a reflection of the ever-changing nature of the universe itself. This uncertainty manifests not in some distant future but in the present moment. Every piece of knowledge we acquire about reality carries within it the imprint of a past reality, a limitation imposed by the dynamic nature of the cosmos. In other words, if we represent a past time as t_0 and the present time as t_1, we can establish that our knowledge $K(t_1)$ is not equivalent to the true reality $R(t_1)$. Instead, our present knowledge can only approximate the state of reality that existed in the past, $R(t_0)$. That is:

$$\lim_{t\to t_1} K(t) \approx R(t_0) \neq R(t_0) \tag{7}$$

This can be seen in the schematic in Figure 6b that illustrates the interplay between an evolving reality (blue curve) and our ever-expanding knowledge (red curve).

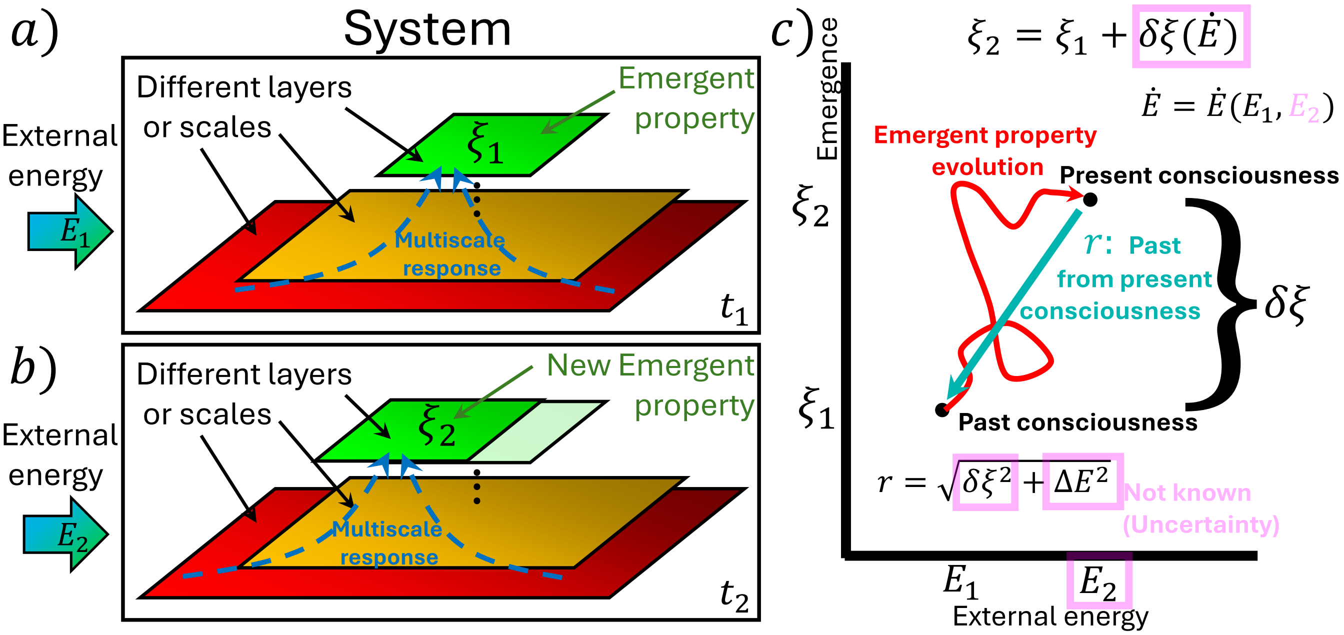

FIG. 7. Schematic of emergent behavior in the context of multiscale thermodynamics. a) shows how an external energy generates a response at multiple scales (red, green, and yellow rectangles) where an emergent behavior ξ_1 appears. b) shows how the emergent behavior changes toξ_2 when the external force changes. c) indicates how emergent behavior changes as a function of the change in external energy (red curve). $\delta\xi$ is the change in emergent behavior that depends on the change in external energy. Since the (present) state of E_2 cannot be known, $\delta\xi$ cannot be known either. If emergence corresponds to consciousness, the present consciousness can only analyze past consciousness through the form $r = \sqrt{\delta\xi^2 + \Delta E^2}$, where r is the measurement of past consciousness from the present consciousness. Thus, $\delta\xi$ and ΔE depend on E_2, so consciousness cannot study itself.

The inherent uncertainty in our understanding is captured by the formula $\Delta R(t_1) = R(t_1) - K(t_1)$ (transparent magenta double arrow in Figure 6b). This represents the gap between the true reality $R(t_1)$ at a given time t_1 and our limited knowledge $K(t_1)$ of that reality. Note that ΔR is always unknown because the R of a present time is inaccessible. The transparent green double arrow emphasizes that despite our efforts, there will always be a time lag, Δt, preventing us from achieving complete knowledge, as it would always refer to a past reality. In the scenario proposed by Wheeler, an inherent uncertainty always exists regarding the location of a photon (or quantum particle) in its present state. In this context, Heisenberg's uncertainty principle, which states that there is a fundamental limit to the precision with which we can simultaneously measure certain pairs of complementary properties of a particle (e.g., Ref. [75]), could be considered an equivalent version of ΔR in a universe with evolving physical constants. Additionally, it can be assumed that this pair of photons departed from the star at a time t_0 when the physical reality was $R(t_0)$, while the measurement process occurs at a time t_1. Consequently, the measurement process increases our knowledge $K(t_1)$ and aligns it with the reality $R(t_0)$ in which the photon left the star. It is crucial to emphasize that $K(t_1)$ is maximized at instant t_1, implying that it is reality itself that limits what can be detected, not a matter of ignorance or inadequate measurement techniques. In essence, the universe itself imposes a constraint on what can be known about it. This suggests that the present does not determine the past; rather, the present is inherently uncertain, preventing us from knowing a particle's state until we acquire sufficient knowledge equivalent to that of a past physical reality (in this case, the photon's actual path).

D. Emergent behaviors

Within the framework of multiscale thermodynamics, emergent behaviors arise from systems seeking to dissipate excess energy macroscopically, resulting in a low D, defined as a balance between different scales. This perspective posits that emergence occurs when numerous system parameters converge in their pursuit of energy expulsion, giving the illusion of coordination. As the theory does not mandate the independence of lower-scale components, it can accommodate both weak and strong emergence. Human body temperature exemplifies this: while composed of Earth-abundant materials, the individual molecules have a low temperature, yet the collective dissipates energy more efficiently, leading to a higher body temperature. Thus, life could be viewed as an energy dissipation mechanism, where order is an emergent property. This interpretation offers a reductionist view of emergence, shifting the paradigm from 'the whole is greater than the sum of its parts' to one where emergence is merely a consequence of energy dissipation across scales.

While this reductionist perspective is appealing, it may oversimplify the complexity of emergent phenomena. Firstly, this perspective necessitates an interplay between different scales or sizes, suggesting that a system cannot be explained solely by its constituent parts. In other words, the interaction between strata or scales gives rise to emergence. This requirement for multi-scale interactions is a fundamental aspect of critical realism [76].). Secondly, inter-scale interactions, triggered by external energy, render multi-scale systems irreducible. This is because emergent behavior is contingent upon context and external influences beyond the system itself. Consequently, the sum of internal elements is insufficient to explain the complete behavior. This insight aligns with critical realism [33]. Finally, considering that both the strength of interactions and their external energy source can fluctuate over time, understanding the emergence process becomes challenging without temporal discrepancies. This implies that a fixed or universal explanation for emergence cannot be expected. In other words, if a system exhibits emergent properties, the causes of such emergence are inaccessible. Figures 7a and 7b illustrate this: an external force induces a multiscale response, leading to an emergent behavior ξ_1 that shifts to ξ_2 when the external energy changes ($\dot{E}$). Mathematically, this is $\xi_2 = \xi_1 + \delta\xi$ (Figure 7c), where $\delta\xi$ is dependent on the change in external energy, $\delta\xi(\Delta E)$. However, ΔE, being the difference between E_2 and E_1 in time (with E_2 being the present external energy), cannot be fully known. In the specific case of consciousness as an emergent phenomenon, a parameter r can be introduced to represent the relationship between the present consciousness ξ_2 and past consciousness ξ_1 (Figure 7c). That is, r represent the measurement of the emergent consciousness ξ_1 from ξ_2. This parameter, $r = \sqrt{\delta\xi^2 + \Delta E^2}$, is dependent on both $\delta\xi$ and ΔE, which are in turn reliant on the unknown E_2.

V. SUMMARY AND DISCUSSIONS

This study posits that multiscale thermodynamics, which is rooted in the generalization of the action-reaction principle by enabling energy dissipation across various scales and potentially accounts for the power-law distributions observed in the universe [25, 26, 38], offers a novel interpretation of foundational aspects of physics, mathematics and reality itself in non-Euclidean universes. As the results encompass several aspects of science; the discussion section is separated mainly into two different topics. That is, the physical and the philosophical consequences.

A. Evolving physical constants

Firstly, both fundamental constants and the intensity of forces evolve over time as the (non-Euclidean) universe expands. To substantiate this claim, it explores the possibility that fundamental parameters such as the golden ratio φ, π, the gravitational constant G_E, or the fine-structure constant α − objects of ongoing research [77–80]− may be dependent on the fractal dimension D, which vary with time. This dependency implies a corresponding evolution of the universe's physical properties. For instance, Equations A5 and A6 link D to φ, while Equation A10 suggests that systems characterized by φ are products of dissipative energy mechanisms. Given the prevalence of φ and π in the fabric of spacetime [81, 82], these constants may be associated with changes in spacetime itself, such as variations in anisotropy, which is a potential feature of non-Euclidean geometries (e.g.,[83]). Furthermore, π is strongly linked to changes in permeability and permittivity of vacuum. It is conceivable that weaker electromagnetic fields existed in the past, hindering matter from coalescing. The possibility of a variable speed of light also warrants consideration in a non-Euclidean universe. Despite high-precision measurements supporting a constant speed of light, the hypothetical scenario of a faster speed of light in the past remains a topic of ongoing investigation, especially if the universe is non-Euclidean. Consistent with this, Figure 5c indicates a potential decrease in both gravitational and electromagnetic forces during the early universe. The lower value of the gravitational constant (black curve) implies a weaker large-scale attraction, potentially delaying the formation of stars and galaxies. Similarly, a smaller fine-structure constant (blue curve) suggests a weaker electromagnetic force, which could have led to less stable atoms and molecules. This increasing fine-structure constant, supported by existing research [84, 85], reinforces the hypothesis of evolving fundamental constants and their profound impact on the (hypothetical non-Euclidean) universe's structure and composition. From a geometric standpoint within multiscale thermodynamics, systems with high D tend to fill their available space [26]. This implies weaker forces initially allowed for a more even distribution of particles in the early universe. However, a decreasing D, indicative of a universe becoming less space-filling, could signify a gradual strengthening of attractive forces. This translates to an increased concentration of mass in localized regions, potentially explaining the formation of structures like planets and biological systems. The geometric perspective of the principium luxuriæ, therefore, could not only justify the existence of attractive forces at different scales but also suggest their potential increase over time and the subsequent formation of agglomerated structures, such as planets up to biological systems. This change in forces also seems to affect time. For instance, an increase in the force of gravity means that a quantity of mass distorts spacetime more. This could cause areas closer to the masses to experience time passing more slowly as the universe evolves. In this context, the expansion of the universe could be interpreted as attempting to counteract the flow of time. This framework challenges the notion of some constants being truly fundamental in the long term in non-Euclidean universes. Thus, forces are a manifestation of a universe trying to get rid of excess energy, which could suggest that the forces in nature are thermodynamic manifestations.

B. Philosophical consequences

The concept of evolving physical constants has profound philosophical implications. Section IV demonstrates a diminished role for "cosmic design" if constants are not fixed in a non-Euclidean universe. The emergence of life, under this framework, would be a consequence of intensifying forces, not a product of chance or divine intervention. This potentially suggests life could be widespread throughout the universe, arising almost simultaneously across various locations. Life, in this scenario, would not be a phenomenon defying the second law of thermodynamics but rather a manifestation of it, a dissipative process. Life, then, could be an ubiquitous yet ephemeral consequence in an ever-evolving universe. With continuously increasing forces, the future could see a collapse or convergence of molecules and mass, potentially leading to widespread black hole proliferation. Note that this idea that gravity is related to entropy on a cosmic scale has been developed for decades [86–88]. Furthermore, the hypothesis of the heat death of the universe, where black holes eventually fade away due to Hawking radiation [88], would not hold with an external energy source. Interestingly, there would be no need for other fine-tuned universes, but rather for "something external." This could suggest the existence of the multiverse perspective, but also the existence of other causes associated with this idea. In this way, the anthropic principle would not hold in these forms if the universe were non-Euclidean.

A second profound philosophical question arises: how does a changing non-Euclidean universe impact our ability to understand it? If fundamental forces are not static but evolve over time, reality itself becomes dynamic. This implies our knowledge is constantly in flux. Even if we capture a snapshot of reality at a specific point (Equation 7), it might only represent a transient state. Consequently, aspects of reality may always remain elusive. Critical realism aligns with this perspective, emphasizing the distinction between the "real world" and the "observable world." This contrasts again with the anthropic principle, which draws conclusions about the universe without fully acknowledging observational limitations. These limitations arise from the assumption of fixed constants and natural laws, which are absent in a universe with evolving physical constants.

The idea of an inherently inaccessible reality due to its ever-shifting nature shares intriguing parallels with Gödel's incompleteness theorems and Heisenberg's uncertainty principle (Section 4.2 and 4.3). These concepts, despite originating from distinct fields (mathematics and quantum mechanics), converge on a common theme: fundamental limitations in achieving complete knowledge. While the limitations of Gödel's theorems arise from inherent truths within a system itself, Heisenberg's principle focuses on measurement precision at the quantum level. This latter concept raises questions about the nature of reality at the quantum scale, such as whether wave-particle duality is an adaptation to a universe with changing physical laws. These intriguing possibilities prompt a re-examination of the fundamental underpinnings of our understanding of reality, particularly the microscopic world. However, it's crucial to emphasize that these explanations remain hypothetical and require further investigation. This is especially true given the unknown nature of the proposed "external force" and the applicability of multiscale thermodynamics at the quantum level. Consequently, the prospect of constant or evolving physical laws remains uncertain, necessitating further research. Despite these uncertainties, this perspective offers new avenues for exploring the evolution of our universe and its potential connection to others.

A final analysis pertains to emergent systems, which have gained prominence within the context of critical realism (e.g., Ref. [89]). This is largely due to the challenges of reducing complex phenomena, such as consciousness, to the mere sum of the atoms constituting the human brain (e.g., Ref. [90]). In this vein, multi-scale thermodynamics can also describe emergent behaviors. However, it requires external energy to produce them. That is, the structure of these systems arises and persists through interaction with the environment rather than as a mechanism spontaneously seeking self-sufficiency in isolation. Here, external energy acts as a catalyst or contextual factor that modulates and conditions the system's behavior. Considering external elements to explain a system's behavior implies the impossibility of reducing a complex system to the mere sum of its parts, as, by definition, something external to the system is not part of the system. The logic of this result supports more social aspects of critical realism, such as the notion that scientific activity is situated within a social context that cannot be ignored [91]. In other words, scientific knowledge emerges (as an organization) from a social context in which scientists operate. It therefore arises from external influences on science.

It is important to note that emergent behaviors may have causes, be they energy or interaction forces, that are inaccessible due to a constantly changing universe. This is relevant because there could be behaviors, such as consciousness, that cannot be explained by the present energetic or interactional conditions, as these were configured in the past. This concept supports the idea that consciousness may not be solely an emergent property, given the existence of non-local neural connections [92], which could imply a temporal component to consciousness.

Given that a universe with changing forces and interactions generates uncertainty, it could be argued that there is no way to fully understand certain emergent systems. In the specific case of consciousness, its ever-shifting nature would make it impossible to comprehend how matter becomes sentient matter. This is most evident in Figure 7c, where the present consciousness, treated as an emergent system ξ_2, cannot be related to a past consciousness ξ_1. As it depends on external energy E_2, which is unknown, consciousness cannot describe itself, leaving it in a plane of knowledge that is completely inaccessible.

C. Euclidean vs non-Euclidean universes

Euclidean universes, predicated on Euclid's postulates, are characterized by a "flat" and predictable geometry. Within these universes, parallel lines never intersect, the sum of a triangle's interior angles invariably equals 180 degrees, and distances are measured using straightforward metrics. Physical laws and fundamental constants, such as π and the speed of light, remain invariant across both time and space. This stability allows for a comprehensive and deterministic description of the universe: in principle, given a system's initial conditions, its future evolution can be predicted with precision. This determinism implies that the universe is entirely knowable, at least theoretically, as the governing laws are fixed and accessible to human understanding.

In contrast, non-Euclidean universes exhibit a more complex and dynamic geometry. Moreover, within the context presented in this work, these universes are characterized by physical constants and laws that evolve over time, introducing a fundamental uncertainty into the description of phenomena. This uncertainty manifests, in a certain respect, analogously to Heisenberg's uncertainty principle (or Gödel's incompleteness theorems), where the precision in measuring certain variables is inherently limited. Furthermore, the principium luxuriae—a multiscale response or dissipation to external influence—may operate within these universes. This energy dissipation across multiple scales can lead to the emergence of complex behaviors and mutable laws, justifying the assertion that these systems are more than the mere sum of their parts, arising instead from the interactions between these scales.

Notably, certain characteristics attributed to non-Euclidean universes, such as uncertainty and the application of the principium luxuriae to diverse systems, are also observed in our own universe, which can be considered Euclidean at human scales. This suggests that the boundaries between these two types of universes may be blurred, implying a possible coexistence of regions with predominantly Euclidean characteristics (with immutable laws and constants) and others with non-Euclidean characteristics (with variable laws and constants) within a single encompassing universe, thus creating a cosmos of even greater complexity.

VI. CONCLUSIONS

The main conclusions of this work are listed below:

- Considering the Fibonacci sequence as a distribution allows it to be linked to the thermodynamic fractal dimension of the universe. In this sense, it is found that the D of the universe is similar to that obtained when the value of φ is used.

- Since the value of D of the universe is estimated to decrease over time, it can be thought that φ is not constant, but also decreases over time.

- Since there are direct relationships between φ and π, it can be considered that π increases as the universe evolves. This means that π would not be constant in the long term for non-Euclidean spaces.

- If π were not constant in a non-Euclidean universe, it would mean that some physical constants would change, such as the magnetic permeability of vacuum, the permittivity of vacuum, the speed of light, Einstein's gravitational constant, or the fine structure constant. This is just a hypothetical academic scenario as there is no evidence for this. The following conclusions are based on this idea as a speculative exercise: non-Euclidean universe.

- A change in the magnetic permeability of vacuum could imply that space is not homogeneous, as there would be an increasing number of regions of space with higher magnetic permeability as the universe evolves.

- The change in π and φ could indicate that the expansion of the universe is anisotropic, as there would be preferred directions of expansion that could change the geometric ratios described by π and φ.

- These changes would be in line with the geometric view of the *Principium Luxuriæ*, as they indicate that the universe is tending towards a lower thermodynamic fractal dimension. This implies that the structures within the universe are beginning to fill less space (compact). This would manifest itself as an increase in electromagnetic and gravitational forces as the universe advances in time.

- It has been suggested that the evolving universe's constants, which affect the forces, can generate life in a transient manner, which eliminates the need for a fine-tuned universe.

- The existence of D requires an external force or energy source. This suggests that electromagnetic and gravitational forces could be thermodynamic manifestations of a universe trying to release excess energy. External energy sources could be other universes. If this is the case, these other universes should also have evolving forces and constants, weakening the anthropic principle.

- Since electromagnetic forces vary, the generation of complex molecules, and thus life, could be a consequence of excess energy released due to the presence of other universes. Life itself could be a dissipative process.

- If the laws governing reality are constantly evolving, there may be aspects of the universe that will forever remain beyond our grasp, perpetually obscured by the ever-changing nature of existence itself. Thus, supporting the fundamental aspect of critical realism.

- Emergent behaviors in multiscale thermodynamics align with the tenets of critical realism, suggesting the interplay of multiple scales or planes of reality.

- As emergent systems necessitate external energy, it can be inferred that emergence cannot be fully described by the system's internal components alone, but always requires an external contribution.

- Given the dynamic nature of universal laws, it is impossible to attain complete knowledge of an emergent system due to inherent uncertainty. If consciousness is considered an emergent phenomenon, it becomes evident that consciousness cannot be studied from a self-referential perspective.

- *Principium Luxuriæ*, changing physical laws, and an indeterminate present seem to be hallmarks of a non-Euclidean universe.

- Universes may conceivably exhibit a heterogeneous structure, comprising both Euclidean and non-Euclidean domains, characterized by regions exhibiting mutable physical laws alongside those exhibiting immutable physical laws.

Finally, it can be concluded that considering the multiscale perspective in the value of some fundamental constants of nature allows us to consider them as values that change as the universe evolves. This means that the analyses and conclusions of this work are only valid for universes with non-Euclidean geometries. However, it is important to emphasize that there is no evidence that these constants change in the long term, so the consequences of this work, although interesting, should be considered as a hypothetical or purely speculative theoretical development.

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CONTRIBUTIONS

P.V.-A. contributed to the first idea, model, plots, tables, writing, and editing process. E.G.C. and P.V.-A. discuss scientific discussion.

COMPETING INTERESTS

The authors declare no competing interests.

Appendix A: Golden ratio, Fractal dimension

The Fibonacci sequence, originally used to model rabbit populations [93, 94], is defined as follows:

$$y_n = 1, 1, 2, 3, 5, 8, 13, 21, ... \tag{A1}$$

The sequence is defined recursively. Figure 1a visualizes its geometric progression as a spiral. Figure 1b demonstrates sequence growth. A logarithmic transformation in Figure 1c linearizes the sequence, enabling a compact log-log plot. This is achieved by:

$$n = -\log r \Leftrightarrow r = 10^{-n} \tag{A2}$$

Figure 1d illustrates a power-law relationship, $y_n = a_0 r^{\alpha_D}$, between variables. Applying the variable change from Equation A2 to the Fibonacci sequence yields an expression in terms of a_0, α_D, and n:

$$y_n = a_0 10^{-\alpha_D n} \tag{A3}$$

The Fibonacci number can be expressed in terms of the exponent α_D using the golden ratio φ, as defined by Equation A3 and explored by Ref. [94–98] as:

$$\varphi = \lim_{n\to\infty} \frac{y_{n+1}}{y_n} = 10^{-\alpha_D} \tag{A4}$$

Refs. [25, 38] link power-law exponent α_D to fractal dimension D as $\alpha_D = D_E - D$–1, where D_E is the Euclidean dimension. Applying this to Equation A4 yields:

$$D = (D_E - 1) + \log_{10} \varphi \tag{A5}$$

For Euclidean dimensions 2 and 3, the fractal dimension D approximates:

$$D \approx 1.2090 \quad \& \quad D \approx 2.2090 \tag{A6}$$

respectively, considering the golden ratio ($\sim$ 1.6180). Applying the base change $\log_{10} \varphi = \ln \varphi / \ln 10$ and the thermodynamic fractal dimension definition $D = -k_V \ln(\omega_0 dS/dS_0)$ with $\omega_0 = e^{(1-D_E)/k_V}$ and k_V a scale-relating constant, yields:

$$\ln \varphi = k_0 - k'_V \ln \omega_0 \frac{dS}{dS_0} \tag{A7}$$

where $k'_V = k_V \ln 10$, $k_0 = (1 - D_E) \ln 10$. Rearranging $k_0 = \frac{-k'_V}{-k'_V} \ln e^{k_0}$ yields:

$$\ln \varphi = -k'_V \ln e^{-\frac{k_0}{k_V}} - k'_V \ln \omega_0 \frac{dS}{dS_0} \tag{A8}$$

Equivalently:

$$\ln \varphi = -k'_V \ln \omega'_0 \frac{dS}{dS_0} \tag{A9}$$

Where $\omega'_0 = \omega_0 e^{-\frac{k_0}{k_V}}$. Equation A5 links φ to D, allowing Equation A9 to relate φ to dS and dS_0 as:

$$\varphi = \Omega_0 \left(\frac{dS}{dS_0} \right)^{k'_V} \tag{A10}$$

Where $\Omega_0 = \omega_0'^{-k'_V}$.

Appendix B: Fractal dimension and other constants

The correlation between D and φ hints at potential links to other fundamental constants. For instance, Ref [99] suggests expressing π via φ as:

$$\sin \left(\frac{\pi}{10} \right) = \frac{1}{2\varphi} \tag{B1}$$

Or equivalently:

$$\pi = 10 \arcsin \left(\frac{1}{2\varphi} \right) \tag{B2}$$

Two fundamental constants depend on π: The gravitational constant, G_E in the framework of general relativity [100] is:

$$G_E = \frac{8\pi G_0}{c^4} \tag{B3}$$

where G_0 is the Newtonian gravitational constant. The second one is the fine-structure constant α [101]:

$$\alpha = \frac{e^2}{2\varepsilon_0 hc} \tag{B4}$$

Where h is the Planck constant and e is the elementary charge, with values of $\sim 6.6 \times 10^{-34}$ $J \times Hz^{-1}$ and $\sim 1.6 \times 10^{-19}$ C, respectively.

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[1] J. H. Lawrence, *The fitness of the environment an inquiry into the biological significance of the properties of matter* (The McMillan Company, New York, USA, 1913).

[2] R. H. Dicke, Dirac's cosmology and mach's principle, Nature **192(1)**, 440–441 (1961), https://doi.org/10.1038/192440a0.

[3] R. Breuer, *The Anthropic Principle, Man as the Focal Point of Nature* (Springer Science+Business Media, New York, USA, 1991).

[4] J. Leslie, *Universes* (Routledge Taylor & Francis Group, London, UK, 1990) https://doi.org/10.4324/9780203053188.

[5] N. A. Manson, Teaching & learning guide for: Cosmic fine-tuning, the multiverse hypothesis, and the inverse gambler's fallacy, Philosophy Compass **17(9)**, 1–9 (2023), https://doi.org/10.1111/phc3.12873.

[6] A. Einstein, Bemerkung zu der franz seletyschen arbeit "beiträge zum kosmologischen system", Annalen der Physik **374(22)**, 436–438 (1922), https://doi.org/10.1002/andp.19223742203.

[7] P. H. Coleman and L. Pietronero, The fractal structure of the universe, Physics Reports **213(6)**, 311–389 (1992), https://doi.org/10.1016/0370-1573(92)90112-D.

[8] M. Joyce, P. W. Anderson, M. Montuori, L. Pietronero, and F. S. Labini, Fractal cosmology in an open universe, Europhysics Letters **50(3)**, 416–422 (2000), http://doi.org/10.1209/epl/i2000-00285-3.

[9] G. Iovane, E. Laserra, and F. S. Tortoriello, Stochastic self-similar and fractal universe, Chaos, Solitons & Fractals **20(3)**, 415–426 (2004), https://doi.org/10.1016/j.chaos.2003.08.004.

[10] G. Calcagni, Fractal universe and quantum gravity, Physical Review Letters **104(25)**, 1–4 (2004), https://doi.org/10.1103/PhysRevLett.104.251301.

[11] J. Gaite, The fractal geometry of the cosmic web and its formation, Advances in Astronomy **2019(1)**, 1–25 (2019), https://doi.org/10.1155/2019/6587138.

[12] A. A. Kirillov, E. P. Savelova, and P. O. Vladykina, Exact fractal model of the universe and possible machine learning methods for the verification of the fractality, The Sixteenth Marcel Grossmann Meeting **2023(1)**, 352–367 (2023), https://doi.org/10.1142/9789811269776_0026.

[13] A. Arneodo, F. Argoul, J. F. Muzy, and M. Tabard, Uncovering fibonacci sequences in the fractal morphology of diffusion-limited aggregates, Physics Letters A **171(1–2)**, 31–36 (1992), https://doi.org/10.1016/0375-9601(92)90128-9.

[14] S. Havlin, S. V. Buldyrev, A. L. Goldberger, R. N. Mantegna, S. M. Ossadnik, C. .-K. Peng, M. Simons, and H. E. Stanley, Fractals in biology and medicines, Chaos, Solitons & Fractals **6(1)**, 171–201 (1995), https://doi.org/10.1016/0960-0779(95)80025-C.

[15] P. Cilliers, Boundaries, hierarchies and networks in complex systems, International Journal of Innovation Management **5(2)**, 135–147 (2001), https://doi.org/10.1142/S1363919601000312.

[16] J. H. Brown, V. K. Gupta, B. .-L. Li, B. T. Milne, C. Restrepo, and G. B. West, The fractal nature of nature: power laws, ecological complexity and biodiversity, Philosophical Transactions B of the Royal Society, Biological Sciences **357(1421)**, 619–626 (2002), https://doi.org/10.1098/rstb.2001.0993.

[17] M. Livio, *The Golden Ratio the Story of Phi, The World's Most Astonishing Number* (Broadway Books, New York, USA., 2002).

[18] J.-C. Perez, Codon populations in single-stranded whole human genome dna are fractal and fine-tuned by the golden ratio 1.618, Interdisciplinary Sciences: Computational Life Sciences **2(1)**, 228–240 (2010), https://doi.org/10.1007/s12539-010-0022-0.

[19] C. M. A. Pinto, A. M. Lopes, and J. A. T. Machado, Double power laws, fractals and self-similarity, Applied Mathematical Modelling **38(15–16)**, 4019–4026 (2014), https://doi.org/10.1016/j.apm.2014.01.012.

[20] S. Ozturk, K. Yalta, and E. Yetkin, Golden ratio: A subtle regulator in our body and cardiovascular system?, International Journal of Cardiology **223(1)**, 143–145 (2016), https://doi.org/10.1016/j.ijcard.2016.08.147.

[21] Z. Sun, T. Cui, Y. Zhu, W. Zhang, S. Shi, S. Tang, Z. Du, C. Liu, R. Cui, H. Chen, and X. Guo, The mechanical principles behind the golden ratio distribution of veins in plant leaves, Scientific Reports **8(13859)**, 1–8 (2018), https://doi.org/10.1038/s41598-018-31763-1.

[22] S. Petoukhov, E. Petukhova, and V. Svirin, New symmetries and fractal-like structures in the genetic coding system, in *Advances in Computer Science for Engineering and Education (ICCSEEA 2018)*, Advances in Intelligent Systems and Computing, Vol. 754, edited by Z. Hu, S. Petoukhov, I. Dychka, and M. He (Springer, Cham, Switzerland, 2019) p. 588–600, https://doi.org/10.1007/978-3-319-91008-6_59.

[23] C. R. Marples and P. M. Williams, The golden ratio in nature: A tour across length scales, Symmetry **14(10)**, 1–20 (2022), https://doi.org/10.3390/sym14102059.

[24] M. Casadio, P. Giannoni, L. Masia, P. Morasso, V. Sanguineti, V. Squeri, and E. Vergaro, Consciousness as the emergent property of the interaction between brain, body, and environment, Journal of Psychophysiology **24(2)**, 125–130 (2010), https://doi.org/10.1027/0269-8803/a000023.

[25] P. Venegas-Aravena, E. Cordaro, and D. Laroze, Natural fractals as irreversible disorder: Entropy approach from cracks in the semi brittle-ductile lithosphere and generalization, Entropy **24(10)**, 1–18 (2022), https://doi.org/10.3390/e24101337.

[26] P. Venegas-Aravena and E. Cordaro, The multiscale principle in nature (principium luxuriæ): Linking multiscale thermodynamics to living and non-living complex systems, Fractal and Fractional **8(1)**, 1–43 (2024), https://doi.org/10.3390/fractalfract8010035.

[27] Y. Baryshev and P. Teerikorpi, Fractal approach to large-scale galaxy distribution, Astrophysics (astro-ph) **1(1)**, 1–95 (2005), https://doi.org/10.48550/arXiv.astro-ph/0505185.

[28] A. A. Mylläri, A. A. Raikov, V. V. Orlov, P. A. Tarakanov, V. N. Yershov, and M. Y. Yezhkov, Fractality of isotherms of the cosmic microwave background based on data from the planck spacecraft, Astrophysics **59(1)**, 31–37 (2016), https://doi.org/10.1007/s10511-016-9413-1.

[29] S. Teles, A. R. Lopes, and M. B. Ribeiro, Galaxy distributions as fractal systems, The European Physical Journal C **82(896)**, 1–16 (2022), https://doi.org/10.1140/epjc/s10052-022-10866-0.

[30] Y. V. Stadnik and V. V. Flambaum, Can dark matter induce cosmological evolution of the fundamental constants of nature?, Physical Review Letters **115(20)**, 1–7 (2015), https://doi.org/10.1103/PhysRevLett.115.201301.

[31] J. .-J. Zhang, L. Yin, and C. .-Q. Geng, Cosmological constraints on $\lambda(\alpha)$ cdm models with time-varying fine structure constant., Annals of Physics **397(1)**, 400–409 (2018), https://doi.org/10.1016/j.aop.2018.08.015.

[32] L. Lombriser, Cosmology in minkowski space, Classical and Quantum Gravity **40(1)**, 1–25 (2023), https://doi.org/10.1088/1361-6382/acdb41.

[33] J. Mingers, The contribution of systemic thought to critical realism, Journal of Critical Realism **10(3)**, 303–330 (2011), https://doi.org/10.1558/jcr.v10i3.303.

[34] A. Edgley, T. Stickley, S. Timmons, and A. Meal, Critical realist review: exploring the real, beyond the empirical, Journal of Further and Higher Education **40(3)**, 316–330 (2016), https://doi.org/10.1080/0309877X.2014.953458.

[35] D. L. Turcotte, *Fractals and Chaos in Geology and Geophysics* (Cambridge University Press, Cambridge, UK, 1997).

[36] N. Kobayashi, Y. Yamazaki, H. Kuninaka, M. Katori, M. Matsushita, S. Matsushita, and L. .-Y. Chiang, Fractal structure of isothermal lines and loops on the cosmic microwave background, Journal of the Physical Society of Japan **80(7)**, 1–5 (2011), https://doi.org/10.1143/JPSJ.80.074003.

[37] P. A. Tarakanov, M. Y. Yezhkov, and M. V. Kostina, Fractal dimension of the cosmic microwave background as a test of 'planck' spacecraft data, Astrophysics **63(1)**, 288–295 (2020), https://doi.org/10.1007/s10511-020-09634-3.

[38] P. Venegas-Aravena, E. G. Cordaro, and D. Laroze, Fractal clustering as spatial variability of mag-

netic anomalies measurements for impending earthquakes and the thermodynamic fractal dimension, Fractal and Fractional **6(11)**, 1–13 (2022), https://doi.org/10.3390/fractalfract6110624.

[39] P. K. Anderson, Variation of the value of pi on non-euclidean surfaces, Electronic Journal of Informatics **4(1)**, 50–57 (2021).

[40] J. D. Barrow, Non-euclidean newtonian cosmology, Classical and Quantum Gravity **31(12)**, 125007 (2020), https://doi.org/10.1088/1361-6382/ab8437.

[41] H. Kragh, Geometry and astronomy: Pre-einstein speculations of non-euclidean space, History and Philosophy of Physics (physics.hist-ph) **1(2)**, 1–76 (2012), https://doi.org/10.48550/arXiv.1205.4909.

[42] F. A. Farris, A noneuclidean universe, in *Expeditions in Mathematics*, edited by T. Shubin, D. F. Hayes, and G. L. Alexanderson (Mathematical Association of America, Washington, D.C., USA, 2011) p. 153–164.

[43] D. J. Griffiths, *Electrodynamics* (Prentice Hall, New Jersey, USA, 1996).

[44] M. H. Weik, Magnetic permeability, in *Computer Science and Communications Dictionary*, Vol. 1, edited by M. H. Weik (Springer, Boston, MA, USA, 2000) pp. XXXVIII, 1066, https://doi.org/10.1007/1-4020-0613-6.

[45] L. Mowla, K. G. Iyer, G. Desprez, V. Estrada-Carpenter, N. S. Martis, G. Noirot, G. T. Sarrouh, V. Strait, Y. Asada, and R. Abraham, The sparkler: Evolved high-redshift globular cluster candidates captured by jwst, The Astrophysical Journal Letters **937(2)**, 1–9 (2022), https://doi.org/10.3847/2041-8213/ac90ca.

[46] R. Gupta, Jwst early universe observations and λcdm cosmology, Monthly Notices of the Royal Astronomical Society **524(3)**, 3385–3395 (2023), https://doi.org/10.1093/mnras/stad2032.

[47] D. J. Griffiths, *Introduction to quantum mechanics* (Prentice Hall, New Jersey, USA, 1995).

[48] R. Heyrovska, Golden ratio based fine structure constant and rydberg constant for hydrogen spectra, International Journal of Sciences **2(2013)**, 28–31 (2013), https://www.ijsciences.com/pub/article/185.

[49] B. Carr and M. Rees, The anthropic principle and the structure of the physical world, Nature **278(1)**, 605–612 (1979), https://doi.org/10.1038/278605a0.

[50] L. A. Barnes, The fine-tuning of the universe for intelligent life, Publications of the Astronomical Society of Australia **29(4)**, 529–564 (2012), https://doi.org/10.1071/AS12015.

[51] G. F. Lewis and L. A. Barnes, *A fortunate universe: Life in a finely tuned cosmos* (Cambridge University Press, Cambridge, UK, 2013).

[52] B. Carter, Large number coincidences and the anthropic principle in cosmology, in *Confrontation of Cosmological Theories with Observational Data*, International Astronomical Union / Union Astronomique Internationale, Vol. 63, edited by M. S. Longair (Springer, Dordrecht, Netherlands, 1974) p. 291–298, https://doi.org/10.1007/1-4020-0613-6.

[53] P. A. M. Dirac, The cosmological constants, Nature **139(1)**, 323–43 (1937), https://doi.org/10.1038/139323a0.

[54] P. Jordan, Formation of the stars and development of the universe, Nature **164(1)**, 637–640 (1949), https://doi.org/10.1038/164637a0.

[55] C. Brans and R. H. Dicke, Mach's principle and a relativistic theory of gravitation, Physical Review **124(5)**, 925–935 (1961), https://doi.org/10.1103/PhysRev.124.925.

[56] P. A. Bertocci, Teleological argument for god, in *An Encyclopedia of Religion* (Springer, Philosophical Library, New York, USA, 1945) p. 763, https://doi.org/10.1007/1-4020-0613-6.

[57] S. Friederich, A new fine-tuning argument for the multiverse, Foundations of Physics **49(1)**, 1011–1021 (2019), https://doi.org/10.1007/s10701-019-00246-2.

[58] P. Helbig, Life, the multiverse, and fine-tuning, Foundations of Physics **53(93)**, 1–23 (2023), https://doi.org/10.1007/s10701-023-00732-8.

[59] J. Ambjørn and Y. Watabiki, Is the present acceleration of the universe caused by merging with other universes?, Journal of Cosmology and Astroparticle Physics **2023(1)**, 1–18, https://doi.org/10.1088/1475-7516/2023/12/011.

[60] H. Fritzsch, J. Solà, and R. C. Nunes, Running vacuum in the universe and the time variation of the fundamental constants of nature, The European Physical Journal C **77(193)**, 1–16 (2017), https://doi.org/10.1140/epjc/s10052-017-4714-z.

[61] R. A. González and L. Bortolotti, Putting scientific realism into perspective, Interdisciplinary Science Reviews **48(2)**, 299–310 (2022), https://doi.org/10.1080/03080188.2022.2156150.

[62] D. G. Stern, Heraclitus' and wittgenstein's river images: Stepping twice into the same river, The Monist **74(4)**, 579–604 (1991), https://doi.org/10.5840/monist199174434.

[63] S. Park, Scientific realism and scientific progress, in *Embracing Scientific Realism*, Synthese Library, Vol. 445, edited by S. Park (Springer, Cham, Switzerland, 2022) p. 155–176, https://doi.org/10.1007/978-3-030-87813-9_8.

[64] K. Gödel, Über formal unentscheidbare sätze der principia mathematica und verwandter systeme i, Monatshefte für Mathematik und Physik **31(1)**, 173–198 (1931), https://doi.org/10.1007/BF01700692.

[65] V. Penchev, The gödel incompleteness theorems (1931) by the axiom of choice, Econometrics: Mathematical Methods and Programming eJournal **13(39)**, 1–4 (2020), https://dx.doi.org/10.2139/ssrn.3649398.

[66] Y. N. Harari, *Sapiens: A Brief History of Humankind* (Harper Collins, New York, USA, 2015).

[67] J. A. Wheeler, How come the quantum?, in *New Techniques and Ideas in Quantum Measurement Theory*, Annals of the New York Academy of Sciences, Vol. 480(1), edited by D. Greenberger (The New York Academy of Sciences, New York, USA, 1986) p. 304–316, https://doi.org/10.1111/j.1749-6632.1986.tb12434.x.

[68] J. A. Wheeler, World as a system self-synthesized by quantum networking, IBM Journal of Research and Development **201(32)**, 4–15 (1988), https://doi.org/10.1007/978-94-009-3061-2_7.

[69] J. A. Wheeler, *At Home in the Universe*, Vol. 9(1) (American Institute of Physics, New York, USA, 1994).

[70] A. V. Nesteruk, A participatory universe of j. a. wheeler as an intentional correlate of embodied subjects and an example of purposiveness in physics, Journal of Siberian Federal University, Hu-

manities & Social Sciences **6(3)**, 415–437 (2013), https://doi.org/10.48550/arXiv.1304.2277.

[71] J. A. Wheeler, The 'past' and the 'delayed-choice' double-slit experiment, Mathematical Foundations of Quantum Theory **1978(1)**, 9–48 (1978), https://doi.org/10.1016/B978-0-12-473250-6.50006-6.

[72] T. Folger, Does the universe exist if we're not looking?, Discover Magazine (2002), https://www.discovermagazine.com/the-sciences/does-the-universe-exist-if-were-not-looking.

[73] D. K. F. Meijer, The universe as a cyclic organized information system: John wheeler's world revisited, NeuroQuantology **13(1)**, 1–23 (2015), https://neuroquantology.com/media/article_pdfs/57-78.pdf.

[74] G. Gbur and T. D. Visser, Young's interference experiment: Past, present, and future, Progress in Optics **67(1)**, 275–343 (2022), https://doi.org/10.1016/bs.po.2022.01.003.

[75] F. Williams, Heisenberg's uncertainty principle, in *Topics in Quantum Mechanics*, Progress in Mathematical Physics, Vol. 27, edited by F. Williams (Birkhäuser, Boston, MA, USA, 2003) p. 157–170, https://doi.org/10.1007/978-1-4612-0009-3_7.

[76] C. Navarrete and T. Fryer, Redefining emergence: Making the case for contextual emergence in critical realism, Journal for the Theory of Social Behaviour **54(2)**, 167–184 (2024), https://doi.org/10.1111/jtsb.12414.

[77] M. A. Sherbon, Fine-structure constant from golden ratio geometry, International Journal of Mathematics and Physical Sciences Research **5(2)**, 89–100 (2018), https://dx.doi.org/10.2139/ssrn.3148761.

[78] M. A. Sherbon, Golden ratio geometry and the fine-structure constant, Journal of Advances in Physics **16(1)**, 362–368 (2019), https://dx.doi.org/10.2139/ssrn.3464431.

[79] S. Pellis, Exact formula for the fine structure constant α in terms of the golden ratio φ, Authorea **2022(1)**, 1–7 (2022), https://doi.org/10.22541/au.166237627.76517060/v1.

[80] N. S. Islam, Mathematical relationship between the fine-structure constant (α) and golden ratio, euler's number, pi & fibonacci sequence, Journal of Research in Applied Mathematics **9(1)**, 11–26 (2023), https://www.questjournals.org/jram/papers/v9-i1/09011126.pdf.

[81] L. D. G. Sigalotti and A. Mejias, The golden ratio in special relativity, Chaos, Solitons & Fractals **30(3)**, 521–524 (2006), https://doi.org/10.1016/j.chaos.2006.03.005.

[82] C. Jozsef, The golden ratio, Journal of Modern Physics **7(14)**, 1944–1948 (2016), http://dx.doi.org/10.4236/jmp.2016.714171.

[83] F. Conti, G. Scarano, and S. Colonnese, Multiscale anisotropic harmonic filters on non euclidean domains, Signal Processing (eess.SP) **1(1)**, 1–5 (2021), https://doi.org/10.48550/arXiv.2102.00743.

[84] M. T. Murphy, J. K. Webb, V. V. Flambaum, V. A. Dzuba, C. W. Churchill, J. X. Prochaska, J. D. Barrow, and A. M. Wolfe, Possible evidence for a variable fine-structure constant from qso absorption lines: motivations, analysis and results, Monthly Notices of the Royal Astronomical Society **327(4)**, 1208–1222 (2001), https://doi.org/10.1046/j.1365-8711.2001.04840.x.

[85] J. K. Webb, V. V. Flambaum, C. W. Churchill, M. J. Drinkwater, and J. D. Barrow, Search for time variation of the fine structure constant, Physical Review Letters **82(5)**, 884–887 (1999), https://doi.org/10.1103/PhysRevLett.82.884.

[86] R. Penrose, Singularities and time-asymmetry, in *General Relativity: An Einstein Centenary Survey*, edited by S. W. Hawking and W. Israel (Cambridge University Press, Cambridge, UK, 1979) p. 581–638.

[87] R. Penrose, The big bang and its thermodynamic legacy, in *Road to reality: a complete guide to the laws of the universe* (Vintage Books, London, UK, 2004) p. 686–734.

[88] C. H. Lineweaver and C. A. Egan, The initial low gravitational entropy of the universe as the origin of design in nature, in *Origin(s) of Design in Nature.*, Cellular Origin, Life in Extreme Habitats and Astrobiology, Vol. 23, edited by L. Swan, R. Gordon, and J. Seckbach (Springer, Dordrecht, Netherlands, 2012) p. 3–16, https://doi.org/10.1007/978-94-007-4156-0_1.

[89] D. Elder-Vass, Emergence and the realist account of cause, Journal of Critical Realism **4(2)**, 315 –338 (2005), https://doi.org/10.1558/jocr.v4i2.315.

[90] M. Silberstein, Strong emergence no, contextual emergence yes, Philosophica **91(1)**, 145–192 (2017), https://doi.org/10.21825/philosophica.82119.

[91] R. Bhaskar, *The Possibility of Naturalism: A philosophical critique of the contemporary human sciences*, Vol. 1 (Routledge, London, UK, 1979) p. 1–238, https://doi.org/10.4324/9781315756332.

[92] H. Wahbeh, D. Radin, C. Cannard, and A. Delorme, What if consciousness is not an emergent property of the brain? observational and empirical challenges to materialistic models, Frontiers in Psychology **13(1)**, 1–15 (2022), https://doi.org/10.3389/fpsyg.2022.955594.

[93] L. Pisano, *Fibonacci's Liber Abaci (Book of Calculation)* (Biblioteca a Nazionale di Firenze, Italy, 1202).

[94] J. J. Tattersall, *Elementary number theory in nine chapters* (Cambridge University Press, Cambridge, UK, 1999).

[95] L. Pacioli, *Divina proportione* (Paganino Paganini, Serenìsima Repùblega de Venèsia, 1509).

[96] S. Jacob, *Ein new und wohlgegrtindt Rechenbuch, auf den Linien und Ziffern, Sampt der Welschen Practica* (Frankfurt am Meyn: Christian Egenolff, 1571).

[97] J. Kepler, *Harmonices Mundi* (Johannes Plancus, Linz, 1619).

[98] J. Choi, A. Atena, and W. Tekalign, The most irrational number that shows up everywhere: The golden ratio, Journal of Applied Mathematics and Physics **11(4)**, 1185–1193 (2023), https://doi.org/10.4236/jamp.2023.114077.

[99] J. C. Pain, Series representations for π^3 involving the golden ratio, Number Theory **1(1)**, 1–4 (2022), https://doi.org/10.48550/arXiv.2206.15281.

[100] A. Einstein, Die grundlage der allgemeinen relativitätstheorie, Annalen der Physik **354(7)**, 769–822 (1916), https://doi.org/10.1002/andp.19163540702.

[101] A. Sommerfeld, Zur quantentheorie der spektrallinien, Annalen der Physik **356(17)**, 1–94 (1916), https://doi.org/10.1002/andp.19163561702.