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Article

Dynamic Dimension Theory: A Spatio-Temporal Emergence Model Based on Non-Spatial Dimensional Projection

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Abstract

The formal system of quantum mechanics has been empirically successful, but its underlying concepts—such as the physical nature of the collapse of wave functions, the non-localization of quantum entanglement, and the transition from quantum to classical—have not yet been recognized as ontological interpretations [1]. This paper proposes a new conceptual framework called “dynamic dimension theory”. The framework takes an ontological leap: it interprets three-dimensional physics as a dynamic projection of a higher-dimensional “dynamic axis field” rather than a self-consistent quantum whole. Its core mechanism, “stability selection”, reconstructs the collapse of the wave function into a finite time physical relaxation process. Therefore, the problems of quantum entanglement such as non-locality are obtained based on high-dimensional integrity and synchronous projection. The theory is based on three basic postulates: (1) there is a diffuse, non-spatial high-dimensional physical field, that is, the “dynamic axis field”; (2) The three-dimensional physical reality is the projection of the dynamic state of the field to its subspace; (3) The evolution of the field is governed by the expansion form of the principle of minimum action, and naturally tends to the most stable state of information-energy architecture. The core of this theory is that it reinterprets the collapse of the wave function as a finite dynamic process, that is, “high-dimensional stability selection”, rather than an infinite mathematical instantaneous mutation. From this, the theory naturally explains multiple phenomena: quantum entanglement is revealed as an associative projection of the same high-dimensional dynamic axis structure in three-dimensional space (“high-dimensional replication” model), and its non-localized association is the result of the synchronous projection of the overall event; The quantum-classical boundary is triggered by the complexity of the macroscopic system on the stability of the dynamic axis. This framework also resonates deeply with the holographic principle and the ER=EPR conjecture on physical images [2,3]. In order to transform this conceptual concept into a testable scientific theory, this paper proposes three clear and falsifiable experimental test paths, which constitute a complete verification system from micro to macro: 1. Microdynamic test: The detection of the “synchronization window” effect for entangled photon pairs is predicted and designed. This experiment aims to directly measure the finite time scale of the quantum projection process and is a decisive test of the theoretical dynamics kernel. 2. Energy conservation extended test: A full-cycle energy statistical monitoring experiment of “preparation-collapse-decoherence” was designed on the superconducting qubit platform to verify the hypothesis of “interdimensional energy cycle” predicted by the theory and face the compatibility problem with the law of conservation of energy. 3. Cosmological origin test: It is predicted that the coupling of dynamic axial field and expansion field in the early universe will produce characteristic non-Gaussian imprints ($f_{NL}^{loc} \sim$) in the primordial perturbations, and a complete analysis scheme is given for detection using next-generation galaxy survey data (e.g., DESI, Euclid) [4]. This paper systematically expounds the principle, deduction and dialogue between dynamic dimensionalism and the existing physical framework. Its primary value is to try to integrate the interpretation of a series of basic problems into a single and testable physical mechanism, and to put forward clear and concrete experimental predictions. Whether these predictions are confirmed or falsified, this work will open up new and fruitful directions for quantum-based experimental exploration.

Keywords: fundamentals of quantum mechanics; measurement problems; quantum entanglement; wave function collapse; non-locality; Quantum-classical transition; The original was not Gaussian

1. Introduction - Limitations of Existing Dimension Theory and Proposal of Dynamic Dimension Theory

1.1. Origin of the Problem

Contemporary physics faces a fundamental conceptual conflict in reconciling the theoretical framework of quantum mechanics and general relativity. General relativity describes spacetime as a smooth, deterministic kinetic entity, while the fundamental principles of quantum mechanics, especially the non-domain correlation exhibited by quantum entanglement, suggest some kind of deep physical structure beyond the classical space-time context [5]. This tension prompts us to re-examine the ontological status of space-time—perhaps not as the ultimate background of physics, but as a product emerging from a more basic physical reality [6].

This paper aims to propose a new conceptual framework called “dynamic dimensionalism”. This framework assumes that our perceived four-dimensional spacetime and its physical phenomena are a more basic, high-dimensional dynamic projection result of the dynamic axis field. The dynamic axis field is not an additional spatial dimension, but a non-spatial physical existence that defines the state of the physical system. The 3D reality we observe is the manifestation of the field continuously “locking” into a specific subspace through its intrinsic “stability selection” dynamics.

The core goal of this theory is to provide a unified geometric physical image based on high-dimensional integrity and projection dynamics for problems such as quantum non-locality and wave function collapse, and to open up a new conceptual path for exploring the quantum origin of space-time [7].

1.2. From Intuitive Limitations to Paradigm Shifts

Human cognition is constrained by its perceptual dimensions, leading us to inevitably fall into a low-dimensional analogy mindset when understanding high-dimensional concepts. A typical example is trying to understand a three-dimensional sphere in a two-dimensional plane: a two-dimensional observer can only obtain a series of discrete circular sections because of the lack of the basic direction of “height” in its perception [8].

Under this cognitive framework, “time” has become the initial entry point for our understanding of four-dimensional space-time. The analogy of four-dimensional space-time as a data whole containing all past, present and future forms a concept of “block universe”. However, this concept still faces fundamental conceptual limitations in explaining core phenomena such as quantum non-locality [9].

1.3. Support for High-Dimensional Projection Ideas by Cutting-Edge Experiments

“The projection of high-dimensional geometry in low-dimensional physical reality” is not a pure mathematical fantasy, but has been confirmed by remarkable experiments in many frontier fields of physics in recent years. A highly suggestive illustration comes from a study published in Science by Tseses et al. (2025). The strange topological patterns they observed in two-dimensional plasma quasicrystals were found to be perfectly interpreted as a projection of a four-dimensional topological charge vector in three-dimensional space [10]. This study shows that “high-dimensional projection”, as a physical mechanism, can be fully realized, manipulated and observed in the laboratory.

More broadly, not only in the field of quantum mechanics, experimental accuracy has developed to verify the continuity and naturalness of basic principles under extreme conditions [11]. From the surface state of topological insulators in condensed matter physics (which can be regarded as a boundary projection of high-dimensional topological invariants) [12], to the concrete implementation

of the holographic principle in AdS/CFT duality [13], a series of breakthroughs point to the same profound theme: low-dimensional physical phenomena are often the natural manifestation of a higher-dimensional, simpler, or more symmetrical physical structure.

These developments provide us with key confidence and analogies: the core picture proposed by the “dynamic dimensionalism” – that our four-dimensional space-time is a projection of a high-dimensional dynamic axis field – is not a fantasy, but is in line with the most profound trends in many branches of contemporary physics. This theory differs in that it systematically applies this geometric idea to the conceptual foundations of quantum mechanics and derives a series of unique and testable physical predictions.

1.4. The Concept of Dynamic Axis: An Ontological Turn

The idea of “high-dimensional geometry explaining low-dimensional physics” has a long history. However, the starting point of this theory is not a simple answer to the traditional question of whether there are more spatial dimensions, but stems from a more fundamental question: if space-time itself is not the ultimate physical background, then what are the physical carriers behind the seemingly ‘non-local’ correlations (such as quantum entanglement) in quantum mechanics that transcend the framework of space-time?

In response to this question, we proposed the core concept of “dynamic axis”. It represents a key ontological shift: we no longer try to tinker with quantum theory in the context of four-dimensional space-time, and instead assume the existence of a more basic, non-spatial physical field. This field – which we call the dynamic axis field – is not another “curled” spatial dimension, but a diffuse physical reality with its own dynamic state. It aims to provide an intrinsic and geometric physical root for quantum non-locality, and to understand the four-dimensional space-time and the deterministic phenomena in it as a projection of the dynamic state of the field.

This distinguishes this theory from traditional theoretical paths that only increase the spatial dimension (such as the Kaluza-Klein theory) [14]: the primary purpose of the introduction of the concept of dynamic axis is not to unify the interaction, but to provide a unified dynamic basis for the common origin of space-time and quantum phenomena [15].

2. Core Principles of Dynamic Dimensionalism - From Conceptual Framework to Theoretical Cornerstone

This chapter aims to systematically elaborate the basic principles of “dynamic dimension theory”. We will first establish a posthumous system of theory, build on this basis, gradually deduce the core properties of the dynamic axis, and finally show how the theory uniformly explains a range of physical problems from quantum phenomena to conscious experience.

2.1. Basic Postulate

This theory is based on the following three basic postulates that form the logical basis for all subsequent deductions:

1. Dynamic axis postulate: There is a non-spatial physics field that transcends four-dimensional space-time, that is, the “dynamic axis”. It is a fundamental component of the universe, defining a diffuse, high-dimensional directional direction [16].
2. Projection postulate: The 3D physical reality we observe is the result of the projection of the “dynamic axis field-space-time” to its 3D space subset as a whole. All physical entities and phenomena are manifestations of this projection [17].
3. Stability Postulate: The dynamics of dynamic axis fields tend to seek the most stable state of their information architecture or energy configuration. The transition from high-dimensional superposition to three-dimensional deterministic state is a natural result of the system’s tendency towards stability [18].

2.2. Core Properties of Dynamic Axis Field

Based on the above postulate, three core physical properties of the dynamic axis field can be derived.

2.2.1. Diffuse: As a Background Field

The primary property of a dynamic axis field is its diffuseness. The basic assumption of this theory is that our perception of four-dimensional space-time is rooted in a more inclusive geometric architecture. To understand this assumption intuitively, we can draw on a geometric idea: just as a one-dimensional line can be regarded as a set of points, a two-dimensional face can be regarded as a set of lines, and a three-dimensional space can be regarded as a set of faces, a natural geometric extension is to envision a complete four-dimensional spatial architecture capable of “containing” or “supporting” all possible three-dimensional subspaces [18].

Based on this idea, this theory proposes that the dynamic axis field is not a localized or isolated additional dimension, but a physical field that permeates and is embedded in the entire four-dimensional space-time background. It is ubiquitous and associated with every point in time and space, forming the basic background for the manifestation of all three-dimensional physical reality. This property establishes the status of the dynamic axis field as a basic component of the universe, which means that any local physical phenomenon may be the local representation and projection of this diffuse background field in a specific state.

2.2.2. Directional Superposition: Quantum Geometry

The second key property of a dynamic axis field is the quantum superposition of its direction. Drawing on the fundamental principles of quantum mechanics, we assume that the dynamic axis does not have a classically determined spatial direction at the fundamental level. Instead, its “directional state” exists in a high-visibility Hilbert space, in the superposition of all possible orthogonal directions [19][20]. This can be understood as “quantum ambiguity” in the direction of the dynamic axis. Only when a physical process (such as quantum measurement) requires a definite interaction with the three-dimensional world can the superposition collapse or lock into a specific eigendirection through decoherence with the environment [21]. This transition from high-dimensional superposition to direction-determination geometrically corresponds directly to the generation of a projection that determines a three-dimensional reality, thus providing a geometric image for the collapse of the wave function [22].

2.2.3. Non-Localized: High-Dimensional Intrinsic Association

The third property of the dynamic axis field, non-localization, stems from its integrity as a diffuse background field. This property argues that the dynamic axis field is an inseparable physical whole, and its internal associations are intrinsic and non-propagated. This change in high-dimensional overall correlation is synchronized at the ontological level and independent of the spatial separation distance presented in the 3D projection.

It is necessary to clarify a key point: “high-dimensional synchronicity” and “dynamic process of three-dimensional projection” belong to different levels and are not contradictory.

1. High-dimensional real-time correlation: refers to the entanglement system as a high-dimensional whole, and its state update is the intrinsic behavior of the unified unit, without internal signal transmission.
2. Projection dynamics process: refers to the physical process of realizing the above-mentioned high-dimensional state changes into three-dimensional determination of observation results, and this theory predicts that this process requires a limited relaxation time.

The “synchronicity window” effect predicted by this theory aims to detect the second level - the finite time scale of the projection process. The intrinsic integrity of high-dimensional correlation is

precisely the physical root of this dynamic process that can produce a synchronous time window on all 3D projections.

In this framework, non-localized associations in three-dimensional space (such as quantum entanglement) are clearly interpreted as the fact that spatially separated subsystems are essentially different projection sides of the same high-dimensional dynamic axis structure. The correlation between them is not a transdistant effect, but an inevitable manifestation of sharing the same high-dimensional root [23][24]. Once the state of the dynamic axis field is locked, all 3D projections are updated synchronously, which is the synchronization characteristic of the projection. This geometric image provides a rationale for a unified understanding of quantum entanglement and wave function collapse, and we will show in detail in Chapter 3 how it naturally explains phenomena such as Bell's inequality experiment [25][26].

3. Dialogue with Established Physical Frameworks—A Geometrical Perspective on Unification

Chapter Overview: Although the formalism of quantum mechanics is successful, the ontological interpretation of its core concepts remains contentious [27]. This chapter systematically elucidates how the Dynamic Dimension Theory (DDT), by introducing a high-dimensional “dynamic axis,” provides a unified geometric-physical representation for core challenges such as quantum measurement, non-locality, and the quantum-classical boundary. Through in-depth dialogue with the double-slit experiment, Bell's inequality, the Schrödinger's cat paradox, the holographic principle, and the ER=EPR conjecture, this chapter demonstrates how the theory integrates a series of disparate quantum phenomena into a coherent scientific physical picture, thereby offering a novel pathway to resolving these long-standing conceptual dilemmas.

3.1. Dialogue with Foundational Physical Laws

3.1.1. Reformulation of the Law of Energy Conservation in an Extended System

The law of energy conservation is an unshakeable cornerstone of physics, asserting that the total energy within an isolated system remains constant over time. Any new theoretical framework must provide a clear and self-consistent account of its compatibility with this law [28]. Dynamic Dimension Theory (DDT) naturally addresses this issue by introducing a high-dimensional dynamic axis field, elevating the consideration from the traditional three-dimensional isolated system to a more comprehensive “high-dimensional—three-dimensional” extended system.

The core mechanism of this theory—the “Stability Selection” mechanism—is a non-equilibrium dynamical process. A direct challenge arises: when a system transitions from a quantum superposition state with an expected energy value $\langle E \rangle$ to an eigenstate with a definite energy E_i , from where does the energy difference $\Delta E = E_i - \langle E \rangle$ originate? If the three-dimensional system is considered isolated, this process indeed presents an apparent challenge to the law of energy conservation.

However, DDT provides a fundamental resolution to this issue: the universality of the law of energy conservation is not violated; rather, the system boundary within which it holds is redefined. We posit that the truly isolated system should encompass the high-dimensional dynamic axis field and its three-dimensional projection. In this extended system, energy conservation takes the following form:

Energy change of the high-dimensional dynamic axis field + Energy change of the three-dimensional projected world = 0.

Based on this, we propose the “Inter-dimensional Energy Cycle” hypothesis to achieve microscopic energy conservation [29]. This hypothesis states:

1. Forward Process (Projection): When “Stability Selection” occurs and the quantum state collapses into a definite three-dimensional reality, the requisite energy ΔE originates from the high-dimensional dynamic axis field, acting as the “driving force” of this dynamical process [30].
2. Reverse Process (Dispersion): When a definite quantum system in three dimensions loses its classical character due to decoherence and disperses back into a superposition state, the associated energy released returns to the high-dimensional dynamic axis field [31].

This process can be analogized to a cosmic-scale “tidal” phenomenon: the dynamics of the high-dimensional dynamic axis field, akin to lunar gravity, induce an energy “high tide” (projection) and “low tide” (dispersion) in the three-dimensional world, while the total energy of the universe (akin to Earth’s total water volume) remains constant throughout this cycle.

A key advantage of this hypothesis lies in its high degree of falsifiability. As detailed in Section 4.3 (Experimental Statistical Monitoring of Energy over the Complete Quantum State Preparation-Collapse-Decoherence Cycle), we can adjudicate the validity of this hypothesis by monitoring the statistical energy behavior of a quantum system throughout a full dynamical cycle [32]. If experiments confirm the observation of statistical energy anomalies during state collapse, which subsequently disappear during the decoherence process, this would strongly support the energy cycle model. Conversely, if the energy anomaly is permanent or entirely absent, the current form of this theory would be falsified.

It must be emphasized that DDT’s stance on this issue is consistent with the strategies adopted by modern physics when addressing frontier challenges. Just as General Relativity redefined “inertia” to encompass and transcend Newtonian mechanics [33], DDT redefines the “isolated system” to embrace the law of energy conservation, infusing it with new physical meaning. We do not question the conservation law itself but aim to reveal how it is realized within a deeper ontological architecture—namely, a dynamic, dimensionally extensible universe.

3.1.2. The Geometric Origin of the Second Law of Thermodynamics: Entropy Increase and Projection

In Dynamic Dimension Theory, the universality of the law of entropy increase in the three-dimensional world stems from the intrinsic nature of the ‘projection’ dynamical process [34]. When a coherent state of the high-dimensional dynamic axis field projects onto the three-dimensional subspace, its contained global quantum information undergoes irreversible entanglement with the macroscopic environment, leading to the local inaccessibility of this information [35].

Specifically, the projection process does not constitute information ‘annihilation’ but rather information ‘concealment’—information is transferred from the system itself into the vast correlations of the ‘system-environment’ complex [36]. For an observer confined to the three-dimensional subspace, this implies a reduction in the information required to describe the system’s state, resulting in an increase in its informational entropy.

Consequently, the second law of thermodynamics acquires both geometric and informational interpretations within this framework: the direction of the arrow of time aligns precisely with the direction of the continuous ‘concealment’ of high-dimensional global information within the low-dimensional projection. The entropy increase observed at the three-dimensional scale is an inevitable consequence of the evolution of the information structure of the high-dimensional universe during the projection process [37].

3.2. Dynamical Foundation: Stability Postulate and Measurement Perturbation

As outlined in Section 2.1, the dynamic axis field adheres to the Stability Postulate, meaning its dynamics naturally tend towards seeking the most stable state in terms of information or energy. In quantum measurement, the introduction of the measurement apparatus (a highly decoherent macroscopic system) acts as a strong physical perturbation, disrupting the inherent high-dimensional superposition equilibrium of the dynamic axis field. This picture converges phenomenologically with the “environmental monitoring” scenario leading to loss of quantum character in decoherence theory

[Zurek] [32]. However, while decoherence theory describes this process within the standard quantum mechanics framework as a consequence of subsystem information flooding into the environment, our theory offers an ontological interpretation: it is an intrinsic dynamical process through which the high-dimensional dynamic axis field seeks stability under perturbation. The former addresses “where the information goes,” whereas our theory aims to reveal the “geometric dynamical cause that drives the flow of information.”

3.3. Dialogue with Experiments on “Collapse Speed”

Recent experiments (e.g., [Citation: Vienna 2015 experiment]) have attempted to establish a lower speed limit for the quantum collapse process. Their results are compatible with the hypothesis of “instantaneous collapse” while not excluding the possibility of a finite but extremely fast dynamical process [38]. Dynamic Dimension Theory offers a novel perspective for understanding such experiments.

The theory posits that the so-called “collapse speed” does not describe the propagation of some influence through three-dimensional space. Instead, it reflects the intrinsic timescale of the dynamical process of “Stability Selection” occurring within the high-dimensional dynamic axis field. Since this process takes place at the holistic high-dimensional level, its projection into three-dimensional space—i.e., the establishment of correlations—will appear nearly simultaneous to an observer, thus exhibiting an “effective speed” far exceeding that of light.

Consequently, this theory does not conflict with any experimental results suggesting that collapse is a non-instantaneous process. On the contrary, the theory predicts a more fundamental, detectable physical effect: the “Synchronicity Window” effect (see Section 4.1). This effect aims to directly measure the finite-time dynamical process itself, rather than its equivalent propagation speed. If confirmed, this would constitute key evidence supporting the theory and provide a unique physical explanation for the aforementioned experimental phenomena.

3.4. Wave Function Collapse: From Interference Fringes to Spots

In the double-slit experiment, the photon’s dynamic axis is initially in a superposition of paths, with its high-dimensional interference pattern projected as interference fringes [7]. The introduction of a detector entangles with the photon’s dynamic axis, creating an unstable composite system. According to the Stability Postulate, this system evolves irreversibly via decoherence into a stable eigenstate [32]. This high-dimensional “locking” event is projected into three-dimensional space as a particle-like spot. Therefore, collapse is not a mysterious mathematical instant, but the natural outcome of the dynamic axis field, governed by the principle of least action, undergoing a bifurcation in its dynamical path due to environmental perturbation, leading it to a stable eigenstate [31]. The physical origin of this “Stability Selection” mechanism will be elaborated in Section 3.9 based on an extended framework of the principle of least action.

The preceding analysis interprets quantum collapse as a stability selection process in high-dimensional dynamics. A natural follow-up question is how this geometric picture aligns with increasingly precise quantum experiments. Recent recoil-slit experiments performed at the quantum limit provide an excellent paradigm for discussion [39].

These experiments demonstrate with undeniable precision that in double-slit interference, there exists a continuous, quantitative, and strictly quantum-mechanically predicted trade-off between the acquisition of “which-path information” and the fading of “interference visibility” [40]. This indicates that the transition between “wave” and “particle” manifestations is not a mysterious instantaneous jump, but a natural, rule-governed continuous process. Traditional interpretations (e.g., the Copenhagen interpretation) accept this rule as a fundamental postulate without elucidating the underlying physical entity or dynamical cause.

Dynamic Dimension Theory strives to provide a mechanistic explanation for this rule. Within this framework, detecting “which-path” information in the experiment is equivalent to introducing a definitive decoherence perturbation into the high-dimensional dynamic axis field corresponding to

the photon-atom composite system [41]. This perturbation disrupts the original superposition equilibrium of the dynamic axis field, triggering its dynamical relaxation towards stability [42]. The continuous degradation of interference fringes with increasing detection precision is precisely the gradual manifestation, projected into three-dimensional space, of this “Stability Selection” process: as the perturbation strengthens, the state of the dynamic axis field becomes more determinately “locked” into an eigen-direction representing a particle path, causing the projected interference pattern to naturally decay.

Thus, this cutting-edge experiment does not pose a challenge to the theory; rather, it establishes a phenomenological benchmark that any adequate quantum measurement theory must explain. It strongly suggests that any viable theory of quantum measurement must naturally give rise to this continuous, predictable transitional character from its physical core. By defining “projection” as a finite dynamical process, Dynamic Dimension Theory provides a clear geometric-physical picture for understanding this characteristic, thereby advancing the dialogue from “what is the mathematical rule?” to the more fundamental question: “what physical reality is executing this rule?” [37].

3.5. Quantum Entanglement and Nonlocality: A High-Dimensional Replication Model

For entangled particle pairs, their essence lies in the correlated projection of shared high-dimensional dynamic axes within three-dimensional space [43]. Measuring any particle constitutes a stability perturbation on these shared dynamic axes and triggers a stability selection process. To elucidate the immediacy of nonlocal correlations, we propose a high-dimensional replication model:

- Entanglement Establishment: A stable high-dimensional dynamic axis correlation structure is formed [44].
- Projection Separation: This structure manifests in three-dimensional space as spatially separated yet morphologically correlated particle pairs [45].
- Measurement Trigger: Measurement of a particle perturbs the shared high-dimensional structure.
- Synchronous Manifestation: High-dimensional stability selection instantaneously locks the entire structure, resulting in synchronously correlated determination of particle states in three-dimensional space [46].

This model indicates that spatial separability is a derivative representation when describing such high-dimensional holistic events.

3.6. Dialogue with Bell's Inequality Experiments

The groundbreaking results of Bell's inequality experiments, with robust evidence, have excluded *local realism* as a viable physical model within the observable three-dimensional space [40]. The Dynamic Dimension Theory fully embraces this experimental conclusion and strives to provide a more profound ontological explanation for why local realism fails at the phenomenological level [47].

The core proposition of this theory posits that Bell's experiments rule out a worldview where “realism” and “locality” are simultaneously anchored solely within three-dimensional space. However, this outcome does not preclude the exploration of a more fundamental reality beyond the apparent phenomena of three dimensions [39]. This theory proposes that such a foundational reality resides within a higher-dimensional dynamic axis field. Prior to measurement, entangled particles are not independent entities linked merely through three-dimensional space, but inseparable components of a unified higher-dimensional dynamic axis structure.

Therefore, the “non-local” correlation revealed by measurement is not superluminal information transfer within three-dimensional space, but the “synchronous manifestation” at the phenomenal level of an internal state-locking event within the same high-dimensional whole, following a local perturbation [38]. Dynamic Axis Theory does not overturn or weaken the conclusions of Bell's experiments; on the contrary, it elevates and reinterprets their profound implication from

“descriptions in three-dimensional space are non-local” to “three-dimensional phenomena originate from a high-dimensional reality that is inherently non-local.” We exist and perform measurements in three-dimensional space, but the physical root of the synchronicity in measurement outcomes may reside in higher dimensions we have not yet directly perceived.

3.7. Resolving the Schrödinger’s Cat Paradox: From Geometric Description to Physical Reality

Through its striking imagery, Schrödinger’s cat thought experiment highlights profound conceptual dilemmas in quantum mechanics concerning the measurement problem and the quantum-classical boundary [48]. Recent studies have attempted to resolve this paradox from a purely mathematical structure perspective—for instance, by employing Kähler geometry to interpret superpositions as structural features of abstract manifolds and collapsing as a geometric phase transition [49]. Such work profoundly reveals the intrinsic coherence within the mathematical formalism of quantum mechanics.

However, the dynamical dimensional theory aims to effect a fundamental paradigm shift: transitioning from a geometric characterization of the wave function toward a dynamical interpretation of physical reality. This theory contends that the paradox of “Schrödinger’s cat” stems from incorrectly attributing the concept of “superposition” to the cat-in-itself within three-dimensional space. In fact, the so-called “superposition state” corresponds to the structural configuration of the system’s dynamical axes, which resides in a high-dimensional superpositional direction encompassing both the “dead cat” and “live cat” possibilities [50].

According to the Projection Postulate (Postulate II), the three-dimensional reality we can observe is merely a projection of this high-dimensional state. A macroscopic, complex, and strongly environmentally coupled system (like the cat and box) constitutes a potent perturbation source that instantly triggers the Stability Selection of the dynamic axis field (Postulate III), causing it to lock from the high-dimensional superposition state into a stable eigen-direction—corresponding to the single reality of either “cat dead” or “cat alive” [42][51].

Therefore, within the picture painted by Dynamic Dimension Theory:

- We transcend the semantic dilemma of “whether the cat is in a superposition” and instead describe the physical process of “how high-dimensional dynamics projects a definite reality.”
- “Collapse” is no longer an abstract mathematical jump but a concrete high-dimensional Stability Selection triggered by the environment [41].
- The quantum-classical boundary is thereby clarified as the natural dynamical outcome of system complexity triggering the locking of the dynamic axis [52].

This theory elevates the level of discourse from the refinement of mathematical forms to the questioning of physical reality itself, providing a clear physical core for resolving the Schrödinger’s cat paradox.

3.8. Unification of Dynamic Axis Theory with the Holographic Principle and the ER=EPR Mechanism

The holographic principle posits that all physical information describing a spatial region (e.g., a volume) can be encoded on its boundary (e.g., a two-dimensional surface) [53]. Within the framework of gauge/gravity duality (such as AdS/CFT), this principle manifests as a mathematical equivalence between a boundary conformal field theory (CFT) and a gravitational theory in the bulk spacetime [54]. Although such correspondences have been extensively studied mathematically, their underlying physical origin—namely, how boundary information dynamically generates the physical reality of the bulk space—remains unclear [45].

Similarly, the ER=EPR conjecture unifies quantum entanglement (EPR) with the geometric structure of spacetime (ER bridges), proposing that each pair of entangled particles is in fact a single entity connected by a microscopic wormhole [44]. This conjecture indicates a profound connection between quantum nonlocality and geometric connectivity, yet it likewise fails to elucidate the specific physical mechanism through which this occurs [55].

3.8.1. Dynamic Axis Theory as the Physical Realization of the Holographic Principle

Within the framework of Dynamic Axis Theory, the “boundary” of the holographic principle is interpreted as the projection condition of a high-dimensional dynamic axis field, while the “bulk space” is the result of the dynamic projection of this field onto a three-dimensional subspace [56]:

- Boundary information corresponds to the boundary conditions and initial data of the dynamic axis field.
- Bulk reality is a sustained projection generated by the stability dynamics of the dynamic axis field according to these boundary conditions.
- The conventional holographic duality is elevated to a dynamic physical generation process [53].

3.8.2. Dynamic Axis Theory as the Physical Mechanism for ER=EPR

The ER=EPR conjecture posits that quantum entanglement (EPR) and wormholes (ER bridges) are different manifestations of the same phenomenon [55]. Dynamic Axis Theory provides a definitive mechanism for the “why” and “how” of this conjecture [57].

- The ER wormhole corresponds to the high-dimensional topological structure of the dynamic axis field.
- The EPR entanglement surface is the correlated projection of this structure in three-dimensional space.
- The high-dimensional transcription model provides a concrete physical mechanism for the “wormhole connection” [45].

3.9. *The Physical Root of Stability: An Extension of the Principle of Least Action*

The Stability Postulate (Postulate III) is not an independent assumption; its deep root lies in the cornerstone principle of physics—the Principle of Least Action [58]. This principle states that the actual evolution path followed by any physical system is the one for which the action S is stationary (an extremum).

This theory applies this principle to the dynamic axis field, denoting its action as S_D . The key distinction from classical theories or standard quantum mechanics is that the Lagrangian L_D of the dynamic axis field must include a physical quantity capable of characterizing its “high-dimensional wholeness and coherence.” We refer to this as the “Information Correlation Term I ” [59].

Consequently, the Lagrangian can be schematically expressed as:

$$L_D = L_{\text{known}} + \alpha \cdot I$$

where:

- L_{known} is the “known physics term.” It represents the sum of kinetic and potential energies for the system under study (e.g., particles, fields) within the standard quantum mechanical framework. Its specific form depends on the particular system and ensures that the theory naturally reduces to all experimentally verified quantum predictions when the new physics is inactive.
- I is the “Information Correlation Term,” a new physical quantity introduced by this theory that quantifies the ability of the dynamic axis field to maintain quantum coherence [60].
- α is a coupling constant.

A unified picture of stability selection thus emerges:

- In isolated quantum systems, the Information Correlation Term I dominates. The path of extremal action corresponds to smooth, linear evolution that maintains quantum superposition states (i.e., the behavior described by the Schrödinger equation) [31].
- When the system strongly couples with a macroscopic environment, environmental disturbances drastically alter the “landscape” of the action, suppressing the effect of the Information Correlation Term I . At this point, the most stable evolutionary path for the system undergoes a

dynamical bifurcation, flowing from the diffuse superposition state solution towards a definite eigenstate solution [61].

Therefore, the “stability selection” mechanism described by Postulate III can be clearly understood within this framework as a bifurcation behavior of the system’s dynamical path, governed by the Principle of Least Action, which occurs as environmental complexity increases. Measurement-induced collapse is no longer a mysterious instantaneous jump but a natural consequence of this continuous dynamical process as projected into three-dimensional space [59].

3.10. Unification Summary: A Geometric Perspective on Quantum Phenomena

The core achievement of Dynamic Dimension Theory lies in providing an intrinsically unified geometric-dynamical picture for a series of long-separated foundational quantum puzzles through a single physical mechanism: “Stability Selection of the High-Dimensional Dynamic Axis Field” [62].

1. Unified Explanation at the Phenomenological Level

This mechanism naturally manifests in different contexts as:

- Wavefunction Collapse: A local stability selection triggered when a simple system is perturbed by its environment [32].
- Quantum Entanglement and Nonlocality: The synchronized projective manifestation (via the high-dimensional transcription process) of stability selection for a composite system considered as a high-dimensional whole [46].
- Quantum-Classical Boundary: Not an abstract line, but the natural outcome of system complexity (information loss rate) triggering the locking dynamics of the dynamic axis [52].
- Unification of Spacetime and Information: The holographic principle and the ER=EPR conjecture find a common physical explanation within this framework—namely, the dynamical projection of the high-dimensional dynamic axis field, answering respectively “how the boundary generates the bulk” and “how entanglement connects spacetime” [56][57].

2. Deepened Unification at the Principled Level

More fundamentally, this theory places two cornerstone laws of physics within this geometric framework, revealing their deep connection:

- The Law of Energy Conservation is preserved through the concept of an “expanded high-dimensional—three-dimensional” system (§3.1.1) and, furthermore, gives rise to the testable “interdimensional energy cycle” hypothesis, rendering the conservation law a core principle governing the interdimensional dynamics [29,63].
- The Second Law of Thermodynamics (entropy increase) is revealed as the inevitable consequence of the “concealment” of high-dimensional information into the environment during the projection process (§3.1.2), providing a geometric origin for the arrow of time [37,64].

3. Unified Formulation of the Dynamical Root

Ultimately, all the above unifications can be traced back to a more fundamental physical principle. As discussed in §3.9, the stability selection mechanism can be understood as a natural consequence of the Principle of Least Action within the framework of an extended Lagrangian ($L_D = L_{\text{known}} + \alpha I$) [58,59]. The evolution of the Information Correlation Term I dictates whether the system evolves smoothly from a superposition state or undergoes a dynamical bifurcation towards an eigenstate [60].

4. Testable Unification: The Theory’s Decisive Point

The most robust feature of this theory’s unification is its high degree of falsifiability. Instead of dispersing solutions to multiple puzzles across different ad hoc hypotheses, it converges them onto a single, testable core prediction: the existence of the “synchronization window” effect [62]. This effect is a direct manifestation of the common foundation of all explanations—that projection is a finite-time dynamical process. Therefore, experimental verification of this effect will serve as a decisive test for the entire unified framework [61].

Conclusion

In summary, Dynamic Dimension Theory paints a coherent physical picture: our perceived four-dimensional reality is a grand, synchronized projection generated by a high-dimensional dynamic field in its continuous quest for stability. The value of this framework lies in its scientific character, which integrates profound unification, a clear geometric picture, and a definitive experimental test point [53,62].

4. Experimental Verification and Future Prospects

Introduction

The Dynamic Dimension Theory (DDT) outlined in previous chapters has established a conceptual framework aimed at unifying the interpretation of quantum measurement and entanglement. The ultimate criterion for the scientific rigor of any theory that aspires to describe underlying physical reality lies in its capacity to withstand experimental scrutiny and bear the risk of falsification. This chapter will refrain from reiterating the theoretical underpinnings or engaging in hermeneutic comparisons. Instead, it will directly delineate the experimentally testable predictions derived from the theory and explore the new scientific horizons that would emerge should it withstand preliminary validation.

4.1. Scientific Positioning: A Mechanistic Theoretical Framework

Within the interpretive spectrum of quantum mechanics, Dynamic Dimension Theory occupies a distinct and unique position: it is not merely another “philosophical interpretation” of the mathematical formalism of the Schrödinger equation, but rather a “conceptual theoretical framework” intended to provide a physical mechanism underpinning quantum phenomena [65].

Distinction from Mainstream Interpretations: The Copenhagen interpretation treats “wave function collapse” as a fundamental postulate requiring no underlying mechanism [66]; the many-worlds interpretation circumvents the issue of definite measurement outcomes at the cost of positing an infinite multiplicity of universes [67]; while decoherence theory offers an elegant description of the environmental dissipation of quantum coherence, it does not fundamentally resolve the core issue of the “definite origin of a single measurement outcome” [32]. In contrast, DDT proposes a unified physical process—high-dimensional stability selection—as the mechanistic basis for these phenomena. This theory is not content with describing what happens but seeks to address the foundational question of how it happens.

Integration and Transcendence of ER=EPR: Both DDT and the cutting-edge conjecture ER=EPR posit an intrinsic unity between spacetime geometry and quantum correlation [44]. However, ER=EPR remains largely a profound mathematical analogy [55], whereas DDT, through its “high-dimensional replication” model, provides a concrete physical mechanism for this correlation. Thereby, the theory elevates the relationship between geometry and entanglement from a mathematical possibility to a physical theory with explicit dynamics [62].

It is precisely this pursuit of underlying mechanisms that necessitates DDT confront the crucible of falsifiability—the hallmark of a scientific theory. Its scientific merit will ultimately be determined by whether the novel predictions it proposes can be corroborated by experimental observation [68].

4.2. Experimental Verification and Falsification Pathways

A robust theoretical framework must delineate clear operational pathways for its own decisive testing. Adhering to Karl Popper’s principle of falsification [69], we propose three distinct, specific, and—in principle—feasible experimental verification pathways, addressing both microscopic quantum phenomena and macroscopic cosmological scales. These pathways collectively constitute a comprehensive falsification system spanning from quantum to cosmic realms.

4.2.1. Detection of the “Synchronization Window” Effect in Entangled Photon Pairs

On the Dynamical Nature of Projection: From Mathematical Instantaneity to Physical Process

Standard quantum mechanics treats wave function collapse as an idealised, instantaneous mathematical transition [66]. However, this treatment is essentially a computational postulate rather than a description of a physical mechanism. From a dynamical perspective, the reorganization of a system from a delocalized superposition state to a definite eigenstate necessarily involves the evolution of the physical state. The notion that such a profound reorganization occurs instantaneously, without any finite timescale, is physically unnatural [70].

The fundamental advancement of Dynamic Dimension Theory lies in its reduction of “projection” or “collapse” from a mathematical abstraction to a genuine physical dynamical process—namely, the finite-time relaxation of the high-dimensional dynamic axis field towards a stable state via “stability selection” under environmental perturbation [62].

Consequently, the “synchronization window” predicted by this theory is an essential requirement of its physical core, representing this intrinsic relaxation time. Should experiments ultimately confirm that this transition is absolutely instantaneous, this core tenet of the theory would be falsified. Regardless of the outcome, the value of the theory lies in its transformation of a metaphysical assumption into a physical question amenable to experimental adjudication [68].

Experimental Principle

In Dynamic Dimension Theory, quantum entanglement originates from the correlated projection of the high-dimensional dynamic axis structure [43]. A central corollary of the theory is that this projection process is not mathematically instantaneous but rather a finite-time dynamics of “stability selection.” This experiment aims to detect the signature of this dynamical process imprinted upon the establishment of entanglement correlations, namely the “synchronization window” effect [62].

Specifically, the theory predicts that when performing measurements on entangled photon pairs, if the time difference Δt between the two measurements approaches zero, the results projected into the three-dimensional world will exhibit a brief period of incomplete determinism due to the high-dimensional dynamic axis’s stability selection not being fully locked in. Statistically, this manifests as: within an extremely short window $|\Delta t - 0| < T_c$ (where 0 corresponds to the eigen-time related to the system’s path difference, and $T_c \sim 100$ ps is the predicted characteristic time), the joint probability distribution for specific measurement outcome combinations will temporarily deviate from the asymptotic values predicted by standard quantum mechanics based on instantaneous collapse [71].

This stands in stark contrast to standard quantum mechanics, which treats the establishment of entanglement correlations as absolutely instantaneous, with the probability distribution remaining constant for any time difference [66].

Quantitative Estimation of Theoretical Prediction

To ensure the proposal’s rigor, we provide a preliminary estimate of the effect magnitude. Based on a simple model of the high-dimensional dynamics (detailed derivation to be presented in subsequent work), we anticipate that within the characteristic time window T_c , the occurrence probability of specific outcome combinations (e.g., obtaining a specific correlation in a Bell basis) may exhibit a relative deviation on the order of approximately 10^{-3} to 10^{-2} from its asymptotic value [72].

Although preliminary, this estimate is crucial. With the statistical power afforded by accumulating $N > 10^9$ coincidence counts, such minor probability shifts are detectable (signal-to-noise ratio $\propto \sqrt{N \cdot \delta P}$) [73]. This quantitative framework translates the abstract concept into a clear experimental target.

Experimental Setup and Methodology

To perform this high-precision measurement, we propose the experimental scheme depicted in Figure 1. The core involves using a pulsed-pump spontaneous parametric down-conversion source to generate polarization-entangled photon pairs (Type-II phase matching producing the $|H\rangle_a|V\rangle_\beta + e^{i\phi}|V\rangle_a|H\rangle_\beta$ state) [74]. Pulsed pumping (e.g., from a femtosecond Ti:Sapphire laser) provides a picosecond-scale time reference for the generation of entangled photon pairs, which is essential for precisely defining Δt [75].

The generated photon pairs (A and B) are directed into two independent detection arms. In the path of photon B, a piezoelectric actuator-driven delay line is inserted, whose delay τ_{means} can be precisely scanned and calibrated over a range of -500 ps to +500 ps [76]. This is key to the experiment: the “synchronization window” effect will manifest as a probability anomaly occurring only when the scanned delay τ_{means} compensates for the system’s intrinsic optical path difference, such that $|\Delta t - \tau_{\text{delay}}| < \tau_{\text{c}}$. This window moves with τ_{means} , thereby distinguishing it from any fixed instrumental artifacts [77].

Each detection arm contains the following key components:

1. **Rapid Measurement Basis Selector:** Driven by two physically isolated and synchronized high-speed true random number generators (QRNGs), electro-optic modulators randomly and rapidly switch between the H/V basis and the $\pm 45^\circ$ basis. The issuance times of the commands from the two QRNGs must satisfy the spacelike separation condition, i.e., their time difference is less than the time required for a photon to travel to the opposite detector (ensured by the optical path length), fundamentally precluding any local realistic explanation limited by the speed of light [45].
2. **Single-Photon Detection and Timing System:** This constitutes the core technical challenge. To resolve a window of $\tau_{\text{c}} \sim 100$ ps, the detector timing jitter must be significantly smaller than this value. Therefore, we recommend employing superconducting nanowire single-photon detectors (SNSPDs) with timing jitter < 20 ps. Their output signals are recorded by a time-to-digital converter with a resolution as high as 2 ps, assigning a precise timestamp and measurement basis information to each photon [79].

Experimental Procedure and Data Analysis

Data acquisition must continue until more than 10^9 valid coincidence events are accumulated [73].

The data analysis procedure is as follows:

1. **Time Alignment:** For each coincidence event, calculate the raw arrival time difference Δt_{raw} .
2. **Delay Calibration:** Based on the currently set τ_{delay} , calculate the calibrated time difference $\Delta t = \Delta t_{\text{raw}} - \tau_{\text{delay}}$ [76].
3. **Data Binning:** Partition all events into fine time bins (e.g., bin width of 10 ps) according to Δt .
4. **Probability Calculation:** For each time bin, instead of calculating the correlation strength S value, directly compute the occurrence frequency of the specific outcome combination predicted by the theory (e.g., the frequency P_{++} of obtaining the result “++” when both sides are set to the $\pm 45^\circ$ basis) [71].
5. **Anomaly Identification:** Plot the curve of this specific probability $P_{++}(\Delta t)$ as a function of Δt . The theory predicts that this curve will exhibit a statistically significant anomalous structure (peak or dip) around $\Delta t \approx 0$, with a width of approximately $2\tau_{\text{c}}$ [62].
6. **Hypothesis Testing:** Employ statistical tests (e.g., t-test) to compare the significance of the difference in mean probability between the “within-window” ($|\Delta t| < 100$ ps) and “outside-window” ($|\Delta t|$ around 1-2 ns) datasets (using a $p < 0.01$ threshold) [80].

Control Experiments and Error Control

The most critical control experiment is: under identical setup conditions, replace the entanglement source with a weak coherent state source emitting a definite polarization state (e.g., $|H\rangle$). Dynamic Dimension Theory predicts that the probability anomaly appears only for quantum entangled states and should be completely absent for definite states [71].

To control systematic errors:

1. **Optical Path Stability:** Utilize active optical feedback to stabilize the path length difference between the two arms to a level much smaller than the photon coherence length (e.g., $< 1 \mu\text{m}$) [77].
2. **Detector Effect Correction:** Precisely model the dead time, afterpulsing, and dark counts of SPADs/SNSPDs, and apply corrections in the analysis to prevent spurious coincidence peaks around $\Delta t \approx 0$ [78].
3. **Randomness Verification:** Subject the QRNG outputs to rigorous tests such as the NIST test suite to ensure their randomness [81].
4. **Background Subtraction:** Precisely measure the accidental coincidence count rate and subtract it from all coincidence data [74].

Technical Challenges and Feasibility Prospects

The primary technical challenge in this experiment lies in the requirement that the detector timing jitter must be substantially shorter than the characteristic time scale T_c of the predicted effect. Currently, commercially available superconducting nanowire single-photon detectors (SNSPDs) can achieve timing jitters better than 20 ps, while state-of-the-art laboratory systems have demonstrated sub-5 ps performance. This indicates that, in principle, there are no fundamental barriers to detecting signals on the order of 100 ps [78].

In recent years, breakthroughs in attosecond science and time–frequency transfer technologies, as evidenced by comprehensive reviews in journals such as *Nature Photonics* and *Reviews of Modern Physics*, have enabled femtosecond and even attosecond-level timing of physical processes [82,83]. The effect predicted in this study provides a profound and well-defined physical objective for such advanced techniques, thereby driving fundamental tests of quantum mechanics into unprecedented regimes of temporal precision [62].

4.2.2. Monitoring Energy Statistics Over the Complete Cycle of State Preparation, Collapse, and Decoherence

Experimental Principle and Hypothesis

Dynamic Dimension Theory (DDT) predicts that in the “high-dimensional to three-dimensional” extended system, energy conservation manifests as an energy cycle between the high-dimensional dynamic axis field and the projected three-dimensional world [29]. This cycle specifically appears during quantum measurement and decoherence processes as:

Forward Process (Energy Outflow): When a measurement triggers “stability selection,” causing the system to collapse from a superposition state to a definite eigenstate, the energy required for this process is sourced from the high-dimensional dynamic axis field. This may lead to a transient anomaly in the statistical expectation value of energy for the three-dimensional subsystem at the moment of collapse [30].

Reverse Process (Energy Inflow): When the system loses quantum coherence due to decoherence and evolves into a statistical mixture, the corresponding energy is expected to flow back to the high-dimensional field, and the energy statistical anomaly in the three-dimensional subsystem should consequently vanish [31].

Therefore, over a complete “preparation \rightarrow collapse \rightarrow decoherence” dynamical cycle, the time-averaged energy of the three-dimensional subsystem should be strictly conserved, but its

instantaneous statistical expectation value might exhibit detectable transient fluctuations on short timescales following collapse [63]. This experiment aims to capture the physical signature of this putative “inter-dimensional energy cycle” through high-precision, repetitive monitoring of energy statistics [29].

Experimental Setup and Methodology

We propose implementing this experiment on a superconducting qubit platform. This platform offers the following indispensable advantages [84]:

State Preparation: Arbitrary energy superposition states can be prepared using precisely modulated nanosecond-scale microwave pulses [85].

Fast Projective Measurement: Strong measurements can be performed, projecting the quantum state onto the energy eigenbasis within an extremely short time (~10 ns), effectively triggering “stability selection” [86].

Controllable Decoherence: Its energy relaxation time (T_1) and decoherence time (T_2) can be precisely characterized and modulated by changing the operating point or introducing controlled noise [87].

Key Experimental Design: To avoid measurement disturbance and achieve signal separation, we adopt a “repeated preparation and delayed comparative measurement” strategy. The specific experimental sequence is shown in Figure 2, with the procedure as follows:

1. **Initialization:** Prepare the qubit in the energy eigenstate $|g\rangle$ (corresponding to energy E_g) [85].
2. **Prepare Superposition State:** Apply a microwave $\pi/2$ pulse to prepare it into the superposition state $(|g\rangle + |e\rangle)/\sqrt{2}$, where $|e\rangle$ is the excited state (energy E_e), with energy difference $\hbar\omega_q = E_e - E_g$ [86].
3. **Trigger Collapse (First Measurement M_1):** At time $t=0$, apply a strong readout pulse to perform a projective measurement via dispersive coupling with the resonator, collapsing the system to $|g\rangle$ or $|e\rangle$. Record this measurement result. This step aims to record the “initial” energy state after collapse [88].
4. **Controlled Decoherence Evolution:** After the first measurement, instead of immediately resetting the system, allow the qubit to evolve freely for a precisely set duration τ under specific environmental conditions (baseline noise or introduced controlled noise). During this period, the system undergoes decoherence, evolving from a pure state to a mixed state [87].
5. **Second Measurement (M_2):** Immediately after the evolution time τ , apply a second strong readout pulse to perform another projective measurement, recording the energy eigenvalue collapsed to at that time [88].
6. **Cycling and Data Acquisition:** Repeat the entire sequence N times (e.g., $N = 10^6$). For each preset evolution time τ , collect datasets of the two measurement results: $\{M_1\}$ and $\{M_2(\tau)\}$. Subsequently, change the τ value (from near zero to significantly larger than T_2) and repeat the entire acquisition process [73].

Data Analysis and Falsification Criteria

The core observable is defined as the average energy difference between two measurements:

$$\Delta(E)(\tau) = 1/N \sum_{i=1}^N [E_{M_2}^{(i)}(\tau) - E_{M_1}^{(i)}]$$

where $E_{\{M\}}$ denotes the energy eigenvalue (E_g or E_e) corresponding to the measurement outcome.

- **Prediction of Standard Quantum Mechanics:** For any τ , $\Delta(E)(\tau) = 0$. This is because the first measurement prepares the system in an energy eigenstate, and in a closed system evolution, the energy expectation value remains constant. Even accounting for decoherence, the diagonal elements of the density matrix (i.e., the energy probability distribution) do not change over time; consequently, the statistical average of the second measurement should equal that of the first [66].

- Prediction of Dynamical Dimension Theory (DDT): Due to energy circulation, $\Delta\langle E\rangle(\tau)$ may be non-zero for small τ . Specifically:
- Signal A (Energy Output): As $\tau \rightarrow 0^+$, $\Delta\langle E\rangle(0^+)$ may deviate significantly from 0, indicating a transient anomaly in the system's energy statistics immediately after the initial collapse.
- Signal B (Energy Reflux): As τ increases ($\tau \sim T_2$), $\Delta\langle E\rangle(\tau)$ should decay exponentially towards 0, signifying the "reflux" of anomalous energy during the decoherence process [31].

Clear Falsification Conditions:

1. If $\Delta\langle E\rangle(\tau)$ shows no statistically significant difference from 0 within measurement error for all τ (including $\tau \rightarrow 0^+$), then the energy circulation prediction of this theory is falsified [68].
2. If $\Delta\langle E\rangle(0^+)$ is significantly non-zero, but this offset does not decay with τ (i.e., the anomaly persists permanently), it contradicts the energy circulation hypothesis, indicating the theory requires major revision [29].
3. If both Signal A and Signal B are observed, but the decay time constant significantly deviates from the system's T_2 , or the net energy transfer is not zero, then the theoretical model requires adjustment [30].

These falsification criteria are explicit, operable, and adhere to the principle of testability for scientific theories [69].

Discriminatory Power Against Existing Theories

This experimental design possesses strong theoretical discriminatory power:

- Observation of complete A and B signals: Strongly supports the energy circulation model of DDT and challenges the standard quantum mechanical picture where the energy expectation value is determined and maintained immediately after measurement [70].
- Observation of only Signal A (permanent offset): Suggests possible energy non-conservation within the existing quantum mechanics framework, potentially triggering a fundamental physics crisis and prompting novel research into the energy dynamics of the measurement process [63].
- Absence of any anomaly: Supports the statistical energy conservation of standard quantum mechanics at current precision levels, indicating that if the DDT energy circulation mechanism exists, its effects are below the current detection threshold [71].

Technical Challenges and Feasibility

The primary challenges and corresponding mitigation strategies for this experiment are as follows:

1. Measurement Fidelity and Statistical Error: High-fidelity single-shot state readout (currently achievable with superconducting qubit fidelities $> 99\%$) and sufficiently large N to reduce statistical errors are required. Projecting $N = 10^6$ can reduce statistical error to the order of 10^{-3} , sufficient to detect the theoretically predicted relative anomaly of $\sim 0.1\%$ [73].
2. System Drift and Error Control: The experiment must be conducted at ultra-low temperatures (~ 10 mK) to suppress thermal excitations [85]. Dynamic feedback stabilization of microwave amplitude and phase is necessary, along with using reference qubits or alternating calibration sequences to counteract slow drifts [86].
3. Measurement-Induced Disturbance: Strong measurements may cause residual qubit excitation or energy level shifts [88]. Comparative experiments involving systematic variation of readout pulse strength can extrapolate results to the limit of an "ideal projective measurement" [87].
4. Precise Control of Decoherence Time: T_2 can be modulated via tailored electromagnetic environments or introduced dynamical decoupling sequences to clearly separate the decay process of Signal B [89].

Feasibility Conclusion: The technological maturity of superconducting qubit platforms elevates this experiment from a conceptual idea to an implementable stage. Recent advances in quantum non-demolition measurements, long coherence times, and high-precision quantum state tomography [90,91] provide a solid foundation for executing such precise statistical measurements. Regardless of the experimental outcome, this endeavor will yield critical data for the intersection of quantum mechanics and thermodynamics at the microscopic scale.

4.2.3. Imprints of Non-Gaussianity in Large-Scale Cosmic Structure

Theoretical Model and Predictions

The core of Dynamical Dimension Theory lies in the existence of a high-dimensional dynamical axis field φ . During the inflationary epoch of the early universe, we propose an interaction between this field and the scalar inflaton field ϕ . This interaction can generate unique primordial density perturbations during inflation.

A simplest, yet sufficient, effective field theory coupling form that reveals the essential physics is:

$$\mathcal{L}_{\text{int}} \supset g/\Lambda (\partial_{\mu} \Phi)(\partial^{\mu} \varphi) \sigma,$$

where g is a dimensionless coupling constant, Λ is the energy scale, and σ is an auxiliary field (or viewed as a perturbation of φ). This derivative coupling can significantly amplify the three-point correlation function (bispectrum) $B_{\zeta}(k_1, k_2, k_3)$ of the primordial curvature perturbation in the squeezed limit ($k_3 \ll k_1 \approx k_2$) [93].

Specifically, this class of models predicts a non-Gaussian signal in the squeezed limit characterized by a scaling relation:

$$\lim_{k_3 \rightarrow 0} B_{\zeta}(k_1, k_2, k_3) \propto 1/k_3^{(n_s - 1)} P_{\zeta}(k_1) P_{\zeta}(k_3)$$

Its amplitude is quantified by the parameter $f_{\text{NL}}^{\text{loc}}$. Standard single-field slow-roll inflation predicts $|f_{\text{NL}}^{\text{loc}}| \ll 1$ [94], whereas the coupling model within this theory, in a reasonable parameter space (e.g., $g \sim \mathcal{O}(1)$, $\Lambda \sim H_{\text{inf}}$), can naturally produce signals with $f_{\text{NL}}^{\text{loc}}$ between 5 and 20 [95].

This prediction is compatible with the latest Planck satellite constraint on primordial non-Gaussianity, $f_{\text{NL}}^{\text{loc}} = -0.9 \pm 5.1$ (68% CL) [96], but definitively lies within the detection capability of next-generation cosmology surveys [97].

Observational Strategy and Data Processing

This test will indirectly probe primordial non-Gaussianity through the statistics of large-scale structure. The primordial $f_{\text{NL}}^{\text{loc}}$ leaves a characteristic imprint on the late-time galaxy distribution via the “scale-dependent bias” effect [98].

Data Sources: We will utilize public data from current and next-generation large surveys, prioritized as follows:

1. **Dark Energy Spectroscopic Instrument (DESI):** Provides high-precision spectroscopic redshifts for tens of millions of galaxies, enabling construction of the deepest and most precise 3D matter density field to date [99].
2. **Euclid Space Telescope:** Through near-infrared photometric surveys, provides precise positions and weak lensing information for billions of galaxies, allowing for independent cross-validation [100].
3. **Future Square Kilometre Array Phase 2 (SKA2):** Through neutral hydrogen surveys, tests the universality of the signal using a completely independent detection method and systematic error budget [101].

Data Processing Pipeline: Will strictly follow the official procedures of the respective international collaborations [99]. Core steps include: galaxy catalog construction, modeling of the

observational selection function, correction for redshift-space distortions, and inversion of the galaxy distribution to infer the initial matter density field. The key aspect of this analysis is the explicit inclusion of the $f_{\text{NL}}^{\text{loc}}$ -dependent scale-dependent term in the galaxy bias model [98]:

$$b(z, k) = b_0(z) + b_1(z) \cdot (f_{\text{NL}}^{\text{loc}} / k^2)$$

where b_0, b_1 are functions of redshift z , and k is the Fourier wavenumber.

Statistical Analysis Plan

We will employ a Bayesian global fitting framework based on the joint analysis of the power spectrum and bispectrum to constrain $f_{\text{NL}}^{\text{loc}}$ [102].

1. Statistic Extraction:

- **Power Spectrum:** Measure the galaxy density field power spectrum $P_g(k, z)$. Constraints on f_{NL} primarily arise from the bias effect on large scales (low k) [98].
- **Bispectrum:** Measure the galaxy density field bispectrum $B_g(k_1, k_2, k_3, z)$, particularly its squeezed configuration. The bispectrum is more sensitive to primordial non-Gaussianity and is key to breaking degeneracies with other cosmological parameters [93].

2. Parameter Inference:

We construct a likelihood function incorporating all standard Λ CDM parameters, bias parameters, and the target parameter $f_{\text{NL}}^{\text{loc}}$. Markov Chain Monte Carlo methods will be used to sample the posterior probability distribution from the observational data [103]. Model comparison will be performed via Bayesian evidence [102].

3. Significance Criterion:

- If the posterior distribution of $f_{\text{NL}}^{\text{loc}}$ shows a significant deviation from zero (e.g., $> 3-5\sigma$), and the Bayesian evidence strongly favors the model including this parameter ($\Delta \ln E > 5$), it will be considered strong support for this theory [104].
- If a tight null constraint is obtained (e.g., $|f_{\text{NL}}^{\text{loc}}| < 2$), the prediction of this theory is falsified within this parameter space.

Systematic Error Control and Validation

To ensure result reliability, the following stringent measures will be implemented:

1. Simulations and Injection Tests:

- Utilize cosmological N-body simulations incorporating the non-Gaussian signal predicted by DDT to generate mock galaxy catalogs [105].
- Inject realistic instrumental effects (e.g., observational noise, incomplete sky coverage) and astrophysical contaminants (e.g., stellar contamination) into the mock data [99].
- Run the full analysis pipeline on this simulated data to verify our ability to unbiasedly recover the input $f_{\text{NL}}^{\text{loc}}$ value [102].

2. Systematic Error Modeling:

- **Observational Effects:** Accurately model the impact of the point spread function, photometric calibration errors, fiber collision effects, etc., on statistical measurements [100].
- **Astrophysical Effects:** Meticulously model and subtract the effects of Galactic foregrounds, intra-cluster light, nonlinear evolution, and baryonic feedback on the matter power spectrum [106].

3. Robustness Checks:

- **Data Splitting:** Perform independent analyses on different sky regions, redshift slices, and galaxy samples to check signal consistency [97].

- Method Comparison: Employ multiple independent non-Gaussianity estimators (e.g., scale-dependent bias method based on power spectrum, modal expansion method based on bispectrum) for cross-validation [93].

Theoretical Discriminatory Power and Scientific Significance

This experiment possesses clear theoretical discriminatory power:

- Detection of a significant signal in the range $5 \leq f_{NL}^{loc} \leq 20$ would constitute a strong challenge to standard single-field slow-roll inflation and provide key clues about its dynamical origin [94].
- The amplitude and shape of the signal predicted by DDT might differ from other models producing large non-Gaussianity (e.g., multi-field inflation, primordial black hole formation models), allowing for subsequent discrimination via detailed bispectrum shape analysis [95].
- A tight null result would place stringent observational constraints on the coupling strength g or energy scale Λ of this theory, motivating refinements of the theoretical model.
- This plan seamlessly integrates the testing of DDT into the forefront of observational cosmology research paradigms, establishing it as a scientific hypothesis amenable to definitive adjudication by forthcoming massive datasets [107].

5. Conclusion and Outlook

This paper systematically elaborates a novel conceptual theoretical framework — Dynamical Dimension Theory (DDT). By introducing a high-dimensional dynamical axis field and its intrinsic stability selection mechanism, this framework provides a unified, mechanistic physical picture for several foundational puzzles in quantum mechanics. We demonstrate that phenomena from wavefunction collapse and the nonlocality of quantum entanglement to the existence of a quantum-classical boundary can be understood as different facets of the projection process from “high-dimensional wholeness” to “three-dimensional determinacy” [62].

The core advancement of this work lies in successfully translating this philosophically unified geometric perspective into three explicit, specific, and falsifiable experimental pathways, forming a complete verification system spanning microscopic to macroscopic scales:

1. Direct Probing of Microscopic Dynamics (Section 4.1): The “synchronicity window” experiment with entangled photon pairs aims to reveal for the first time that quantum projection is not instantaneous but a finite dynamical process. This constitutes the most direct test of the theory’s core mechanism (stability selection requires time).
2. Extended Validation of Energy Conservation (Section 4.2): The “full-cycle energy statistics monitoring” experiment using superconducting qubits aims to probe the revolutionary hypothesis of “interdimensional energy circulation.” This experiment confronts the theory’s most profound potential challenge, and its results will directly adjudicate the compatibility of DDT with the energy conservation law in extended systems.
3. Seeking Origins at Cosmological Scales (Section 4.3): By analyzing specific non-Gaussian imprints in next-generation cosmological survey data, we push the testing of the theory to the very early universe. Confirmation of this prediction would imply that the physics of the dynamical axis field is not only operative at microscopic scales but also left an eternal imprint at the birth of the cosmos.

These three pathways complement each other, forming a cohesive verification network. The “synchronicity window” tests the dynamical kernel, “energy circulation” consolidates compatibility with fundamental laws, and the “cosmological imprint” demonstrates the theory’s breadth in describing reality. Regardless of the outcomes of these experiments, they will inject new, inspiring data into quantum foundations research.

Of course, as a nascent theoretical framework, DDT requires further development in terms of the completeness of its mathematical formalism and the precision of its quantitative predictions,

which are undoubtedly important directions for future work. Looking ahead, our research will proceed along three clear paths:

1. Theoretical Deepening: Dedicate efforts to develop the rigorous mathematical foundation of the theory, complete the Lagrangian formulation of the high-dimensional dynamical axis dynamics, and explore its potential unification with gravity [108].
2. Experimental Advancement: Fully promote the key experimental tests proposed herein, seeking close collaboration with leading experimental teams to translate theoretical predictions into laboratory reality.
3. Paradigm Extension: Should DDT withstand initial experimental tests, it opens the possibility of a “new paradigm for quantum engineering” – i.e., actively guiding the outcomes of quantum processes by understanding and manipulating the stability properties of systems within the high-dimensional dynamical axis. This holds transformative prospects for quantum technology [109].

Concluding Remarks

Dynamical Dimension Theory, as the name suggests, aims to describe a dynamic, dimensionally extensible reality. It already provides a fresh geometric perspective for contemplating the nature of the quantum world. Now, accompanied by the proposal of a series of clear, operable experimental schemes, this earnest conceptual die has been cast. We await, and firmly believe, that the scientific process will render its final judgment based on experimental data. It is through this cycle of bold conception and rigorous testing that science continually advances.

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