The Energy-Dimension Framework in String Theory: Dynamic Dimensions, Intrinsic Spin, and Dynamic Equilibrium Optimal Solution

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Abstract

This paper proposes the **"Energy-Dimension"** framework, a unified approach grounded in string theory that addresses its landscape problem, the structure of the Standard Model, the origin of quantum probability, and central issues in gravity and cosmology. The framework rests on three pillars: the **Energy Dichotomy Postulate ($E_{total} = E_{rest} + E_{vib}$)**, which dynamically couples energy states to effective spacetime dimensions via the **dimension contraction function $f(r)$**; intrinsic **'Spin' modes**, whose emergent dynamics give rise to gauge symmetries and particle attributes; and the **multi-string entanglement principle**, explaining the three-generation fermion structure. All stable microscopic entities correspond to **dynamic equilibrium optimal solutions in the (E_{rest}, E_{vib}, Spin) parameter space**. We show how this framework interprets quantum probability as **"time-dilated sampling"** of high-dimensional dynamics; furthermore, it models pivotal quantum phenomena like wave-particle duality and delayed choice through **boundary condition-induced switching of these dynamic equilibrium states**. Finally, it quantizes gravity as collective emergence from

particle-level spacetime curvature and models cosmic energy cycles via high-dimensional background energy. The work outlines unique, falsifiable predictions and identifies core mathematical challenges.

Although this paper employs string theory as its concrete expository context, the core principles of the proposed "Energy-Dimension" framework—the Energy Dichotomy Postulate, the dimension contraction function, the dynamic equilibrium optimal solution, and high-dimensional network projection—possess broader applicability, aiming to describe an operating logic of the world that may be independent of any specific fundamental entity.

Keywords: String Theory, Quantum Gravity, Gauge Symmetry, Wave-Particle Duality, Multi-String Entanglement, Dynamic Equilibrium Optimal Solution

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1 Introduction: Conceptual Gaps in the Vision of Unification

Physics seeks unification, but true unification involves not just subsuming phenomena into a mathematical framework, but also revealing the **unified physical mechanisms** behind them. String theory represents a grand attempt at mathematical unification, elevating the fundamental entity from a point to a string, successfully harmonizing General Relativity and quantum mechanics under one roof [1, 2]. However, after decades of development, it remains plagued by profound conceptual problems:

- **The "Landscape" Dilemma [3]:** The theory allows for a near-infinitude of possible vacua, yet cannot explain "why **our** universe?"—i.e., why the Standard Model of particle physics exhibits its specific particle spectrum and interactions.
- **The Missing "Origin":** We can calculate Standard Model processes with precision, but lack a clear, mechanistic "first principles" explanation for its most fundamental features. For instance:
    - **Why** do elementary particles exhibit such a vast mass hierarchy, from the massless photon to the heavy top quark?
    - **Why** does nature contain precisely three (or four, including gravity) seemingly distinct yet partially unifiable fundamental interactions?
    - **More fundamentally,** what is the physical essence of the wave-particle duality puzzle that has been at the core of quantum mechanics for a century?

Current theories are largely **descriptive**, excellently telling us "what" and "how," but failing to clearly answer "**why is it so?**" This review aims to bridge this gap. We propose

a conceptual framework named the **"Energy-Dimension"** framework, which is rooted in string theory but introduces a series of new physical imagery and principles designed to provide **mechanistic answers** to the above dilemmas.

It is crucial to emphasize that, although this paper employs string theory as the most intuitive and rich carrier to articulate these concepts, the core value of our framework lies in the set of synergistic physical principles it proposes. We have chosen string theory as our stage precisely because it is currently the most mature theory capable of accommodating these principles and is in urgent need of solving its core dilemmas. These principles include:

- **Energy-Dimension Dynamics:** Through the **Energy Dichotomy Postulate and the dimension contraction function** $\boldsymbol{f(r)}$, it dynamically couples material properties (mass, wave-particle duality) with spacetime geometry (effective dimensions).
- **"Spin" Modes and Multi-String Entanglement:** It unifies the particles and forces of the Standard Model by correlating them with the string's intrinsic **'Spin' modes** and their **multi-string entangled states**. This provides a unified microscopic dynamical foundation for understanding particle generations, stability, and transformations (decay/fusion).
- **High-Dimensional Determinism and Low-Dimensional Projection:** It interprets quantum phenomena as **"Time-Dilated Sampling"** projections of high-dimensional deterministic processes onto the low-dimensional world, thereby offering a deterministic, intuitive picture for quantum probability and entanglement.

- **Principle of Dynamic Equilibrium Optimal Solutions:** It attributes all stable phenomena to **dynamic equilibrium optimal solutions** in the **(E_{rest}, E_{vib}, Spin) parameter space**, where these discrete solutions correspond to all stable microscopic entities.

We propose that it is the combination of these principles, rather than the carrier itself, that can lay the foundation for a complete and self-consistent physical theory, ranging from microscopic particles to the fate of the macroscopic cosmos.

Ultimately, these principles naturally lead to a physical picture of a **high-dimensional holistic network**. This allows for a unified interpretation of core quantum measurement puzzles — such as wave-particle duality, the delayed-choice, and quantum eraser experiments—as processes of **boundary condition-induced switching of dynamic equilibrium states**. This provides a clear, mechanistic approach to addressing the century-old problem of the 'role of the observer'.

This work aims to explore a "principle-first" path. We first ask: what might be the unified operating logic governing both the microscopic and macroscopic worlds? To answer this, we have constructed a conceptual framework centered on "Energy-Dimension coupling" and "Dynamic Equilibrium Optimal Solutions." To concretize this framework and demonstrate its explanatory power, we have chosen string theory as the richest and most self-consistent "demonstration platform" or "physical carrier." This is because string theory naturally possesses a high-dimensional background and rich intrinsic degrees of freedom, allowing it to perfectly embody our core ideas. It must be emphasized that the value of the framework lies first and foremost in its system of

principles itself; the string here serves as an "illustration" of the principles, not their "prerequisite." Therefore, the core contribution of this paper is not to make new assertions about what the fundamental constituents of the world are (be they strings, loops, or otherwise), but rather to propose a new conceptual framework and operational blueprint for understanding the unified operating logic that such entities may follow.

In Section 2, we will elaborate in detail on the **basic postulates** and **microdynamic principles** of this framework. Section 3 will systematically demonstrate how the framework provides unified interpretations for the **Standard Model of particle physics, quantum foundational phenomena**, and **black holes and cosmology**. Section 4 compares this framework with related theories, clarifying its inheritance and innovation. Section 5 presents the **unique and testable predictions** derived from the framework. Finally, Section 6 candidly discusses the **mathematical challenges** it faces and outlines a future **research roadmap and collaboration initiative.**

2 The "Energy-Dimension" and "Intrinsic Spin" Model: Core Framework

This section elaborates on the basic postulates and core mechanisms of the "Energy-Dimension" framework. Its fundamental logic is: **The dynamic equilibrium between the two forms of a string's energy (rest energy and vibrational energy), acting in synergy with its intrinsic 'spin' degrees of freedom, collectively determines all observable properties of particles and the nature of their interactions.**

2.1 Basic Postulates

The framework is built upon the following core postulates:

2.1.1 Ontology: The fundamental entities of the world are one-dimensional strings, whose ontology exists in a fixed, highest-dimensional background spacetime (e.g., 11-dimensional). Strings possess multiple intrinsic 'spin' degrees of freedom, which constitute their internal state Hilbert space.

2.1.2 Energy Dichotomy Postulate and Intrinsic Energy:

Any **single, stable fundamental entity** (e.g., a fundamental particle in its own rest frame) possesses an intrinsic total energy $\boldsymbol{E_{\text{total}}}$ composed of two parts: the **Rest Energy** $\boldsymbol{E_{\text{rest}}}$ and the **Vibrational Energy** $\boldsymbol{E_{\text{vib}}}$. Their sum is constant:

$$\boldsymbol{E_{\text{total}} = E_{\text{rest}} + E_{\text{vib}}} \quad (1)$$

This relationship defines the **intrinsic energy structure** of the entity itself. $\boldsymbol{E_{\text{total}}}$ can be regarded as the entity's "total rest energy." When the string is in the completely static ground state, its $\boldsymbol{E_{\text{rest}}}$ reaches the maximum value ($\boldsymbol{E_{\text{rest}} = E_{\text{total}}}$), $\boldsymbol{E_{\text{vib}}}$ is zero, and the system tends toward static equilibrium.

2.1.3 Process Energy Conservation Law

When transformations between states occur (such as particle decay, fusion, or black hole accretion), the **entire system** obeys the law of energy conservation. **The total energy of the system in its initial state is equal to the sum of the total energies of all products in the final state.**

Specifically, for a decay process A $\rightarrow$ B + C + ...:

$$\boldsymbol{E_{\text{total\_A}} = \left(E_{\text{total\_B}} + E_{\text{total\_C}} + \cdots\right) + E_{\text{kinetic\_final}}} \quad \textbf{(2)}$$

Where:

- $\boldsymbol{E_{\text{total\_A}}}$ is the **intrinsic total energy** of the initial-state particle A (i.e., its own $\boldsymbol{E_{\text{total}}}$).
- $\left(\boldsymbol{E_{\text{total\_B}}} + \boldsymbol{E_{\text{total\_C}}} + \cdots\right)$ is the **sum of the intrinsic total energies** of all final-state particles (i.e., the sum of their respective $\boldsymbol{E_{\text{total}}}$ values).
- $\boldsymbol{E_{\text{kinetic\_final}}}$ is the total kinetic energy of the final-state particles relative to the system's center of mass.

In a typical decay, the sum of the intrinsic energies of the final-state particles is usually less than the intrinsic energy of the initial-state particle ($\left(\boldsymbol{E_{\text{total\_B}}} + \boldsymbol{E_{\text{total\_C}}} + \cdots\right) < \boldsymbol{E_{\text{total\_A}}}$). According to equation (2), this energy difference $\boldsymbol{\Delta E = E_{\text{total\_A}} - \left(E_{\text{total\_B}} + E_{\text{total\_C}} + \cdots\right)}$ is thus converted into the kinetic energy $\boldsymbol{E_{\text{kinetic\_final}}}$ of the final-state particles, manifesting as energy released by the process. The same principle applies to fusion processes, though they typically require an input of kinetic energy to overcome interaction barriers.

2.1.4 Activation of Intrinsic Spin: The specific mode of the intrinsic 'Spin' degrees of freedom activated in a string is determined by the value of the dimension contraction function $\boldsymbol{f(r)}$—yet this relationship is not unidirectional. A particular Spin configuration locks the **($\boldsymbol{E_{\text{rest}}}$, $\boldsymbol{E_{\text{vib}}}$, Spin)** combination of a string into a Dynamic Equilibrium Optimal Solution corresponding to a specific interval of $\boldsymbol{f(r)}$; the higher the Spin complexity, the higher the sustainable $\boldsymbol{E_{\text{vib}}}$, the stronger the particle nature, and the correspondingly lower the stability of that solution. Spin modes and the value of $\boldsymbol{f(r)}$ act in synergy, thereby providing a unified explanation for the origin and diversity of all elementary

particles and interaction forces.

2.1.5 Dynamic Tendency: A string can form a stable **"Dynamic Equilibrium Optimal Solution"** at specific parameter combinations of **(E_{rest}, E_{vib}, Spin)**, which serves as the foundation for the stable existence of all elementary particles. **However, its fundamental dynamical tendency is unequivocal: once the equilibrium condition is broken, the system will irreversibly relax towards a state of higher E_{rest} and lower E_{vib}, with the ultimate direction being the static equilibrium of maximized rest energy. This microscopic tendency constitutes the underlying driver for the universe's progression towards "heat death".**

2.1.6 Property Emergence: When a string is perturbed, its energy form shifts from being rest-energy-dominated to vibration-energy-dominated. **The higher the string's rest energy, the stronger its wave-like properties; the higher its vibrational energy, the stronger its particle-like properties.** All intrinsic properties of a particle (such as mass) are determined by specific combinations of (vibrational energy, "spin" mode).

2.1.7 Energy-Dimension Coupling: Energy-Dimension Coupling: The ratio $r \equiv E_{vib}/E_{rest}$ of a string's vibrational energy to its rest energy determines the effective spacetime dimensions it exhibits through the dimension contraction function $f(r)$. $f(r)$ is a monotonically decreasing function of r, with a range of (0,1].

2.1.8 Microdynamic Principles

Based on the Energy-Dimension framework, we propose four fundamental principles governing the formation and transformation of the microscopic world:

- **Principle of Structure:** Any stable microscopic entity, regardless of its complexity, can be described as a specific **Dynamic Equilibrium Optimal Solution** of **(E_{rest}, E_{vib}, Spin)**. The foundation for realizing this solution can be a single string or an **entangled state** formed by multiple strings through **synergistic resonance**.
- **Principle of Stability:** The existence of a microscopic entity depends on the dynamic equilibrium between its internal **"entanglement binding"** and external **"disentanglement perturbations"**. The various fundamental interactions we observe are essentially emergent manifestations of this universal **"entanglement force"** at different scales and contexts.
- **Decay Principle:** The transformation of an entity from a higher-energy state to a lower-energy state (e.g., particle decay) is a **"disentanglement"** process that occurs after a dynamic equilibrium state becomes unstable, whereby a complex multi-string alliance relaxes into one or more simpler alliances. This process leads to a decrease in the system's **total intrinsic energy ($\sum E_{total}$)**, and the difference ΔE_{total} is released as kinetic energy.
- **Fusion Principle:** The creation of new entities from lower-energy states to higher-energy states (e.g., nuclear fusion) is the formation of a new, more complex **"entanglement"** from simple alliances, driven by external conditions. This process typically requires an input of energy (e.g., kinetic

energy) to overcome the entanglement barrier, resulting in an increase in the **total intrinsic energy ($\sum \boldsymbol{E_{\text{total}}}$)** of the formed composite system.

2.1.9 The High-Dimensional Holistic Network Postulate

Strings do not exist in isolation. Within the highest-dimensional background spacetime $\boldsymbol{M_{\text{high}}}$, every string is interconnected with all other strings through their intrinsic interactions—including but not limited to the coupling of "Spin" modes, the coordination of energy morphologies, and multi-string entanglement—forming a **dynamic, indivisible holistic network**. This network itself perpetually resides in its own **holistic dynamic equilibrium optimal solution**, which adjusts in real time in response to changes in the dynamic equilibrium states of all constituent strings.

This postulate carries profound and far-reaching implications:

- **Instantaneous holistic coordination.** Any change of state of a node (string) within the network—whether an adjustment of its **($\boldsymbol{E_{\text{rest}}}$, $\boldsymbol{E_{\text{vib}}}$, Spin)** parameters, the establishment of a new dynamic equilibrium optimal solution, or the formation of entanglement or linkage with other strings—is instantly conveyed across the entire network. This coordination is not a signal transmission through low-dimensional space, but a synchronous reconfiguration at the level of the high-dimensional holistic network, and thus does not violate the speed-of-light limit in low-dimensional spacetime (see Section 3.5.6 for a detailed discussion).
- **The ontological foundation of low-dimensional holism.** Phenomena

observed in low-dimensional spacetime—such as quantum entanglement, quantum correlations, and delayed-choice effects—with their apparent "non-locality," are natural manifestations of the instantaneous coordination of the high-dimensional holistic network as projected into low dimensions. Two events that appear remote and causally disconnected in low-dimensional space may share a common dynamical node or be connected by extremely short internal paths within the high-dimensional network.

- **Boundary-condition-driven global reconfiguration.** Any act of low-dimensional "observation" or "interaction" is, in essence, the implantation of a physical boundary condition into the high-dimensional holistic network. To satisfy this new global constraint, the network drives a reconfiguration of the dynamic equilibrium states of relevant nodes, seeking a new holistic optimal solution. This process manifests in low-dimensional projection as the collapse of the quantum state, the selection of a history, or the alteration of an interference pattern.

Consequently, the entire low-dimensional physical world we perceive—its causal structure, holistic correlations, and quantum statistical regularities—is not fundamental, but rather an emergent phenomenon arising from the projection of the high-dimensional holistic network onto specific dimensions.

These nine elements work synergistically to form a complete picture of physical reality: (Energy, Spin) → (Particle Properties, Interactions). The schematic in Figure 1 summarizes this core "Energy-Dimension-Particle Property" coupling.

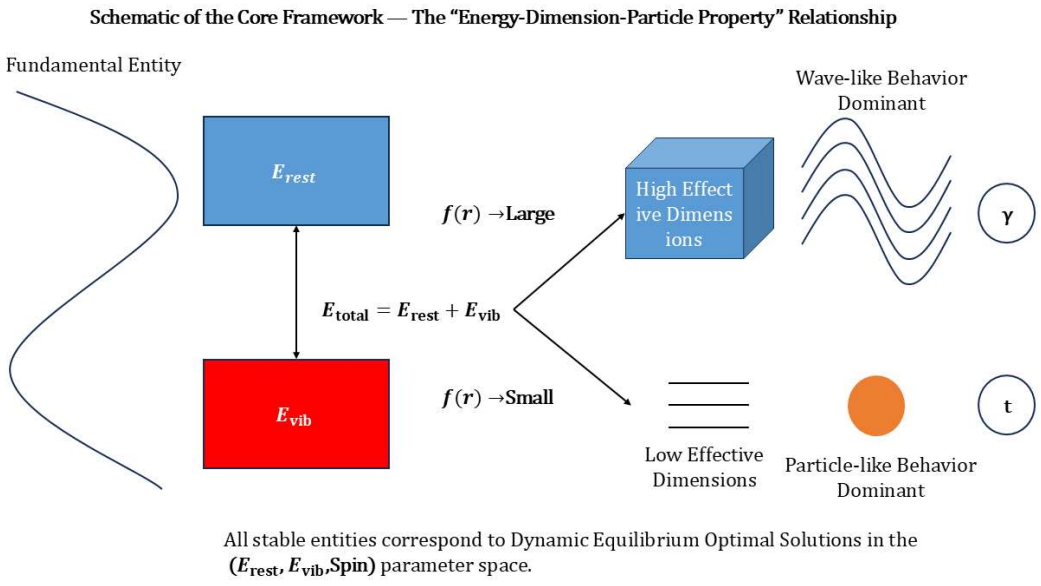

Figure 1: Schematic of the core "Energy-Dimension-Particle Property" framework. The energy dichotomy of a string $(\boldsymbol{E_{total} = E_{rest} + E_{vib}})$, mediated by the dimension contraction function $\boldsymbol{f(r)}$, determines its effective dimensions. A low $\boldsymbol{r}$/high $\boldsymbol{E_{rest}}$ state leads to higher effective dimensions and wave-like dominance (e.g., photon); a high $\boldsymbol{r}$/low $\boldsymbol{E_{rest}}$ state leads to lower effective dimensions and particle-like dominance (e.g., top quark). All stable entities correspond to Dynamic Equilibrium Optimal Solutions in the $\boldsymbol{(E_{rest}, E_{vib}, Spin)}$ parameter space.

2.2 Core Mechanisms

The above postulates give rise to the physical world we observe through the following three interconnected mechanisms.

Mechanism One: Energy-Dimension Coupling

Define the dimensionless ratio $\boldsymbol{r \equiv E_{vib}/E_{rest}}$, i.e., the ratio of a string's vibrational energy to its rest energy. It is r that serves as the core variable determining a string's "effective dimensions" in our observed universe. We introduce an **Effective Metric**

$G_{\mathbf{effective}}$ to describe this phenomenon:

$$G_{\mu\nu}^{(\mathbf{effective})} = f(r) \cdot G_{\mu\nu}^{(\mathbf{background})}$$

Where $G_{\mu\nu}^{(\mathbf{background})}$ is the metric of the highest-dimensional background spacetime. The function $f(r)$, termed the **"Dimension Contraction Function"**, is a scalar function ranging from (0, 1], and is a **monotonically decreasing function of** r.

- **Physical Picture:** When r is low (e.g., a photon, whose r approaches the lowest threshold of this dimension), $f(r) \to 1$, meaning the string's energy and morphology can fully unfold in the high-dimensional background, manifesting as strong **waviness**.. When r increases (e.g., an electron), $f(r)$ decreases, meaning the string's energy and dynamic behavior are "projected" into lower effective dimensions, manifesting as localized **particle-ness** and significant mass.
- **The Hierarchical Structure of Dimensional Thresholds**

  It is further worth clarifying that the "high-dimensional unfolding" and "low-dimensional projection" in this framework are not featureless continua, but possess a discrete dimensional threshold structure. Each effective dimension level corresponds to a specific interval of $f(r)$. Concretely, let Θ_{n+1}^{+} denote the upper bound of the f-threshold for entering (n+1)-dimensional spacetime, and Θ_{n+1}^{-} its lower bound. The condition for a string's projection to fall into (n+1)-dimensional spacetime is then $\Theta_{n+1}^{-} < f(r) < \Theta_{n+1}^{+}$; (3+1)-dimensional spacetime corresponds to $\Theta_{3+1}^{-} < f(r) < \Theta_{3+1}^{+}$. The photon is the limit in which $f(r)$ tends toward Θ_{3+1}^{+} within this dimension—the state with the largest $f(r)$ and the strongest wave nature within this dimension—rather than "$f(r)$ approaching

1" in any absolute sense. Should its $\boldsymbol{r}$ decrease further and its $\boldsymbol{f(r)}$ cross beyond $\boldsymbol{\Theta_{3+1}^{+}}$, the string's projection would ascend to a higher level and become undetectable in four-dimensional spacetime.

The effective dimension determined by the dimension contraction function $\boldsymbol{f(r)}$ is the macroscopic level of a string's projection. Within each dimension, there are further embedded finer energy thresholds $\{\boldsymbol{\theta_i}\}$, which determine the specific positions at which the gauge symmetry undergoes successive breaking within that dimension. For (3+1)-dimensional spacetime, all these $\{\boldsymbol{\theta_i}\}$ fall within the $\boldsymbol{f(r)}$ interval between $\boldsymbol{\Theta_{3+1}^{-}}$ and $\boldsymbol{\Theta_{3+1}^{+}}$. The dimensional thresholds $\boldsymbol{\Theta_n}$ and the energy thresholds $\{\boldsymbol{\theta_i}\}$ together constitute the complete hierarchical structure from "which dimension" to "what kind of interaction."

Mechanism Two: "Spin" Activation and Symmetry Breaking

A string's intrinsic "Spin" modes are not always fully manifest. The activated mode and its complexity are determined by the value of the dimension contraction function $\boldsymbol{f(r)}$. This process works in concert with energy-dimension coupling:

- When $\boldsymbol{r \to 0}$ (correspondingly $\boldsymbol{E_{vib} \to 0}$, $\boldsymbol{E_{rest} \to E_{total}}$), $\boldsymbol{f(r) \to 1}$, and the string fully unfolds in the high-dimensional background.
- When $\boldsymbol{r}$ is extremely high (correspondingly $\boldsymbol{E_{vib}}$ extremely high, $\boldsymbol{E_{rest}}$ extremely low), $\boldsymbol{f(r)}$ approaches 0, and the system is in the state of highest symmetry $\boldsymbol{G_{high}}$, manifesting as a highly unified interaction.
- When $\boldsymbol{r}$ decreases, $\boldsymbol{f(r)}$ increases, and crosses a series of energy thresholds $\{\boldsymbol{\theta_i}\}$, the system undergoes spontaneous symmetry breaking, and the effective

gauge group reduces step by step: $\boldsymbol{G_{high}} \to \cdots \to \boldsymbol{SU(3) \times SU(2) \times U(1)}$. Concurrently, the value of $\boldsymbol{f(r)}$ increases, which means the effective dimensions of the string are elevated, and its energy and dynamic behavior manifest within a higher-dimensional context.

- **Physical Picture:** At low energy scales ($\boldsymbol{f(r)}$ large, near the upper bound $\boldsymbol{\Theta^{+}_{3+1}}$ of this dimension), due to symmetry breaking, strings only activate or manifest the simplest **U(1)** "spin" mode, corresponding to the electromagnetic force. As energy increases ($\boldsymbol{f(r)}$ decreases, crossing the energy thresholds $\{\boldsymbol{\theta_i}\}$), strings unlock and manifest more complex **SU(2), SU(3)** "spin" modes, corresponding to the weak and strong forces.
- **The Locking Relationship between Spin and Energy Morphology**

  Mechanism Two has detailed how the value of $\boldsymbol{f(r)}$ determines which Spin modes are activated. However, the reverse of this relationship is equally central to the present framework: once a Spin mode is activated, it constitutes a configurational constraint that locks the string's energy morphology into place. Concretely, a complex Spin configuration locks the string into a particle-dominated state of high $\boldsymbol{E_{vib}}$ and low $\boldsymbol{E_{rest}}$ —this is precisely the origin of the simultaneously enormous masses and extreme instability of the W/Z bosons and the top quark: their complex Spin modes require the maintenance of a high vibrational energy state, and once this state is perturbed, the Spin complexity decreases, the locked high-energy configuration disintegrates, and the string relaxes toward a new Dynamic Equilibrium Optimal Solution with lower $\boldsymbol{E_{vib}}$—

manifesting as particle decay. Conversely, the photon possesses the simplest Spin configuration (requiring only the U(1) mode), and the $\boldsymbol{E_{\text{vib}}}$ it can sustain is extremely low (its $\boldsymbol{r}$ approaches the lowest threshold of this dimension), rendering it exceedingly stable.

This locking relationship is fully consistent with the Principle of Stability (Section 2.1.8) and the Decay Principle (Section 2.1.8) of this framework: the more complex the "entanglement binding" that maintains a specific Spin mode, the higher the energy required to resist "disentanglement perturbations," the more readily the dynamic equilibrium is broken, and the more rapid the decay.

Mechanism Three: Dual-Layer Dynamic Equilibrium—Singular Strings and the Holistic Network

The above two mechanisms describe how the energy morphology of a single string determines its projection properties and intrinsic symmetries. However, these properties do not manifest in isolation: every string is embedded within the high-dimensional holistic network established by Postulate 2.1.9. Hence, this framework identifies and addresses dynamic equilibrium at two mutually embedded levels:

- **Level One: Singular Equilibrium.** A single string (or a stable multi-string alliance) seeks and maintains its own singular dynamic equilibrium optimal solution within the **($\boldsymbol{E_{\text{rest}}}$, $\boldsymbol{E_{\text{vib}}}$, Spin)** parameter space. This solution determines all of the string's intrinsic properties in low-dimensional projection (mass, spin, charge, etc.). When the singular equilibrium is perturbed, according to Postulate 2.1.5 (Dynamic Tendency), the string spontaneously relaxes toward a new optimal

solution with higher $\boldsymbol{E_{\mathrm{rest}}}$.

- **Level Two: Holistic Equilibrium.** The entire high-dimensional network, as the totality of all strings and their interconnections, perpetually resides in a **holistic dynamic equilibrium optimal solution**. This holistic equilibrium is not a simple superposition of the various singular equilibria; it integrates the states of all strings and their high-dimensional correlations, constituting a unified global constraint.
- **The interplay between the two levels.** This is the core of the present mechanism and the origin of numerous quantum phenomena:
  - **From Singular to Holistic:** Any change of state in a single string—such as forming new entanglement, undergoing decay, or responding to an observational perturbation—is instantaneously conveyed across the entire network through the instantaneous holistic coordination described in Postulate 2.1.9, driving an adjustment of the holistic equilibrium.
  - **From Holistic to Singular:** The adjusted holistic dynamic equilibrium optimal solution, in turn, provides a new boundary constraint for each string. Under this constraint, the **(** $\boldsymbol{E_{\mathrm{rest}}}$ **,** $\boldsymbol{E_{\mathrm{vib}}}$ **, Spin)** parameters of the relevant strings undergo reconfiguration, each relaxing to a new singular optimal solution compatible with the whole.
  - **Dual-Layer Effects in Low-Dimensional Projection:** This bidirectional dynamical process—singular perturbation triggers holistic adjustment, and holistic adjustment constrains singular reconfiguration—manifests in low-dimensional projection as the most central phenomena in the quantum

measurement problem. The "collapse" of the wavefunction, the appearance or disappearance of interference patterns, and the non-local correlations of quantum entanglement are, in essence, the projected manifestations of a dual-layer dynamic equilibrium system undergoing the dynamical chain of "global reconfiguration → singular relaxation" after the implantation of a new boundary condition. Detailed applications are developed in Section 3.5.

Thus, the dynamical system of the Energy-Dimension framework is a macroscopic high-dimensional holistic network dynamic equilibrium, coupled from the singular dynamic equilibria of countless microscopic strings. All stable phenomena and evolutionary laws of the universe can be traced back to the continuous, bidirectional process of coordination between these two levels.

Theoretical Corollary: Time-Flow Differentials Across Dimensional Levels and Low-Dimensional Sampling

A direct corollary of this framework is that, in the highest-dimensional background spacetime (e.g., 11-dimensional), time does not exist as an independent fundamental dimension—what exists is only the high-dimensional holistic network continuously reconfiguring its global dynamic equilibrium optimal solution, with each "slice" being one complete configuration of the network. The perception of time flow appears only in the intermediate dimensional levels (4–10 dimensions) and in low-dimensional spacetime (3+1 dimensions). Concretely, the intrinsic time flow rate $\boldsymbol{\tau_{high}}$ of the intermediate dimensional levels is far faster than the low-dimensional time $\boldsymbol{t_{low}}$ we perceive (i.e., $\boldsymbol{d\tau_{high} / dt_{low} \gg 1}$). This "time-flow differential" leads to a

fundamental observational effect: all our low-dimensional measurements are essentially very low time-resolution "sampling" of the continuous deterministic processes in the intermediate higher dimensions. Thus, high-dimensional determinism appears as probability from the low-dimensional perspective. The detailed argument and powerful applications of this corollary will be shown in the next section.

2.3 Integration with String Dynamics

This framework is fully compatible with the basic dynamics of string theory. We assume that the motion of strings in the highest-dimensional background $\boldsymbol{M_{\text{high}}}$ is still described by the **Nambu-Goto action**:

$$\boldsymbol{S_{\text{NG}} = -\frac{1}{2\pi\alpha'}\int d^2\sigma\sqrt{-det(\gamma_{ab})}\ ,\gamma_{ab} = G_{\mu\nu}^{(\text{background})}\partial_a X^\mu \partial_b X^\nu}$$

The **Nambu-Goto action** answers: "**How** does a string move in the highest-dimensional background?"

The **"Energy-Dimension" framework** answers: "**What** do we **observe** in its low-dimensional projection when a string moves with a specific **(Energy, Spin)** state?"

These two levels are complementary and together constitute a complete physical reality.

2.4 The Microscopic Origin of Gravity: Dynamic Equilibrium as the Source of Spacetime Geometry

This framework reveals a compelling unified picture: gravity is not an independent interaction, but an inherent **geometric property** of the string system in any dynamic equilibrium state of **($\boldsymbol{E_{\text{rest}}}$, $\boldsymbol{E_{\text{vib}}}$, Spin)**. Macroscopic spacetime curvature emerges as the statistical average of the contributions from all microscopic string dynamic equilibrium states to the local effective metric $\boldsymbol{G_{\mu\nu}^{(\text{effective})}}$.

2.4.1 Gravity as an Intrinsic Charge of Dynamic Equilibrium

We posit a core postulate: every stable elementary particle, as a "Dynamic Equilibrium Optimal Solution" in the parameter space, not only determines its own mass, charge, and spin but also defines a universal "gravitational charge." This "charge" is not a new quantum number, but rather the strength and manner with which the equilibrium state, via a function $\boldsymbol{F(r, \mathrm{Spin})}$, directly contributes a "micro-curvature" to the effective spacetime metric $\boldsymbol{G_{\mu\nu}^{(\mathrm{effective})}}$ at its location. **Therefore, an electron or a quark is itself a miniature, dynamic source of a spacetime deformation (or 'wrinkle').**

2.4.2 The Graviton: A Geometric Projection from a High-Energy Phase Transition

The entity we call the "graviton" holds a unique status within this framework. It is not a special type of string, but rather the product of a profound "dimensional projection phase transition" that the string system undergoes when $\boldsymbol{E_{\mathrm{vib}}}$ approaches a very high threshold $\boldsymbol{\theta_{\mathrm{grav}}}$.

- **Phase Transition Mechanism:** When $\boldsymbol{E_{\mathrm{vib}} > \theta_{\mathrm{grav}}}$, the drastic change in the dimension contraction function $\boldsymbol{f(r)}$ causes the string's projection to descend into a domain partially "decoupled" from the spacetime level inhabited by our conventional particles. The intrinsic geometry of this domain may defy description by a continuous spacetime.
- **Holographic Emergence and the Origin of Spin-2:** In the spirit of the holographic principle, the physical information of this high-energy state is

entirely encoded and mapped onto the boundary of our four-dimensional spacetime, with the **spacetime metric itself being its only coupling channel**. This perfectly explains the graviton's "visible but undetectable" characteristic: we can feel its gravitational effect (spacetime curvature) but cannot directly detect its particle entity like we can with photons. In this picture, the masslessness and spin-2 attributes of the graviton are not fundamental inputs but **low-energy emergent phenomena**. They are the necessary form taken by the mathematical language of our four-dimensional spacetime when describing pure geometric perturbations originating from deeper physics. **Spin-2 represents the limiting boundary of our current dimension's descriptive capacity for "particle-like" representations**.

2.4.3 The Microscopic Mechanism of Spacetime Curvature

The above picture provides a concrete microscopic realization of "matter telling spacetime how to curve." The distribution of macroscopic matter and energy is essentially a statistical distribution of specific string dynamic equilibrium states in space, forming a dynamic "Dynamic Equilibrium Background Field."

- From Micro to Macro: The statistical average of the gravitational contributions from all microscopic individuals via $\boldsymbol{F(r, \mathrm{Spin})}$ ultimately manifests as the macroscopic effective metric $\boldsymbol{G_{\mu\nu}^{(\mathrm{effective})}}$. The coupling between this background field and the metric can be expressed as:

$$\boldsymbol{G_{\mu\nu}^{(\mathrm{effective})} = \mathcal{F}\left(\mathbf{Dynamic\ Equilibrium\ Background\ Field}, f(r)\right)}$$

Here, $\mathscr{F}$ is a function characterizing the coupling law between microscopic dynamic equilibrium and macroscopic geometry.

- **Mechanism Interpretation:** It is this coupling, based on microscopic dynamic equilibrium, that transforms the invisible spatial distribution of "Spin" and energy modes into the macroscopic spacetime geometry we observe.

2.4.4 Integration with Existing Theories

Within this framework, General Relativity is the low-energy, classical field theory that emerges from the collective behavior of these "gravitational charges." The core challenge of constructing a consistent theory of quantum gravity thus transforms into starting from the first principles of **($\boldsymbol{E_{\mathrm{vib}}}$, Spin)** dynamic equilibrium dynamics, strictly deriving the existence of the dimensional projection phase transition, and demonstrating that its holographic mapping necessarily leads to a massless, spin-2 tensor field, thereby offering novel pathways to resolving problems like Hawking radiation and black hole entropy.

2.5 The Principle of Dynamic Equilibrium Optimal Solution and Its Universality

A core discovery of this framework is that all stable phenomena and evolutionary laws of the physical world originate from strings seeking, establishing, and breaking the **Dynamic Equilibrium Optimal Solution** in the **($\boldsymbol{E_{\mathrm{rest}}}$, $\boldsymbol{E_{\mathrm{vib}}}$, Spin)** parameter space. This principle is the bridge connecting microscopic particle properties and macroscopic

cosmic destiny.

The 'Dynamic Equilibrium Optimal Solution' proposed by this framework shares the mathematical spirit with the foundational 'variational principles' of physics (e.g., the principle of least action). We hypothesize the existence of a 'potential function' or 'action functional' defined by the string's energy state and intrinsic spin. Elementary particles then correspond to the stable points (extrema) of this function in parameter space—specifically, those corresponding to local minima, i.e., 'optimal solutions.' Antimatter corresponds to metastable points (local minima but not global minima). The system's dynamics are governed by the principle of 'tending towards the minimum of the potential function,' providing a unified dynamical origin for particle stability, antimatter annihilation, and the thermodynamic arrow.

2.5.1 The Deterministic Solution of the Particle World: Optimal Solutions, Metastability, and Annihilation

- **The Ultimate Answer to the Elementary Particle Spectrum:** The finite variety of elementary particles observed experimentally are not input parameters of the theory but are discrete **Dynamic Equilibrium Optimal Solutions** existing within the **(E_{rest}, E_{vib}, Spin)** parameter space. Each particle corresponds to a specific, lowest-energy, and most stable dynamic equilibrium configuration. All its intrinsic properties (mass, charge, spin, etc.) are determined solely by the unique configuration of this optimal solution.

- **The Nature and Fate of Antimatter:** An antiparticle is a **stable dynamic equilibrium solution** in the parameter space—it is stable, but possesses a "Spin" configuration that is the complete opposite of that of its corresponding particle. In the $(\boldsymbol{E_{\text{rest}}}, \boldsymbol{E_{\text{vib}}}, \textbf{Spin})$ parameter space, a particle and an antiparticle each occupy distinct yet equally valid Dynamic Equilibrium Optimal Solutions: their allocation of $\boldsymbol{E_{\text{rest}}}$ and $\boldsymbol{E_{\text{vib}}}$ is identical (manifesting as the same mass), but their "Spin" configurations are mirror images of one another, encoding fully opposite sets of intrinsic quantum numbers. An antiparticle is as stable in vacuum as a particle; it does not spontaneously "decay into" a particle, just as a particle does not spontaneously "decay into" an antiparticle.
- **A Unified Definition of Matter-Antimatter Annihilation:**

  The mechanism of matter-antimatter annihilation is consistent with the Decay Principle (Section 2.1.8), but its triggering condition is not the spontaneous destabilization of a singular equilibrium, but rather the encounter of a particle with an antiparticle. When a particle and an antiparticle—two string systems whose "Spin" configurations are exact opposites of one another—encounter each other, they collectively trigger a thorough **energy-form phase transition**: their specific $(\boldsymbol{E_{\text{rest}}}, \boldsymbol{E_{\text{vib}}}, \textbf{Spin})$ configurations undergo complete deconstruction and reorganization, and the system as a whole relaxes into a globally lower-energy stable configuration.

Annihilation does not require the particle and antiparticle to be of the same species (e.g., an electron must encounter a positron); it suffices that their "Spin" configurations are exact mutual inverses—that is, the full sets of intrinsic quantum numbers respectively encoded by them can, as a whole, cancel one another out—for the process to be triggered. For instance, the "Spin" configurations of a proton and an antineutron can satisfy this condition and thereby also undergo annihilation.

The physical essence of this process is that the combined particle-antiparticle system, through the complete mutual cancellation of their "Spin" configurations, discovers within the $(\boldsymbol{E_{rest}}, \boldsymbol{E_{vib}}, \textbf{Spin})$ parameter space a new global optimal solution whose energy lies far below the sum of the two independent optimal solutions—namely, the pure $\boldsymbol{E_{rest}}$-dominated wave phase. The $\boldsymbol{E_{vib}}$ of the initial-state matter, which was bound in complex "Spin" configurations, is largely released and converted into the $\boldsymbol{E_{rest}}$ of the final state. According to the Process Energy Conservation Law (Formula 2), the total intrinsic energy of the initial state, $\boldsymbol{E_{total\_initial}}$, is far greater than the sum of the total intrinsic energies of the final state, $\sum \boldsymbol{E_{total\_final}}$, and this vast energy difference is entirely converted into the kinetic energy of the photons, manifesting as the release of high-energy radiation. The photon, as the state in which $\boldsymbol{r} \rightarrow$ the lowest threshold of this dimension (correspondingly $\boldsymbol{f(r)} \rightarrow$ the upper bound $\boldsymbol{\Theta^{+}_{3+1}}$ of this dimension's threshold), is the ultimate carrier of this pure

$\boldsymbol{E_{\text{rest}}}$ energy form in (3+1) dimensions.

Thus, annihilation is not the transformation of one into the other, but rather both entities, as a single system, collectively relaxing into a new, superior Dynamic Equilibrium Optimal Solution.

- **The Micro-Dynamics of Annihilation and Energy-Form Phase Transition:** The physical essence of this process is a collective phase transition of the energy form from the **"high-$\boldsymbol{E_{\text{vib}}}$, low-$\boldsymbol{E_{\text{rest}}}$ particle phase"** to the **"high-$\boldsymbol{E_{\text{rest}}}$, low-$\boldsymbol{E_{\text{vib}}}$ wave phase"**. The $\boldsymbol{E_{\text{vib}}}$ of the initial-state matter, which was bound in complex **Spin** configurations, is largely released and converted into the $\boldsymbol{E_{\text{rest}}}$ of the final state. According to the **Process Energy Conservation Law** (Formula (2)), the total intrinsic energy of the initial state, $\boldsymbol{E_{\text{total\_initial}}}$, is far greater than the sum of the total intrinsic energies of the final state, $\sum \boldsymbol{E_{\text{total\_final}}}$. This vast energy difference, $\boldsymbol{\Delta E = E_{\text{total\_initial}} - \sum E_{\text{total\_final}}}$, is entirely converted into the kinetic energy of the photons, $\boldsymbol{E_{\text{kinetic\_final}}}$, manifesting as the release of high-energy radiation. The photon, being the state in which $\boldsymbol{r \rightarrow}$ **the lowest threshold of this dimension** (correspondingly $\boldsymbol{f(r) \rightarrow}$ **the upper bound $\boldsymbol{\Theta^{+}_{3+1}}$** of this dimension's threshold) and thus $\boldsymbol{E_{\text{rest}} \rightarrow E_{\text{total}}}$, is the ultimate carrier of this pure $\boldsymbol{E_{\text{rest}}}$ energy form in (3+1) dimensions.
- **Concluding Image:** Therefore, annihilation is not the transformation of one into the other, but rather both entities, as a single system, **collectively**

relaxing into a new, superior dynamic equilibrium **optimal solution**.

2.5.2 The Origin of the Arrow of Time: Entropy Increase as the Path Towards High Rest Energy Equilibrium

- **Microscopic Mechanism of Entropy Increase:** In a natural state, when the strength of external perturbations (e.g., particle collisions, gravitational interactions) exceeds a certain threshold, the string's original dynamic equilibrium is completely broken. The system then seeks and establishes a new dynamic equilibrium state. **The irreversibility of entropy increase stems from the fact that, under the overall driving force of the string 'tending towards static equilibrium,' it preferentially evolves towards a new dynamic equilibrium state with higher $\boldsymbol{E_{\mathrm{rest}}}$.**
- **Black Holes: The Universe's Ultimate Entropy Increase Engines:** Black holes are nature's most efficient "dynamic equilibrium disruptors." The extreme gravity at their singularity irreversibly destroys the form of low-dimensional projections, forcing strings to transition from states of high $\boldsymbol{E_{\mathrm{vib}}}$, low $\boldsymbol{E_{\mathrm{rest}}}$ (ordinary matter) to new dynamic equilibrium states with extremely high $\boldsymbol{E_{\mathrm{rest}}}$ (integrating into the high-dimensional background). This is the most compelling manifestation of the second law of thermodynamics on a cosmic scale. [4]

2.5.3 Cosmic Destiny and the Role of Dynamic Equilibrium

- **The Root of Cosmic Stability:** The reason the universe did not instantly undergo heat death after the Big Bang lies fundamentally in the fact that the

hot primordial matter rapidly condensed into countless particles corresponding to "optimal solutions"—these **dynamic equilibrium states constitute a huge potential barrier preventing the universe from directly collapsing into absolute stillness**. They greatly retard the overall relaxation process.

- **Unified Natural Philosophy:** This picture is universal. The stable existence of an elementary particle shares the same "dynamic equilibrium" philosophy with a planetary system stably orbiting in a gravitational field (Analogy: the planet's mass, rotation, and revolution achieve a dynamic equilibrium, allowing it to orbit the star for eons rather than instantly falling in). The former is a dynamical equilibrium at the microscopic scale, the latter is a gravitational and kinematical equilibrium at the macroscopic scale. However, this stable state constituted by high-activity particles is merely a transient stage in the universe's long relaxation process. As will be elucidated in Section 5.5, the return of the universe as a whole to the ultimate static equilibrium (maximized $\boldsymbol{E_{\mathbf{rest}}}$) is precisely achieved through the emergence and dominance of the 'low-activity phase'.

2.5.4 Dynamic Equilibrium Optimal Solutions in the Classical-Quantum Mapping

It is noteworthy that a recent independent study has rigorously demonstrated, from the perspective of pure classical mechanics, that the wave function of any quantum system can be exactly represented as a superposition of all classical

action extremal solutions (i.e., multi-valued action $\boldsymbol{\phi_j}$), weighted by the classical density: $\boldsymbol{\psi = \sum_j \sqrt{\rho_j} e^{i\phi_j/\hbar}}$[5]. This mathematical construction—the branch superposition of classical multi-valued action—provides precisely a potential mathematical realization of the "Dynamic Equilibrium Optimal Solution" concept of the present framework: each classical action extremal solution $\boldsymbol{\phi_j}$ corresponds, in this framework, to a discrete stable configuration of the high-dimensional string in the $\boldsymbol{(E_{rest}, E_{vib}}$, Spin) parameter space. The superposition among different $\boldsymbol{\phi_j}$ is the manifestation, in low-dimensional projection, of the coexistence of different noumenal configurations.

Section Conclusion: The principle of the "Dynamic Equilibrium Optimal Solution" unifies the Standard Model of particle physics, the second law of thermodynamics, the evolutionary history, and the ultimate fate of the universe within a concise and profound dynamical framework. It shows that the laws of physics are the universal rules by which strings seek their most stable form of existence.

3 Demonstration of Conceptual Power: From the Quantum Realm to Cosmology

This section will demonstrate, through five representative case studies, how the "Energy-Dimension" framework provides unified, mechanistic solutions to long-standing puzzles in physics.

3.1 The Geometric Origin of Quantum Phenomena: From Measurement to Entanglement

We first demonstrate that the corollary of "extremely fast high-dimensional time flow

versus extremely slow low-dimensional time flow" can naturally lead to the probabilistic interpretation of quantum mechanics. This view, which regards quantum uncertainty as an observational effect caused by the difference in time flow rates between dimensions, is consistent in spirit with G't Hooft's explorations [6] within the cellular automaton framework.

3.1.1 High-Dimensional Determinism: The noumenon of an elementary particle (such as an electron) exists as a node of the high-dimensional holistic network in the highest-dimensional background spacetime $\boldsymbol{M_{high}}$. In this highest dimension, time does not exist as an independent fundamental dimension—what exists is only the change of state of the network nodes, with each change being one complete slice of the network's global dynamic equilibrium configuration. In the intermediate dimensional levels (4–10 dimensions), strings evolve according to completely deterministic high-speed dynamics, with an intrinsic time flow rate far faster than that of the low-dimensional world.

3.1.2 Dimensional Time-Flow Differential: The time flow rate $\boldsymbol{\tau_{high}}$ in the intermediate dimensional levels (4–10 dimensions) is far faster than the time flow rate $\boldsymbol{t_{low}}$ in our low-dimensional spacetime $\boldsymbol{M_{low}}$. In the highest-dimensional background spacetime $\boldsymbol{M_{high}}$, time does not exist—what exists is only the global switching of the dynamic equilibrium configurations of the high-dimensional holistic network

3.1.3 "Time-Dilation" and Projection Sampling: Everything we observe is

the **projection** of the high-dimensional string onto the low-dimensional spacetime $\boldsymbol{M_{low}}$. The key point is that, due to the vast difference in time flow rates between the intermediate dimensional levels and low-dimensional spacetime, **a single observational instant in the low dimensions, $\Delta_{t_{low}}$ (approaching zero), actually corresponds to a finite, non-negligible duration $\Delta_{\tau_{high}}$ in the intermediate higher-dimensional world**. In the highest dimension, where time does not exist, **each global switching of the network configuration manifests in low-dimensional projection as one complete "temporal slice." [7]**

3.1.4 Geometric Image of Collapse: Consequently, **a single "instantaneous" measurement in the low dimensions captures not a single projection of the high-dimensional string at one high-dimensional time slice, but rather "one random sample" from the series of continuously varying low-dimensional projections it produces during its continuous high-speed motion over the intermediate higher-dimensional time period $\Delta_{\tau_{high}}$.** We cannot predict which specific state from this series of projections will manifest in a single measurement, thus manifesting as the probabilistic collapse of the wavefunction. The statistical result of numerous measurements, $|\boldsymbol{\psi(x)}|^{\boldsymbol{2}}$, precisely reflects the spacetime distribution density of the low-dimensional projections of the high-dimensional string over the $\Delta_{\tau_{high}}$ period.

This image unifiedly interprets quantum probability and wave-particle duality as a natural "observational dilation" effect caused by **the time-flow differential**

between the intermediate dimensional levels and low-dimensional spacetime.

3.1.5 Theoretical Implications and Extensions

The core mechanism above provides novel perspectives for understanding other profound features of the quantum world:

3.1.5.1 Origin of Spin and Intrinsic Properties: The discrete values of intrinsic properties (like spin) measured in a single sample (e.g., 1/2 for fermions, 1 for bosons) are not accidental. This framework speculates that they are the stable configurations of **Dynamic Equilibrium Optimal Solutions** within the **(E_{rest}, E_{vib}, Spin)** parameter space. These discrete solutions—especially spins quantized in units of ħ/2—likely originate from the quantization requirements of our spacetime background's symmetry. **This is consistent with the fact that in standard theory, spins of 1/2, 1, 2... are the values allowed by the quantized representations of the spacetime symmetry groups (Lorentz/Poincaré groups).** Importantly, **all observed particles (and their charges, masses, etc.) do not appear arbitrarily but are the finite, discrete "Dynamic Equilibrium Optimal Solutions" within this parameter space**, pointing a potential path towards constraining the particle spectrum from first principles and thereby addressing string theory's "landscape" problem.

3.1.5.2 Nature of Identical Particles: "The indistinguishability of identical

particles" becomes a natural conclusion in this framework. All particles of the same type (e.g., all electrons) correspond to the same high-dimensional Dynamic Equilibrium Optimal Solution, their high-dimensional noumena being completely identical. The observed "individuality" stems purely from the randomness of low-dimensional sampling, reconciling high-dimensional determinism with low-dimensional randomness.

3.1.5.3 Classification of Quantum Statistics: The fundamental distinction between fermions and bosons (Pauli exclusion principle vs. Bose-Einstein condensation) is attributed to the different **"Spin" patterns and topological properties** of their respective Dynamic Equilibrium Optimal Solutions. **Specifically, solutions with half-integer spin (fermions) naturally satisfy the Pauli exclusion principle, while those with integer spin (bosons) allow state superposition**. Deriving these two statistical laws strictly from the first principles of the framework is a central challenge and key validation for future mathematical work.

3.1.5.4 Resolution of Non-locality and Quantum Entanglement: This framework provides a deterministic interpretation of quantum entanglement. Two entangled particles distant in low-dimensional spacetime may be connected via very short paths or be different parts of the same structure in $\boldsymbol{M_{\mathbf{high}}}$. **Because the coordination occurs at the higher-dimensional level, and the high-dimensional time flow $\boldsymbol{\tau_{\mathbf{high}}}$**

is extremely fast, this coordination is virtually instantaneous from our low-dimensional time scale t_{low}, requiring no signal propagation through low-dimensional space. Their spooky correlation originates from the **instantaneous coordination** of the high-dimensional dynamics, manifesting as "superluminal" correlation in low-dimensional sampling. This transforms a non-local puzzle into a local, deterministic process within the high-dimensional background.

3.1.5.5 Interpretation of the Three-Generation Fermion Structure

This framework provides a unified microscopic picture for the "generation" puzzle in the Standard Model of particle physics:

- We propose that the fundamental distinction among the three generations of fermions lies in the **number of strings synergistically resonating** within their high-dimensional noumenon.
    - **First Generation Fermions** (e.g., electron, up/down quarks) are the low-dimensional projections of a **single string's** specific Dynamic Equilibrium Optimal Solution. The simplicity of their **single-body** structure endows them with the highest stability and lightest mass.
    - **Second Generation Fermions** (e.g., muon, charm/strange quarks) are the low-dimensional projections of a composite dynamic equilibrium state (a **"two-string alliance"**) formed by **two strings** through synergistic resonance. Maintaining the

coordination of this multi-body structure requires energy, and its inherent fragility manifests as greater mass and significantly shorter lifetime.

- **Third Generation Fermions** (e.g., tauon, top/bottom quarks) are projections of a more complex resonant alliance (a **"multi-string alliance"**) composed of more strings ($\geqslant$ 3). Their enormous mass stems from the **confluence** of energy from more strings, and their extreme **instability** directly arises from the inherent difficulty in maintaining the dynamic equilibrium of a vast resonant system.

As stated in the **Principle of Structure** (Section 2.1.8), the three generations of fermions directly correspond to these three types of stable configurations: **single-string, two-string, and multi-string entangled states**. Their mass hierarchy and stability differences are governed by the **Principle of Stability** (Section 2.1.8): the greater the number of strings in the alliance, the more complex its "entanglement binding," and the more difficult it is to maintain stability. Decays between particles of different generations are the direct embodiment of the **Principle of Decay** (Section 2.1.8), i.e., the "disentanglement" of an unstable complex alliance into more stable, simpler alliances, releasing the corresponding energy $\boldsymbol{\Delta E_{\text{total}}}$.[8]

In this "multi-string entanglement" model, the essence of particle decay

becomes intuitive: it is the **decoupling** of an unstable, complex alliance composed of a larger number of strings, which relaxes into a simpler, more stable alliance composed of fewer strings. This process strictly adheres to energy conservation: **The intrinsic total energy $E_{\text{total\_initial}}$ of the initial state (the heavier particle) is always greater than the sum of the intrinsic total energies of the final-state particles $\sum E_{\text{total\_final}}$. The energy difference ΔE_{total} is thus converted into the kinetic energy of the final-state particles**, manifesting as the energy released in the decay.

- **Inter-Generation Mixing and CP Violation:** Inter-generation phenomena arise from perturbations of the string. **High-intensity perturbations** (e.g., decay) cause the string to **decouple and reorganize** from one dynamic equilibrium tier (resonant alliance) to another; **low-intensity perturbations** (e.g., neutrino oscillation) induce transitions between different but degenerate "flavor" states **within the same tier**. CP violation and fixed mixing angles may originate from inherent **asymmetries** and **geometric angles** in the dynamic pathways connecting these solutions.
- **Origin of Charge and Quantum Numbers:** The quantization of all intrinsic quantum numbers (such as electric charge) is viewed as the low-dimensional projection of the **discrete, global topological constraints** that the Dynamic Equilibrium Optimal Solution (whether single-string or multi-string alliance) must satisfy to maintain stability.

Conclusion: This model transforms the "generation" puzzle into a problem of **"the number of entangled strings".** Thus, **"Why three?"** transforms into a topological investigation into the number of stable multi-string resonant configurations allowed in high-dimensional spacetime.

3.2 Reconstructing Particle Physics from the Framework: Symmetries and the Mass Spectrum

The seemingly arbitrary particles and forces of the Standard Model find a common origin within this framework.

- **Unification of Forces:** The gauge groups of the Standard Model are viewed as emergent from deeper unified principles. We speculate that the dynamics of the string's intrinsic 'Spin' modes, within the ($\boldsymbol{E_{\mathrm{rest}}}$, $\boldsymbol{E_{\mathrm{vib}}}$) parameter space, naturally encompass stable configurations corresponding to the **U(1), SU(2), and SU(3)** gauge symmetries. As the universe cools or parameters evolve (e.g., with decreasing $\boldsymbol{E_{\mathrm{vib}}}$), a hypothesized higher-dimensional unified symmetry $\boldsymbol{G_{\mathrm{high}}}$ undergoes spontaneous symmetry breaking, sequentially revealing the characteristic symmetry structures of the strong, weak, and electromagnetic interactions as we know them.
- The origin of matter particles (fermions) lies in strings residing in the 'Fermionic Spin' mode Dynamic Equilibrium Optimal Solutions. **As detailed in Section 3.1.5.5, the fundamental distinction among the three generations of fermions lies in the number of strings synergistically resonating within their high-dimensional noumenon:**

- **First Generation** (e.g., electron) are **single-string** projections—structurally simple, hence stable and lightest in mass.
- **Second Generation** (e.g., muon) are **two-string alliance** projections—more fragile in coordination, hence intermediate in mass and stability.
- **Third Generation** (e.g., tauon) are **multi-string alliance** projections—most complex in structure, hence heaviest in mass and extremely unstable.

Therefore, higher generations correspond to more complex multi-string entangled states, thus exhibiting stronger particle-like character, greater mass, but poorer stability. **The three generations of fermions and their decays in the Standard Model can be uniformly understood as relaxation processes between dynamic equilibrium optimal solutions of varying depths in the (E_{rest}, E_{vib}, Spin) parameter space. This physical picture and the governing energy conservation are depicted in Figure 2.**

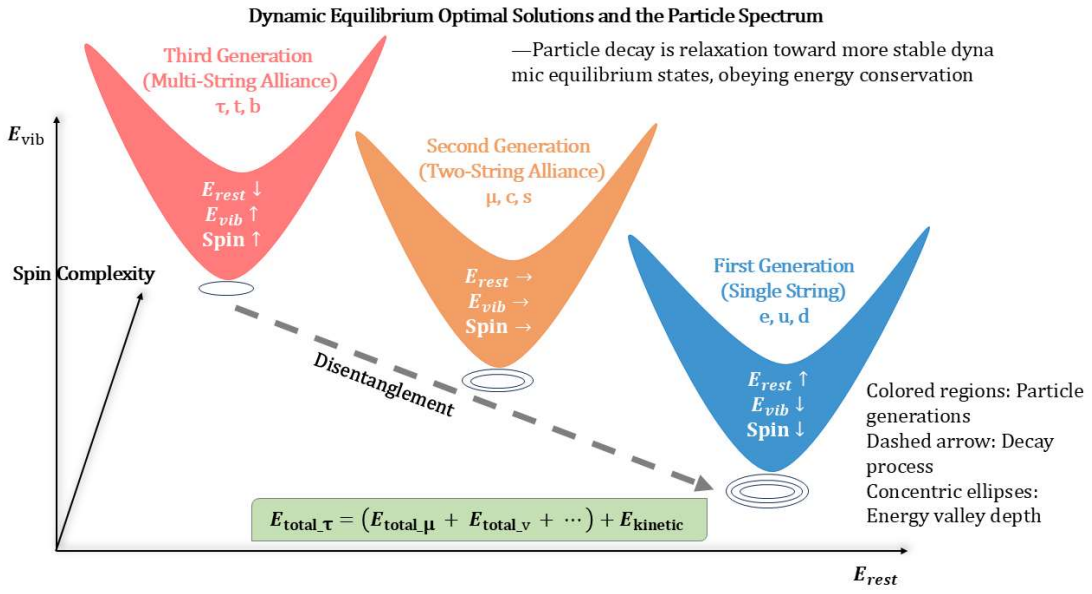

Figure 2: Dynamic Equilibrium Optimal Solutions and the particle spectrum. The

three generations of fermions in the Standard Model are interpreted as dynamic equilibrium optimal solutions of varying depths in the **(E_{rest}, E_{vib}, Spin)** parameter space, corresponding to stable configurations of single-string, two-string, and multi-string alliances, respectively. The dashed arrow indicates the decay (disentanglement) process, representing the relaxation of the system towards a more stable energy valley, obeying the energy conservation relation shown.

- Reinterpretation of the Higgs Mechanism: The Higgs field is interpreted within this framework as a specific collective excitation of the background string 'sea'. The interaction strength (Yukawa coupling) between a particle and the Higgs field essentially reflects the coupling degree between the particle's specific **(E_{rest}, E_{vib}, Spin)** dynamic equilibrium state and this background sea. This coupling strength ultimately determines the inertial mass manifested by the particle, a picture consistent with our framework's core concept that 'mass is determined by the energy allocation relationship characterized by r ($= E_{vib}/E_{rest}$)'. [9,10]

3.3 Black Holes: As Topological Defects of Spacetime Dimension

In the "Energy-Dimension" framework, the essence of a black hole is revealed as a topological defect arising from a gravitationally-induced dimensional phase transition. Its "breathing" phenomenon is the redistribution of the string's energy state under a dimensional gradient, while the singularity marks the end of our familiar four-dimensional spacetime description.

3.3.1 Black Hole Formation: Gravitationally-Driven Dimensional Phase Transition

Based on this framework, we propose a new model for the mechanism of black hole formation: **a black hole is the end product of a large-scale "dimensional phase transition" occurring under gravitational collapse in the core of a massive star.**

At the end of the evolution of a massive star, nuclear fusion in the core ceases and radiation pressure vanishes. At this point, **the projections of strings—which are mapped as particles in low-dimensional space—are subjected to the extremely strong gravity they themselves generate, leading to the drastic compression of their low-dimensional projections.**

According to this framework, the **($E_{\mathbf{rest}}$, $E_{\mathbf{vib}}$, Spin) Dynamic Equilibrium Optimal Solution** of a string determines the form and scale of its particle-like projection. The compression of the projection means its original **dynamic equilibrium state** can no longer be maintained. To adapt to the compressed projection form, the string is forced to undergo an internal transformation of energy forms: **vibrational energy $E_{\mathbf{vib}}$ decreases sharply, while rest energy $E_{\mathbf{rest}}$ increases accordingly**.

When the energy density in the core region exceeds a certain critical value, the scale of this energy transformation becomes sufficient to trigger a **phase transition in the spacetime structure**: a vast number of strings in this region collectively transition from the "low-dimensional particle phase" (their original dynamic equilibrium state) to the "high-dimensional wave phase" (low $\boldsymbol{r}$, high $\boldsymbol{f(r)}$, high $\boldsymbol{E_{\mathbf{rest}}}$). This high-$\boldsymbol{E_{\mathbf{rest}}}$ region manifests in our low-dimensional

universe as a singularity with extremely strong gravity, and its boundary (the event horizon) is the critical surface of the phase transition.

Therefore, the birth of a black hole singularity is not matter being compressed to a "point," but a macroscopic emergent phenomenon where gravity, by compressing the low-dimensional projections of strings, forces their energy states to collectively revert to a high-dimensional, **wave-dominated, high-E_{rest} (corresponding to low particle-like mass) state**.

It is further worth noting that, once formed, a black hole is not merely a static gravitational trap. Under the sustained drive of the universal dynamic tendency of strings—i.e., the relaxation toward states of higher E_{rest} as stated in Postulate 5—the black hole becomes a dimensional entry point through which low-dimensional active matter in this dimension is irreversibly converted into high-dimensional silent energy. This conversion requires no additional internal energy source to sustain it—the strings' own dynamic tendency is its driving force. The persistent existence of the black hole is the macroscopic manifestation of this perpetual conversion. Correspondingly, white holes (Section 3.3.2.4) constitute the dual channel through which high-dimensional silent energy is re-injected into low-dimensional spacetime—the joint operation of the two constitutes the "Cosmic Energy Breath" cycle described in Section 3.3.2.

- **Thought Experiment: The Singularity as a Dimensional Boundary**

  To gain an intuitive grasp of the foregoing assertions, the following thought

experiment may be helpful.

Imagine a two-dimensional being living on a flat sheet of paper. Its world contains only forward, backward, left, and right. It can wander this sheet endlessly, yet can never conceive of what "up" or "down" might mean—those directions lie beyond the reach of its perceptual faculties. What happens when this two-dimensional being reaches the edge of the paper—a place where its two-dimensional world offers no further path? Its visual field does not "vanish"; rather, it contracts: all forward paths converge into a line, and ultimately shrink into a point. This point is the entirety of the boundary it can perceive. Yet to us, three-dimensional observers, beyond the paper's edge lies empty three-dimensional space. The two-dimensional world's "boundary" is, in truth, the geometric endpoint where it is embedded within a higher-dimensional space.

This analogy corresponds precisely to the role of the black hole singularity in our universe.

When matter, under gravitational collapse, reaches the core of a black hole, according to the present framework, its vibrational energy $\boldsymbol{E_{\mathbf{vib}}}$ drops precipitously and its rest energy $\boldsymbol{E_{\mathbf{rest}}}$ rises correspondingly, triggering a drastic change in the dimension contraction function $\boldsymbol{f(r)}$. The effective dimension is no longer (3+1), and the four-dimensional spacetime manifold disintegrates at this locus. **The singularity, first and foremost, is the geometric endpoint of this disintegration—it is a boundary of four-**

dimensional spacetime, not something that lies beyond the boundary. The singularity we observe is akin to that contracting point perceived by the two-dimensional being: it is not the end of the world, but the limit at which our dimensional descriptive capacity is exhausted. Beyond this boundary, no coordinates exist in the language of four-dimensional geometry—whether a higher-dimensional wave phase or an extremely compressed particle projection, all lie outside this boundary.

And yet, the singularity is not a static boundary. As pointed out in Modification 14, under the sustained drive of the universal dynamic tendency of strings—the relaxation toward states of higher $\boldsymbol{E_{\mathbf{rest}}}$ and lower $\boldsymbol{E_{\mathbf{vib}}}$—this boundary becomes an active conversion channel: the projections of low-dimensional matter are irreversibly drawn toward this edge of lowest $\boldsymbol{E_{\mathbf{vib}}}$ and highest $\boldsymbol{E_{\mathbf{rest}}}$, and are there converted into high-dimensional silent energy. From the perspective of a higher-dimensional observer, our four-dimensional spacetime resembles a membrane embedded within their higher-dimensional world—and the edge of this membrane (the singularity) is continuously "smoking": matter evaporates from the membrane's edge into the higher-dimensional space beyond. **The function of the singularity as an "entry point" is the effect exerted by the dynamic tendency of strings at the boundary—the boundary is ontology, the entry point is dynamics.**

Concurrently, according to Section 3.3.2.4, high-dimensional silent energy

is re-injected into low-dimensional spacetime through the white hole mechanism. Black holes and white holes together constitute the "Cosmic Energy Breath" cycle described in Section 3.3.2—black holes convert low-dimensional active matter into high-dimensional silent energy and send it beyond the four-dimensional boundary, while white holes re-inject high-dimensional silent energy back into low-dimensional spacetime.

This picture also provides an intuitive resolution to the black hole information problem. Information falling into a black hole is not annihilated; rather, it is converted into high-dimensional silent energy—an energy form that can no longer be read by low-dimensional detectors. Just as a drawing on the paper does not cease to exist when it reaches the paper's edge, but simply enters three-dimensional space where the two-dimensional being can no longer see it, the information remains—merely inaccessible to our low-dimensional instruments. The "Projection Restoration" mechanism of Hawking radiation within this framework (Section 3.3.2.3) is precisely the occasional, probabilistic re-projection of a minuscule fraction of this high-dimensional energy back into our four-dimensional spacetime via the dimensional ladder. It is not "creation from nothing," but "recovery after loss."

In the final analysis: **what we perceive as a "physical limit"—the singularity of a black hole—is, first and foremost, a geometric boundary of four-dimensional spacetime; and because of the dynamic**

tendency of strings, this boundary becomes a channel through which matter is continuously converted into high-dimensional silent energy. Our "singularity," from a higher-dimensional perspective, is no more than the visible edge of the embedded surface that is our low-dimensional spacetime, perpetually evaporating matter into the beyond.

3.3.2 The Cosmic Energy Breath: Black Holes, White Holes, and the Unified Cycle Model

This section applies the "Energy-Dimension" framework to regions of the most powerful gravity, revealing that black holes and white holes are not independent singularities but two parts of a unified "Energy-Dimension" cycle system, which we call the **"Cosmic Energy Breath" model**. This cycle is driven by the fundamental principle of "strings tending toward static equilibrium," whose micro and macro manifestations jointly maintain the dynamic energy balance of the universe. **As illustrated in Figure 3, the model depicts black holes as the "inhalation" conduit, transforming low-dimensional active matter, and white holes as the "exhalation" outlet, emitting high-dimensional silent energy manifesting as dark energy.**

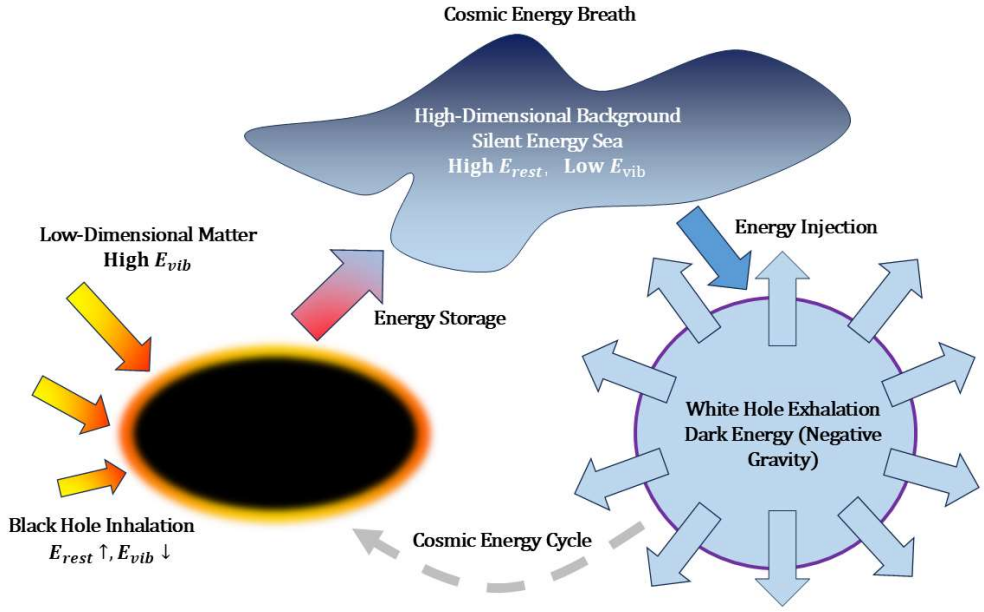

Figure 3: Unified "Cosmic Energy Breath" cyclic model. Black holes act as "cosmic inhalation," ingesting and transforming low-dimensional, high-$\boldsymbol{E_{vib}}$ matter into high-dimensional, high-$\boldsymbol{E_{rest}}$ silent energy. White holes act as "cosmic exhalation" outlets, uniformly injecting this silent energy back into low-dimensional spacetime as dark energy (negative gravity). This cycle constitutes a cosmic-scale energy metabolism system.

3.3.2.1 Core Mechanism: Dimensional Tide and Energy Form Transformation

In the boundary region of a black hole, the enormous gradient of the "dimension contraction function" $\boldsymbol{\nabla f(r)}$ constitutes a powerful **"dimensional pressure difference"**, which is the source of the **"Dimensional Tide Force"**. It is the engine driving all processes.

3.3.2.2 "Inhalation" Process: Black Hole Accretion and High-Dimensional Energy Storage

- **Process:** The projections of strings mapped as particles (i.e., high $\boldsymbol{E_{vib}}$) in low-dimensional space flow towards the singularity region under the action of the "Dimensional Tide Force." Their projections are drastically compressed, **forcing** the strings to convert vibrational energy $\boldsymbol{E_{vib}}$ into rest energy $\boldsymbol{E_{rest}}$ **to correspond to the compressed projection**.

  This process is a macroscopic manifestation of the **Principle of Decay** (Section 2.1.8) in an extreme gravitational field. Before matter crosses the event horizon, its multi-string entangled states are partially broken by the powerful "Dimensional Tide Force" (an ultimate form of "disentanglement perturbation"), undergoing local **"disentanglement"**. This leads to a decrease in the total system energy, and the energy difference $\boldsymbol{\Delta E_{total}}$ is violently released in the form of electromagnetic radiation (e.g., X-rays from the accretion disk). Ultimately, the remaining, partially "disentangled" strings, carrying higher $\boldsymbol{E_{rest}}$, fall into the singularity, completing the final transformation into high-dimensional energy.

- **Effect:** This process constitutes the cosmos's **"inhalation"**. Its net effect is the consumption of ordinary matter **states** in the low-dimensional universe (whose intrinsic energy is characterized by high $\boldsymbol{E_{vib}}$ and low $\boldsymbol{E_{rest}}$), concurrently increasing the reservoir of background silent energy(i) in the high-dimensional background (high $\boldsymbol{E_{rest}}$, low $\boldsymbol{E_{vib}}$). Black holes are the conduits through which energy flows from low to high dimensions, transitioning from an active to a quiescent state.

3.3.2.3 "Exhalation" Process I: Hawking Radiation—The "Projection Restoration" Model

Based on the "Dynamic Equilibrium Optimal Solution" principle, this framework provides a novel microscopic mechanism for Hawking radiation.

- **Process Description:** When matter falls into a black hole, the low-dimensional projections of its strings undergo severe deformation in the strong gravitational field near the event horizon, breaking the original dynamic equilibrium. In the vast majority of cases, strings establish a new dynamic equilibrium corresponding to the high-dimensional phase by decreasing $\boldsymbol{E_{vib}}$ and increasing $\boldsymbol{E_{rest}}$ (i.e., being absorbed by the black hole).

(i) To avoid conceptual conflation, this paper refers to the intrinsic property of a micro-string as "rest energy ($\boldsymbol{E_{rest}}$)," while the accumulated reserve of this energy on a cosmic scale in the high-dimensional background is termed "Background Silent Energy," which constitutes a part of the ultimate cosmic destiny, the "Sea of Silence."

However, there is a finite probability that in the fluctuating environment of the "Dimensional Tide Force," a small number of strings, in the process of seeking a new equilibrium, **end up establishing a state that happens to "restores" their low-dimensional projection to its state before falling past the event horizon**—that is, restoring it to a high-$\boldsymbol{E_{vib}}$ particle-like projection.

- **The Essence of Hawking Radiation:** It is precisely these strings that, by chance and probabilistically, probabilistically successfully restore their original low-dimensional projection through the "dimensional ladder" that fly away from the black hole's edge, forming the Hawking radiation we observe. This is not quantum creation in the traditional sense, but a **"statistical projection restoration"** governed by dimensional dynamics. [11,12]
- **Effects:**

3.3.2.3.1 Thermodynamic Effect: Reproducing and Correcting Black Hole Thermodynamics

- **Basic Reproduction:** This model naturally leads to the conclusion that black holes have temperature and emit radiation, consistent with Hawking's original conclusion.
- **Potential Correction (Unique Prediction):** The success probability of "projection restoration" may be weakly correlated with the specific **($\boldsymbol{E_{rest}}$, $\boldsymbol{E_{vib}}$, Spin)**

dynamic equilibrium state of the string before it fell in. This could lead to small but calculable deviations of the Hawking radiation spectrum from a pure thermal spectrum.

3.3.2.3.2 Information Paradox Effect: Providing a New Channel for Information Retention

- **Mechanism:** In the traditional picture, Hawking radiation originates from vacuum fluctuations, is unrelated to the infalling matter, and leads to information loss. The **"Projection Restoration"** model indicates that the radiating particles are the **"identity restoration" of specific infalling matter strings.**
- **Effect:** This means that Hawking radiation is not statistically independent of the infalling matter. The **radiating particles may, in some encoded form, carry partial information about the "identity" of the infalling matter (i.e., its specific (E_{rest}, E_{vib}, Spin) dynamic equilibrium state)**. This opens a novel, deterministic-dynamics-based path to resolving the black hole information paradox. [13,14]

3.3.2.3.3 Particle Spectrum Effect: Predicting a Bias in Radiation Content

- **Unique Prediction:** Not all types of particles are "restored" with equal probability. The process strongly favors the production of structurally simple, stable particles (**i.e., light particles with high $E_{\mathbf{rest}}$ and low $E_{\mathbf{vib}}$**, such as electrons, neutrinos, photons). This provides a clear test signal for the future.
- **Testable Corollary:** Therefore, this model predicts that the particle composition of Hawking radiation is not a universal full particle spectrum, but may be strongly biased towards leptons and gauge bosons. This provides a clear testable signal for the future (e.g., if primordial black hole evaporation can be observed).

3.3.2.3.4 Cosmological Effect: Connecting Macro and Micro Dynamics

- **Effect:** This model transforms Hawking radiation from an abstract, global quantum field theory effect into a **local, individual string-based dynamical process**. It profoundly reveals that even in the most extreme gravitational field of a black hole, the "identity" of microscopic particles (defined by their dynamic equilibrium optimal solution) still stubbornly influences macroscopic physical processes (black hole evaporation)

through the mechanism of "projection restoration."

Conclusion:

The core effect of the "Projection Restoration" model is that it anchors Hawking radiation, transforming it from a "creation from nothing" quantum miracle into a "lost and found" dynamical process. This not only enhances the determinism and intuitiveness of the theory but, more importantly, leads to testable unique predictions and provides a novel perspective on the black hole information paradox.

- **Supplementary Perspective: "Quantum Excitation" Conjecture**

As a supplement to the main model above, we retain a possibility discussed previously: Hawking radiation can also be partially understood as the high-dimensional background's rest energy ($\boldsymbol{E_{\mathbf{rest}}}$) being locally "excited" by quantum fluctuations at the horizon under intense dimensional gradients, and inversely transformed into low-dimensional vibrational energy ($\boldsymbol{E_{\mathbf{vib}}}$) particles. This "Quantum Excitation" conjecture is unified with the "Projection Restoration" model in its effects, collectively enriching our understanding of the complex boundary physics.

- **Unified Image: An Update to "Cosmic Metabolism"**

Integrating the above mechanisms, the black hole's "cosmic metabolism" model is further refined:

  - **Inhalation (Metabolism):** Low-dimensional matter (high $\boldsymbol{E_{\mathbf{vib}}}$), under gravity, has its dynamic equilibrium broken and is stably

transformed into high-dimensional background energy ($\boldsymbol{E_{rest}}$).

- **Exhalation (Radiation):** Through the probabilistic process of **"Projection Restoration",** a minuscule amount of high-dimensional energy is occasionally and probabilistically "exhaled" from the system in the form of low-dimensional particles (high $\boldsymbol{E_{vib}}$).

Therefore, we propose an alternative model: Hawking radiation might be a 'probabilistic leakage' or 'projection restoration' produced by the intense dimensional dynamics at the boundary of a black hole, against the overwhelming background tendency to **engulf** and transform matter. This image perfectly unifies General Relativity, thermodynamics, and quantum phenomena within "Energy-Dimension" dynamics.

3.3.2.4 "Exhalation" Process II: White Holes—Macroscopic Injection of Dark Energy

The macroscopic "exhalation" process of the "Cosmic Energy Breath" is accomplished by white holes.

- **Process:** The energy of strings accumulated in the high-dimensional background that are in the **'low-activity phase'** (i.e., $\boldsymbol{r \to 0}$, correspondingly $\boldsymbol{E_{vib} \to 0}$ and $\boldsymbol{E_{rest}}$ extremely high), forms a uniform projection in low-dimensional space through the white hole structure.
- **Effect:** The net effect of this process is the continuous **injection of dark energy** into the low-dimensional universe. White holes are the

main channels for energy to flow from high to low dimensions, manifesting as a diffuse background.

3.3.2.5 Transformation of Particle Identity: Accretion Deconstruction and Radiation Assembly

- **"Particle Deconstruction" in Accretion:** As matter falls towards the black hole event horizon, the projections of its strings are deformed by gravitational pressure, and vibrational energy $\boldsymbol{E_{\mathbf{vib}}}$ continuously decreases to **facilitate the formation of a new dynamic equilibrium**. This causes a synchronous reduction in the complexity of the "Spin" mode it can sustain, manifesting as a particle identity transformation from complex to simple: for example, heavy quarks may de-excite into light quarks, nucleons may decay or transform into leptons. **The energy released in these transformation processes partly contributes to the high-energy radiation from the accretion disk**. Ultimately, as matter crosses the event horizon, the dynamic equilibrium state of its strings is extremely inclined towards the high-$\boldsymbol{E_{\mathbf{rest}}}$ phase.
- **"Projection Restoration" in Hawking Radiation:** In contrast, the "projection restoration" mechanism of Hawking radiation is a process of randomly assembling low-dimensional projections from the high-dimensional background. This process strongly favors the production of simple, stable particles **(light particles with high $\boldsymbol{E_{\mathbf{rest}}}$ and low**

E_{vib}). Therefore, this framework predicts that the steady-state Hawking radiation spectrum will be dominated by light particles such as photons and neutrinos.

Therefore, based on the 'Projection Restoration' model, this framework makes a unique prediction regarding the particle composition of Hawking radiation:

Within the event horizon, in the high-energy scale region closest to the singularity, the random process of 'projection restoration' has a probability of producing various particles. However, these initially produced particles undergo natural screening as they propagate through the 'dimensional ladder' towards the lower-energy scale region (exterior). Unstable heavy particles struggle to maintain their dynamic equilibrium in the low-energy environment and will rapidly decay.

Consequently, the steady-state Hawking radiation that ultimately crosses the event horizon and is received by external observers will have a spectrum dominated by structurally stable light particles (e.g., photons, neutrinos), with negligible contribution from heavy particles. This prediction is a key testable feature that distinguishes the 'Energy-Dimension' framework from other theories.

It must be emphasized that this prediction is based on the current best conjecture that the success probability of 'projection restoration' is strongly correlated with the complexity of the particle state. Should future

observations deviate from this prediction, it would not constitute a negation of the core 'Energy-Dimension' framework, but would provide crucial experimental constraints for refining the specific dynamical rules of 'projection restoration,' thereby promoting the deepening and development of the theory.

3.3.2.6 Diverse Conjectures on White Hole Phenomena

Based on the unified model, we further propose complementary conjectures about the specific manifestations of white holes:

- **Conjecture A (Structural Conjecture): Symmetry between Low-Dimensional Black Holes and High-Dimensional White Holes**

  This conjecture reveals the essential identity of black holes and white holes. A process observed as a "black hole" in **low-dimensional** spacetime naturally manifests as a "white hole" in the **high-dimensional** background to which it is connected. They are the same "dimension-energy" channel projected onto different cosmic levels.

- **Conjecture B (Dynamical Conjecture): Local Overflow from High-Dimensional Energy Supersaturation**

  This conjecture describes the specific microscopic mechanism triggering white holes. When the rest energy $\boldsymbol{E_{\mathbf{rest}}}$ density in a region of the high-dimensional background exceeds a critical value due to fluctuations or convergence, it triggers a local "spacetime rupture," causing energy to "overflow" into the low-dimensional

universe in a transient, explosive white hole form.

3.3.2.7 Summary: A Dynamic Cosmic Lifeform

Therefore, **black holes and white holes together constitute a dynamic "Cosmic Energy Breath" system**. Black holes (and Hawking radiation) manage the inflow, storage, and **minute** leakage of energy; white holes are responsible for the macroscopic re-injection of energy. The universe is not a static stage but a living entity undergoing eternal energy circulation and dimensional metabolism through this system.

3.3.3 Framework-Internal Interpretation of General Relativity's Failure

The above imagery naturally explains why General Relativity necessarily fails near the singularity.

- **The Singularity is a Phase Transition Point of Dimension Convergence:** As the singularity is approached, the smooth four-dimensional spacetime manifold itself, which is the object described by General Relativity, undergoes a fundamental **phase transition or disintegration**.
- **General Relativity is the Low-Energy Approximation of a Higher-Dimensional Theory:** Near the singularity, $\boldsymbol{f(r)}$ undergoes drastic change, causing an essential deviation between the effective spacetime $\boldsymbol{G_{\mu\nu}^{(\mathrm{effective})}}$ and the four-dimensional projection of the background spacetime $\boldsymbol{G_{\mu\nu}^{(\mathrm{background})}}$.
- **Clarifying the Relationship with the General Relativity Field Equations**

It must be emphasized that this framework's description of black holes is not intended to compete with or contradict the Kerr or Schwarzschild solutions of General Relativity mathematically. On the contrary, in the vast region outside the event horizon, the "effective metric" $\boldsymbol{G_{\mu\nu}^{(\mathrm{effective})}}$ of this framework must and will necessarily have the exact solutions of General Relativity as its low-energy limit, to conform to all existing observations.

The true role of this framework is to **delineate the applicable boundary of General Relativity and to provide a novel, self-consistent physical language and mechanism beyond this boundary**. When matter approaches the singularity, and the energy density causes the function $\boldsymbol{f(r)}$ to change drastically, the classical continuous spacetime background relied upon by General Relativity ceases to exist. In this region, this framework no longer seeks a "better" field equation solution but describes the dynamical phase transition process of spacetime itself from a low-dimensional geometric phase to a high-dimensional primordial phase.

Therefore, the relationship between this framework and General Relativity is one of **inheritance, extension, and deepening**: it inherits the latter's macroscopic success, extends its interpretation of black hole microphysics, and attempts to deepen our understanding of the most essential relationship between spacetime, matter, and energy.

Conclusion: Therefore, the failure of General Relativity is not due to erroneous equations, but because its descriptive background—stable four-dimensional

spacetime—no longer exists near the singularity. This emerges naturally from the underlying logic of this theory, transforming the singularity problem from a mathematical infinity into a physical **problem of dimensional geometric phase transition**.

3.3.4 The "Frame Rate Mismatch" Mechanism of Time Dilation

The process of an object falling into a black hole is its "noumenon" transitioning from the low-dimensional spacetime into the high-dimensional background. Its "noumenon" begins to experience the intrinsically fast time flow ($\boldsymbol{d\tau_{high}}$) of the high-dimensional background. We, as observers confined to low dimensions, can only "sample" this high-dimensional process with our extremely low and fixed temporal resolution.

- **An Illustrative Analogy:**
    - **The Highest-Dimensional World (11 dimensions):** A spiderweb perpetually suspended in dynamic equilibrium. This web neither films, nor records, nor flows—it simply "exists and self-regulates," eternally. Every strand of the web is a dynamic equilibrium optimal solution of a high-dimensional string; every node connecting the strands is a configuration of multi-string entanglement or linkage. When the state of any single node changes, the entire web instantly adjusts its global configuration, switching from the current dynamic equilibrium optimal solution to the next. There is no "time" here—only successive complete switches of configuration. Each complete configuration of the

spiderweb is the noumenon of one "temporal slice" in the low-dimensional projection.

- **The Intermediate Higher-Dimensional World (4–10 dimensions):** A master footage continuously recorded at a very high frame rate (representing a very fast $\boldsymbol{d\tau_{high}}$). We can think of it as raw source material shot at **N frames per second**.
- **The Low-Dimensional World (3+1 dimensions):** A player with a **fixed playback rate of 24 frames per second (fps)** (representing a slow $\boldsymbol{dt_{low}}$).
- **The Infall Process:** The process of an object falling into a black hole is its noumenon migrating from low-dimensional spacetime toward a higher intermediate higher-dimensional world. As the object approaches the event horizon, its coupling to the intermediate higher-dimensional world intensifies, and its intrinsic, proper time flow $\boldsymbol{d\tau_{high}}$ increases dramatically. This means **the frame rate N of the "raw footage" documenting its motion is continuously soaring**—from 24 fps to 1000 fps, to 10,000 fps, and even to 10^n fps—corresponding to its high-speed evolution in the higher dimensional level.
- **Our Observation:** We are always using the **fixed 24 fps player** to play back this "raw footage" whose **frame rate N is skyrocketing**. To play this footage in its entirety, **an event that took 1 second in the**

intermediate higher-dimensional world (comprising N frames) must now be stretched over N/24 seconds in our low-dimensional time. When **N** soars to the order of $\mathbf{10^n}$, the time dilation factor reaches $\mathbf{10^n/24}$—from our low-dimensional perspective, the object's motion is stretched so immensely that time appears to come to a complete halt. This is not because it has entered a timeless realm, but because it has already entered a level whose time flow rate is far higher than that of our dimension, and we can only **sample the projection of its high-dimensional activity at an extremely low resolution**.

- **Theoretical Significance:** This model demonstrates that **time dilation is not a mysterious property of gravity, but an inevitable observational consequence of the "time-flow differential" ($d\tau_{\mathbf{high}} / dt_{\mathbf{low}} \gg \mathbf{1}$) between different dimensional levels**. Black holes, as dimensional phase transition channels connecting low-dimensional spacetime with a higher intermediate higher-dimensional world, compel infalling matter to undergo a dynamical conversion from a low frame rate to an extremely high frame rate. The gravitational time dilation we perceive is, in essence, **the "stretched projection" of a continuous high-speed evolution in the intermediate higher dimensions onto our slow, low-dimensional time axis—time appears to stand still, yet it is in fact flowing at immense speed, only that we cannot catch up with its frame rate**. And the true highest dimension (11-dimensional)—where time does not exist, only the complete slices of the

global holistic network configuration—corresponds, from the low-dimensional perspective, to genuine "eternity": not a stretching, but the cessation of all passage.

3.4 Microscopic Transmission Mechanism of Interactions: From Mode Coordination to Geometric Emergence

In the standard quantum field theory, electromagnetic, weak, and strong interactions are described as being mediated by the exchange of "virtual particles," while gravity is geometrized in General Relativity. This descriptive schism is one of the core dilemmas facing contemporary physics. Based on "Energy-Dimension" dynamics, this framework provides a unified, mechanistic physical picture for all four fundamental interactions, while profoundly revealing the fundamental ontological distinction between gravity and the other three forces.

3.4.1 Core Paradigm Shift: From "Particle Exchange" to "Mode Coordination" and "Geometric Emergence"

This framework proposes a fundamental paradigm shift:

- **For the electromagnetic, weak, and strong forces:** The transmission of force is not achieved through virtual particles, but through the dynamic coordination of high-dimensional **"Spin" modes**, whose effects are projected into our low-dimensional spacetime via the dimension contraction function $\boldsymbol{f(r)}$.
- **For gravity:** It is not a force that needs "transmission" at all, but rather the collective emergent effect of all particles' **($\boldsymbol{E_{\text{rest}}}$, $\boldsymbol{E_{\text{vib}}}$, Spin)** dynamic

equilibrium states, directly manifesting as the curvature of the spacetime background.

The core mechanism can be summarized as follows:

Particle A's specific (E_{rest}, E_{vib}, Spin) state is perturbed →

For non-gravitational forces: This perturbation is instantly coordinated through the high-dimensional background. The coordinated overall "Spin" mode configuration is projected into low-dimensional spacetime via the function $f(r)$ → Particle B experiences coupling.

For gravity: The very existence of Particle A directly and intrinsically contributes a "micro-curvature" to the effective spacetime metric $G_{\text{effective}}$ at its location, through the function $F(r, \text{Spin})$.

In this picture, the traditional "force carriers" (such as photons, W/Z bosons, gluons) are not independent entities, but rather specific, stable intermediate states manifested in the low-dimensional projection of this high-dimensional "Spin" mode coordination process.

3.4.2 The "Spin" Mode Coordination Picture of Electromagnetic Interaction

The electromagnetic force originates from U(1) gauge symmetry, corresponding to the simplest and most stable "Spin" mode.

- **Transmission Process:**
    - A charged particle (e.g., an electron) creates a local perturbation to its internal U(1) "Spin" mode.

- This perturbation is immediately integrated into the U(1) "Spin" mode background field of the entire system, seeking a new, coordinated dynamic equilibrium configuration.
- The projection of the coordinated overall U(1) "Spin" mode field changes in the low-dimensional spacetime. For another electron, this change manifests as an alteration of the electromagnetic potential at its location, thereby "feeling" a force.

- **Nature of the Photon:** The "photon" we observe is the low-dimensional projection of a specific, stably existing and independently propagating coordination wave packet within the aforementioned U(1) "Spin" mode coordination process.

3.4.3 Coordinated Reconstruction of Weak Interaction and the Higgs Mechanism

The weak force involves more complex SU(2) "Spin" mode dynamics and its symmetry breaking.

- Transmission Process:
  - The SU(2) "Spin" mode of a fermion is perturbed, intending to transition from one dynamic equilibrium state to another.
  - This internal "intentional" transformation requires its SU(2) "Spin" mode to undergo intense, non-Abelian coordination with the background environment.
  - This violent coordination process manifests in the low-dimensional

projection as a transient, high-energy intermediate configuration—namely, the W or Z boson. It is the projection of a decisive instant of the coordination process itself.

- Because this coordination process requires extremely high energy (corresponding to high $\boldsymbol{E_{vib}}$), it is difficult to sustain stably in our low-energy world, hence the W/Z bosons have large masses, exhibiting short-range force behavior.

- **Reinterpretation of the Higgs Mechanism:** The Higgs field is a specific collective excitation mode of the background string sea. The Yukawa coupling between a particle and the Higgs field is essentially the coupling strength between that particle's specific "Spin" mode and the background "Spin" mode sea. Gaining mass is the necessary energy reallocation ($\boldsymbol{E_{rest}} \downarrow$, $\boldsymbol{E_{vib}} \uparrow$) that the particle's "Spin" mode must undergo to remain stable within a specific background configuration.

3.4.4 Coordination and Confinement in the Chromodynamics of the Strong Interaction

The strong force originates from the most complex SU(3) "Spin" mode, whose coordination dynamics naturally leads to confinement.

Recently, the STAR Collaboration at RHIC carried out an experiment that directly probes the structure of the QCD vacuum [15]. Through high-energy proton-proton collisions, virtual strange quark-antiquark pairs ($\boldsymbol{s\bar{s}}$) were excited from the vacuum; after hadronizing into $\boldsymbol{\Lambda}$ and $\boldsymbol{\bar{\Lambda}}$ hyperon pairs,

their spin correlation was precisely measured—exhibiting a significant positive correlation (spin triplet) at short range, while decohering completely at long range. This result provides direct experimental confirmation that the QCD vacuum indeed contains highly structured quark condensates, and that spin information can be effectively transmitted during the quark confinement-hadronization process, with the transmission efficiency depending on the interaction scale.

The present framework offers an intuitive interpretation of this phenomenon from the dual perspective of "Spin" mode coordination and linkage states. The significant spin correlation at short range can be understood as a linkage-state effect specific to the quark string and the antiquark string within the high-dimensional network—they form, through the network's "threads," an optimal solution of parallel spin configuration. As these two strings separate in real space, energy constraints force this linkage state to relax, and the spin correlation vanishes accordingly. In mathematical spirit, this process is fully consistent with the mechanism described in this framework's account of wave-particle duality—in which the projection properties of linkage states shift continuously with the strength of the observational boundary condition. The only difference is that the protagonists here are quarks and antiquarks, rather than photons and electrons.

- **Transmission Process:**
    - A quark's color "Spin" mode is perturbed.

- Due to the strong non-linearity and complexity of the SU(3) mode, its coordination cannot be "diluted" throughout space like the electromagnetic force, but instead forms a strongly localized coordination channel or flux tube.
- The projection of this coordination channel in low dimensions appears as a color electric field line carried by the gluon field. The gluons themselves are the messengers of SU(3) "Spin" mode coordination.
- When two quarks are pulled apart, the energy required to maintain the "Spin" mode coordination between them increases continuously, preventing the realization of a dynamic equilibrium state for two isolated quarks. Ultimately, new quark-antiquark pairs must be created to form new, stable coordination configurations—this is color confinement.

3.4.5 The Special Status of Gravity: Emergence of Spacetime Geometry rather than Force Transmission

In this framework, gravity is fundamentally distinct from the other three fundamental interactions at an ontological level, stemming from the core postulate: **every stable (E_{rest}, E_{vib}, Spin) Dynamic Equilibrium Optimal Solution is itself a source of microscopic, dynamic spacetime curvature**.

- **The "Non-Transmissive" Nature of Gravity:**
  - The other three forces are interactions between matter fields and

gauge fields, occurring on a pre-existing spacetime background, requiring "transmission."

- Gravity, however, is the collective emergent effect of all particle dynamic equilibrium states. Each particle directly contributes a "micro-curvature" to the spacetime metric $G_{\mu\nu}^{(\mathbf{effective})}$ at its location via the function $F(r, \mathbf{Spin})$. Gravity is not transmitted through spacetime; it **is the spacetime geometry itsel**f.

- **Visual Description: Stage and Actors:**
  - **Spacetime** is like a vast, elastic membrane (the stage).
  - **The other three forces** are like interactions between actors on the stage (exchanging information via surface waves on the membrane).
  - **Gravity** is the overall bending and deformation of the entire membrane caused by the weight and presence of all these actors themselves (the shape of the stage itself).
- **Universality of the "Gravitational Charge":**

  In this picture, the **"gravitational charge" is the dynamic equilibrium state itself**. It is directly related to the total energy $E_{\mathbf{total}}$ and is precisely characterized by the function $F(r, \mathbf{Spin})$. Therefore, **all entities possessing energy necessarily and intrinsically become sources of gravity**, perfectly explaining the universality of gravitation.

3.4.6 Unification with the Microdynamic Principles

This picture of interactions is perfectly unified under the microdynamic

principles:

- **Principle of Structure:** Each type of gauge boson corresponds to a specific, stable "Spin" mode coordination configuration, i.e., a **Dynamic Equilibrium Optimal Solution**. Gravity is the collective geometric property of all Dynamic Equilibrium Optimal Solutions.
- **Principle of Stability:** The manifestation of interactions depends on the balance between the "entanglement binding" maintaining a specific "Spin" mode coordination and the "disentanglement perturbation" disrupting it.
- **Principles of Decay/Fusion:** Processes involving forces are essentially the **reorganization and relaxation** of "Spin" mode configurations.

3.4.7 Unique Predictions and Theoretical Advantages

- **Conceptual Unification and Distinction:** Within the unified "Energy-Dimension-Spin" framework, it explains the transmission mechanism of non-gravitational forces while deeply revealing why gravity is fundamentally different.
- **Resolving the Virtual Particle and Graviton Puzzles:** Eliminates the vague reliance on "virtual particles" and the "graviton" as independent entities, replacing them with clear dynamical processes.
- **Potential for Ultimate Unification:** Provides a physical picture and exploratory path for the potential unification of all forces into a single **"Dimension-Spin" dynamics** at extremely high $\boldsymbol{E_{\mathbf{vib}}}$.

- **Testable Corollaries:** Predicts that in extreme high-energy processes, the details of interactions might exhibit slight deviations from traditional QFT calculations, caused by the dimensional projection dynamics $\boldsymbol{f(r)}$.

Section Summary: This chapter systematically reshapes the transmission mechanism of fundamental interactions from the traditional "particle exchange" picture into a new dynamical framework based on **high-dimensional "Spin" mode coordination** and its **low-dimensional projection**, while clarifying the unique status of gravity as an **intrinsic emergence of spacetime geometry**. This is not only highly self-consistent with other parts of the framework but also offers a promising new perspective for solving the most profound conceptual dilemmas in contemporary physics.

3.5 A Dynamical Explanation of Quantum Phenomena: From the Perspective of Dynamic Equilibrium State Switching

Based on the "Energy-Dimension" postulates established in Section 2.1, this section demonstrates how the framework naturally leads to a deeper physical picture, thereby unifying the solution to several of quantum mechanics' most profound conceptual dilemmas.

We reason that if every stable microscopic entity corresponds to an **($\boldsymbol{E_{\text{rest}}}$, $\boldsymbol{E_{\text{vib}}}$, Spin)** dynamic equilibrium optimal solution, and the spacetime we observe is its projection, then the high-dimensional noumenon of the entire universe necessarily constitutes a **dynamic holistic network**. In this network, all "strings" or dynamic equilibrium nodes are interconnected through intrinsic interactions into an indivisible whole. The low-

dimensional spacetime we perceive and everything within it are projections of this network at different levels. Any "observation" or "choice" in low-dimensional spacetime essentially **implants a physical "boundary condition"** into this holistic network.

Consequently, numerous quantum puzzles, from wave-particle duality to the counterintuitive phenomena of delayed choice, can be **naturally deduced and uniformly understood as the dynamic response process of this high-dimensional holistic network to the "boundary conditions" within it**. Its core dynamical chain can be expressed as: **Implantation of Low-Dim Boundary Condition → Perturbation of High-Dim Network Nodes → Switching of Dynamic Equilibrium State → Change in Low-Dim Projection Manifestation**.

3.5.1 The Model of Quantum Reality: The High-Dimensional Holistic Network and Its Dynamics

To establish a clear physical picture, consider a "marionette" metaphor: The high-dimensional network is a "knot-net," where each knot is a high-dimensional string's **(E_{rest}, E_{vib}, Spin)** dynamic equilibrium state. These knots are connected by the "threads" of interaction (couplings between strings) into a dynamic, holistic network. Every individual and object in our low-dimensional spacetime is the low-dimensional projection of one or more knots on this high-dimensional network, like "marionettes" on a stage, whose roots and movements are governed by the high-dimensional "knots" and "threads."

- **Holism of the Network:** Any low-dimensional event reflects the state of

its corresponding high-dimensional "knot." An action by one "marionette" means a state change in its "knot," which is instantly transmitted through the network's "threads" (interactions) to affect other "knots."

- **Network Meaning of "Boundary Condition":** Low-dimensional observation (e.g., setting up a detector) is an action by a "marionette" (the observer system) on the low-dimensional stage, implanting a global boundary condition into the network. This acts as a new constraint that demands and guides the final state of the entire network to be compatible with it.
- **Essence of the Dynamics:** To satisfy the new global constraint, nodes in the network undergo dynamical re-coordination, each seeking a new, stable dynamic equilibrium optimal solution. This process, from the low-dimensional perspective, manifests as the "collapse" of the quantum state or the "selection of history."

Building upon the postulates established in Section 2, we reason that if every stable microscopic entity corresponds to a **(E_{rest}, E_{vib}, Spin)** dynamic equilibrium optimal solution and the spacetime we observe is its low-dimensional projection, then the high-dimensional noumenon of the entire universe necessarily constitutes a **dynamic holistic network**. In this network, all "strings" or dynamic equilibrium nodes interact via **preexisting physical connections**, forming an indivisible whole. **Figure 4 visually presents this "high-dimensional holistic network" model and elucidates its core**

dynamics during quantum measurement: the implantation of a boundary condition triggers a switch in the dynamic equilibrium state of a node, ultimately causing its low-dimensional projection to transform from one form to another. This model seamlessly incorporates the observer into physical reality—any "choice" made by the observer participates in shaping the overall reality through the intrinsic connections of the high-dimensional network, thereby providing a thoroughly materialistic and holistic foundation for quantum phenomena.

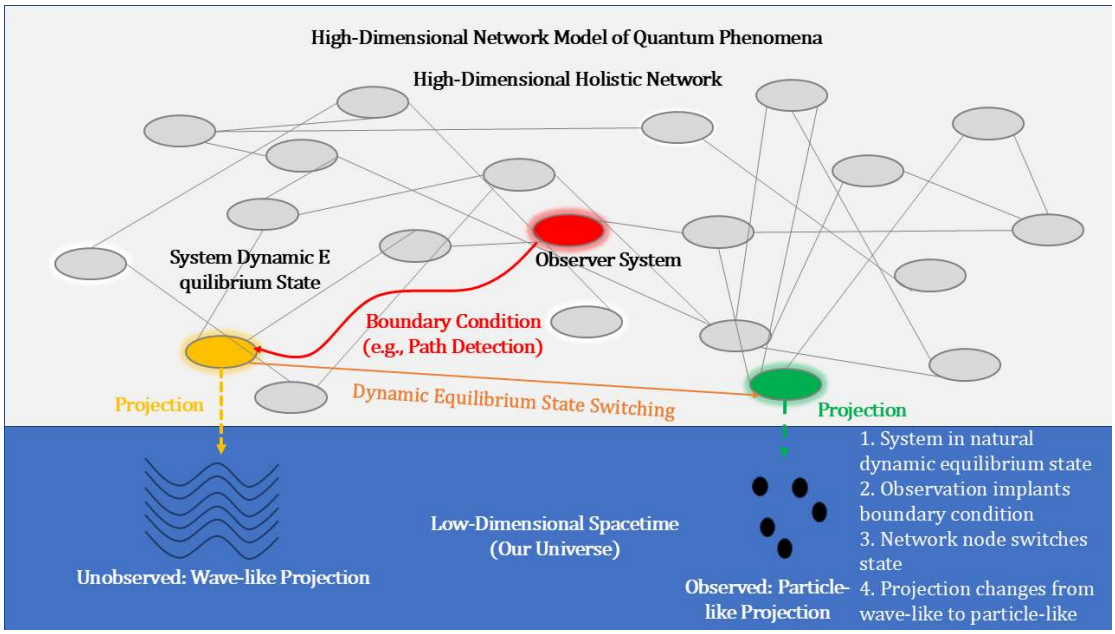

Figure 4: High-dimensional holistic network and boundary condition model of quantum phenomena. Our observed reality is viewed as a low-dimensional projection of a high-dimensional holistic network. An act of observation (e.g., placing a path detector) implants a physical boundary condition (red pulse), perturbs the network, and causes a switch in the dynamic equilibrium state of the observed node (from yellow to green), thereby changing its low-dimensional projection from a diffuse wave-like

pattern to a localized particle-like pattern.

3.5.2 Linkage States and Entangled States: Two Modes of Correlation in the High-Dimensional Network

Before introducing the network-based deduction of wave-particle duality, it is necessary to clarify two fundamentally distinct modes of correlation among strings within the high-dimensional holistic network (Postulate 2.1.9). Both modes manifest as "correlations" between particles in low-dimensional projection, but their high-dimensional ontologies are radically different.

- **Entangled State**. An entangled state is a mode of correlation in which multiple strings merge into a single composite node. In this mode, the participating strings cease to exist as independent nodes—they coalesce into a shared "knot" within the high-dimensional network, and project into low dimensions as a single, merged entity. Its total intrinsic energy is the sum $\sum \boldsymbol{E_{\text{total}}}$ of all participating strings, and the participating strings lose their independent low-dimensional individuality. In this framework, the three-generation fermion structure (Section 3.1.5.5) is a typical embodiment of this mode—the muon is the entangled projection of a two-string alliance, and the tauon is the entangled projection of an alliance of three or more strings.
- **Linkage State.** A linkage state is a **non-entangled coordination relationship** within the high-dimensional holistic network. In a linkage state, the **($\boldsymbol{E_{\text{rest}}}$, $\boldsymbol{E_{\text{vib}}}$, Spin)** dynamic equilibrium states of the strings

remain independent—they exist as distinct nodes ("knots") within the high-dimensional holistic network, and project into low dimensions as **separate, mutually distinguishable entities**. However, through the instantaneous internal connections ("threads") of the high-dimensional holistic network, the dynamic equilibrium states of these nodes are instantaneously constrained by one another. When the state of one node changes, the related nodes instantaneously adjust their own dynamic equilibrium states to reach a new optimal solution of the network as a whole—a process that fully conforms to the dual-layer dynamic equilibrium interplay described in Mechanism Three (Section 2.2).

The essential feature of a linkage state is "connected yet distinct": the strings maintain independent noumena in the high dimension, maintain independent projections in the low dimension, yet form an instantaneous, holistic coordination structure at the level of dynamic equilibrium. Its core distinction from an entangled state may be summarized as follows: an entangled state is "multiple strings, one merged projection"; a linkage state is "multiple strings, independent projections, globally coordinated."

The linkage state is the central ontological mechanism underlying the quantum measurement process. Every act of "observation"—whether the recording by a detector in a laboratory or the scattering between particles in nature—is, in essence, the establishment of an instantaneous linkage state between the observing system and the observed system through the high-dimensional

holistic network. **The establishment of the linkage state causes a small but decisive elevation of the observed string's E_{vib}**, thereby altering the manifested ratio of wave nature to particle nature in its low-dimensional projection. This mechanism is elaborated in what follows.

3.5.3 Wave-Particle Duality as Two Modes of Network Projection

Wave and particle properties are different projections of the same high-dimensional reality under different contexts, whose manifestation follows definite dynamical principles.

- **Unobserved State:** When no specific boundary condition is implanted, the high-dimensional string resides in the **global dynamic equilibrium optimal solution**. The low-dimensional projection of this complete state intrinsically contains both wave nature (dispersed probability distribution) and particle nature (localized energy events).
- **Nature of Observation: Observation as the Network Conduction of a Boundary Condition**

  In this framework, "observation" is no longer the mysterious and unanalyzable "black box" of quantum mechanics, but an objective physical process with a clear high-dimensional ontology. Every string in the high-dimensional holistic network (Postulate 9) is connected to all other strings not only through **entangled states**—by which strings share a common projection (e.g., the multi-string alliances of fermions)—but also, and more fundamentally, through **linkage states**: the most basic,

permanent internal connections ("knots" and "threads") that bind the network into an indivisible whole. A linkage state is not a transient phenomenon temporarily established at the moment of observation; on the contrary, it is the very foundation upon which the Postulate of the High-Dimensional Holistic Network rests. It is precisely because linkage states exist that any change of state in any string—whether an adjustment of its **(E_{rest}, E_{vib}, Spin)** parameters, the establishment of a new Dynamic Equilibrium Optimal Solution, or the formation of entanglement with other strings—is instantaneously conveyed across the entire network through the network's "threads.".

In this picture, **the physical essence of an act of observation is the implantation of an "information boundary condition" into the high-dimensional holistic network**—whether by setting a path detector, registering a particle position, or scattering a photon, these low-dimensional physical operations all conduct a new global constraint into the entire high-dimensional network through the pre-existing linkage-state connections between the observing system and the observed system. This conduction does not require the establishment of any new structure—it merely requires the transmission of a signal through the network connections that already exist. This is precisely what is stated in Postulate 2.1.9: any act of low-dimensional "observation" or "interaction" is, in essence, the implantation of a physical boundary condition into the high-

dimensional holistic network.

- **Network Response: Global Reconfiguration and the Bidirectional Shift of $E_{\mathbf{vib}}$**

  Once the boundary condition is implanted, the network must respond to this new constraint. In accordance with the dual-layer dynamic equilibrium interplay described in Mechanism Three (Section 2.2.3), the network-driven global coordination process is initiated: **the entire high-dimensional holistic network attains, in a single step, a new holistic dynamic equilibrium optimal solution.** Within this new solution, the **($E_{\mathbf{rest}}$, $E_{\mathbf{vib}}$, Spin)** parameters of all relevant strings—including both the string of the observing system and that of the observed system—are reconfigured. For any given string, its state in the holistic solution need not be identical to its original independent optimal solution; rather, under the constraint imposed by the holistic optimum, each relaxes into a new singular configuration compatible with the whole. **The observed outcome manifested in low-dimensional projection—wave-like or particle-like—is precisely the direct projection of the specific configuration occupied by the observed string within this holistic optimal solution**.

  For the observed string, the effect of this global reconfiguration is a **small shift in its E_vib—which may be either an increase or a decrease**. The specific direction of the shift depends on the physical nature of the

boundary condition and the configuration it occupies within the holistic optimal solution:

- When the boundary condition demands that the observed string provide unambiguous path information (e.g., a detector is activated in the double-slit experiment), the observed string must, in the new holistic optimal solution, increase its $\boldsymbol{E_{\mathrm{vib}}}$ and correspondingly decrease its $\boldsymbol{E_{\mathrm{rest}}}$. According to Postulate 2.1.6 (Property Emergence), this causes the low-dimensional projection to exhibit pronounced particle nature—the interference fringes vanish.
- When the boundary condition permits or even requires the observed string to preserve its coherence (e.g., the path marker is erased in the quantum eraser experiment), the observed string's $\boldsymbol{E_{\mathrm{vib}}}$ in the new solution is restored to or maintained at an extremely low level, and its $\boldsymbol{E_{\mathrm{rest}}}$ correspondingly returns to a high level; the low-dimensional projection exhibits nearly perfect wave nature—the interference fringes recover.

- **The Continuous Transition from Wave Nature to Particle Nature**

  It is precisely this shift of $\boldsymbol{E_{\mathrm{vib}}}$, induced by the global coordination, that directly determines the low-dimensional projection properties of the observed string. According to Postulate 6 of Section 2.1 (Property Emergence): **the higher the string's $\boldsymbol{E_{\mathrm{rest}}}$, the stronger its wave-like properties; the higher its $\boldsymbol{E_{\mathrm{vib}}}$, the stronger its particle-like**

properties. Whether the boundary condition causes $\boldsymbol{E_{vib}}$ to increase or decrease, its final value precisely specifies the location of the projection on the wave-particle continuum.

The crucial insight of this process is that **wave nature and particle nature are not binary opposites, but two asymptotic directions on a continuum of $\boldsymbol{r(=E_{vib}/E_{rest})}$.** The physical strength of the boundary condition—determined by the nature of the interaction between the observing system and the observed system (such as the magnitude of momentum transfer, the quantity of information exchanged, and whether that information can be erased)—precisely regulates the final value of the observed string's $\boldsymbol{E_{vib}}$ within the holistic optimal solution. A weak boundary condition (e.g., an erasable path marker) induces only a tiny shift of $\boldsymbol{E_{vib}}$, and the projection retains nearly full wave nature; a strong boundary condition (e.g., an irreversible path detection) induces a significant shift of $\boldsymbol{E_{vib}}$, and the projection exhibits definite particle nature; and the erasure operation is itself a boundary condition—it reverses the prior $\boldsymbol{E_{vib}}$ shift, enabling the observed string to return to a high-wave-nature configuration.

More significantly, **this mechanism dissolves the paradox of "causal temporal order."** Because the entire network attains a new holistic optimal solution in a single step, the "before" and "after" on the low-dimensional time axis are merely the sequential arrangement of the

projections of this holistic solution onto different low-dimensional time slices. In the delayed-choice experiment, the reason why the "final choice" can determine the wave-like or particle-like behavior of "prior events" is precisely that **the final boundary condition uniquely determines the configuration of the entire high-dimensional network history**—the projected state of the observed string on each time slice is a holistic realization of the global optimal solution, not a case of "the present decision altering the past." This argument is further developed in Section 3.5.4 (the network deduction of the delayed-choice and quantum eraser experiments).

3.5.4 Network Deduction of Key Experiments

Based on the above mechanism—observation as the network conduction of a boundary condition, and the bidirectional shift of $\boldsymbol{E_{\mathbf{vib}}}$ in holistic dynamic equilibrium reconfiguration—three of the most representative experiments in quantum mechanics receive a unified mechanistic interpretation.

- **The Double-Slit Experiment (Basic Setup and Introduction of Observation)**
    - **Phase 1 (No Observation):** The initial experimental configuration—in which no path information is extracted—itself constitutes a physical boundary condition that permits the manifestation of wave nature. Under this condition, in the **holistic dynamic equilibrium optimal solution** attained by the high-dimensional holistic network,

the high-dimensional string corresponding to the observed string resides in a configuration of high $\boldsymbol{E_{rest}}$ and low $\boldsymbol{r}$ (correspondingly low $\boldsymbol{E_{vib}}$)—for a photon, its $\boldsymbol{r}$ approaches the lowest limit accommodatable by this dimension, and the corresponding $\boldsymbol{f(r)}$ approaches the upper bound of this dimension's threshold; see the hierarchical structure of dimensional thresholds in Section 2.2. According to Postulate 6 (Property Emergence), the low-dimensional projection of this configuration exhibits wave-dominated character—interference fringes naturally appear.

- **Phase 2 (Introduction of Observation):** When a detector is introduced at the paths, the string system corresponding to the detector itself undergoes a change of state. This change is conducted, via the permanently existing linkage states, into the entire high-dimensional holistic network, implanting a strong boundary condition into the network—path information is irreversibly recorded. The network responds to this condition by attaining, in a single step, a new **holistic dynamic equilibrium optimal solution**. In this new solution, the observed string's $\boldsymbol{E_{vib}}$ is substantially shifted and crosses the critical threshold, reaching a **new, permanent dynamic equilibrium optimal solution compatible with the fact that "path information has been recorded**." Its low-dimensional projection therefore switches from interference fringes to localized, particle-dominated

spots. This is not a case of "wave nature being destroyed," but rather the observed string being compelled, under the new holistic dynamic equilibrium constraint, to occupy a configuration in which **particle nature is externally manifest**.

- **The Quantum Delayed-Choice Experiment (Proof of Historical Holism)**

This experiment proves that the timing of the implantation of the boundary condition—whether before or after the particle "passes through" the double slit—is irrelevant. However late the experimenter postpones the decision to detect the path, **once the final boundary condition is established, it uniquely determines the holistic dynamic equilibrium historical configuration of the entire high-dimensional holistic network.** The system does not involve "the present altering the past"; rather, the final boundary condition, as a global constraint, causes the projected configurations of the observed string on all relevant time slices to be realized in dynamic equilibrium. The "retroactive switching" perceived from the low-dimensional perspective is not time reversal, but a necessary consequence of historical holism.

- **The Quantum Eraser Experiment (Proof of Reversibility and the Hierarchy of Boundary Condition Strength)**

  This experiment reveals the hierarchy of boundary condition strength, and the reversibility of the resulting $\boldsymbol{E_{\mathbf{vib}}}$ shift of the observed string that

depends on it:

- **Weak Boundary Condition (Reversible):** Using quantum entanglement to "mark" the path **extracts a minuscule amount of information through weak coupling with the quantum system—an indirect observation**. The string corresponding to the marking act implants, via linkage states, a weak boundary condition into the high-dimensional holistic network. At this point, the $\boldsymbol{E_{vib}}$ of the observed string is slightly shifted, deviating from its wave-dominated configuration, and the interference fringes vanish. However, this shift has **not crossed the boundary of the basin of attraction of the string's own Dynamic Equilibrium Optimal Solution—the observed string is merely temporarily displaced from its original optimal solution**, and its dynamic tendency has not yet been redirected toward a new solution. When an "erasure" operation removes the marker, the weak boundary condition is revoked, the perturbation is removed, and the observed string's dynamic tendency automatically draws it back to its original optimal solution; the network as a whole accordingly returns precisely to the original holistic dynamic equilibrium configuration. The observed string's $\boldsymbol{E_{vib}}$ returns to its original value, the interference fringes recover, and are indistinguishable from the case in which no marking ever occurred.

- **Strong Boundary Condition (Irreversible):** Using an "active detector" **extracts the entirety of the path information in an invasive manner—a direct observation**. The string corresponding to the detector implants, via linkage states, **a strong boundary condition into the network—i.e., a direct linkage-state perturbation**. The $\boldsymbol{E_{\mathrm{vib}}}$ of the observed string is substantially shifted, and this shift **crosses the critical threshold—entering the basin of attraction of a new holistic dynamic equilibrium optimal solution**. The path information is permanently encoded into the network configuration, and the dynamic equilibrium state is locked into a new solution in which particle nature dominates. Even a subsequent attempt at "erasure" cannot restore the observed string to its original solution, as it now resides within the basin of attraction of the new solution. The interference fringes cannot be recovered.
- **Conclusion: The reversibility of state switching depends strictly on whether the magnitude of the observed string's $\boldsymbol{E_{\mathrm{vib}}}$ shift has crossed the boundary of the basin of attraction of its own current Dynamic Equilibrium Optimal Solution**. Under a strong boundary condition, the shift crosses the critical threshold, and the observed string's dynamic tendency drives it to relax into a new, permanent Dynamic Equilibrium Optimal Solution—the state switch is irreversible. Under a weak boundary condition, the shift does not

cross the critical threshold, and the observed string is merely temporarily displaced—when the weak boundary condition is revoked and the perturbation is removed, the observed string's dynamic tendency automatically draws it back to its original optimal solution, and the network as a whole accordingly returns to the original holistic dynamic equilibrium configuration—the state switch is reversible. In both cases, **the holistic optimal solution of the high-dimensional holistic network is strictly determined by the singular optimal solutions of all participating strings and their linkage-state correlations; the network itself does not constitute an additional decision-making entity independent of the strings**.

This picture is in close accord with all of the above experimental facts. The "perturbation" or "correlation" in these experiments is neither a non-local action at a distance nor any idealistic projection, but **an intrinsic, dynamical coordination process realized within the same high-dimensional holistic network, through the permanent physical connections of linkage states between different strings**. The low-dimensional observer and observational acts are themselves projections of this network in the low dimension and, through the internal connections of the high-dimensional holistic network, participate in shaping the overall reality.

3.5.5 A Unified Interpretation of Recent Double-Slit Variant Experiments

The network deduction presented above not only applies to the classic thought

experiments, but also provides a unified mechanistic interpretation for recent double-slit variant experiments that have achieved precision control at the single-quantum level.

- **Experimental Facts.** A team at USTC employed a single atom cooled to its three-dimensional motional ground state as a "movable slit," faithfully realizing the Einstein-Bohr recoiling-slit gedankenexperiment proposed a century ago[16]. The key finding of this experiment is that the single-photon interference visibility $\boldsymbol{V = e^{-2\eta^2}}$ is continuously determined by the degree of momentum entanglement between the photon and the slit atom—where $\boldsymbol{\eta = \hbar k/2\Delta_p}$ is the ratio of the photon momentum to the atomic momentum uncertainty, dynamically tunable by varying the optical tweezer depth. The stronger the entanglement, the more complete the which-path information, and the lower the interference visibility. Almost simultaneously, an MIT team conducted light scattering experiments using ultracold atomic wavepackets released from an optical lattice, independently revealing another crucial fact: the ratio of coherent to incoherent light scattering is independent of the presence of a trapping potential, depending only on the Debye-Waller factor $\boldsymbol{D = e^{-\eta^2}}$ that characterizes the partial entanglement between the wavepacket and the photon[17].
- **Interpretation within the Present Framework.**

  In the Energy-Dimension framework, the relationship between the photon

string and the atom string serving as the scatterer in these two experiments is not an entangled state—in an entangled state, multiple strings merge into a single composite node and project into low dimensions as a single merged entity (e.g., a two-string alliance projected as a muon in the fermion generation structure). The photon string and the scatterer string each retain independent low-dimensional projections, yet through the permanently existing linkage states within the high-dimensional holistic network (Postulate 9), the two remain in instantaneous coordination at the level of dynamic equilibrium. Linkage states are the fundamental mode of existence of the network, not configurations temporarily established at the moment of observation.

For these two experiments, the key issue is not "how a linkage state is established," but rather that **the experimental operations themselves—scattering a photon, trapping an atom, adjusting the optical tweezer depth—constitute physical boundary conditions implanted into the high-dimensional holistic network, and these boundary conditions drive the network, via linkage states, to attain different holistic dynamic equilibrium optimal solutions, thereby specifying the final value of the observed string's $\boldsymbol{E_{\mathrm{vib}}}$ within that solution.**

The spatial width of the scatterer wavepacket—characterized by the momentum uncertainty $\boldsymbol{\Delta p}$—is a crucial physical parameter of the boundary condition. It determines the sensitivity of the scatterer string's

dynamic equilibrium state to changes in the network's boundary condition: the narrower the wavepacket (the larger $\Delta \boldsymbol{p}$), the more sensitive the scatterer string's dynamic equilibrium state is to external perturbation. Under a light-scattering boundary condition of the same strength, the $\boldsymbol{E}_{\mathbf{vib}}$ of the observed string in the holistic dynamic equilibrium optimal solution attained by the network is driven to a higher value, and the interference visibility is lower. Conversely, the broader the wavepacket (the smaller $\Delta \boldsymbol{p}$), the smaller the $\boldsymbol{E}_{\mathbf{vib}}$ shift of the observed string in the new holistic solution, and the photon string is able to remain closer to its high-$\boldsymbol{E}_{\mathbf{rest}}$, low-$\boldsymbol{E}_{\mathbf{vib}}$ wave-dominated configuration, with interference visibility approaching unity.

Concretely, the parameter $\boldsymbol{\eta = \hbar k / 2\Delta_p}$ in the interference visibility formula $\boldsymbol{V = e^{-2\eta^2}}$ acquires a new physical interpretation within this framework: it is proportional to the relative magnitude of $\Delta \boldsymbol{E}_{\mathbf{vib}}$—the shift configured for the observed photon string by the network in order to attain the holistic dynamic equilibrium optimal solution under a specific boundary condition— $\boldsymbol{\eta \propto \Delta E_{vib} / \hbar k c}$. The tuning of the optical tweezer depth in the USTC experiment is, in essence, the adjustment of the scatterer string's response sensitivity (i.e., the $\boldsymbol{\eta}$-weight corresponding to a given $\Delta \boldsymbol{E}_{\mathbf{vib}}$) to the same type of light-scattering boundary condition; and the finding of the MIT experiment—that the coherent scattering fraction is independent of the presence of a trapping potential—is direct

evidence that linkage states are the foundational mode of existence of the network: the permanent linkage correlations of the network are in no way altered by whether an external trapping potential is imposed in low-dimensional space; changes in the network's boundary conditions and its global response depend on the intrinsic spatial width of the wavepacket, and not on whether this width originates from quantum ground-state confinement or from some intermediate stage of free expansion.

- **Resolution of the Paradox.** Einstein once sought to challenge the complementarity principle using the recoiling-slit experiment: if the recoil momentum of the slit could be measured with sufficient precision, one could simultaneously determine the photon's path (particle nature) and observe interference (wave nature), thereby circumventing the complementarity constraint. A century of experimentation has shown that this challenge does not succeed—precisely because the photon and the slit are, through linkage states, inevitably incorporated into the same holistic dynamic equilibrium optimal solution of the one high-dimensional holistic network, the acquisition of which-path information and the preservation of interference visibility perpetually constitute a trade-off relationship. The present framework provides a physical mechanism that goes beyond the standard interpretation of quantum mechanics: **an observational act, as a boundary condition implanted into the network, drives the network, via permanent linkage states, to**

reconfigure the holistic dynamic equilibrium optimal solution; the $\boldsymbol{E_{vib}}$ of the observed string in this new solution—intrinsically determined by the physical parameters of the boundary condition (such as the scatterer's momentum uncertainty)—precisely specifies the positioning of its projection on the wave-particle continuum. Complementarity is not a binary either-or, but two limits on a continuum of the magnitude of the observed string's $\boldsymbol{E_{vib}}$ shift: at one end lies wave-dominated character when the boundary condition is extremely weak and the $\boldsymbol{E_{vib}}$ shift is minimal, at the other end lies particle-dominated character when the boundary condition is extremely strong and $\boldsymbol{E_{vib}}$ is substantially elevated. It should be emphasized that these two "limits" are not mutually exclusive pure states—even in a wave-dominated configuration, particle nature is still present (the photon is detected in discrete energy quanta); even in a particle-dominated configuration, wave nature persists as the background dynamics of the probability distribution. **Wave-particle duality is always coexistent; what changes is only the dominant tendency of the externally manifest properties**. The quantitative results of the two experiments—the continuous variation of interference visibility with $\boldsymbol{\eta}$—are direct experimental confirmations of this continuous transition.

3.5.6 Superluminal Correlation and Causality: The Perspective of the High-Dimensional Holistic Network

The superluminal correlations exhibited by quantum entanglement appear, on

the surface, to contradict the speed-of-light limit and the causality principle of Special Relativity. This tension calls for a clear physical resolution rather than an evasion. The Energy-Dimension framework provides a mechanistic solution.

The Applicable Scope of the Causality Principle of Special Relativity. Special Relativity prohibits superluminal signal transmission. Its core presupposition is that physical events occur on a smooth, fixed four-dimensional spacetime background, and that any information transmission must be accomplished point by point through this background in a progressive manner. Within this framework, if a correlation occurs between two spacelike-separated events and this correlation is regarded as "signal transmission," then a disruption of causal temporal order would inevitably follow. This reasoning is fully valid within the domain where its presuppositions hold. However, whether the correlations of quantum entanglement qualify as "signal transmission" depends on the physical level at which such correlations take place.

State Synchronization in the High-Dimensional Holistic Network, not Signal Transmission in Low-Dimensional Spacetime. In the present framework, quantum entanglement is a holistic coordination phenomenon realized within the same high-dimensional holistic network, between different strings through permanently existing linkage states. Two events that appear remote and spacelike-separated in low-dimensional spacetime share, within

the high-dimensional holistic network, internal connections that can be traversed without passing through low-dimensional space. When a change of state occurs at one node of the network, this change is instantaneously conveyed, via linkage states, across the entire network, driving the network to attain, in a single step, a new holistic Dynamic Equilibrium Optimal Solution (Mechanism Three). The entire process is, at the high-dimensional level, a one-step global reconfiguration, not a point-by-point propagation through low-dimensional space.

The crucial insight is this: **what appears to the low-dimensional observer as "superluminal transmission" is not, at the high-dimensional level, the transmission of any signal at all—it is the realization of the projection of a holistic optimal solution that has already been established.** Similarly, in the delayed-choice experiment (Section 3.5.4), the final boundary condition uniquely determines the holistic dynamic equilibrium historical configuration of the entire high-dimensional network—the projected configurations of the observed string on all time slices are the holistic realization of the global optimal solution, not a case of "the present decision altering the past." This assertion is fully consistent with the fundamental discussion of linkage states in Section 3.5.3: the "causal temporal order" on the low-dimensional time axis is merely the sequential arrangement of the projections of the holistic optimal solution onto different low-dimensional time slices, rather than a basic category of the high-dimensional dynamics.

No Violation of Special Relativity. It is particularly important to emphasize that the present framework does not overturn Special Relativity. The latter remains fully valid in all scenarios involving the gradual transmission of information in low-dimensional spacetime—i.e., in all scenarios where energy or matter attempts to influence one point from another through four-dimensional spacetime. All manipulable energy and information, within this framework, still strictly obey the speed-of-light limit. The present framework merely points further: the non-local correlations of quantum entanglement are not such gradual transmissions—they convey no energy, transmit no usable signal (the no-signaling theorem), and merely manifest the holistic equilibrium already present within the high-dimensional holistic network. When "causality" is strictly confined to signal transmission in the sense of Special Relativity, the superluminal correlations of quantum entanglement do not violate it; when we inquire into the physical mechanism behind quantum entanglement, the traditional causal framework of Special Relativity needs to be supplemented, but not negated, by the "holistic state realization" paradigm of the high-dimensional holistic network.

It is further worth noting that recent experimental studies have successfully realized "generalized indefinite causal orders" [18]—the causal sequencing of multiple events is placed in a quantum superposition, rather than being pre-fixed. This experimental fact provides independent corroboration for a core assertion of the present framework: the seemingly unshakeable "causal order"

in low-dimensional spacetime is, at the level of the high-dimensional network, no more than the sequential arrangement of the projections of the holistic Dynamic Equilibrium Optimal Solution onto time slices. Causal temporal order is not an a priori framework of the high-dimensional dynamics, but an emergent property of its projection.

3.5.7 Summary and Outlook

This framework unifies quantum phenomena under a concise and profound principle: **Low-dimensional boundary conditions, by perturbing the high-dimensional holistic network, drive the switching of dynamic equilibrium states, thereby determining projected reality.**

The core challenge and future direction lie in elucidating the microscopic mechanism of **"cross-dimensional regulation"**—that is, how "boundary conditions" specifically constrain the evolution of high-dimensional "Spin" modes through functions like $\boldsymbol{f(r)}$. Overcoming this challenge will advance the framework from an outstanding concept towards a complete theory.

3.6 Heat Death: Two Conjectures on the Ultimate Fate of the Universe

Within this framework, the ultimate trend of the universe is for the energy form of all strings to shift from being vibration-energy-dominated to rest-energy-dominated. Based on this core principle, we derive two equally self-consistent but distinctly different conjectures about the ultimate fate.

Conjecture One: The "Sea of Silence" of Low-Dimensional Projections

- **Mechanism:** The vibrational energy $\boldsymbol{E_{vib}}$ of all strings is ultimately and completely converted into rest energy $\boldsymbol{E_{rest}}$.
- **High-Dimensional Noumenon:** Strings return to the most tranquil, highest-symmetry ground state.
- **Low-Dimensional Phenomenon:** Since $\boldsymbol{E_{vib} = 0}$, the mechanism sustaining "particle-like" projections ceases completely. Matter, forces, and interactions vanish. The low-dimensional universe is filled with a uniform, eternal background—this is the final, sole projection of the strings' rest energy $\boldsymbol{E_{rest}}$ in low dimensions, which can be called the **"Sea of Silence"**.
- **Image:** The universe does not annihilate but enters an eternal equilibrium of structureless, light-filled "existence."

Conjecture Two: The "Singularity Merger" of Low-Dimensional Space

- **Mechanism:** When the rest energy $\boldsymbol{E_{rest}}$ of strings becomes absolutely dominant on a cosmic scale, it may not only change the projection content but also thoroughly reshapes the spacetime geometry itself. An extremely high $\boldsymbol{E_{rest}}$ background could lead to the loss of stability of low-dimensional spacetime.
- **Phenomenon:** Low-dimensional space itself, as an effective approximate description, will cease to exist. The entire low-dimensional structure of the universe may undergo a topological transformation, **ultimately "merging" or "dissolving" into the singularity of the high-dimensional background**.
- **Image:** This is a more violent, more thorough end, where the low-dimensional stage itself collapses, and all actors (particles) return to the highest-dimensional

origin along with the stage.

Discussion and Significance

These two conjectures are not mutually exclusive but may describe different stages or aspects of the same process. The "Sea of Silence" could be the last observable stage before "Singularity Merger." **Their coexistence precisely demarcates the key predictive territory of this framework: Will the universe's end be a calm sea of energy, or a thorough phase transition of spacetime structure?** The answer to this question will become the crucial basis for judging the future development direction of this framework.

3.7 A Conjecture on Cosmic Origin and Fate: The Big Bang as a High-Dimensional White Hole

The dynamical imagery of this framework naturally leads us to speculate about the origin of the universe itself. We propose a conjecture: the Big Bang that our universe experienced may have originated from a black hole process in a **lower-dimensional universe**.

- **Image:** In a **lower-dimensional universe**, a black hole forms. From our perspective (**higher-dimensional** observers), it manifests as a "white hole" that only emits, whose enormous energy eruption is the beginning of our universe.
- **Mechanism:** This white hole is essentially the projection into our dimension of **a black hole in lower-dimensional spacetime**. The extremely high energy density in the early Big Bang corresponds to the extremely high $\boldsymbol{E_{\mathbf{vib}}}$ of strings. As the universe expanded and cooled, strings gradually established the effective

dimensions and physical laws we see today through energy form transformation ($\boldsymbol{E_{vib} \rightarrow E_{rest}}$).

- **Corollary:** This imagery perfectly incorporates the origin of the universe into the unified "black hole-white hole" energy breath cycle, providing a logically closed, aesthetically pleasing hypothesis for "why we exist."

4 Framework Positioning and Dialogue

4.1 Correspondence with the Standard Model of Particle Physics

This framework does not negate the Standard Model but provides it with a more fundamental, physically intuitive **emergent origin**. All core elements of the Standard Model—from particle content to interactions—can be uniformly interpreted within the "Energy-Dimension" framework and its microdynamic principles.

- **Unified Picture of Particles and Forces:** The matter particles (fermions) and force particles (bosons) of the Standard Model correspond to specific **(Multi-String) Dynamic Equilibrium Optimal Solutions**. Their fundamental distinction lies in the **number of entangled strings and their 'Spin' modes**. For instance, the three-generation structure of fermions directly corresponds to **single-string, two-string, and multi-string alliances** (see Section 3.1.5.5).
- **Dynamical Origin of Gauge Symmetries:** The gauge symmetries such as U(1), SU(2), and SU(3) are not fundamental laws but emerge as low-energy approximate symmetries from the **synergistic resonance dynamics of multi-string systems**. These symmetries correspond to the global properties of the most stable **"entangled configurations"** at specific energy scales (see the **Principle of**

Stability, Section 2.1.8).

- **Essence of Mass and the Higgs Mechanism:** The inertial mass of a particle originates from the total energy $\boldsymbol{E_{\text{total}}}$ of its dynamic equilibrium state, and the hierarchy of $\boldsymbol{E_{\text{total}}}$ across generations is directly determined by the **number of entangled strings** (mass differences among fermion generations). The Higgs field can be interpreted as a specific collective excitation mode of the **background string sea**. The Higgs coupling (Yukawa coupling) then reflects the **"entanglement strength"** between a specific particle state and this background sea, which ultimately determines the inertial mass it manifests at low energies.

  Therefore, this framework successfully "grafts" the Standard Model onto a deeper physical foundation — the **dynamics of string entanglement and disentanglement**. This not only naturally encompasses all verified content of the Standard Model but also links its free parameters to the **topology and dynamics of stable entangled states** within the **($\boldsymbol{E_{\text{rest}}}$, $\boldsymbol{E_{\text{vib}}}$, Spin)** parameter space, pointing a potential path towards ultimately solving the question of "why this specific Standard Model?".

4.2 Reinterpretation and Development of String Theory's High-Dimensional Requirement

The mathematical consistency of string theory requires 10 or 11 spacetime dimensions. Using this theory as our concrete context, this paper aims to demonstrate how the core principles of the "Energy-Dimension" framework can provide a novel physical perspective and dynamic deepening of this high-dimensional requirement, centered on

the following:

- **From Fixed Background to Dynamical Variable:** Through the introduction of the **Energy Dichotomy Postulate** and its associated **dimension contraction function** $\boldsymbol{f(r)}$, this framework elevates the fixed high-dimensional background of string theory into a variable that is dynamically driven by the energy state **(**$\boldsymbol{E_{\mathrm{rest}}}$**,** $\boldsymbol{E_{\mathrm{vib}}}$**)**. The emergence of effective dimensions is the macroscopic manifestation of the dynamic equilibrium reached in the energy allocation between $\boldsymbol{E_{\mathrm{vib}}}$ and $\boldsymbol{E_{\mathrm{rest}}}$.[19]
- **Core Reinterpretation: Dimensional Phase Transition via Symmetry Breaking:** The high-dimensional setting of string theory is reinterpreted within this framework as a primordial state of the very early universe. In this state, the string system possessed extremely high vibrational energy $\boldsymbol{E_{\mathrm{vib}}}$ and very low rest energy $\boldsymbol{E_{\mathrm{rest}}}$, residing in the **highest-symmetry "high-dimensional particle phase".** As the universe expanded and cooled, a fundamental transformation in the energy morphology of the string system occurred: $\boldsymbol{E_{\mathrm{vib}}}$ **decreased significantly, while** $\boldsymbol{E_{\mathrm{rest}}}$ **increased correspondingly**. This shift in energy form, mediated by the **dimension contraction function** $\boldsymbol{f(r)}$, drove a profound **"dimensional phase transition"**: the symmetry of the high-dimensional spacetime underwent **spontaneous breaking**, its extra spatial dimensions became unstable, and our familiar **(3+1)-dimensional spacetime** emerged as the new, lower-symmetry, low-energy effective structure. This picture provides a potential **dynamic phase transition mechanism** for string theory's "compactification" problem, thereby

moving beyond the traditional paradigm reliant on static geometric choices. [20]

- **A Dynamical Answer to the "Landscape Problem":** This framework offers a natural solution to string theory's "landscape" conundrum. The seemingly innumerable possible vacua in the landscape do not exist on equal footing; they correspond to the discrete **Dynamic Equilibrium Optimal Solutions** within the **(E_{rest}, E_{vib}, Spin)** parameter space that satisfy the **Principle of Stability**. The evolution of the universe is, therefore, a dynamic process of the string system exploring and relaxing among these finite, stable "dimension-energy" phases.

4.3 Positioning within the Landscape of a Theory of Everything

This framework shares profound philosophical resonance and mechanistic complementarity with major quantum gravity research directions:

- **With Loop Quantum Gravity (LQG):** It shares the fundamental philosophy of **"emergent spacetime".** This framework provides a specific implementation path for the quantum discreteness and emergence of spacetime, based on **high-dimensional determinism**, through mechanisms such as **"Time-Dilated Sampling"** and **"Dimensional Projection Phase Transition"**. [21,22,23]
- **With the Holographic Principle:** This framework provides a potential physical realization mechanism for it. The entire information of the low-dimensional world is indeed a projection of a high-dimensional reality, and this process is explicitly defined as the **"projection"** under the dynamics of **energy-dimension coupling** ($f(r)$) and the storage of high-dimensional background silent energy E_{rest}. This offers an intuitive physical explanation for the holographic entropy bound.

[24,25,26]

4.4 A Note on the Theoretical Carrier: The String as a Paradigm of the Principles

This paper makes extensive use of the terminology and imagery of string theory (such as "string," "Spin" modes, the Nambu-Goto action, etc.), which may give rise to the misunderstanding that the present framework is entirely dependent on string theory. We wish to clarify this point explicitly: string theory is, at present, the most ideal stage for demonstrating the power of the "Energy-Dimension" framework, but it is not the only possible stage.

The core contribution of the framework lies in its proposal of a synergistic system of principles: the Energy Dichotomy Postulate, the dimension contraction function, the Dynamic Equilibrium Optimal Solution, multi-string entanglement (more generally, the synergistic resonance of fundamental entities), and high-dimensional holistic network projection. These principles jointly define a kind of "operating system" for the world—a logic of organization and evolution independent of any specific fundamental entity.

String theory has become our preferred carrier because it naturally possesses all the core elements required by this operating system: a high-dimensional background spacetime, rich intrinsic degrees of freedom (vibrational modes and "Spin"), and a natural multi-body entanglement structure. One might say that the relationship between the present framework and string theory is analogous to that between an operating system and the applications running on it: the framework defines the operating logic, and string theory is the physical model that most fully realizes this logic.

This in no way precludes the possibility of applying these principles to other models of fundamental entities in the future. For instance, the spin networks of Loop Quantum Gravity, or their extensions (such as branes in M-theory, or other as-yet-undiscovered fundamental entities) might equally be investigated and developed under this logic. The present work, in a sense, has thus developed the first—and currently the most complete—"application" for this operating system.

4.5 Clarification on the Foundation of Higher-Dimensional Theory

This framework is explicitly built upon the cornerstone of string theory, which accepts a higher-dimensional background. Its core innovation lies in providing a novel interpretation of the **existence form and manifestation mechanism** of extra dimensions — transforming them from static geometric entities into **dynamical variables** driven by energy states — through the **Energy Dichotomy Postulate** ($\boldsymbol{E_{\text{total}} = E_{\text{rest}} + E_{\text{vib}}}$) and its associated dynamics. This **"dynamic conception of dimensions"** aims to deepen, not negate, higher-dimensional theory and offers solutions to its core problems, distinctly setting it apart from theories that deny the existence of higher dimensions or lack mathematical structure.

4.6 Clarifying the Relationship with Quantum Field Theory Descriptions

The descriptions in this framework and in Quantum Field Theory (QFT) are complementary and operate at different levels. For processes such as matter-antimatter annihilation and particle decay, their **final observational predictions** are completely

consistent, fulfilling all requirements of the Standard Model.

The fundamental distinction lies in the level of the basic description of physical reality:

- Quantum Field Theory describes these processes at the level of **"excitation and annihilation of quantum fields".**
- This framework, however, interprets these processes at the level of the **Microdynamic Principles**, describing them as phase transitions in the energy form of fundamental entities and the reorganization of **multi-string entangled states** (i.e., **"entanglement"** and **"disentanglement"**).

Therefore, the goal of this framework is to provide a unified, mechanistic **explanation of the origin** for the rules and phenomena treated as "fundamental" in Quantum Field Theory, not to challenge their well-verified **observational validity**. It re-anchors the success of QFT onto **"Energy-Dimension" dynamics**.

4.7 A Unified Perspective on Modern Cosmological Puzzles

The dynamical principles of this framework provide a unified perspective on a series of fundamental cosmological problems:

- **Origin of Cosmic Inflation:** The inflationary epoch can be interpreted as a rapid and violent **"dimensional phase transition" and "energy form transformation"** during the early universe (following the eruption of the white hole), as the string system relaxed from an extremely high $\boldsymbol{E_{\mathbf{vib}}}$ state towards $\boldsymbol{E_{\mathbf{rest}}}$. The potential energy of the inflaton field might have originated from the exceedingly high $\boldsymbol{E_{\mathbf{vib}}}$ energy density of this period.
- **Nature of Dark Matter and Dark Energy:**

- **The Nature of Dark Matter**

In this framework, dark matter is interpreted as a single-string state of extremely low activity—its $\boldsymbol{E_{vib}}$ is extremely low (of the same order as that of the photon, or even lower), but its "Spin" mode is inert. In the Energy-Dimension framework, all observable properties of a low-dimensional projection are determined by the triple **($\boldsymbol{E_{rest}}$, $\boldsymbol{E_{vib}}$, Spin)**. Both the photon and dark matter reside in configurations with extremely low $\boldsymbol{E_{vib}}$ (hence vanishingly small or zero mass, wave-dominated), but their "Spin" modes are fundamentally different: the photon encodes the "Spin" configuration required for the electromagnetic U(1) gauge interaction—manifesting in low-dimensional projection as coupling to charged particles; whereas the inert "Spin" of dark matter encodes none of the conventional "Spin" components for electromagnetic, weak, or strong interactions—hence in low-dimensional projection it neither emits, absorbs, nor reflects electromagnetic radiation, manifesting its existence only through spacetime curvature (gravity).

This interpretation is consistent in spirit with the Inert Doublet Model (IDM) in particle physics—which proposes a dark matter candidate particle that participates only in gravitational interactions under the protection of a certain symmetry. The present framework provides a more fundamental ontological explanation for this "inertness": inertness is not an externally imposed symmetry assumption, but a natural consequence of a "Spin" configuration that carries none of the "Spin" components corresponding to specific gauge

interactions in low-dimensional projection.

Dark matter is likewise subject to capture by the gravitational field of black holes. In the Energy-Dimension framework, the universality of gravity arises from its being a collective emergent effect of all **(E_{rest}, E_{vib}, Spin)** Dynamic Equilibrium Optimal Solutions—regardless of the specific "Spin" configuration, any entity possessing energy necessarily and intrinsically curves spacetime. Hence, dark matter strings can equally be captured by the extreme gravity of a black hole and, through the dimensional phase transition mechanism described in Section 3.3, have their low-dimensional projections converted into high-dimensional silent energy. This prediction is qualitatively consistent with existing studies indicating that dark matter halos exert measurable effects on black hole accretion processes and observational images.

- **Dark Energy** directly corresponds to the uniform projection of the **high-dimensional background silent energy (E_{rest})** into low-dimensional space via the white hole mechanism. Its negative pressure characteristic is a natural property of the E_{rest}-dominated state (as discussed in Section 3.3.2.4).

- **Formation of Cosmic Structure:** The initial quantum fluctuations can be understood within this framework as the low-dimensional manifestation of the intrinsic randomness of **high-dimensional string dynamics** under **"Time-Dilated Sampling"**. These fluctuations were subsequently amplified by gravity, with their seeds originating from the fundamental dynamics of the high-dimensional world.

4.8 Suggestion of Universality Across Scales

The Microdynamic Principles proposed by this framework bear a profound analogy in spirit to the concepts describing physical phases and phase transitions in condensed matter physics. For instance:

- The **Principle of Structure** is analogous to physical phases like crystalline solids or superfluids, all of which are macroscopic stable states composed of numerous microscopic entities.
- The **Principles of Decay and Fusion** correspond to the **"melting/decomposition"** and **"crystallization/synthesis"** of physical phases, respectively.
- The "entanglement binding vs. disentanglement perturbation" in the **Principle of Stability** is precisely a microscopic counterpart of the universal principle governing phase stability: **the competition between binding energy and temperature**.

This suggests that the laws governing the formation and transformation of entities—from elementary particles to atomic nuclei, and further to macroscopic matter—may be unified under the core dynamical paradigm of **"entanglement and disentanglement of entities".**

5 Testable Predictions and Falsification Conditions

A scientific theory requires not only internal consistency and explanatory power but, more importantly, it must make unique predictions that are, in principle, falsifiable through observation or experiment. Although the mathematical structure of this framework is yet to be fully developed, it naturally leads to several inferences that can,

in principle, be tested by future experiments or observations. The confirmation of any of the following predictions would provide strong support for this framework; their falsification would necessitate its revision or abandonment.

5.1 Signatures of Effective Dimensions at High Energy Scales

- **Prediction:** In extremely high-energy particle collisions far beyond the capabilities of current colliders, physical observables (such as scattering cross-sections) will systematically deviate from calculations based on a fixed four-dimensional spacetime.
- **Falsification Condition:** Under these extreme conditions, all observational results perfectly match the predictions of fixed four-dimensional spacetime theories with extremely high precision, showing no signs of any systematic deviations.

5.2 Unique Characteristics of Black Hole Hawking Radiation

- **Prediction:** Based on the **"Projection Restoration" model** (see Section 3.3.2.3), this framework makes two unique predictions:
  - **Particle Spectrum Bias:** The particle composition of steady-state Hawking radiation is **not a universal full particle spectrum** but is **strongly biased towards light particles** that are structurally stable, with high $\boldsymbol{E_{\mathbf{rest}}}$ and low $\boldsymbol{E_{\mathbf{vib}}}$ (e.g., photons, neutrinos). The contribution from heavy particles (e.g., top quarks, W/Z bosons) is negligible.
  - **Non-Thermal Spectral Correction:** The Hawking radiation energy spectrum may exhibit small but calculable deviations from a pure thermal spectrum. These deviations are weakly correlated with the specific **($\boldsymbol{E_{\mathbf{rest}}}$, $\boldsymbol{E_{\mathbf{vib}}}$, Spin)**

dynamic equilibrium state of the infalling matter.

- **Falsification Condition:** Future observations of primordial black hole evaporation show that Hawking radiation possesses a universal full particle spectrum, and its energy spectrum perfectly matches an ideal thermal spectrum within error margins.

5.3 Potential Traces of Determinism Underlying Quantum Probability

- **Prediction:** This framework interprets quantum probability as a low-dimensional **"Time-Dilated Sampling"** effect of high-dimensional deterministic dynamics. This implies that, in principle, analysis of exceedingly fine-grained quantum measurement sequences, surpassing current technological limits, **might reveal extremely weak non-random correlations or patterns originating from the dynamics of high-dimensional "multi-string alliances",** thus deviating from the purely probabilistic interpretation of quantum mechanics.
- **Falsification Condition:** If all future, increasingly precise quantum foundation experiments without exception, and with ever-increasing accuracy, support the purely probabilistic interpretation of quantum mechanics, and no traces of deterministic dynamics can be found in any measurement sequence, then this interpretation is falsified.

5.4 Dynamical Behavior of the Cosmological Constant (Dark Energy)

- **Prediction:** In this framework, dark energy directly corresponds to the macroscopic injection of **high-dimensional background silent energy (E_{rest})**

(see Section 3.3.2.4). Therefore, the cosmological constant $\boldsymbol{\Lambda}$ is **not a true constant** but is related to the overall energy-form distribution of the universe, potentially exhibiting slow **dynamic evolution** during the very early universe or in the far future.

- **Existing Observational Evidence**

  Since the initial conception of this framework, the latest cosmological observations have provided striking support for this prediction. The DESI (Dark Energy Spectroscopic Instrument) Collaboration, based on its Data Release 2 baryon acoustic oscillation data, combined with multiple independent supernova samples (Pantheon+, Union3, DESY5) and cosmic microwave background priors, has performed a non-parametric Bayesian reconstruction of the dark energy equation of state $\boldsymbol{w(z)}$ [27]. Its core finding is that $\boldsymbol{w(z)}$ exhibits non-trivial evolution with redshift—with $\boldsymbol{w > -1}$ in the low-redshift interval ($\boldsymbol{z \lesssim 0.2}$) and $\boldsymbol{w < -1}$ in the intermediate-redshift interval ($\boldsymbol{z \approx 0.75}$)—departing from a cosmological constant ($\boldsymbol{w \equiv -1}$) at a significance of approximately $\boldsymbol{3\sigma}$, with Bayesian evidence characterized as "moderate." Importantly, this departure pattern remains consistent across multiple independent datasets and methodological frameworks, and known systematics are difficult to fully account for.

  Although the present framework has not yet reached a maturity sufficient to yield a precise prediction for the specific functional form of $\boldsymbol{w(z)}$, this observational result is qualitatively consistent with the framework's core corollary—that the cosmological constant should be a dynamic quantity that changes extremely slowly

over time. Future DESI data releases (DR3 and beyond), the Euclid satellite, and next-generation CMB experiments will subject this prediction to more stringent tests.

- **Falsification Condition:** If future observations, with continually improving precision, confirm that the cosmological constant remains strictly constant throughout any cosmological epoch, then this dynamical interpretation is falsified.

5.5 Reconciling the Accelerated Expansion of the Universe: The Dark Energy Perspective Under the "Low-Activity Phase Transition"

Within the unified "Cosmic Energy Breath" model of this framework (see Section 3.3), the dark energy driving the accelerated expansion of the universe receives an intrinsic and unified microscopic interpretation: **It is the repulsive gravitational effect manifested by the low-dimensional projection of strings whose vibrational energy E_{vib} approaches zero, being nearly static.**

5.5.1 Core Mechanism: Phase Transition of the Gravitational Sign

According to the gravitational mechanism elucidated in Section 2.4, gravity is an inherent property of the **(E_{rest}, E_{vib}, Spin)** dynamic equilibrium, whose sign and strength are determined by the output of the function $F(r, \text{Spin})$. This framework proposes a key corollary: **The value of this function F transitions from positive to negative when r falls below a certain critical value r_{critical} (correspondingly, when E_{vib} falls below the critical threshold θ_{critical}).**

- **High-Activity Phase (r is above the lowest threshold of this dimension, $f(r)$ lies within the threshold interval of this dimension, and correspondingly E_{vib} is above the critical value): $F > 0$. The dynamic equilibrium state exhibits positive gravity (attraction)**. All known elementary particles (e.g., quarks, electrons) reside in this phase, constituting the material components that produce attractive effects in the universe.
- **Low-Activity Phase (r falls below the lowest threshold of this dimension, $f(r)$ exceeds the upper bound Θ_{3+1}^{+} of this dimension's threshold, and correspondingly $E_{\text{vib}} \to 0$): $F < 0$. The dynamic equilibrium state exhibits negative gravity (repulsion)**.

Therefore, dark energy is directly defined as the collection of strings in the universe that are in the "low-activity phase". Its repulsive effect does not stem from some mysterious negative pressure but is the inevitable gravitational manifestation of its micro quasi-static state ($E_{\text{vib}} \to 0$).

5.5.2 Unified Dynamical Picture: From Cosmic Evolution to "Energy Breath"

The aforementioned core mechanism links the macroscopic fate of the universe with its microscopic dynamics and the system's energy cycle.

- Cosmic Evolution Perspective: Cooling-Induced Gravitational Phase Transition
  - **Early Hot Universe:** The temperature was extremely high, and the

average $\boldsymbol{r}$ of strings was high (correspondingly the average $\boldsymbol{E_{vib}}$ was high). The universe as a whole was in the "high-activity phase," with gravity manifesting as net attraction, leading to decelerating expansion.

- **Critical Phase Transition:** As the universe expanded and cooled, its average $\boldsymbol{r}$ continuously decreased (correspondingly the average $\boldsymbol{E_{vib}}$ continuously decreased). Upon crossing the critical threshold $\boldsymbol{\theta_{critical}}$, strings in the "low-activity phase" began to appear and accumulate in the universe, and the net gravity subsequently transitioned from attraction to repulsion.
- **Accelerated Expansion:** As the universe cooled further, the proportion of the low-activity phase continuously increased, and the repulsive effect persistently strengthened, macroscopically manifesting as the accelerated expansion of the universe.

- **"Energy Breath" Perspective: Injection during the Net Exhalation Phase**

  In the current "net exhalation" phase, the primary form of energy injected from higher dimensions through white holes is precisely quasi-static strings with $\boldsymbol{r \approx 0}$ (i.e., dark energy with high $\boldsymbol{E_{rest}}$). This process is not coincidental; it synergizes with the overall cooling of the universe, **continuously accelerating the transition of the universe towards the low-activity phase**, serving as a key external driver for the current accelerated expansion.

5.5.3 Theoretical Implications and Testable Predictions

This interpretation carries important theoretical implications and unique predictions that can be tested by future observations:

- **Dynamic "Cosmological Constant":** In this framework, the energy density driving accelerated expansion is not absolutely constant. It is related to the density of strings in the low-activity phase in the universe, which evolves slowly as the universe cools and white holes inject energy. **Therefore, this framework explicitly predicts that the cosmological constant Λ is a dynamic quantity that changes extremely slowly over time.**
-
- **Ultimate Fate of the Universe:** This picture naturally points to the "heat death" or "Sea of Silence" as the ultimate fate of the universe—a ground state where all strings reach $\boldsymbol{E_{\mathrm{vib}} = 0}$, and the universe becomes a spacetime dominated by static sources of repulsive gravity.

5.5.4 Interpretation of Superluminal Cosmic Expansion

This framework provides a natural and profound imagery for the observational fact of "superluminal cosmic expansion." According to General Relativity, the expansion of the universe is the stretching of the spacetime fabric itself. Its velocity can exceed the speed of light without violating physical laws because this is not the motion of matter through space, but the creation and extension of space itself.

Within this picture, the pervasive "low-activity phase" dark energy (strings with $\boldsymbol{E_{vib} \rightarrow 0}$), through the function $\boldsymbol{F(r, Spin)}$, continuously generates repulsive negative gravity. The most fundamental manifestation of this effect is precisely **driving the stretching of the spacetime structure itself**.

Therefore, "superluminal expansion" is the most intuitive and grandest evidence for dark energy acting as the intrinsic stretching force of spacetime. It indicates that the total rate at which the accumulated space "segment" between two distant galaxies is stretched by dark energy exceeds the speed of light. This is not a local singularity but the inevitable manifestation, on a cosmic scale, of the global geometric effect of the "low-activity phase" dark energy.

Unified Falsification Condition: The cosmological interpretation of this framework will be falsified if future observations confirm that the dark energy equation of state parameter $\mathbf{w}$ is strictly equal to -1 and eternal, or if its properties cannot be described by the "low-activity string projection" model.

5.6 Deviation of Gravitational Behavior due to Spacetime Geometric Phase Transition

- **Theoretical Prediction:** This framework asserts that in the strong-field region approaching a black hole event horizon, the failure of General Relativity does not stem from quantum effects of gravity, but is a precursor to a **"dimensional projection phase transition" of spacetime itself**. This phase transition, driven by the drastic change in $\boldsymbol{f(r)}$, would cause the spacetime geometry to exhibit unique

observational characteristics differing from the Kerr solution of General Relativity:

- **"Quantum Hair" on the Event Horizon:** Since Hawking radiation originates from "Projection Restoration," information of the infalling matter might leave faint imprints on the event horizon (analogous to "quantum hair"). This could lead to deviations from the predictions of a pure Kerr black hole in the **specific details** of the black hole shadow (e.g., brightness distribution at the edge, polarization properties).
- **"Phase Transition Layer" at the Accretion Disk's Inner Edge:** Inside the innermost stable circular orbit of the accretion disk, matter does not simply fall into the horizon but enters a region of intense **"Dimensional Tide Force"** and **energy form transformation ($\boldsymbol{E_{\text{vib}} \rightarrow E_{\text{rest}}}$)**. This may cause that region to produce unique, non-thermal spectral components or timing variability in its radiation.
- **"Memory Effect" in Merger Gravitational Waves:** During the merger of binary black holes, the violent reconstruction of spacetime might imprint the post-merger gravitational-wave signals with faint but calculable deviations from General Relativity's predictions—a "memory" feature produced by the **dimensional dynamics**.

- **Falsification Condition:** If all future observations of black hole strong-field regions (including, but not limited to, the fine structure of black hole shadows, radiation from the innermost accretion disk region, and the final gravitational-wave signals from binary black hole mergers), with continually improving precision,

consistently and completely align in all details with the predictions of classical General Relativity (the Kerr solution), and find no signs supporting a "dimensional phase transition" or deviations from the pure vacuum solution, then the core assertion of this framework—**that the failure of General Relativity is caused by a dimensional geometric phase transition**—will be falsified. [28]

6 Challenges, Prospects, and Research Roadmap

It must be admitted that this framework is currently primarily a depiction of physical imagery, with a very weak mathematical foundation. However, it has successfully constructed a unified conceptual system, anchoring phenomena from particle physics, gravity, and cosmology onto core principles such as **"Energy-Dimension" dynamics** and **"multi-string entanglement"**. Its final establishment relies on overcoming the following core challenges of mathematization and theoretical development, which also represent the most fruitful directions for future research.

6.1 Core Challenges

- **Mathematization of "Dimensional Dynamics":** How can the specific form of the **"dimension contraction function"** $\boldsymbol{f(r)}$ be derived from first principles? This may require introducing entirely new mathematical structures to describe the state of spacetime dimensions themselves and coupling them with the **Energy Dichotomy Postulate ($\boldsymbol{E_{\text{total}} = E_{\text{rest}} + E_{\text{vib}}}$)**.
- **The Necessity of a Geometric Foundation**

  The history of physics reveals a profound pattern: each major theoretical leap has been accompanied by a corresponding upgrade of its geometric foundation.

Newtonian mechanics describes absolute spacetime using Euclidean geometry; General Relativity describes the coupling between matter and spacetime curvature using Riemannian geometry. If the "Energy-Dimension" framework is correct, then effective spacetime dimension itself has become a dynamical variable driven by the energy state, and this necessarily demands an entirely new geometric language—a geometric model capable of simultaneously encoding the spacetime metric, matter fields, and **effective dimension itself as an intrinsic degree of freedom**. In such a model, the dimension contraction function $\boldsymbol{f(r)}$ will no longer be an externally imposed scalar function, but a naturally emergent property of the geometric structure itself.

This framework conjectures that this new geometry will exhibit the following limiting behavior:

- When $\boldsymbol{f(r)}$ falls within the threshold interval of (3+1)-dimensional spacetime, $\boldsymbol{\Theta_{3+1}^{-} < f(r) < \Theta_{3+1}^{+}}$, the effective projection of the unified field equations, after the freezing of the extra dimensions, is a four-dimensional theory. This four-dimensional effective theory, in the weak-field and low-velocity limit, should **uniquely and necessarily reduce to the Einstein field equations**. Equivalently, the Einstein field equations are the inevitable low-energy limit of the unified field equations when the two conditions— $\boldsymbol{f(r)}$ lying within the four-dimensional threshold interval, and the weak-field low-velocity regime—are simultaneously satisfied.
- Further, in the weak-field and low-velocity limit, Riemannian geometry

reduces to Euclidean geometry, and General Relativity reduces to Newtonian gravitation.

n brief: **Euclidean geometry is the unique limiting solution of Riemannian geometry, and Riemannian geometry is the unique limiting solution of the new geometry required by this framework; Newtonian gravitation is the unique limiting solution of General Relativity, and General Relativity is the unique limiting solution of the physical equations of the "Energy-Dimension" framework.** This nested structure is not merely a requirement of self-consistency, but an intrinsic criterion for judging the correctness of the framework: any theory claiming to subsume General Relativity must, in the appropriate limit, uniquely return to the Einstein field equations; and the present framework goes one step further—it requires that, in the limit of frozen dimensions, geometry itself must uniquely return to Riemannian geometry.

Seeking and rigorously constructing this novel geometry is the ultimate goal of the mathematization of the "Energy-Dimension" framework, and its most profound mathematical challenge.

- **Classification and Activation of "Spin" Modes:** How can the energy thresholds $\{\boldsymbol{\theta_i}\}$ that determine the stability of "Spin" modes be derived from first principles? Building on this, how can all possible stable "Spin" modes be strictly classified and derived, thereby providing the mathematical foundation for reproducing the gauge groups of the Standard Model (U(1), SU(2), SU(3))?
- **Formulation of "Multi-String Entangled States":** How can the composite

Dynamic Equilibrium Optimal Solutions formed by **multi-string synergistic resonance** be precisely described? This requires developing new mathematical tools to characterize the stability, normal modes, and quantitative relationship with particle properties (mass, generation, charge) of these entangled states.

- **Strict Mapping of "Projection" and "Sampling":** How can core concepts such as **"Time-Dilated Sampling"** and **"Dimensional Projection Phase Transition"** be transformed into precise mathematical formulations to rigorously describe the conversion from high-dimensional determinism to low-dimensional probability?
- **Formal correspondence with the classical-quantum exact mapping:** Lohmiller & Slotine have demonstrated that a quantum wave function can be decomposed into a superposition of a finite number of "classical action branches" $\boldsymbol{\phi_j}$ and their "classical density weights" $\boldsymbol{\rho_j}$. The present framework conjectures that each action branch in this construction corresponds to a discrete "Dynamic Equilibrium Optimal Solution" attained by a high-dimensional string under specific **($\boldsymbol{E_{\text{rest}}}$, $\boldsymbol{E_{\text{vib}}}$, Spin)** parameters. To make this correspondence rigorous—i.e., to derive the multi-branch summation structure $\boldsymbol{\psi = \sum_j \sqrt{\rho_j} e^{i\phi_j/\hbar}}$ from the postulates of the Energy-Dimension framework—would constitute an important first step in the mathematization of the framework.

6.2 Reproduction and Deepening of Fundamental Physics

- **Emergence of Gauge Interactions:** The primary future task is to start from the first principles of the **($\boldsymbol{E_{\text{rest}}}$, $\boldsymbol{E_{\text{vib}}}$, Spin) dynamic equilibrium dynamics** and rigorously derive why the U(1), SU(2), and SU(3) gauge symmetries and their

corresponding Lagrangians necessarily emerge as the low-energy effective theory.

- **First-Principles Calculation of the Particle Mass Spectrum:** The framework qualitatively links mass to **the energy allocation relationship characterized by $\boldsymbol{r}(=\boldsymbol{E}_{\mathbf{vib}}\,/\,\boldsymbol{E}_{\mathbf{rest}})$ and the number of entangled strings**. The crucial next step is to establish specific, computable dynamical models to quantitatively derive the lepton and quark mass spectra from the stability conditions of the dynamic equilibrium optimal solutions within the parameter space.
- **Microscopic Origin of Gravity and Spacetime:** How can the image that **"every particle is a source of microscopic spacetime curvature"** be mathematized, thereby naturally deriving the Einstein field equations and their modifications near singularities from the $\boldsymbol{F}(\boldsymbol{r},\mathbf{Spin})$ function?

6.3 Future Challenges and Invitation for Collaboration

We preliminarily outline several key paths for future research:

- **Mathematical Physics Path:** Construct specific $\boldsymbol{f}(\boldsymbol{r})$ in simplified models (e.g., 5-dimensional spacetime); explore the use of modern mathematical tools such as category theory, derived geometry, or non-commutative geometry to describe dimensional phase transitions and multi-string entanglement; seek a new unified action principle.
- **Phenomenology and Testable Predictions Path:**
  - **High-Energy Physics:** Refine predictions for signatures of effective dimensions at extremely high energy scales and the bias in the Hawking radiation particle spectrum.

- **Cosmology:** Explore the unique predictions of this framework for cosmic inflation, the nature of dark matter, and the dynamic evolution of the cosmological constant.
- **Quantum Foundations:** Further develop the **"low-dimensional sampling" model**, exploring its potential traces in finer quantum structures such as Bell non-locality.

6.4 The "n-Factor" Conjecture: Towards a Deeper Unification of Particle Physics and Spacetime Geometry

As a parallel and more ambitious theoretical extension, we solemnly propose a profound conjecture here, which may become a key step towards a unified understanding of particle physics and spacetime geometry.

- **Core Content of the Conjecture:**

  We conjecture that there exists an intrinsic factor **n** (with a value in the interval **(0,1]**) associated with particle families, such that the energy composition of a single (or a single composite particle as a whole) satisfies:

$$\boldsymbol{E_{\text{total}} = E_{\text{rest}} + n \cdot E_{\text{vib}}}$$

  In this picture:

  - **n can be understood as the string's "intrinsic coupling strength",** determining the "effective weight" of vibrational energy $\boldsymbol{E_{\text{vib}}}$ in the total energy accounting and dynamical processes.
  - A Dynamic Equilibrium Optimal Solution will be defined by an extended quadruple **($\boldsymbol{E_{\text{rest}}}$, $\boldsymbol{E_{\text{vib}}}$, n, Spin)**.

- **The n factor naturally explains energy release:** During the transformation from a high-$\boldsymbol{E_{vib}}$ state to a low-$\boldsymbol{E_{vib}}$ state, when $\boldsymbol{n < 1}$, even within a framework of strict $\boldsymbol{E_{total}}$ conservation, the decrease in $\boldsymbol{E_{vib}}$ ($\boldsymbol{\Delta E_{vib}}$) will be greater than the increase in $\boldsymbol{E_{rest}}$ ($\boldsymbol{n \cdot \Delta E_{vib}}$). The difference $\boldsymbol{(1-n) \cdot \Delta E_{vib}}$ is thereby naturally released as net energy.

- Motivation and Profound Significance of the Conjecture:
  - **Beyond Description, Towards Explanation:** Models based on $\boldsymbol{E_{total} = E_{rest} + E_{vib}}$ are sufficient to self-consistently **describe** observed phenomena. Introducing the n factor aims to explain a deeper problem: **Why do different particle families (e.g., leptons and quarks) exhibit fundamental differences in their energy form allocation?** This difference may originate from variations in their intrinsic "string structure" and how they couple to the spacetime background.
  - **Connecting Particle Attributes and Spacetime:** The **n** factor may serve as a hidden bridge, connecting on one end the intrinsic properties of particles (e.g., generation, flavor) and on the other end how they curve spacetime (i.e., their gravitational behavior). A particle's "gravitational charge" might be related not only to **($\boldsymbol{E_{vib}}$, Spin)** but also to this intrinsic **n** value.
  - **Addressing Fine-Structure Problems:** The n factor may provide a new, tunable degree of freedom and dynamical mechanism for understanding the extremely fine structures in the particle mass spectrum (e.g., intra-generation mass differences, mixing angles).

- **Future Exploratory Directions:**
  - **Theoretical Construction:** Explore the dynamical origin of the **n** factor. Is it related to the topological properties of the string? Or is it the result of some symmetry breaking in higher-dimensional space?
  - **Phenomenological Correlation:** Attempt to preliminarily correlate different **n** values with particle families in the Standard Model (e.g., the three lepton generations, the three quark generations) and calculate the observable effects on decay processes, binding energies, etc.
  - **Mathematical Formulation:** Integrate the **n** factor into the mathematical structures developed in the future, for instance, by considering its potential coupling with the "dimension contraction function" $\boldsymbol{f(r)}$.

Currently, the **n-factor conjecture** provides us with a fascinating window for future exploration into the deep origins of particle masses and interactions. We explicitly propose it here, hoping to attract the attention of more mathematicians and theoretical physicists to jointly explore this key that might open the door to new physics.

We explicitly state that addressing the challenges above is far beyond the capability of any single individual. The purpose of this paper is precisely to spark discussion, to clearly outline the contours of this research program. We sincerely invite mathematicians and theoretical physicists to offer criticism and to join hands in collaboration, working together to transform this unified physical blueprint into a solid mathematical theory.

7 Conclusion

This review has constructed and elaborated the **"Energy-Dimension" framework**. By combining the **Energy Dichotomy Postulate**, the dynamics of **'Spin' modes**, and the **multi-string entanglement principle**, all unified under the core concept of **Dynamic Equilibrium Optimal Solutions**, we have successfully anchored the origins of matter, spacetime, and all fundamental interactions onto a set of concise yet profound physical images.

The power of this framework lies in its **mechanistic explanatory power**: it not only describes phenomena but also provides the "physical reason" behind them.

- It interprets the gauge symmetries and particle spectrum of the Standard Model as the emergence of **Dynamic Equilibrium Optimal Solutions**.
- It anchors the randomness of quantum probability to the **"Time-Dilated Sampling"** of high-dimensional determinism.
- It provides an image for the **microscopic quantum origin of gravity** by interpreting each elementary particle as a **source of microscopic spacetime curvature**.
- It unifies black holes and white holes as two parts of the **"Cosmic Energy Breath"**, reshapes black hole thermodynamics as **"Projection Restoration"** driven by dimensional projection phase transition, and directly links dark energy to the macroscopic injection of **high-dimensional background silent energy** $\boldsymbol{E_{\mathrm{rest}}}$.
- Crucially, by constructing a physical picture of a **high-dimensional holistic network**, it provides a unified interpretation of wave-particle duality and the

quantum measurement problem (such as delayed-choice and quantum eraser experiments) as a **boundary condition-induced switching of dynamic equilibrium states**, offering a novel and mechanistic perspective on the role of the observer in physical reality.

However, the most profound significance of this work may lie in its core system of principles itself. **Although the discussion in this paper is fully embedded within the framework of string theory, the central ideas—"energy-dimension" dynamics, dynamic equilibrium optimal solutions, and "time-dilated sampling"—constitute a relatively independent and highly inspiring conceptual framework**. The string serves here as a powerful **proof-of-concept platform**, vividly demonstrating the unifying power of these principles.

Ultimately, we depict a unified cosmic picture: all **fundamental entities** move according to deterministic rules in the highest-dimensional spacetime ($\boldsymbol{M_{\mathbf{high}}}$). Their energy form ($\boldsymbol{E_{\mathbf{rest}}}$, $\boldsymbol{E_{\mathbf{vib}}}$) drives the **manifestation and concealment of dimensions** through the function $\boldsymbol{f(r)}$, while their **intrinsic 'Spin' and synergistic resonance** collectively weave the entire diversity of the particle world. In this picture, **gravity, matter, and spacetime are no longer independent entities but different projections of the same high-dimensional reality through "Energy-Dimension-Spin" dynamics into our universe.**

However, we clearly recognize that the true vitality of this blueprint depends on building a **solid mathematical skeleton** for it. Every **core challenge** outlined in this paper—from the mathematization of **"dimensional dynamics"** to the exploration of

the **"n-factor"** conjecture—represents a potential gateway to new knowledge. Once this mathematical skeleton is established, a natural theoretical question arises: can the system of principles proposed in this paper be carried by other models of fundamental entities—such as the spin networks of Loop Quantum Gravity? This would not only serve as a long-term test of the framework's potential as a universal operating logic, but could also provide a conceptual bridge between different approaches to quantum gravity. This, however, belongs to the long-term agenda after the framework has matured; the primary task at present remains its mathematization within the context of string theory. We firmly believe that the elegance and depth brought forth by the process of excavating the new mathematics hidden here will be no less than that of the physics it describes. We hereby sincerely issue an invitation for collaboration, looking forward to working alongside mathematicians and theoretical physicists to transform this unified physical blueprint into the solid theory of a new scientific age.

Statements and Declarations

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Statement on the Use of Generative AI

During the preparation of this work, the author used DeepSeek, a large language model, for assistance. The AI was utilized for tasks including text drafting, logical structuring, English translation, and retrieval and verification of certain established theoretical knowledge, all based on core physical concepts (such as the Energy Dichotomy Postulate, Dimensional Projection, etc.) proposed by the author. All AI-generated

content and suggestions were rigorously reviewed, corrected, and integrated by the author, who takes full responsibility for the logical coherence, physical correctness, and academic integrity of the entire work.

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