

RESEARCH ARTICLE

Field Interaction Theory ‘Qd12 Infinite Eternal Matrix Energy Field’ Fit-Qd12 Canonical Series I: The Qd₁₂ Matrix – a Mathematically Closed, Information-Preserving Operator-Geometric Framework

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Abstract

Mathematical Closure of the Qd₁₂ Operator Framework

Field Interaction Theory Qd₁₂(FIT-Qd₁₂) is formulated as an operator–geometric framework based on a twelve-dimensional spectral system defined by a Dirac-type operator on a compact manifold with boundary. In this work, we present a framework supporting mathematical closure under standard analytic assumptions by demonstrating that the construction admits a spectral-triple-type realization compatible with the formalism of noncommutative geometry. In particular, the associated operator admits a boundary-compatible self-adjoint extension under an appropriate domain specification consistent with Atiyah–Patodi–Singer boundary conditions, possesses compact-resolvent structure on a compact manifold with suitable boundary conditions, and admits a finite spectral action with a well-defined heat-kernel expansion under standard ellipticity and boundary regularity assumptions. These properties support spectral finiteness, stability of the operator formulation, and a unitary evolution structure under the induced operator dynamics within the stated admissible domain.

Within this operator-theoretic setting, the framework admits a structured extension in which adjacent operator regions are connected through layered interface components, including an intermediate negative-energy (NE) sector, a boundary encoding structure, and a regulating interface governing spectral compression. These components provide a consistent setting in which localized finite instabilities, interpreted as dimensional collapse, may be modeled without invoking geometric singularities. Collapse is treated as a bounded spectral reorganization associated with admissibility conditions on the coupled operator system.

The closure results established here are independent of specific physical interpretations. Applications involving dark-sector phenomenology, cosmological evolution, neutrino propagation, gravitational-wave signatures, and effective gravitational behavior are not required for mathematical consistency and are developed in the broader FIT-Qd₁₂ program. In the present work, such topics are referenced only as possible effective descriptions and observational test channels supported by the operator framework.

The phenomenological interpretations discussed in later sections should be understood as sector-level consequences and test domains, not as independent assumptions required for mathematical closure. In particular, dark-sector behavior is treated as an effective projection of operator geometry: dark-matter-like behavior is framed primarily as non-projecting or weakly projecting spectral curvature, while dark-energy-like behavior is interpreted as Qd₁₂substrate pressure expressed through APS-compatible ledger dynamics. Neutrino, gravitational-wave, and CMB signatures are likewise presented as observational probes of the boundary, fiber, DVz, and mass-gap sectors rather than as single-outcome confirmation or falsification tests.

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The analysis also outlines how internal algebraic structure within the spectral system can support gauge symmetries, fermionic representations, and scalar-sector candidates compatible with known low-energy physics. This provides a pathway from operator geometry to phenomenological modeling, while leaving detailed parameter extraction, anomaly classification, compactification analysis, and fully interacting dynamics to subsequent work.

Taken together, these results show that the FIT-Qd₁₂ construction defines a mathematically consistent, spectrally finite, and boundary-compatible operator framework under the stated assumptions. No claim of absolute uniqueness is made in this paper. Rather, FIT-Qd₁₂ is presented as an admissible realization within a constrained class of operator–geometric theories satisfying boundedness, boundary compatibility, and information-consistency conditions.

The central claim of this work is not that a complete physical model has been established, but that admissible operator–geometric frameworks may be more tightly constrained than commonly assumed. When spectral consistency, boundary-compatible unitarity, and information preservation are imposed simultaneously, the resulting class of viable structures becomes highly restricted. FIT-Qd₁₂ is presented as one realization of this restricted class, with empirical viability determined by future quantitative modeling, numerical extraction, and cross-domain consistency tests.

Keywords: Qd₁₂ Operator Framework, Spectral Operator Theory, Self-Adjoint Operators, Spectral Action, Operator Geometry, Boundary-Compatible Evolution Information Preservation, Holographic Boundary (2DHL), Dimensional Viscosity Zone (DVz), Dimensional Collapse, Quantum Gravity, Cosmology, Dark Matter (Curvature-first Geometric Interpretation), Dark Energy (Qd₁₂ Substrate Pressure Through APS Ledger Dynamics), Neutrinos as Fiber-Sector Probes, Boundary-Imprint Cosmology, Noncommutative Geometry.

1. Introduction — Toward a Consistent Operator–Geometric Framework

The central challenges in fundamental physics arise not from a lack of predictive models, but from the absence of a clearly defined, globally consistent mathematical structure capable of placing them within a common framework of analytic and physical consistency. Quantum field theory (QFT) provides an accurate description of particle interactions, yet presupposes a fixed spacetime background and does not incorporate gravity at a fundamental level. General relativity (GR), by contrast, describes spacetime dynamically, but predicts singularities under gravitational collapse where classical description breaks down. Modern cosmology extends these frameworks through phenomenological components—including dark matter, dark energy, and inflation—that are not derived from a single underlying structure.

Taken together, these theories are individually successful but, in their standard formulations, do not constitute an information-consistent framework in which all sectors of physical behavior arise from a common mathematical foundation. The primary issue is therefore not the absence of viable models, but the absence of a structure that enforces consistency across domains. The framework considered here does not modify General Relativity within its empirically validated regime; rather, it constrains the class of

admissible operator–geometric structures from which such effective descriptions may arise.

One approach to this problem is to shift emphasis from model construction to admissibility constraints. Rather than attempting to combine existing theories directly, one may ask

What mathematical structures remain when configurations incompatible with fundamental consistency conditions are excluded?

Representative admissibility conditions include

- Compatibility with unitary evolution structures,
- Spectral boundedness and operator finiteness,
- Boundary-compatible dynamics,
- Global information consistency.

The central question is whether there exists an operator framework in which these conditions can be simultaneously realized under a common analytic structure.

The Field Interaction Theory Qd₁₂(FIT-Qd₁₂) framework proposes that physical structure may be described as arising from such a constrained operator system. In this formulation, the fundamental object is a Dirac-type operator acting on a Hilbert space, together with an associated algebra and a boundary-compatible extension defined on an appropriate operator domain.

Geometry, matter representations, and dynamical behavior are treated as structures encoded by the spectral and algebraic data of this system.

Within this framework, a Qd12field is not interpreted as a classical spacetime manifold, but as an operator-defined region embedded within a larger system of interacting regions. In the extended operator interpretation, adjacency between such regions is modeled through a structured interface consisting of:

- An intermediate negative-energy (NE) sector,
- A boundary encoding of spectral evolution, referred to as the two-dimensional holographic ledger,
- And a Dimensional Viscosity Zone (DVz) regulating spectral compression.

This layered structure provides a setting in which interactions may be constrained, instabilities localized, and consistency conditions maintained across adjacent operator regions.

Dimensional collapse is modeled as a finite, operator-bounded instability associated with admissibility conditions on localized spectral compression. Unlike classical gravitational collapse, this process is formulated without requiring geometric divergences within the stated operator framework. Instead, it corresponds to a bounded reorganization of spectral degrees of freedom into an effective lower-dimensional description. The geometry of the interface may influence the symmetry properties of this emergent regime, allowing for both approximately isotropic and anisotropic configurations.

In the resulting effective four-dimensional description, large-scale physical behavior may be interpreted as arising from geometric contributions associated with boundary, substrate, fiber, and intermediate-layer structure. In this interpretation:

- Dark matter-like behavior may be associated primarily with non-projecting or weakly projecting spectral curvature modes,
- Dark energy-like behavior may be associated with Qd12 substrate pressure expressed through APS-compatible ledger dynamics,
- Neutrino behavior may provide a phase-sensitive probe of fiber-sector and boundary-coupled structure,
- And large-scale structure may reflect underlying operator geometry.

These interpretations are not required for the mathematical framework developed here and are referenced only as possible effective descriptions.

Canonical clarification. The dark-sector interpretations introduced here should not be read as rigid exclusions of all particle-like or scalar-field-like effective descriptions. In FIT-Qd12, dark-matter-like behavior is curvature-first, not an absolute no-particle claim. Particle-like dark-sector excitations, if observed, may still be compatible with the framework if they arise as emergent, projected, semi-projecting, or residue modes of the underlying Qd12/RTF operator geometry. Similarly, dark-energy-like behavior may appear Λ -like, weakly evolving, or effectively scalar-field-like in four-dimensional phenomenology, provided the effective behavior can be traced to Qd12 substrate pressure expressed through APS-compatible ledger dynamics.

Within broader phenomenological extensions of the framework, neutrinos may serve as candidate probes of boundary-coupled and fiber-sector dynamics. Due to their weak interaction, long coherence length, and oscillation phase sensitivity, neutrinos may retain information about fiber-sector phase geometry, chirality, mass-gap structure, and boundary/ledger coupling. They are not introduced here as a separate ontological class of “information particles,” but as fiber-dominant projected modes whose observable oscillation behavior may encode information about the underlying operator geometry.

This role is not required for the analytic results established in this work.

An important structural question concerns the dimensionality of the underlying operator system. Within the admissibility framework described above, the combined requirements of spectral finiteness, boundary compatibility, information consistency, and controlled collapse dynamics place strong constraints on allowed configurations. The construction developed in this work identifies a twelve-dimensional operator structure as one consistent realization within this admissible class.

1.1 Scope and Status of Results

This work establishes, under stated analytic assumptions:

- The existence of a boundary-compatible operator framework defined on an appropriate domain,
- The existence of a self-adjoint extension compatible

- with Atiyah–Patodi–Singer boundary conditions,
- Compact-resolvent structure on a compact manifold with suitable boundary conditions,
- Finiteness of the spectral action under standard ellipticity and heat-kernel regularity assumptions,
- And a unitary evolution structure under the induced operator dynamics within the admissible domain.

This work does not establish

- Full self-adjointness of the unrestricted interacting operator algebra,
- A complete anomaly classification,
- A complete compactification classification,
- Final numerical parameter extraction,
- Or empirical validation of the physical interpretations.

These topics are treated as extensions of the FIT-Qd₁₂ program and are addressed in the broader Canonical, Completeness, Technical Validation, and Proof Series.

The observational and phenomenological channels discussed in this paper should be interpreted as structured test domains rather than single-point proof or falsification conditions. A failed or absent signature in one sector constrains the corresponding realization, parameter channel, or observational mechanism; it does not automatically falsify the full operator framework unless the failure produces global incoherence across the shared Qd₁₂ parameter structure.

1.2 Program Context and Scope

This paper presents a mathematically consistent operator framework supporting closure under stated analytic assumptions. It does so by demonstrating that the proposed construction admits a spectral-triple-type realization with controlled analytic properties, without asserting full regularity or uniqueness.

At the level of the non-interacting and boundary-compatible operator system, the paper

- Defines the underlying spectral operator and associated algebra,
- Specifies boundary-compatible operator domains,
- Models finite, non-singular collapse behavior within a coupled operator setting,
- Analyzes stability conditions for adjacent operator regions,

- And outlines how effective physical structures may arise from the spectral framework.

The emphasis throughout is on existence, consistency, and admissibility under stated assumptions, rather than on uniqueness or complete physical derivation.

The results presented here do not assume a unified theory a priori. Instead, they examine the consequences of imposing admissibility constraints on operator structure. Within this context, the Qd₁₂ construction is presented as an admissible, mathematically consistent realization of an information-preserving operator framework under the stated assumptions, with extensions to full interacting dynamics and phenomenological applications addressed in subsequent work.

Reader Guidance. Sections 2–8 establish the operator-geometric and boundary-compatible framework used throughout the paper. Sections 9–18 are interpretive extensions showing how the same structure may support effective cosmological, dark-sector, neutrino, gravitational-wave, CMB, and observational descriptions. These later sections are not required for the mathematical consistency results claimed in this work. They are included to identify how the foundational framework connects to the broader FIT-Qd₁₂ program and to future empirical tests.

The empirical logic of the broader program is not based on fitting isolated anomalies. FIT-Qd₁₂ is evaluated by whether it can recover established physics while explaining otherwise disconnected experimental residuals as correlated consequences of one admissible Qd₁₂ operator geometry. The decisive test is therefore cross-domain parameter coherence: whether gravitational, cosmological, CMB, neutrino, dark-sector, and information-preservation channels can be organized by a shared boundary, fiber, DVz, mass-gap, and projection structure.

2. The Qd₁₂ Operator–Geometric System

The Qd₁₂ operator system, also referred to as the Qd₁₂ Matrix Field, defines the foundational operator–geometric structure of the FIT-Qd₁₂ framework. It is not introduced as a spacetime manifold, nor as a quantum field defined on a background geometry. Instead, it is formulated as a spectral operator system whose internal structure is constructed to encode geometric, gauge-compatible, and matter-like degrees of freedom within a unified analytic setting.

Within this formulation, spacetime, fields, and dynamical behavior are not taken as fundamental

inputs. Rather, they are treated as effective descriptions associated with the spectral and algebraic organization of the operator system under admissibility constraints.

2.1 The Twelve-Dimensional Spectral Operator System

The Qd₁₂ operator system is defined by a spectral-triple-type structure: (A_{12}, H, D_{12}) where

- A_{12} is a *-algebra of bounded operators representing admissible configurations,
- H is a Hilbert space carrying a representation of A_{12} ,
- D_{12} is a densely defined Dirac-type operator, assumed to admit a boundary-compatible self-adjoint extension on an appropriate operator domain consistent with Atiyah–Patodi–Singer (APS) boundary conditions.

This structure is treated as a spectral-triple-type realization under standard analytic assumptions; full regularity in the sense of noncommutative geometry is not asserted in this work.

Within this framework, physically relevant quantities including curvature, gauge-compatible structure, and mass-scale information — may be encoded in the spectral properties of D_{12} , such as

- Eigenvalue distribution,
- Multiplicity structure,
- And phase organization.

Geometry and matter-like structures are therefore interpreted as effective features of spectral organization, rather than independent foundational inputs.

2.2 A Formal Status of Structures

The structures introduced in this section have distinct formal roles within the present work.

- The spectral-triple-type structure (A_{12}, H, D_{12}) , together with its assumed analytic properties, is treated as a mathematically defined object within the scope of this paper.
- The Rope–Thread–Fiber decomposition is introduced as a functional organization consistent with the operator structure, but is not presented as a uniquely derived decomposition at the level of operator domains.

- The intermediate NE sector and the Dimensional Viscosity Zone (DVz) are introduced as modeled structural components of the extended operator framework. A complete operator-theoretic classification of these components is not assumed here and remains part of the broader FIT-Qd₁₂ formalization program.

Accordingly, this section defines the core operator system and identifies structured extensions used in later interpretation, while distinguishing those extensions from the analytic results established in subsequent sections.

2.3 Dimensional Structure and Functional Decomposition

The twelve-dimensional structure of the operator system admits a functional decomposition into three interacting sectors

- *Four effective spacetime dimensions (Rope sector).*

These arise only after dimensional reduction or projection and correspond to an emergent geometric description. They are not treated as fundamental coordinates of the underlying operator system.

- *Six internal dimensions (Thread sector).*

These encode internal degrees of freedom associated with gauge-compatible structure, flavor organization, and curvature channels. In appropriate effective limits, they may support structures compatible with Standard Model-like organization.

- *Two compact fiber parameters (Fiber sector).*

These encode phase structure, modular ordering, and coherence properties. They are not interpreted as physical time coordinates. Their compact structure may contribute to chirality, spectral stability, and mass-scale organization in effective descriptions.

The resulting 4–6–2 decomposition is functional rather than purely geometric, reflecting the role of different operator components in the emergence of effective physical behavior.

2.4 Rope–Thread–Fiber (RTF) Operator Structure

The operator D_{12} admits a schematic functional decomposition of the form:

$$D_{12} = D_R + D_T + D_F$$

Corresponding to the Rope, Thread, and Fiber sectors.

- The Rope (R) component is associated with large-scale geometric behavior in the effective description.
- The Thread (T) component encodes internal structure associated with gauge-compatible interactions and matter-like degrees of freedom.
- The Fiber (F) component governs phase coherence, chirality, and spectral stability.

This decomposition is used as a functional organization of the operator and is not asserted as a unique or canonical decomposition at the level of operator domains. It provides a structured mechanism by which different physical features may arise from a unified operator system. The spectral action associated with D_{12} supports effective behavior when restricted to appropriate subspaces or projected regimes.

2.5 Global Structure of the Operator System

Individual Qd₁₂ operator regions are modeled as embedded within a larger system of interacting regions, forming a structured configuration space of admissible operator domains.

These regions are

- Defined by common admissibility constraints,
- Coupled through boundary-compatible interfaces,
- And stabilized through constrained interaction.

Localized collapse or reconfiguration processes are modeled so as not to disrupt the global structure under admissible conditions. Instead, they correspond to localized spectral reorganizations within an overall stable operator system.

2.6 Boundary Encoding and the 2D Holographic Ledger

Each Qd₁₂ operator region is associated with a boundary structure referred to as the two-dimensional holographic ledger (2DHL). Formally, this boundary is modeled through a boundary-compatible self-adjoint extension consistent with APS-type boundary conditions. The uniqueness of this boundary selection is not asserted here and is treated in the broader FIT-Qd₁₂ program.

Within the present framework, the ledger may be interpreted as

- Encoding aspects of spectral evolution,
- Constraining admissible boundary conditions,
- Supporting global information consistency,

- And providing a basis for emergent temporal ordering.

These interpretations are not required for the analytic results established in this paper but provide a bridge to phenomenological interpretation.

2.7 Intermediate NE Sector

The framework introduces an intermediate sector, referred to as the NE sector, mediating between the bulk operator region and the boundary structure.

This sector is modeled as

- Mediating coupling between bulk and boundary,
- Contributing to effective curvature in projected descriptions,
- And participating in the regulation of spectral interaction.

In later phenomenological interpretations, contributions from this sector may be associated with gravitational effects not captured by visible matter alone. This interpretation is not required for the analytic framework developed here.

2.8 Dimensional Viscosity Zone (DVz)

The framework introduces the Dimensional Viscosity Zone (DVz) as a regulated interface constraining interaction between adjacent Qd₁₂ operator regions.

The DVz is characterized by

- Suppression of uncontrolled spectral propagation,
- Localized regions of enhanced compression,
- And expansion away from these regions, limiting instability propagation.

Candidate collapse regions are modeled as being associated with local minima of DVz thickness, which act as preferred channels for spectral compression. Within this framework, the DVz

- Localizes collapse processes,
- Suppresses multi-directional instability,
- And contributes to overall system stability.

The DVz is therefore treated as a dynamically regulated interface enforcing admissibility constraints. A complete operator-theoretic characterization of this structure remains outside the scope of the present work.

2.9 Effective Curvature Structures

Within the operator framework, curvature is encoded

through spectral operators rather than classical tensor fields.

Relevant structures include

- Boundary-associated curvature contributions influencing effective large-scale behavior,
- Intermediate-layer curvature contributions associated with gravitational effects in projected regimes,
- And DVz-related operators governing stability and localization.

These contributions are modeled as arising from the spectral action of D_{12} and may contribute to macroscopic behavior after projection into an effective spacetime description.

2.10 Relation to Closure

The structures described in this section define the operator–geometric setting in which the analytic consistency results of subsequent sections are established. In particular, the assumed existence of a boundary-compatible operator domain, together with regulated inter-region interaction, provides the framework within which spectral finiteness, stability, and consistency under admissibility constraints may be analyzed.

Section 2 therefore establishes the structural foundation upon which the mathematical results of the following sections are built, without asserting closure independently of the analytic assumptions made explicit in those sections.

3. The Seven-Layer Adjacency Architecture

The Qd₁₂ operator system is not treated as an isolated construction, but as part of an extended configuration of interacting operator-defined regions. Interactions between adjacent regions are modeled within a structured, boundary-mediated architecture that constrains spectral propagation, regulates collapse behavior, and supports global consistency under admissibility conditions.

Within the framework, interaction between neighboring operator regions may be represented schematically as

$$Qd_{12}(A) | NE(A) | Ledger(A) | DVz | Ledger(B) | NE(B) | Qd_{12}(B)$$

This seven-layer structure is introduced as an admissible interface consistent with boundary-compatible operator extensions and global consistency

requirements. It is not presented as a uniquely derived decomposition at the present stage of the formalism.

3.1 The Admissible Adjacency Stack

For any pair of adjacent Qd₁₂ operator regions, the interface may be described in terms of:

- The bulk operator region of field A,
- An intermediate (NE) sector associated with A,
- A boundary encoding structure (Ledger A),
- The Dimensional Viscosity Zone (DVz),
- The corresponding boundary of field B (Ledger B),
- The NE sector associated with B,
- The bulk operator region of field B.

This layered configuration is motivated by the requirement that operator domains admit boundary-compatible self-adjoint extensions while maintaining global consistency under admissibility constraints. At the operator level, such interfaces are assumed to admit boundary-compatible self-adjoint extensions, which constrain admissible coupling between adjacent operator domains and motivate the layered structure introduced here.

Within this framework, the adjacency stack may be interpreted as

- Separating operator regions while permitting controlled interaction,
- Constraining spectral coupling through boundary mediation,
- And providing a structured interface for admissible dynamical evolution.

3.2 DVz Geometry and Collapse Localization

The Dimensional Viscosity Zone (DVz) is introduced as a dynamically structured interface regulating spectral interaction between adjacent regions.

At an effective level, the DVz may be characterized by:

- Localized regions of reduced effective separation, where spectral compression may concentrate,
- Extended regions of increased separation, where compression is suppressed.

These features may be associated with

- Boundary curvature contributions,
- Intermediate-layer (NE) coupling,
- And constraints on spectral propagation.

Within this structure, candidate collapse regions are modeled as being associated with local minima of DVz thickness, where admissibility conditions for spectral compression may be approached. The DVz is therefore interpreted as an effective representation of constraints on spectral propagation between operator domains, rather than as an independently defined geometric manifold.

3.3 Anisotropic Interface Structure

The DVz interface may exhibit anisotropic structure at the operator level. In particular:

- Certain directions of adjacency may correspond to more localized spectral compression channels,
- Others may correspond to more distributed interaction.

These variations may influence the symmetry properties of the resulting effective description after collapse. They are interpreted as features of the operator configuration, rather than as fixed geometric directions in emergent spacetime.

3.4 Suppression of Non-Admissible Collapse

Regions of the DVz where effective separation remains large may act to suppress admissible collapse transitions.

In such regions:

- Spectral compression may be insufficient to approach admissibility conditions,
- Collapse processes may be disfavored,
- Multi-region alignment may be suppressed.

This may contribute to

- Localization of collapse events,
- Suppression of multi-directional instability,
- Reduction of correlated collapse across multiple regions.

These features are modeled as arising from the structure of the operator interface rather than from externally imposed constraints.

3.5 Boundary Curvature and Dimensional Tension

Interaction between adjacent regions reflects the interplay of:

- Boundary curvature, encoded in the ledger-associated operator structure,

- Intermediate-layer dynamics associated with the NE sector,
- And constraints within the operator system that may be interpreted as dimensional tension.

Together, these contributions may influence

- Effective separation between regions,
- Geometry of the DVz interface,
- And localization of candidate collapse channels.

In effective descriptions, these interactions may contribute to large-scale geometric behavior.

3.6 Stability of the Extended Operator System

The layered adjacency architecture provides a structural setting in which stability of the extended operator system may be analyzed.

Key features include

- Localization of admissible collapse regions,
- Bounded interaction between operator domains under admissibility constraints,
- Separation maintained through boundary-compatible structure,
- Consistency of the layered interface across the system.

These features support the interpretation that local spectral reconfigurations need not generically destabilize the global structure within the stated admissible framework. A full stability proof for interacting configurations is not asserted here and remains part of the broader program.

Residual interactions may occur between effective subsystems within a given operator region, while interactions between distinct regions are modeled as remaining constrained by boundary-mediated interfaces.

3.7 Formal Status of the Adjacency Architecture

The seven-layer structure introduced here is to be understood as a structural representation consistent with the requirements of boundary-compatible operator theory, rather than as a fully derived classification.

Specifically

- The existence of boundary-compatible operator domains is assumed within the analytic framework,

- The detailed layered structure is introduced as an admissible configuration consistent with these requirements,
- And a complete operator-theoretic derivation of all interface components remains part of the ongoing formalization program.

Accordingly, this section defines a consistent structural setting for inter-region interaction without asserting uniqueness or completeness of the decomposition.

3.8 Relation to Closure

The adjacency architecture defined in this section provides a structural framework within which the analytic consistency results of subsequent sections may be established.

In particular, the assumed existence of:

- Boundary-compatible interfaces,
- Regulated spectral interaction across regions,
- And localized admissibility conditions

provides a setting in which spectral finiteness, stability, and consistency under the operator framework may be analyzed.

This structure connects the local spectral properties of the operator system to the global consistency conditions required for mathematical closure, without asserting closure independently of the analytic assumptions made explicit in subsequent sections.

4. Spectral Dynamics and the Qd₁₂ Operator Geometry

The dynamical behavior of the Qd₁₂ operator system is described in terms of the spectral properties of a Dirac-type operator, D_{12} , defined on a Hilbert space H and admitting a boundary-compatible self-adjoint extension on the stated domain. All pre-collapse structure is encoded in

- The spectrum of D_{12} ,
- Its eigenspaces and multiplicities,
- And the algebraic relations between D_{12} and associated operators.

Within this framework, dynamics are not described as fields evolving on a spacetime manifold. Instead, they arise from spectral organization, operator interaction, and boundary-compatible evolution within a closed operator system.

4.1 Spectral Operator Structure

The Qd₁₂ system is defined by a spectral-triple-type structure: (A_{12}, H, D_{12}) where:

A_{12} is a $*$ -algebra of bounded operators, H is a Hilbert space of admissible states,

D_{12} is a densely defined Dirac-type operator admitting a boundary-compatible self-adjoint extension whose spectrum encodes geometric and dynamical structure. The operator D_{12} admits a functional decomposition: $D_{12} = D_R + D_T + D_F$ corresponding to:

- Rope sector (R): contributions associated with effective large-scale geometry,
- Thread sector (T): internal structure associated with gauge-like and matter-like degrees of freedom,
- Fiber sector (F): phase structure, modular evolution, and coherence properties.

This decomposition is used as a functional organization of the operator and does not constitute a unique operator-theoretic splitting.

4.2 Spectral Mode Decomposition

At the level of functional classification, the spectrum of D_{12} may be organized into families of eigenmodes reflecting different structural contributions within the operator system.

These may be classified as

- Phase-dominant modes (A-type), associated with coherent spectral alignment and phase structure,
- Compression-dominant modes (B-type), associated with redistribution of spectral weight and coupling between bulk and intermediate structure,
- Curvature-dominant modes (E-type), associated with variations in effective geometric structure.

These mode families are not propagating waves in spacetime, but intrinsic spectral structures describing the distribution of operator energy and phase.

4.3 Operator Coupling and Boundary Interaction

Formally, interaction between spectral structure and geometric features is described using commutator relations of the form:

$$[D_{12}, K_boundary], [D_{12}, C_NE],$$

$$[D_{12}, K_DVZ],$$

where these operators are introduced as elements of an extended operator algebra. A complete specification

of their domains and algebraic relations is deferred to subsequent work.

These commutators characterize how spectral structure may influence

- Boundary evolution and encoding,
- Intermediate-layer dynamics,
- Localization of admissible regions for spectral concentration.

Thus, dynamics are mediated by operator algebra rather than external fields.

4.4 DVz-Regulated Spectral Concentration

The DVz interface is modeled as regulating spectral concentration between adjacent regions.

Spectral alignment across mode families may be associated with localized enhancement of spectral intensity when

- Phase coherence (A-type modes),
- Compression dynamics (B-type modes),
- Curvature contributions (E-type modes) are simultaneously reinforced.

Such concentration is dynamically relevant only in regions where DVz structure permits sufficient localization. In particular:

- Regions of reduced DVz separation support concentration,
- Regions of larger separation suppress it.

This defines a geometry-dependent constraint on spectral dynamics within the model, preventing uncontrolled accumulation.

4.5 Collapse as a Spectral Admissibility Condition

Dimensional collapse is formulated as a transition in spectral organization. Collapse is associated with the approach to an admissibility regime in which

- Spectral concentration approaches a regime where stability conditions are no longer satisfied,
- Boundary-compatible conditions become dynamically dominant,
- Reorganization into an effective lower-dimensional description is modeled as occurring.

This transition is

- Bounded at the operator level,
- Non-singular within the operator framework,

- Localized to admissible regions determined by interface structure.

Earlier formulations based on explicit norm inequalities are replaced by a structural admissibility condition consistent with the closure framework.

4.6 Symmetry and Collapse Regimes

The symmetry properties of the post-collapse effective structure are associated with the distribution of spectral alignment prior to collapse.

- Distributed spectral alignment is associated with approximately symmetric effective configurations.
- Localized or anisotropic alignment is associated with direction-dependent structure.

These regimes arise from internal spectral organization rather than externally imposed geometry.

4.7 Summary of Spectral Dynamics

The spectral dynamics of the Qd₁₂ system may be summarized as follows

- The operator D₁₂ encodes dynamical structure within the operator framework.
- Spectral mode families describe the organization of phase, compression, and curvature contributions.
- Commutator relations characterize coupling between spectral structure and boundary/intermediate layers.
- The DVz interface regulates localization of spectral concentration.
- Dimensional collapse is modeled as a bounded, non-singular reorganization under admissibility constraints.

This formulation provides a consistent operator-theoretic description of pre-collapse dynamics and establishes the mechanism by which effective physical structure may arise from spectral organization.

5. Spectral Collapse as an Admissibility Transition

Within the FIT-Qd₁₂ framework, the emergence of an effective spacetime configuration is described as a transition in the spectral organization of the underlying operator system. This process, referred to as dimensional collapse, is modeled without requiring a geometric singularity or stochastic fluctuation. Instead, it is formulated as a reorganization of spectral structure associated with a regime in which

admissibility conditions can no longer be maintained within the pre-collapse representation.

The purpose of this section is to characterize this transition in operator-theoretic terms and to describe the coupled mechanisms that govern it within the stated framework.

5.1 Collapse as a Stability Boundary in Operator Space

The Qd₁₂ system is defined by the spectral-triple-type structure (A₁₂, H, D₁₂). Perturbations to the spectral configuration, arising from internal operator interaction and boundary coupling, modify the effective structure of D₁₂.

Rather than defining collapse through a fixed inequality, it is more precise to interpret it as the approach to a stability boundary in operator space, determined by the simultaneous requirements of

- Spectral boundedness,
- Boundary-compatible self-adjoint extension,
- And global information consistency.

Dimensional collapse is modeled as occurring when a local spectral configuration approaches a regime in which these conditions can no longer be simultaneously maintained within the original representation. At this point, the system is represented as transitioning to a new admissible configuration.

5.2 Boundary Instability and Domain Stability

The boundary structure, referred to as the two-dimensional holographic ledger, is mathematically associated with a boundary-compatible self-adjoint extension of the operator D₁₂.

As spectral concentration increases locally

- Boundary-associated curvature operators may grow in magnitude,
- The compatibility conditions required for an APS-type extension may become increasingly constrained,
- And the stability of the pre-collapse operator domain may be reduced.

This behavior is not a physical deformation of a classical boundary, but an operator-level effect involving the stability of the admissible domain of D₁₂ under boundary constraints. Collapse is therefore associated with the loss of stability of the pre-collapse operator domain under increasing spectral concentration, rather than with a geometric divergence.

5.3 Intermediate-Layer Coupling Dynamics

The intermediate NE layer mediates coupling between the bulk spectral structure and the boundary.

Under increasing spectral concentration

- Coupling between bulk modes and boundary operators may intensify,
- Intermediate-layer operators may exhibit enhanced curvature-like contributions,
- And spectral weight may be redistributed toward the boundary interface.

This process contributes to the approach to the stability boundary but does not independently determine collapse. It forms part of a coupled operator system involving spectral modes, boundary conditions, and interface geometry.

5.4 DVz-Regulated Localization of Collapse

The Dimensional Viscosity Zone (DVz) is modeled as a regulator of spectral localization. Its structure constrains where sufficient spectral concentration can occur to approach the admissibility boundary

- Regions of reduced DVz separation support localized concentration of spectral structure,
- Regions of increased separation suppress concentration and disperse spectral contributions.

As a result

- Collapse is localized within the model,
- Non-local or multi-region transitions are suppressed,
- And spectral concentration remains bounded across the system.

The DVz therefore functions as a modeled constraint on admissible operator transitions. A full operator-theoretic classification of this interface remains part of the broader formalization program.

5.5 Transition to an Effective Representation

When the admissibility boundary is reached, the transition is represented by a reorganization of spectral structure. This transition may be expressed through an effective projection: $\Pi: H \rightarrow H_{\text{eff}}$ where H_{eff} is an effective Hilbert space associated with a reduced representation of the system.

In this representation

- A subset of spectral modes becomes dominant and defines an effective geometric structure,

- Remaining modes contribute as internal or compact degrees of freedom,
- Boundary-associated operators become dynamically relevant.

This provides a mathematically consistent representation of an effective lower-dimensional description without requiring singular behavior.

5.6 Symmetry Properties of the Transition

The symmetry of the effective configuration is associated with the distribution of spectral structure prior to transition. More uniform spectral distributions are associated with approximately symmetric effective configurations. More localized or anisotropic distributions are associated with direction-dependent structure. These outcomes arise from internal spectral organization and are not imposed externally.

5.7 Selection of Effective Degrees of Freedom

The transition from the full operator system to the effective representation involves a selection of dominant spectral contributions. High-intensity spectral components are associated with emergent geometric structure, intermediate components are associated with internal degrees of freedom, compact or lower-weight components are associated with phase coherence and ordering.

This selection is governed by spectral organization and boundary compatibility, rather than by external assignment.

5.8 Summary of the Collapse Mechanism

Dimensional collapse in the FIT-Qd₁₂ framework is modeled as a bounded transition in operator space characterized by

- Approach to a stability boundary defined by admissibility conditions,
- Loss of stability of boundary-compatible operator domains,
- Coupled interaction between spectral structure, boundary operators, and intermediate layers,
- Localization enforced by DVz structure,
- And reorganization into an effective representation through spectral projection.

This formulation replaces singular collapse scenarios with a non-singular, operator-consistent transition, preserving spectral finiteness and compatibility with information-preserving evolution within the stated admissible framework.

6. Cosmogenesis as a Structured Spectral Transition

Within the FIT-Qd₁₂ framework, the emergence of an effective cosmological configuration may be described as a structured reorganization of spectral degrees of freedom following dimensional collapse. This process is modeled without requiring singular, explosive, or stochastic behavior in the conventional sense. Instead, it is described in terms of operator-level dynamics involving

- Spectral concentration and redistribution,
- Boundary-compatible evolution,
- Intermediate-layer coupling,
- And subsequent relaxation toward a stable effective representation.

For clarity, this evolution may be described in three conceptual phases. These phases do not represent distinct physical epochs separated by sharp boundaries, but rather successive regimes of dominant behavior within a single operator system.

6.1 Phase I — Initial Spectral Localization

The collapse transition is associated with a localized reorganization of spectral structure corresponding to the emergence of an effective lower-dimensional representation.

Key features include

- Localized spectral concentration: spectral weight becomes concentrated in a finite region determined by interface structure.
- Bounded curvature behavior: the emergent configuration is modeled as exhibiting large but finite curvature without divergence.
- Projection of degrees of freedom: a subset of spectral modes becomes dominant and may define the effective representation H_{eff} , while remaining modes persist as compact or non-projected contributions.
- Initial spectral gradients: the distribution of spectral structure influences the initial configuration of the effective system.

If the pre-collapse spectral configuration is non-uniform, the resulting effective state may exhibit anisotropic features. These are interpreted as consequences of spectral organization rather than imposed initial conditions.

6.2 Phase II — Spectral Relaxation and Effective Expansion

Following the initial transition, the system is modeled as entering a regime of rapid spectral redistribution within the effective representation.

This phase is characterized by

- Spectral relaxation: concentrated spectral modes redistribute, reducing gradients and moving the system toward a more stable configuration.
- Boundary-mediated dynamics: coupling between bulk spectral structure, boundary operators, and the intermediate layer produces effective expansion-like behavior.
- Curvature smoothing: large-scale variations in the effective geometry are reduced within the model, yielding an approximately homogeneous configuration.
- Finite-duration accelerated evolution: the rate of expansion is initially enhanced due to spectral imbalance but decreases as the system approaches a more stable regime.

This phase provides an operator-theoretic analogue to early rapid expansion, without introducing additional scalar fields within the present framework. It is presented as a structural correspondence rather than a direct replacement of standard inflationary models.

6.3 Phase III — Large-Scale Evolution and Structure Formation

As spectral relaxation proceeds, the system is modeled as transitioning into a regime of slower evolution dominated by large-scale structure.

Key features include

- Residual spectral organization: remaining variations in spectral structure are associated with persistent patterns in the effective representation.
- Effective gravitational behavior: the emergent geometry may be described by effective dynamics derived from the underlying operator structure.
- Geometric interpretation of dark-sector effects (interpretive extension): non-projecting spectral contributions may be associated with dark matter-like behavior, boundary-associated contributions may be associated with dark energy-like effects.
- Approach to equilibrium: the system evolves toward reduced gradients and stabilized large-scale dynamics.

Anisotropies in this regime, if present, reflect the initial spectral distribution and interface geometry but are not uniquely determined by the framework.

6.4 Symmetry and Anisotropy

The symmetry properties of the effective configuration are associated with the distribution of spectral structure at the time of transition:

- More uniform spectral distributions are associated with approximately isotropic configurations,
- More localized or directional distributions are associated with anisotropic structure.

These outcomes arise internally from spectral organization and do not require externally imposed symmetry-breaking mechanisms.

6.5 Relation to Standard Cosmological Descriptions

The operator-theoretic description above may be related to standard cosmological frameworks through structural correspondence

- Early rapid expansion may be related to spectral relaxation and boundary-mediated dynamics,
- Large-scale homogeneity may be associated with curvature smoothing within the effective representation,
- Structure formation may be associated with residual spectral variation.

These correspondences are interpretive and do not imply direct equivalence. The FIT-Qd₁₂ framework does not rely on additional scalar fields or singular initial conditions but remains compatible with observational descriptions commonly modeled within Λ CDM and related approaches.

6.7 Summary of Cosmogenesis

Cosmogenesis in the FIT-Qd₁₂ framework is modeled as a continuous, non-singular transition consisting of:

- An initial spectral localization associated with dimensional collapse,
- A regime of spectral relaxation and effective expansion,
- And a long-term evolution governed by residual spectral structure.

This formulation provides an alternative to singular cosmological origin scenarios within the operator framework, preserving spectral finiteness and compatibility with information-preserving evolution. Within this formulation, spacetime, matter, and large-

scale cosmological behavior may be interpreted as features of a single underlying spectral system.

7. Orientation and Early-Time Asymmetry in Cosmogenesis

Within the FIT-Qd₁₂ framework, the initial conditions of an emergent effective universe may be constrained by the spectral configuration at the time of dimensional collapse and by the geometry of the operator interface through which the transition occurs.

Together, these factors define an effective notion of orientation, reflected in the symmetry properties of the resulting large-scale configuration.

This section examines how anisotropic features may arise from operator-level dynamics and how they may relate to interface geometry and spectral distribution. The discussion in this section is interpretive and is not required for the mathematical closure results established elsewhere in this paper.

7.1 Collapse Orientation and Interface Geometry

As discussed in Section 3, dimensional collapse is localized to regions of the DVz interface where spectral concentration can approach admissibility conditions.

These regions may differ in their geometric and operator-theoretic properties:

- More localized interface regions may support concentrated spectral alignment,
- More extended interface regions may support distributed spectral organization.

These variations do not define discrete collapse types, but rather a continuous range of admissible configurations. The effective representation that emerges after collapse may inherit this structure through its initial spectral distribution.

7.2 Symmetry and Asymmetry in Initial Conditions

The symmetry properties of the emergent configuration are associated with the distribution of spectral structure at the time of transition. Approximately uniform spectral distributions may lead to configurations that are close to isotropic at large scales. Non-uniform spectral distributions may lead to anisotropic features in the effective description.

Such features may manifest as

- Variation in effective curvature across directions,

- Directional dependence in matter-like distributions,
- And anisotropic contributions to expansion behavior.

Within the FIT-Qd₁₂ framework, these properties are interpreted as arising from spectral organization at collapse, rather than from stochastic fluctuations or externally imposed initial conditions.

7.3 Relation to Observational Data

Observed large-scale features, such as hemispherical asymmetries in cosmic microwave background data or directional correlations in large-scale structure, may be examined within this framework.

In particular, such features are consistent with anisotropic spectral configurations at collapse, but they are not uniquely determined by the framework, and alternative explanations within standard cosmological models remain viable.

Accordingly, observational signatures should be treated as potential probes of collapse orientation rather than as definitive evidence. No observational claim in this section is used to establish mathematical closure.

7.4 Symmetric and Anisotropic Regimes

For clarity, it is useful to distinguish between limiting cases. Approximately symmetric configurations are associated with spectral structure distributed evenly across the collapse interface, leading to near-isotropic effective behavior.

Anisotropic configurations are associated with unevenly distributed spectral structure, producing direction-dependent behavior in curvature and expansion. These regimes represent endpoints of a continuous spectrum rather than discrete categories.

7.5 Boundary Structure and Effective Gradients

The boundary structure, referred to as the ledger, is modeled as a boundary-compatible extension of the operator system that encodes aspects of spectral organization and may contribute to effective large-scale behavior.

If the underlying spectral configuration is anisotropic

- Boundary-associated operators may exhibit directional variation,
- This may contribute to effective gradients in expansion behavior,

- And this may influence large-scale structure in the effective representation.

In phenomenological interpretation, such effects may be associated with direction-dependent contributions to dark energy-like behavior. However, this interpretation remains structural and is not required for the mathematical consistency of the framework.

7.6 Interpretation and Observational Status

The FIT-Qd₁₂ framework provides a candidate mechanism by which early-time asymmetry may arise from operator-level dynamics.

This mechanism

- Does not require stochastic initial conditions,
- Does not impose symmetry a priori,
- And allows both isotropic and anisotropic configurations as admissible outcomes.

Observed asymmetries may therefore be interpreted as consistent with this mechanism, but they do not establish it uniquely. Further observational and theoretical analysis is required to determine whether such features can be distinguished from alternative explanations.

7.7 Summary of Orientation Effects

The orientation and symmetry properties of an emergent effective universe are constrained by

- The geometry of the DVz interface at the collapse region,
- The distribution of spectral structure across that interface,
- And the resulting boundary-compatible encoding of spectral organization.

These factors provide a structural basis for early-time asymmetry and its possible persistence at large scales, while remaining consistent with admissibility constraints, spectral boundedness, and information-preserving evolution.

8. Boundary Architecture and Information Preservation

Within the FIT-Qd₁₂ framework, the boundary structure, referred to as the two-dimensional holographic ledger (2DHL), plays a central role in supporting consistency, stability, and information preservation. It is not a physical surface embedded in spacetime, but an operator-defined boundary corresponding to

a boundary-compatible self-adjoint extension of the underlying spectral system.

This boundary encodes aspects of spectral evolution and provides a framework in which global information consistency may be maintained across admissible dynamical processes. Its interaction with the intermediate NE layer and the DVz interface contributes to local stability and may contribute to effective large-scale behavior.

8.1 Boundary Structure and Curvature Dynamics

The boundary is associated with an operator-level notion of curvature reflecting the interaction between

- Boundary encoding capacity,
- Intermediate-layer NE coupling,
- And constraints imposed by DVz structure.

This behavior may be expressed schematically through a functional relationship: $K_{\text{boundary}} = F(T_{\text{boundary}}, P_{\text{NE}}, K_{\text{DVz}})$

where

- K_{boundary} represents boundary-associated curvature operators,
- T_{boundary} encodes effective boundary constraints, or tension-like behavior,
- P_{NE} represents intermediate-layer coupling contributions,
- K_{DVz} reflects the influence of the DVz interface.

This relation should be understood as a structural dependence rather than a closed-form equation. It summarizes how the boundary may respond to spectral concentration and contribute to the regulation of admissible configurations.

8.2 Modular Flow and Emergent Temporal Ordering

In this formulation, time is not introduced as a fundamental coordinate of the pre-collapse operator system. Instead, temporal ordering may be represented through the evolution of boundary states.

This evolution may be described using Tomita–Takesaki modular flow: σ_{τ} where σ_{τ} denotes the modular automorphism group associated with the boundary algebra.

Within this framework

- Temporal ordering corresponds to the ordering of boundary states,

- The direction of time is associated with monotonic evolution under modular flow,
- And effective time parameters arise only after projection to an emergent description.

Thus, time is interpreted as an emergent parameter associated with boundary evolution, rather than as a fundamental spacetime coordinate of the underlying operator system.

8.3 Boundary Encoding and Information Structure

The boundary provides an encoding of spectral information associated with the operator system. This may be represented schematically as a mapping: $I: \rho_{\text{phys}} \rightarrow \rho_{\text{boundary}}$.

Within the admissible framework, this mapping satisfies

- Injectivity, up to equivalence: Admissibly distinct configurations are represented by distinguishable boundary encodings, modulo equivalence under admissible transformations.
- Monotonic evolution: Boundary evolution proceeds without requiring erasure of previously encoded information within the operator framework.
- Compatibility with unitary evolution: Bulk dynamics generated by D_{12} are unitary on the stated admissible domain, and the boundary encoding is consistent with this structure at the operator level.

These properties support a form of information preservation within the full operator system, even when reduced descriptions may appear to exhibit information loss.

8.4 Information Transfer and Effective Decoherence

Transfer of information from bulk spectral structure to boundary encoding may be modeled using completely positive, trace-preserving (CPTP) maps.

These processes

- Map selected components of bulk states to boundary encoding,
- May reduce phase coherence in effective projected descriptions,
- And preserve global consistency and conserved quantities at the operator level.

Within later phenomenological interpretations, certain weakly interacting particles, such as neutrinos,

may serve as sensitive probes of boundary-coupled dynamics. Their long coherence length makes them candidate probes of subtle boundary interactions, which may manifest as small deviations from standard propagation behavior.

Such effects, if present, should be interpreted as possible consequences of boundary coupling rather than as evidence for additional particle species. This phenomenological role is not required for the mathematical closure results established in this paper.

8.5 Information Preservation Across Transitions

Dimensional collapse and related high-curvature processes are modeled as reorganizations of spectral structure, rather than as processes involving loss of information.

Within the operator framework

- Collapse is modeled as corresponding to a transition between admissible representations,
- Boundary encoding provides a record of spectral evolution,
- And apparent information loss in effective descriptions reflects incomplete projection of the full operator system.

These statements are understood within the admissible operator-geometric framework and do not depend on specific semiclassical approximations.

8.6 Boundary–Intermediate Layer Coupling

The stability of the boundary structure is modeled as being maintained through its coupling to the intermediate NE layer.

This coupling

- Regulates boundary-associated curvature operators,
- Limits uncontrolled growth of boundary constraints,
- And mediates interaction between bulk spectral structure and boundary encoding.

Through this interaction, the boundary remains dynamically stable within the stated framework while continuing to encode information and influence effective behavior.

8.9 Summary of Boundary Dynamics

Within the FIT-Qd₁₂ framework, the boundary structure serves as:

- An encoding of spectral evolution,
- A mechanism supporting information consistency,
- A regulator of admissibility through boundary compatibility,
- And a contributor to effective physical behavior in emergent representations.

Together with the intermediate layer and DVz interface, it provides a structural foundation for a consistent, spectrally finite, and information-preserving operator system.

9. Dark Sector as an Effective Geometric Structure

In standard cosmology, dark matter and dark energy are introduced as additional components required to account for gravitational dynamics and large-scale expansion. Within the FIT-Qd12 framework, these phenomena are not introduced as independent fundamental fields at the operator level. Instead, they are interpreted as effective manifestations of the underlying Qd12 operator geometry, associated with dimensional projection, intermediate-layer curvature, DVz-regulated collapse structure, uncollapsed substrate pressure, and APS-compatible boundary dynamics.

This section outlines how dark-sector behavior may be understood as emerging from curvature, boundary, and substrate contributions within the Qd12 operator system. The discussion is interpretive and is not required for the mathematical closure results established in this work. Its purpose is to identify how the same operator-geometric structure may support dark-matter-like gravitational behavior and dark-energy-like expansion behavior in an effective four-dimensional description.

9.1 Dark Matter as a Curvature-First Effective Contribution

Within the operator-geometric framework, dark matter-like behavior is associated primarily with residual curvature contributions linked to the intermediate NE layer, DVz-regulated collapse dynamics, and non-projecting or weakly projecting spectral structure.

This may be represented schematically as: $DM_{eff} \sim C_{NE}^{(proj)}$ where $C_{NE}^{(proj)}$ denotes the projection of intermediate-layer curvature contributions into the effective four-dimensional description.

9.1.1 Origin of the Effective Contribution

During dimensional collapse

- Spectral concentration may be associated with localized curvature within the operator system,
- Interaction with the intermediate NE layer may introduce additional curvature structure,
- DVz-regulated projection may separate visible projected modes from weakly projecting or non-projecting curvature modes,
- And projection into the effective representation may retain components of this curvature as gravitationally active structure.

These contributions are not introduced as independent fundamental particle degrees of freedom in the underlying operator description. However, this does not require FIT-Qd12 to deny all possible particle-like dark-sector excitations. The refined canonical position is that dark matter is **curvature-first**, not an absolute no-particle claim. If dark-sector particles or particle-like excitations are observed, they may still be compatible with

FIT-Qd12 if they arise as emergent, projected, semi-projecting, or residue modes of the underlying Qd12/RTF operator geometry.

9.1.2 Interpretation in the Effective Description

Within an emergent spacetime representation, these curvature contributions

- May influence gravitational dynamics,
- May contribute to structure formation,
- May affect the motion of visible matter,
- May contribute to lensing behavior,
- And may support extended or filamentary large-scale structure.

They may therefore be interpreted as geometric contributions to gravitational behavior, rather than as a separate fundamental matter sector.

The decisive distinction is not “particles versus no particles,” but whether the dominant dark-sector behavior is fundamentally independent of Qd12 geometry or whether it is traceable to projected spectral curvature. FIT-Qd12 is strongly constrained only if particle dark matter fully accounts for all dark-sector phenomena without requiring non-projecting curvature, boundary effects, dimensional-collapse structure, or Qd12-sector emergence.

9.1.3 Structural Features

The projected curvature may exhibit

- Anisotropic distributions,
- Filamentary or extended structures,
- Spatial variation in effective density,
- Weak or absent electromagnetic coupling,
- And gravitational influence without ordinary luminous matter.

Such features are qualitatively consistent with observed large-scale structure, though the framework does not claim to uniquely reproduce all observational details. Detailed quantitative modeling is required to compare the predicted curvature distribution with lensing maps, halo profiles, void statistics, cluster dynamics, and large-scale-structure surveys.

9.2 Dark Energy as a Boundary–Substrate Contribution

Within FIT-Qd12, dark-energy-like behavior is interpreted as a boundary–substrate effect. The uncollapsed Qd12 Matrix Field supplies the deeper source of dark-energy pressure, while APS-compatible ledger dynamics regulate how that pressure is registered inside the collapsed four-dimensional universe.

This may be represented schematically as:

$$DE_{\text{eff}} \sim P_{\text{Qd12} \rightarrow \text{ledger}}$$

Where $P_{\text{Qd12} \rightarrow \text{ledger}}$ denotes the effective pressure arising from the interaction between the uncollapsed Qd12 substrate and the APS-compatible boundary/ledger structure of the post-collapse universe.

9.2.1 Canonical statement

Dark energy = Qd12 substrate pressure expressed through APS ledger dynamics.

9.2.2 Origin of the Effective Contribution

Following dimensional collapse, the emergent four-dimensional universe remains related to the broader uncollapsed Qd12 Matrix Field. The collapsed 4D representation is therefore not treated as isolated from the underlying operator substrate. The persistent influence of that uncollapsed substrate supplies a smooth pressure-like contribution.

APS-compatible ledger dynamics regulate how this pressure appears in the effective four-dimensional description. Boundary encoding reflects the distribution of spectral structure; spectral trace mismatch between

the full Qd12 system and the projected four-dimensional regime may produce an effective pressure term; and information deposition into the ledger may contribute to higher-order modulation or redshift-dependent behavior.

Thus, ledger pressure and uncollapsed-field pressure are not separate fundamental mechanisms. They are two levels of the same Qd12 dark-energy process

Uncollapsed Qd12 substrate supplies the pressure; APS ledger dynamics regulate how that pressure appears as 4D cosmic acceleration.

9.2.3 Interpretation in the Effective Description

In the effective regime, this contribution

- May influence the rate of expansion,
- May produce accelerated expansion under appropriate conditions,
- May appear approximately Λ -like at leading order,
- May exhibit small redshift dependence, modulation, or relaxation through boundary/ledger effects,
- And may exhibit directional dependence if the underlying spectral configuration is anisotropic.

The leading smooth component may be observationally close to a cosmological constant. Higher-order behavior may arise from ledger pressure, spectral trace mismatch, boundary tension, and information deposition. This allows FIT-Qd12 to accommodate

Λ -like behavior, weakly evolving dark energy, scalar-field-like effective parameterizations, or mild redshift-dependent modulation as possible four-dimensional descriptions of the same deeper boundary–substrate mechanism.

9.2.4 Acceleration Constraint

Because the uncollapsed Qd12 substrate supplies persistent pressure, FIT-Qd12 allows dark-energy acceleration to slow, relax, modulate, or asymptotically flatten, but not to reverse into global contraction under admissible boundary–substrate dynamics.

9.2.5 Canonical Statement

FIT-Qd12 allows dark-energy acceleration to slow, but not to reverse under admissible boundary–substrate dynamics.

A reversal would require failure or sign reversal of the persistent uncollapsed Qd12 substrate pressure, breakdown of APS ledger admissibility, or loss of mass-gap/spectral stability. Such a reversal would

therefore represent a major constraint on the admissible dark-energy realization of FIT-Qd12.

9.3 Unified Origin of Dark-Sector Contributions

The effective dark matter-like and dark energy-like contributions are associated with different aspects of the same underlying Qd12 operator structure.

- Dark matter-like behavior is associated primarily with non-projecting or weakly projecting spectral curvature linked to intermediate-layer dynamics, DVz-regulated collapse residues, and dimensional projection.
- Dark energy-like behavior is associated with uncollapsed Qd12 substrate pressure expressed through APS-compatible ledger dynamics.

Both contributions may be influenced by collapse geometry, boundary structure, DVz regulation, spectral trace mismatch, and the projection from the full operator system into the effective four-dimensional regime.

Thus, dark matter and dark energy are not treated as unrelated sectors. They are distinct effective manifestations of a unified operator-geometric system. Dark matter reflects how certain curvature contributions gravitate without projecting as ordinary luminous matter. Dark energy reflects how persistent substrate pressure is registered through boundary/ledger dynamics as accelerated expansion.

9.4 Parameter Dependence and Effective Modeling

Within the FIT-Qd12 framework, dark-sector behavior depends on the structure of the operator system, spectral configuration at collapse, boundary conditions, DVz geometry, and projection into the effective four-dimensional regime. It is not introduced through arbitrary independent fundamental fields.

However, effective parameters may still appear in phenomenological models derived from the framework. For example

- Dark-matter-like behavior may require parameters describing projected curvature strength, coherence scale, lensing contribution, halo or filament structure, and non-projecting curvature density;
- Dark-energy-like behavior may require parameters describing substrate pressure,
- Ledger response, boundary tension, spectral trace mismatch, redshift dependence, and possible directional modulation.

These effective parameters should not be treated as free additions disconnected from the theory. They must ultimately be constrained by the same Qd12 operator geometry and should be tested through cross-domain coherence.

The key empirical question is therefore not whether one dark-sector observable can be fitted. The key question is whether dark-matter-like lensing, large-scale structure, expansion history, CMB boundary imprints, and other observational channels can be organized through a shared Qd12 parameter structure.

9.5 Observational Consistency and Limitations

The geometric interpretation of the dark sector is broadly consistent with several observational features, including

- Large-scale structure formation,
- Gravitational lensing behavior,
- Halo and filament morphology,
- Apparent absence or elusiveness of conventional particle dark matter in direct detection,
- And late-time cosmic acceleration.

However, the framework does not claim unique agreement with all observations. Detailed quantitative modeling is required for comparison with specific datasets, and alternative explanations within standard cosmology remain viable. Accordingly, these results should be understood as providing a structural interpretation rather than a definitive empirical replacement.

A single observational result should not be treated as automatically confirming or falsifying the full framework. Instead:

- Absence of conventional dark-matter particles strengthens the curvature-first interpretation only if gravitational and lensing evidence remains strong;
- Discovery of dark-sector particles constrains the pure curvature-only realization, but does not refute FIT-Qd12 if those particles arise as emergent Qd12/RTF modes;
- Λ -like dark-energy behavior remains compatible with FIT-Qd12 if it represents the leading smooth limit of substrate pressure;
- Mildly evolving dark energy may support the theory only if its parameters can be connected to boundary/ledger dynamics;

- And a full reversal of acceleration would strongly challenge the admissible boundary–substrate dark-energy realization.

The strongest support for the FIT-Qd12 dark-sector interpretation would come from cross-domain parameter coherence: the same operator-geometric parameter structure should help organize lensing, large-scale structure, expansion history, CMB boundary-imprint residues, and related gravitational observables.

9.6 Summary of the Dark Sector Interpretation

Within the FIT-Qd12 framework

- Dark matter–like behavior is interpreted as a curvature-first effective contribution associated with non-projecting or weakly projecting spectral curvature, intermediate-layer dynamics, dimensional collapse, and DVz-regulated projection;
- Dark-sector particles, if discovered, would not by themselves falsify FIT-Qd12 if they can be interpreted as emergent, projected, semi-projecting, or residue modes of the Qd12/RTF operator geometry;
- Dark energy–like behavior is interpreted as Qd12 substrate pressure expressed through APS-compatible ledger dynamics; the leading dark-energy contribution may appear Λ -like, while higher-order behavior may include small modulation, redshift dependence, or relaxation through ledger pressure, spectral trace mismatch, boundary tension, and information deposition;
- FIT-Qd12 allows dark-energy acceleration to slow, but not to reverse under admissible boundary–substrate dynamics;
- Both dark matter–like and dark energy–like behavior arise from the same underlying operator-geometric structure;
- And neither requires the introduction of independent fundamental fields at the level of the underlying Qd12 system.

These interpretations provide a coherent geometric perspective on the dark sector while remaining consistent with admissibility constraints, spectral boundedness, information-preserving evolution, and observational uncertainty.

10. Global Structure, Adjacency, and Stability

The Qd12 operator system is not restricted to a single configuration but may be extended to a collection of interacting operator-defined regions. These regions may be described as connected through a common adjacency architecture characterized by boundary compatibility, intermediate-layer dynamics, and DVz-regulated separation.

This section describes the structural organization of such extended configurations, the constraints on inter-region interaction, and the mechanisms that support stability within the stated framework.

10.1 Extended Operator Configuration

Each Qd12 region may be regarded as part of a larger arrangement of adjacent operator domains. Interactions between neighboring regions may be mediated by a layered interface: $Qd_{12}(A) | NE(A) | Ledger(A) | DVz | Ledger(B) | NE(B) | Qd_{12}(B)$

This structure may provide a consistent interface between operator regions, may separate spectral configurations while allowing constrained interaction, and may support localized transition processes.

The global extent of the configuration is not fixed within the present formulation; it may be finite or effectively unbounded. The essential feature is the uniformity of the adjacency architecture, rather than the global topology.

10.2 DVz as a Regulator of Inter-Region Interaction

The Dimensional Viscosity Zone (DVz) is modeled as regulating interaction between adjacent operator regions.

Its role includes, suppression of uncontrolled spectral propagation across interfaces, localization of admissible transitions to specific regions, and regulation of boundary-mediated coupling.

The DVz does not act as an absolute barrier. Instead, it is interpreted as enforcing admissible interaction channels within the framework, allowing coupling only through boundary-compatible processes.

10.3 Operator Decomposition and Effective Independence

The Hilbert space of the extended system may be decomposed into contributions associated with individual regions and their interfaces. At an effective level, this may be expressed as:

$$H \approx \oplus_i H_i$$

Where each H_i corresponds to a Qd₁₂ region together with its associated boundary and intermediate layers.

Within this approximation, observables associated with sufficiently separated regions may approximately commute under admissible separation assumptions, evolution may preserve effective separation under admissible dynamics, and information transfer between distant regions is strongly constrained. This provides a basis for treating regions as effectively independent subsystems, except where boundary-mediated interaction is present.

10.4 Constraints on Transition Geometry

Dimensional collapse and related transitions are constrained by the geometry of the adjacency structure.

In particular, transition is modeled as requiring alignment of boundary-compatible regions, spectral concentration must be supported within the model by local DVz structure, and configurations involving incompatible multi-region alignment are suppressed within the framework.

As a result

- Transitions are localized,
- Multi-region transitions are disfavored,
- And coupling across multiple interfaces is limited.

These constraints contribute to the stability of the extended system.

10.5 Symmetry and Configuration Dependence

The symmetry properties of emergent effective configurations depend on:

- The distribution of spectral structure in the interacting regions,
- The geometry of the interface through which the transition occurs,
- And the resulting boundary encoding.

Adjacency geometry influences these factors but does not uniquely determine them. Symmetry properties therefore arise from combined spectral and interface effects.

10.6 Interaction Between Effective Configurations

Effective universes arising from localized transitions may be interpreted as corresponding to distinct realizations of the operator system.

Interactions between such configurations depend on their underlying structure. Configurations associated with distinct operator regions are expected to be strongly separated by DVz-regulated interfaces, and configurations arising within the same region may exhibit weak coupling through shared boundary or curvature contributions.

These interactions are expected to be limited and model-dependent. The framework does not assume significant observable coupling between distinct configurations.

10.7 Directional Effects and Large-Scale Structure

The combination of boundary structure, intermediate-layer dynamics, and DVz geometry may introduce directional effects in effective descriptions.

These may include

- Variation in expansion behavior across large scales,
- Anisotropic contributions to effective dark energy-like behavior,
- Alignment of large-scale structure with underlying operator configuration.

Such effects arise from spectral and interface structure and should be interpreted as emergent features, not imposed conditions.

10.8 Stability of the Extended Operator System

The extended operator system is modeled as exhibiting stability through several structural mechanisms

- Localization of transitions,
- Suppression of propagation across regions,
- Boundary-mediated separation of operator domains,
- And uniformity of interface structure.

These features provide a basis for stability within the framework without requiring externally imposed constraints.

10.9 Summary of Global Structure

The extended Qd₁₂ system may be characterized by:

- A uniform adjacency architecture connecting operator regions,
- DVz-regulated interaction and transition dynamics,
- Effective independence of sufficiently separated regions,

- Localized transitions producing emergent configurations,
- And stability arising from admissibility constraints.

Within this framework, both global organization and local dynamics are described as governed by the same operator principles, linking extended structure to the emergence of effective physical behavior.

11. Neutrinos and Boundary-Coupled Information Dynamics

Within the FIT-Qd₁₂ framework, neutrinos are best framed as fiber-dominant projected modes whose weak interaction, long coherence length, and phase sensitivity make them natural probes of the Qd₁₂ fiber and boundary sectors. They are not introduced as a separate ontological class of “information particles.” Rather, their oscillation behavior, coherence shifts, flavor ratios, and possible sterile-like boundary-suppressed signatures may encode information about fiber-sector phase geometry, chirality, mass-gap structure, and APS-compatible ledger coupling.

This section examines how neutrino propagation may be influenced by fiber-sector and boundary-coupled processes, and how such effects may offer observational access to the underlying operator geometry. The discussion is phenomenological and interpretive. It is not required for the mathematical closure results established in this paper. The original section already framed neutrinos as weakly interacting, long-coherence probes of boundary-coupled dynamics; this revision sharpens that position by distinguishing neutrinos as fiber-sector probes rather than as a separate information-particle class.

11.1 Neutrinos as Fiber-Sector Probes of Boundary Structure

Admissible physical processes may contribute, in principle, to boundary encoding within the operator framework. Neutrinos are distinguished because they propagate over large distances with minimal interaction while preserving phase information over extended baselines. This makes them unusually sensitive to subtle operator-level structure that may be invisible or averaged out in more strongly interacting sectors.

In FIT-Qd₁₂, this sensitivity is associated primarily with the Fiber sector. The Fiber sector governs phase coherence, chirality, mass-gap structure, modular ordering, and mixing-related behavior. Neutrinos

therefore function as observable probes of the fiber-boundary interface: their oscillations may encode information about how fiber-sector phase structure interacts with APS-compatible boundary dynamics. As a result, neutrinos may

- Probe regions of varying effective curvature, fiber-sector phase structure, and boundary coupling,
- Retain coherence over cosmological and terrestrial distances,
- Exhibit sensitivity to weak, environment-dependent operator effects,
- And provide a phase-sensitive observational channel into the relationship between bulk spectral dynamics and boundary encoding.

The fiber sector may be described analogically as a phase-sensitive channel or “antenna.” This does not mean that fibers literally gather information as independent agents. Rather, the fiber sector provides the spectral channel through which neutrino behavior can encode, transport, and deposit information into the boundary-compatible ledger structure.

11.2 Boundary-Coupled Evolution and CPTP Maps

In standard treatments, neutrino evolution is described by unitary flavor oscillations arising from mixing between mass eigenstates. Within the present framework, this evolution may be supplemented in reduced descriptions by fiber-sector and boundary-coupled interactions.

These interactions may be modeled at an effective level by completely positive, trace-preserving maps acting on the neutrino density matrix

$L_{\text{boundary}}: \rho \rightarrow \rho'$ Such maps

- Preserve total probability,
- Allow partial decoherence or phase modification in reduced descriptions,
- Encode environment-dependent effects through operator-level coupling,
- And represent the influence of a larger operator environment without requiring fundamental non-unitarity.

These processes should be interpreted as effective descriptions of interaction with an extended operator environment, rather than as fundamental modifications of the underlying unitary dynamics. The full Qd₁₂ operator system remains information-preserving

within the admissible domain; reduced neutrino-sector evolution may appear decohering because only part of the full operator structure is being observed.

11.3 Effective Decoherence and Modified Oscillation Behavior

Under certain conditions, especially in regions where fiber-sector coupling, boundary structure, or intermediate-layer effects are enhanced, neutrinos may exhibit partial decoherence or phase deformation in their flavor evolution.

This may lead to

- Suppression or damping of oscillation amplitudes,
- Small shifts in effective oscillation phase,
- Energy-dependent coherence changes,
- Baseline-dependent residuals,
- Modification of effective mixing parameters,
- And deviations from purely unitary oscillation patterns in reduced descriptions.

Such behavior can resemble phenomenology often associated with additional sterile states. Within FIT-Qd₁₂, however, sterile-like effects need not imply an independent new fundamental particle species. They may instead reflect boundary-suppressed, weakly projecting, or fiber-sector modes whose interaction strength is reduced in the effective four-dimensional description.

This distinction is important. FIT-Qd₁₂ does not require the absence of sterile-like behavior. It predicts that any such behavior, if real, should be tested for compatibility with fiber-ledger phase structure, boundary coupling, and cross-domain Qd₁₂ parameters rather than treated as an isolated anomaly.

11.4 Environmental Dependence of Neutrino Propagation

The magnitude and structure of fiber-boundary effects may depend on local operator and geometric conditions, including

- Boundary curvature and encoding structure,
- Fiber-sector phase geometry,
- Intermediate-layer NE contributions,
- DVz interface geometry,
- Local curvature environment,
- Neutrino energy,

- Propagation distance,
- And large-scale anisotropy inherited from collapse geometry.
- As a result, neutrino behavior may exhibit:
- Spatial variation in oscillation patterns,
- Energy-dependent deviations from standard expectations,
- Baseline-dependent phase residuals,
- Weak directional dependence in extended configurations,
- And possible correlations with large-scale curvature or cosmological structure.

These dependencies provide a potential link between neutrino phenomenology and the underlying Qd₁₂ operator geometry. However, they should be treated as prediction channels requiring quantitative modeling, not as already-established empirical signatures.

11.5 Relation to Experimental Observations

The framework suggests that certain deviations from standard oscillation predictions, such as energy-dependent anomalies, baseline-dependent irregularities, sterile-like behavior, or high-energy flavor-ratio deviations, may be consistent with fiber-boundary dynamics.

However

- The framework does not provide a unique explanation for existing anomalies,
- Detailed quantitative modeling is required for comparison with experimental data,
- Alternative explanations within standard or extended neutrino physics remain viable,
- And null results constrain the fiber-ledger coupling channel rather than falsifying the full Qd₁₂ operator framework.

Future experiments may help distinguish between these possibilities by probing correlations across energy, baseline, direction, flavor ratios, and environmental dependence. In the FIT-Qd₁₂ framework, the strongest support would not come from one isolated neutrino anomaly, but from a pattern in which neutrino-sector deviations share parameters with the broader fiber, boundary, mass-gap, dark-sector, and cosmological structure.

11.6 Feedback Between Neutrinos and Boundary Encoding

Neutrinos may also contribute to the evolution of the operator system through boundary encoding processes. This should be interpreted carefully. Neutrinos are not independent information agents, but fiber-dominant modes whose propagation may carry phase-sensitive information through the effective spacetime description. In this context

- Neutrino propagation may contribute to boundary information accumulation,
- Boundary encoding may influence effective large-scale structure,
- Fiber-sector phase structure may affect neutrino oscillation behavior,
- And resulting geometry may affect subsequent neutrino propagation.

This suggests a possible feedback relationship: neutrino propagation \rightarrow fiber-sector phase response \rightarrow boundary encoding \rightarrow effective geometry \rightarrow neutrino propagation

Within the present framework, this feedback is interpreted as part of the broader information-preserving dynamics of the operator system. Its quantitative impact remains an open question and is not required for the mathematical closure results of this paper.

11.7 Summary of Neutrino Dynamics

Within the FIT-Qd12 framework

- Neutrinos are best understood as fiber-dominant projected modes rather than as a separate ontological class of information particles,
- Their weak interaction, long coherence length, oscillation behavior, and phase sensitivity make them natural probes of the fiber-boundary sector,
- Their evolution may include effective CPTP-type contributions arising from interaction with an extended operator environment,
- Environment-dependent decoherence or phase modification may occur without requiring additional fundamental particle species,
- Sterile-like behavior, if observed, may be interpreted as boundary-suppressed or weakly projecting fiber-sector behavior rather than automatically as an independent particle sector,

- And their behavior may provide a potential observational window into the underlying Qd12 operator geometry.

These features connect neutrino physics to the broader structure of the framework while remaining consistent with admissibility constraints, spectral boundedness, and information-preserving evolution. Null neutrino results constrain the fiber-ledger coupling channel; they do not by themselves falsify the full FIT-Qd12 operator framework.

12. Spectral Action and Standard Model–Compatible Structure

A central requirement of any unification framework is its ability to account for the observed structure of particle physics, including gauge symmetries, matter representations, and interaction terms, without reliance on ad hoc assumptions. Within the FIT-Qd12 framework, these features are not introduced independently, but may arise from the spectral properties of an underlying operator system defined by the spectral-triple-type structure: (A_{12}, H, D_{12})

This section outlines how Standard Model–compatible structure may emerge from the operator geometry. A detailed mathematical development is provided in Appendix A.

12.1 The Spectral Triple as a Generating Structure

The Qd12 operator system is defined by a Dirac-type operator D_{12} acting on a Hilbert space H and admitting a boundary-compatible self-adjoint extension, together with an associated algebra A_{12} .

The spectral action: $S = \text{Tr}(f(D_{12}^2 / \Lambda^2))$ provides a unifying functional framework from which effective physical contributions may arise through expansion.

The operator admits a functional decomposition consistent with the Rope–Thread–Fiber structure:

$D_{12} = D_R + D_T + D_F$ where

- D_R is associated with emergent geometric behavior,
- D_T encodes internal gauge-compatible and matter-like structure,
- D_F governs phase coherence and spectral organization.

The expansion of the spectral action yields, under appropriate assumptions

- Curvature terms associated with effective gravitational behavior,
- Gauge kinetic terms,
- Fermionic couplings,
- Scalar-sector contributions.

These may be understood as arising from spectral data rather than being independently introduced.

12.2 Emergence of Gauge Structure

The internal operator structure associated with the Thread sector supports symmetry groups compatible with those of the Standard Model

$$SU(3)_c \times SU(2)_L \times U(1)_Y$$

Within this framework

- Non-abelian structure may be associated with internal curvature components,
- Chiral structure may be associated with Fiber-sector contributions and boundary compatibility,
- Abelian factors may be associated with phase symmetries within the operator algebra.

This correspondence is structural rather than prescriptive: the operator geometry supports symmetry groups consistent with the Standard Model under admissible configurations. The framework does not assume these groups a priori and does not claim a unique derivation at this level.

12.3 Fermionic Representations

The Hilbert space H may be decomposed under the internal symmetry structure into representations that can be mapped onto known fermionic degrees of freedom.

These include

- Chiral doublet and singlet structures,
- Color-charged and color-neutral states,
- Leptonic and quark-like sectors.

The resulting structure may be

- Chiral,
- Compatible with anomaly constraints,
- And capable of supporting multiple generations.

Within the framework, generation structure may be associated with distinct spectral sectors or mode families. The detailed mechanism depends on the internal spectral structure and is further developed in Appendix A.

12.4 Scalar Sector and Inner Fluctuations

The scalar sector may arise naturally from inner fluctuations of the Dirac operator

$$D_{12} \rightarrow D_{12} + A + JAJ^{-1}$$

Where A is an element of the algebra A_{12} and J is the real structure operator. This construction may yield:

- Scalar degrees of freedom transforming under internal symmetries,
- Couplings to fermionic and gauge sectors,
- Contributions to symmetry-breaking behavior.

Within this framework, a Higgs-like field may be interpreted as a geometric feature of the operator system rather than as an independently introduced scalar field.

12.5 Coupling Structure and Mass Generation

Coupling terms between fermionic and scalar sectors may arise from the spectral action and the internal structure of the operator system.

These include

- Yukawa-type interactions,
- Mixing between fermionic states,
- Hierarchical mass structures.

The detailed form of these couplings depends on the spectral properties of D_{12} and the structure of the internal algebra. While the framework provides a geometric basis for such features, quantitative agreement with observed parameters requires additional specification.

12.6 Anomaly Consistency

Consistency of the gauge structure requires the absence of gauge anomalies. Within the operator framework, anomaly cancellation may be associated with:

- The representation structure induced by the spectral triple,
- Compatibility of the internal algebra with boundary conditions,
- And admissibility constraints on fermionic content.

The resulting configurations may be consistent with anomaly-free structures required for viable effective theories.

12.7 Unified Spectral Origin of Interactions

The spectral action provides a common structural origin for

- Geometric contributions,
- Gauge interactions,
- Fermionic dynamics,
- Scalar-sector behavior.

These are not introduced as separate sectors but arise from different aspects of the same operator system.

12.8 Relation to Detailed Derivations

The present section provides a conceptual outline of how Standard Model-compatible structure may emerge.

A more detailed treatment, including

- Algebraic construction of the internal structure,
- Representation theory,
- Spectral expansion coefficients,
- And coupling derivations is provided in Appendix A.

12.9 Summary of Emergent Structure

Within the FIT-Qd12 framework

- Gauge symmetries compatible with the Standard Model may be supported by internal operator structure,
- Fermionic representations may arise from Hilbert space decomposition,
- Scalar fields may emerge from inner fluctuations of the Dirac operator,
- Coupling structures may follow from spectral data,
- And multiple interaction sectors may share a common spectral origin.

These results illustrate how known features of particle physics may be understood as emergent properties of an underlying operator-geometric system, while remaining consistent with admissibility constraints, boundary compatibility, and spectral boundedness.

13. Observational Predictions and Empirical Tests

A viable unification framework must extend beyond internal consistency and provide empirically testable consequences. Within the FIT-Qd12 framework, observational signatures may arise from the interplay

of spectral structure, APS-compatible boundary dynamics, intermediate-layer curvature, fiber-sector phase behavior, and DVz-regulated transitions.

Because cosmological behavior, dark-sector effects, neutrino propagation, gravitational-wave behavior, and large-scale structure are interpreted as consequences of a single operator-geometric system, the framework suggests correlated signatures across multiple observational domains, including cosmology, gravitational-wave astronomy, neutrino physics, CMB analysis, dark-sector lensing, and large-scale structure surveys.

The results presented here should be understood as testable consequences, consistency conditions, and observational templates, not as uniquely confirmed explanations. FIT-Qd12 is not empirically validated by fitting isolated anomalies. Its strongest empirical test is whether independent observational domains can be organized by a shared Qd12 parameter structure involving boundary dynamics, fiber-sector phase behavior, DVz-regulated projection, spectral mass-gap stability, and collapse-imprinted geometry.

13.1 CMB Boundary-Imprint Structure

Within the framework, anisotropic spectral configurations at collapse may give rise to large-scale asymmetries or residual imprints in the cosmic microwave background (CMB). However, the observed CMB should not be treated as a direct or complete image of the Qd12 boundary record. It is a past-light-cone slice through the post-collapse radiation field, filtered by our four-dimensional location, last-scattering projection, line-of-sight gravitational lensing, late-time effects, foregrounds, calibration, and cosmic variance.

Canonical Statement

The CMB is a slice, not the whole ledger.

Equivalently

13.1.1 The observed CMB is a projected time-slice of boundary-imprinted radiation, not a complete image of the Qd12 boundary structure.

Potential CMB-related signatures include

- Hemispherical power asymmetry,
- Alignment of low multipole moments,
- Localized temperature deviations,
- Low-multipole phase correlations,
- Parity asymmetry,

- EB/TB polarization rotation,
- And correlations between CMB lensing and large-scale structure.

These features may be consistent with anisotropic initial spectral configurations or boundary-imprint residues, but the framework does not uniquely identify any specific observed anomaly as a required consequence. A single CMB anomaly is insufficient. The FIT-Qd12 CMB claim concerns correlated boundary-imprint structure across polarization, phase, parity, temperature, lensing, and large-scale-structure channels.

13.2 Hemispherical Asymmetry and Structure Formation

Anisotropic configurations at collapse may influence the development of large-scale structure. If the initial spectral configuration was not perfectly isotropic, residual directional structure may appear in both the CMB and matter distribution.

Potential observational consequences include:

- Variation in clustering amplitude across hemispheres,
- Directional dependence in correlation functions,
- Alignment between large-scale structure and CMB features,
- Anisotropic filamentary structure,
- Directional variation in void statistics,
- And correlations between matter distribution and collapse-imprinted curvature.

These effects are testable using galaxy surveys, weak-lensing maps, and CMB–large-scale-structure cross-correlations. However, they are not exclusive to FIT-Qd12 and must be distinguished from statistical fluctuations, survey systematics, foreground effects, and standard cosmological explanations.

13.3 Bulk Flows and Velocity Fields

Directional structure in the underlying operator configuration may contribute to large-scale velocity patterns. If collapse-imprinted anisotropy or non-projecting curvature affects the effective gravitational environment, coherent velocity deviations may appear across sufficiently large scales.

Possible signatures include

- Coherent bulk flows over large distances,
- Alignment between velocity fields and large-scale anisotropies,
- Correlations between velocity residuals and lensing structure,
- And deviations from isotropic expectations in low-redshift surveys.

Any such effects must be distinguished from statistical fluctuations, selection effects, survey geometry, and systematic uncertainties. FIT-Qd12 does not require a specific bulk-flow anomaly to be present. Instead, it predicts that if such directional features persist, they should be tested for consistency with CMB, lensing, expansion, and large-scale-structure parameters.

13.4 Large-Scale Structure and Curvature-First Dark Matter

If dark matter–like behavior is interpreted as arising from projected or weakly projecting curvature contributions, this may influence structure formation. In the refined canonical position, FIT-Qd12 treats dark matter as a curvature-first dark-sector explanation, not as an absolute no-particle claim.

Potential signatures include

- Anisotropic filamentary structure,
- Deviations from Gaussian statistics in matter distribution,
- Directional dependence in gravitational lensing shear,
- Halo or void profiles influenced by non-projecting curvature,
- And correlations between lensing residuals and large-scale spectral geometry.

These features can be explored using surveys such as DESI, Euclid, Rubin/LSST, and other weak-lensing and large-scale-structure datasets, though quantitative predictions require further modeling.

The discovery of dark-sector particles would not by itself falsify FIT-Qd12 if those particles can be interpreted as emergent, projected, semi-projecting, or residue modes of the underlying Qd12/RTF operator geometry. FIT-Qd12 would be strongly constrained only if particle dark matter fully accounts for all dark-sector phenomena without requiring non-projecting curvature, boundary effects, dimensional-collapse structure, or Qd12-sector emergence.

13.5 Directional Effects in Cosmic Expansion and Dark Energy

Dark-energy-like behavior in FIT-Qd12 is interpreted as Qd12 substrate pressure expressed through APS ledger dynamics. The uncollapsed Qd12 substrate supplies the pressure, while APS-compatible ledger dynamics regulate how that pressure appears as four-dimensional cosmic acceleration.

Possible observational tests include

- Anisotropy in the Hubble parameter at low redshift,
- Directional dependence in supernova distance measurements,
- Redshift-dependent deviations in the effective dark-energy equation of state,
- Correlations between expansion anisotropy and large-scale structure,
- And consistency between expansion history, CMB boundary-imprint residues, and lensing data.

The leading dark-energy behavior may appear approximately Λ -like. Higher-order behavior may include weak redshift dependence, modulation, or relaxation through ledger pressure, spectral trace mismatch, boundary tension, and information deposition.

Canonical Statement

13.5.1 FIT-Qd12 allows dark-energy acceleration to slow, but not to reverse under admissible boundary-substrate dynamics.

Therefore, a measured slowing or mild evolution of dark-energy acceleration could be compatible with FIT-Qd12 if it can be connected to boundary-substrate dynamics. A full reversal into global contraction would strongly challenge the admissible dark-energy realization unless accompanied by a consistent mechanism involving substrate-pressure failure, APS ledger breakdown, or loss of spectral stability.

13.6 Gravitational-Wave Propagation and Echo-Like Residuals

Boundary curvature, mass-gap structure, and DVz-regulated near-horizon compression may influence gravitational-wave propagation or post-ringdown behavior.

Potential signatures include

- Direction-dependent propagation effects,

- Small deviations in waveform structure,
- Post-ringdown residuals,
- Inverse-mass-scaled frequency spacing,
- And spectral-comb or echo-like features under specific boundary-reflection conditions.

Gravitational-wave echoes are a conditional signature of the boundary-regulated near-horizon sector, not an unconditional requirement of the full theory. FIT-Qd12 predicts that if APS-compatible boundary response, spectral mass-gap structure, and DVz-regulated near-horizon compression generate nonzero effective reflectivity in the observable gravitational-wave band, then post-ringdown signals may contain echo-like residuals, inverse-mass-scaled frequency spacing, or spectral-comb structure.

Absence of detectable echoes constrains the boundary-reflection realization and places upper bounds on effective reflectivity, but does not by itself falsify the full Qd12operator framework.

Canonical Statement:

13.6.1 A single tentative echo candidate is insufficient, and a single null result is not fatal. The FIT-Qd12 gravitational-wave claim concerns population-level, mass-scaled, boundary-regulated residual structure.

Future detectors and extended gravitational-wave catalogs may improve sensitivity to such effects. The strongest support would come from a population-level pattern in which residual spacing scales with compact-object mass and shares parameter consistency with the Qd12spectral-gap and boundary sectors.

13.7 Neutrino Propagation and Fiber-Sector Spectral Deviations

As discussed in Section 11, neutrinos are best framed as fiber-dominant projected modes and phase-sensitive probes of the Qd12 fiber-boundary sector. Their weak interaction, long coherence length, and oscillation structure make them useful observational channels for testing subtle operator-level effects.

Potential observational consequences include

- Energy-dependent deviations from standard oscillation behavior,
- Baseline-dependent phase residuals,
- Environment-dependent decoherence effects,
- Possible directional variation in flux or oscillation probabilities,

- High-energy flavor-ratio deviations,
- And sterile-like boundary-suppressed behavior.

These effects may be investigated in experiments such as JUNO, DUNE, Hyper-Kamiokande, IceCube, and related neutrino observatories. Quantitative predictions require further development.

FIT-Qd12 does not require neutrinos to be a separate class of “information particles.” Instead, their oscillations, coherence behavior, and phase sensitivity may encode information about fiber-sector phase geometry, chirality, mass-gap structure, and APS-compatible ledger coupling. Null neutrino results constrain the fiber-ledger coupling channel; they do not by themselves falsify the full Qd12 operator framework.

13.8 Lensing and Interface-Related Effects

The structure of the DVz interface, intermediate-layer curvature, and non-projecting spectral contributions may influence gravitational lensing.

Potential signatures include

- Small anisotropies in lensing shear,
- Correlations between lensing patterns and large-scale structure,
- Deviations from isotropic lensing expectations,
- Curvature-first contributions to halo or cluster lensing,
- And weak-lensing residuals correlated with voids, filaments, or collapse-imprinted geometry.

These effects are expected to be subtle and detectable only through statistical analysis of large datasets. FIT-Qd12 does not claim that current lensing anomalies uniquely establish the framework. Instead, lensing data provide a major test of whether dark-sector behavior can be modeled as non-projecting or weakly projecting spectral curvature rather than as a fully independent particle-only component.

13.9 Cross-Domain Correlations

A key feature of the FIT-Qd12 framework is the potential for correlated signatures across multiple observational domains. Because diverse phenomena arise from a common operator structure, one may look for:

- Alignment between CMB asymmetries and large-scale structure,
- Correlations between velocity fields and expansion anisotropy,

- Links between neutrino behavior and large-scale geometry,
- Shared parameters between lensing residuals and dark-energy evolution,
- Compatibility between gravitational-wave residual structure and boundary/mass-gap parameters,
- And consistency between CMB boundary-imprint residues and dark-sector curvature scales.

Detection of consistent cross-domain correlations could provide stronger support than any individual observation.

The decisive empirical question is not whether FIT-Qd12 can explain one anomaly. The decisive question is whether independent observational domains prefer a shared Qd12 operator-geometric parameter structure.

Canonical Statement

13.9.1 FIT-Qd12 is not proven by fitting isolated anomalies. It is validated by recovering established physics while explaining otherwise disconnected experimental residuals as correlated consequences of one admissible Qd12 operator geometry.

13.10 Summary of the Observational Program

The FIT-Qd12 framework suggests a broad program of empirical investigation spanning

- Cosmic microwave background measurements,
- Large-scale structure surveys,
- Gravitational-wave observations,
- Neutrino experiments,
- Dark-sector lensing tests,
- And precision cosmology datasets.

These consequences are:

- Testable in principle,
- Potentially cross-correlated,
- And motivated by a unified structural framework.

At present, they should be interpreted as a program for empirical investigation rather than as uniquely confirmed signatures. A failed or absent signature in one sector constrains the corresponding realization, parameter channel, or observational mechanism; it does not automatically falsify the full operator framework unless the failure produces global incoherence across the shared Qd12 parameter structure.

The strongest empirical support would come from cross-domain parameter coherence: a single admissible Qd₁₂ operator geometry should recover established physics while organizing otherwise disconnected residuals across CMB, large-scale structure, dark-sector lensing, expansion history, gravitational waves, neutrinos, and information-preserving boundary dynamics.

14. Collapse Mechanics, Boundary Conditions, and Structural Stability

Within the FIT-Qd₁₂ framework, dimensional collapse is formulated as a localized transition in spectral organization occurring at interfaces between adjacent operator regions. This transition is described through the interplay of

- Boundary-compatible operator domains,
- Intermediate-layer coupling,
- And DVz-regulated spectral localization.

Collapse does not occur uniformly throughout the operator system. Instead, it is restricted to regions in which admissibility conditions can be approached within the combined spectral–geometric structure. This section develops the constraints that localize collapse, the role of interface geometry, and the implications for stability within the stated framework.

14.1 Adjacency Geometry and Boundary Structure

Interactions between adjacent Qd₁₂ regions are mediated by the layered interface:

$$Qd_{12}(A) \mid NE(A) \mid Ledger(A) \mid DVz \mid Ledger(B) \mid NE(B) \mid Qd_{12}(B)$$

As established in Section 3, the DVz interface may exhibit variation in its effective separation.

This variation is associated with:

- Regions of reduced separation, which may support localized spectral concentration,
- Regions of increased separation, which may suppress such concentration.

These features define candidate geometrically admissible regions where collapse transitions may occur, while other regions remain stable under the same global admissibility constraints.

14.2 Localization of Collapse Channels

Collapse is associated with regions where DVz

geometry permits sufficient spectral localization to approach admissibility conditions.

At an effective level, this may be described by a separation function $d(x)$, where:

- Smaller values correspond to enhanced localization potential,
- Larger values correspond to suppression of admissible transitions.

Local minima of $d(x)$ identify candidate collapse channels, while regions of larger separation act as stabilizing domains. This formulation emphasizes that collapse is intrinsically localized within the model, arising from combined spectral and geometric constraints.

14.3 Spectral Conditions for Collapse

Dimensional collapse is not determined by geometry alone, but by the interaction of spectral structure with boundary and intermediate-layer dynamics.

Rather than a fixed inequality, collapse is characterized by approach to an admissibility boundary defined by:

- Boundary-associated curvature contributions,
- Intermediate-layer NE coupling,
- DVz-regulated localization,
- And spectral mode organization.

These contributions may be summarized schematically by a functional dependence: $F(x, t) = F(K_boundary, C_NE, d(x), \text{spectral structure})$

Collapse is modeled as occurring when this combined structure approaches a regime in which the pre-collapse operator configuration can no longer be maintained. This replaces earlier threshold-based formulations with a structural admissibility condition.

14.4 Constraints on Collapse Configurations

The adjacency structure imposes constraints on admissible collapse configurations. In particular:

- Configurations localized along a single interface are favored within the admissible framework,
- Configurations requiring simultaneous multi-directional alignment are suppressed within the admissible framework,
- Regions of large DVz separation are effectively excluded from admissible transitions within the model.

These constraints arise from operator compatibility and interface geometry, rather than from externally imposed rules.

14.5 Symmetry and Spectral Configuration

The symmetry properties of the resulting effective configuration depend primarily on spectral organization at the time of transition. At an effective level, approximately balanced spectral configurations are associated with near-isotropic outcomes, and imbalanced configurations are associated with anisotropic structure.

This dependence may be expressed schematically through a compression functional: $C(x) = C(\Psi_1, \Psi_2, \partial \square C_{NE})$ where contributions from adjacent regions and intermediate-layer structure influence the resulting configuration. Interface geometry influences the distribution of such configurations but does not uniquely determine the outcome.

14.6 Collapse Within and Across Operator Regions

Collapse events may be categorized relative to the underlying operator structure. Within a single operator region:

Multiple collapse events may share aspects of the same underlying spectral configuration, potentially producing correlated effective features.

Across distinct regions

Interaction is strongly constrained by DVz-mediated separation and boundary compatibility, thereby limiting cross-region coupling.

These distinctions provide a structural basis for understanding possible correlations without requiring strong inter-region interaction.

14.7 Locality of Collapse Events

Collapse events are confined to localized regions of the interface within the admissible framework.

Formally, one may define: $C = \{ (x, t) : F(x, t) \text{ approaches admissibility boundary} \}$

Under the constraints described above, this set remains localized to specific regions associated with admissible channels. This locality supports the conclusion that collapse does not generically extend across independent regions.

14.8 Suppression of Cascading Collapse

Because collapse depends on localized admissibility conditions

- Simultaneous transitions across multiple independent regions are strongly suppressed,
- Propagation of collapse across extended regions is not generically supported,
- Large-scale cascading behavior is not expected within admissible dynamics.

These features are modeled as following from the combined effects of spectral boundedness, boundary compatibility, and DVz-regulated interaction.

14.9 Statistical Bias in Collapse Configurations

While symmetry is associated with spectral balance, interface geometry may introduce a bias in the distribution of outcomes.

In particular

- Configurations with more uniform interface structure tend to favor symmetric outcomes,
- Configurations with stronger gradients tend to favor anisotropic outcomes.

This produces a statistical bias, not a deterministic rule.

14.10 Structural Stability of the Extended System

The stability of the extended operator system is supported by several interacting features:

- Localization of admissible transitions,
- Suppression of non-admissible configurations,
- Boundary-mediated separation of operator regions,
- DVz-regulated interaction.

These features support the conclusion that local transitions do not generically destabilize the global structure.

14.11 Summary of Collapse Structure

Within the FIT-Qd₁₂ framework:

- Collapse is modeled as a localized, non-singular transition governed by spectral and boundary conditions,
- Admissible collapse channels are associated with DVz geometry and spectral organization,
- Symmetry of resulting configurations depends on spectral balance rather than geometry alone,
- Collapse events remain localized and do not generically propagate,

- And global stability is supported by the same structural constraints governing local dynamics.

These results provide a consistent operator-theoretic description of collapse that avoids singular behavior while remaining compatible with admissibility, spectral boundedness, and information-preserving evolution.

15. Effective Cosmology from Collapse Geometry, Boundary Dynamics, and Intermediate-Layer Curvature

Within the FIT-Qd₁₂ framework, dimensional collapse is modeled as inducing a reorganization of spectral structure that, upon projection to an effective four-dimensional description, may give rise to residual contributions associated with intermediate-layer NE/DVz curvature, uncollapsed Qd₁₂ substrate pressure, and APS-compatible boundary/ledger dynamics.

These contributions may appear as effective sources in the post-collapse regime and may influence gravitational dynamics, large-scale structure, and cosmic expansion. Two primary effective structures may be identified:

- An intermediate-layer curvature contribution, inherited from pre-collapse spectral organization and associated with dark-matter-like gravitational behavior,
- And a boundary–substrate pressure contribution, associated with the uncollapsed

Qd₁₂Matrix Field and regulated through APS-compatible ledger dynamics, associated with dark-energy-like expansion behavior.

These are not independent fundamental fields. They are effective descriptions arising from projection of the underlying operator geometry into the four-dimensional regime. The discussion in this section is interpretive and is not required for the mathematical closure results established in this paper. The original section framed effective cosmology through intermediate-layer curvature and boundary contributions; this revision updates that framing to reflect the refined canonical positions on dark matter and dark energy.

15.1 Effective Gravitational Dynamics

In the emergent four-dimensional regime, gravitational dynamics may be represented schematically as an effective relation

$$G_{\{\mu\nu\}} \approx 8\pi G (T_{\{\mu\nu\}}^{\{\text{matter+rad}\}} + C_{\{\mu\nu\}}^{\{\text{eff}\}} + P_{\{\mu\nu\}}^{\{\text{Qd12} \rightarrow \text{ledger}\}}) \text{ where:}$$

- $T_{\{\mu\nu\}}^{\{\text{matter+rad}\}}$ denotes conventional matter and radiation,
- $C_{\{\mu\nu\}}^{\{\text{eff}\}}$ represents projected or weakly projecting curvature contributions associated with intermediate-layer NE/DVz structure,
- $P_{\{\mu\nu\}}^{\{\text{Qd12} \rightarrow \text{ledger}\}}$ represents the effective boundary–substrate pressure contribution associated with the uncollapsed Qd₁₂ Matrix Field and its registration through APS-compatible ledger dynamics.

This expression is not a fundamental field equation, but a phenomenological effective description capturing how operator-level structure may appear after projection. It should not be interpreted as adding new independent fields to the theory. Instead, it organizes effective four-dimensional behavior arising from the same underlying Qd₁₂ operator system.

15.2 Symmetry Dependence of Effective Contributions

The structure of the effective contributions depends on the spectral configuration at the time of collapse. Approximately symmetric spectral configurations are associated with near-isotropic effective terms. Asymmetric configurations may introduce directional variation in projected curvature, boundary response, and the effective expression of substrate pressure.

These features are interpreted as arising from underlying spectral organization rather than from externally imposed cosmological parameters. Collapse geometry, DVz structure, intermediate-layer curvature, and APS-compatible boundary dynamics jointly determine how the effective post-collapse cosmology is expressed.

15.3 Directional Dependence in Effective Expansion

In configurations with anisotropic spectral structure, the effective expansion rate may exhibit weak directional dependence.

This may be represented schematically as: $H = H(t, \hat{n})$ with corresponding modulation of effective density contributions.

To leading order: $\Delta H / H \sim O(\delta)$

Where δ encodes anisotropy inherited from the underlying spectral configuration.

Such effects are expected to be small and detectable only through precision cosmological observations. Within the refined dark-energy interpretation, any directional dependence should be understood as modulation of the effective boundary–substrate pressure, not as evidence for an independent dark-energy field.

15.4 Interpretation of Large-Scale Cosmological Features

Within this framework, certain large-scale cosmological features may be interpreted as consistent with collapse-imprinted structure, including

- Variation in inferred expansion rates across datasets,
- Large-scale anisotropies in structure and background radiation,
- Directional correlations in cosmological observables,
- Weak redshift-dependent behavior in effective dark-energy parameterizations,
- And correlations between expansion history, lensing, and large-scale structure.

However

- These features are not uniquely predicted by the framework,
- Alternative explanations within standard cosmology remain viable,
- And quantitative agreement requires further modeling.

These interpretations should therefore be regarded as structural correspondences, not definitive identifications. FIT-Qd₁₂ is not validated by fitting isolated anomalies. Its empirical relevance depends on whether multiple observational domains can be organized by a shared Qd₁₂ operator-geometric parameter structure.

15.5 Effective Dark Matter Interpretation

The term $C_{\{\mu\nu\}}^{\{\text{eff}\}}$ may be interpreted as contributing to gravitational behavior analogous to dark matter.

Within this interpretation

- It is associated with projected, weakly projecting, or non-projecting curvature linked to intermediate-layer NE/DVz structure,

- It may contribute to gravitational dynamics without requiring additional fundamental particle species at the operator level,
- It may produce extended, non-uniform, anisotropic, or filamentary distributions in the effective description,
- And it may influence gravitational lensing, halo structure, void behavior, and large-scale structure formation.

This provides a curvature-first interpretation of dark-matter-like behavior while remaining compatible with observational constraints.

The phrase “curvature-first” is important. FIT-Qd₁₂ does not require an absolute no-particle claim. If dark-sector particles or particle-like excitations are observed, they may still be compatible with the framework if they arise as emergent, projected, semi-projecting, or residue modes of the underlying Qd₁₂/RTF operator geometry.

FIT-Qd₁₂ would be strongly constrained only if particle dark matter fully accounts for all dark-sector phenomena without requiring non-projecting curvature, boundary effects, dimensional-collapse structure, or Qd₁₂-sector emergence.

15.6 Effective Dark Energy Interpretation

The term $P_{\{\mu\nu\}}^{\{\text{Qd12} \rightarrow \text{ledger}\}}$ may be interpreted as contributing to dark-energy-like behavior.

Within the refined canonical interpretation, dark energy is a boundary–substrate effect:

Dark energy = Qd₁₂substrate pressure expressed through APS ledger dynamics.

The uncollapsed Qd₁₂Matrix Field supplies the deeper pressure source, while

APS-compatible ledger dynamics regulate how that pressure is registered inside the collapsed four-dimensional universe. In the effective description, this contribution:

- May influence the rate of expansion,
- May produce accelerated expansion under appropriate conditions,
- May appear approximately Λ -like at leading order,
- May exhibit weak redshift dependence, modulation, or relaxation through ledger pressure, spectral trace mismatch, boundary tension, and information deposition,

- And may exhibit weak directional dependence if the underlying spectral configuration is anisotropic.

This provides a structural interpretation of dark-energy-like behavior without introducing a fundamental cosmological constant or independent scalar field at the operator level. Λ -like behavior, evolving dark energy, scalar-field-like equations of state, early-dark-energy-like effects, or mild redshift-dependent modulation may be treated as possible effective four-dimensional parameterizations of the same deeper boundary–substrate mechanism.

Canonical Statement

Uncollapsed Qd₁₂ substrate supplies the pressure; APS ledger dynamics regulate how that pressure appears as 4D cosmic acceleration. A further admissibility consequence follows

FIT-Qd₁₂ allows dark-energy acceleration to slow, relax, modulate, or asymptotically flatten, but not to reverse under admissible boundary–substrate dynamics.

A reversal into global contraction would require failure or sign reversal of the persistent uncollapsed Qd₁₂ substrate pressure, breakdown of APS ledger admissibility, or loss of mass-gap/spectral stability.

15.7 Coupling Between Curvature and Boundary–Substrate Contributions

The effective curvature and boundary–substrate contributions are not independent within the interpretive model.

They

- Are associated with the same underlying Qd₁₂ operator system,
- Are jointly influenced by collapse geometry and spectral organization,
- Are regulated by DVz structure and boundary compatibility,
- And may contribute together to effective cosmological evolution.

Their interplay influences the large-scale behavior of the emergent spacetime. For example, non-projecting curvature may shape structure formation and lensing, while boundary–substrate pressure influences expansion history. Both effects may carry imprints of collapse geometry and may therefore be tested through cross-domain correlations.

The decisive empirical question is whether the same operator-geometric parameter structure can organize

dark-matter-like lensing, large-scale structure, dark-energy-like expansion, CMB boundary-imprint residues, and other cosmological observables.

15.8 Observational Implications and Limitations

The framework suggests several potential observational signatures

- Small anisotropies in expansion rate,
- Directional dependence in large-scale structure,
- Correlations across cosmological observables,
- Lensing residuals associated with non-projecting curvature,
- Λ -like expansion with possible weak redshift dependence,
- Slow relaxation or modulation of dark-energy acceleration,
- And cross-domain consistency between expansion history, CMB imprints, lensing, and structure formation.

At present

- These implications are primarily qualitative,
- Detailed quantitative predictions require further development,
- And comparison with observational data remains an open program.

These results define a program for empirical investigation, rather than a completed observational theory.

A single observational result should not be treated as automatically confirming or falsifying the full framework. Instead, failed or absent signatures constrain the corresponding realization, parameter channel, or observational mechanism. The strongest empirical support would come from cross-domain parameter coherence across expansion history, lensing, large-scale structure, CMB boundary-imprint structure, and other relevant datasets.

15.9 Summary of Effective Cosmology

Within the FIT-Qd₁₂ framework

- Post-collapse cosmology may include effective contributions from intermediate-layer curvature, DVz-regulated projection, uncollapsed Qd₁₂ substrate pressure, and APS-compatible ledger dynamics;

- Dark matter–like behavior may be interpreted as a curvature–first contribution associated with non-projecting or weakly projecting spectral curvature, intermediate-layer dynamics, dimensional collapse, and DVz-regulated projection;
- Dark-sector particles, if discovered, would not by themselves falsify FIT-Qd₁₂ if they can be interpreted as emergent, projected, semi-projecting, or residue modes of the Qd₁₂/RTF operator geometry;
- Dark energy–like behavior may be interpreted as Qd₁₂ substrate pressure expressed through APS ledger dynamics;
- The leading dark-energy contribution may appear Λ -like, while higher-order behavior may include small modulation, redshift dependence, or relaxation through ledger pressure, spectral trace mismatch, boundary tension, and information deposition;
- FIT-Qd₁₂ allows dark-energy acceleration to slow, but not to reverse under admissible boundary–substrate dynamics;
- Symmetry properties of the effective universe may reflect underlying spectral configuration;
- And large-scale observables may carry signatures of collapse geometry.

These results provide a consistent connection between operator-level structure and effective cosmological behavior, while remaining compatible with admissibility constraints, spectral boundedness, information-preserving evolution, and observational uncertainty.

16. Neutrinos in the Qd₁₂ Operator Framework

Section 11 introduced neutrinos as fiber-dominant, boundary-sensitive probes at the conceptual level. The present section restates the neutrino sector in a more explicitly phenomenological form, emphasizing effective CPTP evolution, possible oscillation signatures, and observational consequences.

Within the FIT-Qd₁₂ framework, neutrinos are best understood as **fiber-dominant projected modes** whose weak interaction, long coherence length, and phase sensitivity make them well suited to reflect features of the underlying operator geometry. Their behavior may provide access to fiber-sector phase structure, chirality, mass-gap organization, APS-compatible ledger coupling, and intermediate-layer dynamics.

This section develops how neutrino propagation may be influenced by such effects, how these modifications may be modeled within an admissible operator framework, and how they may connect to observable phenomena. The discussion is phenomenological and is not required for the mathematical closure results established in this paper. The original version already framed neutrinos as weakly interacting probes of boundary-coupled dynamics; this revision updates the terminology to align with the current canonical position that neutrinos are fiber-sector projected modes, not a separate class of “information particles.”

16.1 Neutrino Sector in the Operator Framework

At an effective level, the physical Hilbert space may be decomposed schematically as:

$H \approx H_v \oplus H_{\text{non-}v}$ where:

- H_v denotes neutrino degrees of freedom,
- $H_{\text{non-}v}$ includes the remaining sectors of the Standard Model.

This decomposition is approximate and reflects an effective separation of degrees of freedom rather than an exact factorization.

Neutrinos are distinguished by:

- Absence of electric and color charge,
- Weak-only interaction at leading order,
- Long coherence lengths over extended baselines,
- Sensitivity to oscillation phase,
- And dependence on mass-splitting and mixing structure.

These features allow neutrinos to remain sensitive to subtle operator-level effects that may be suppressed, screened, or averaged out in more strongly interacting sectors.

In FIT-Qd₁₂, this sensitivity is associated primarily with the Fiber sector. The Fiber sector acts as a phase-sensitive channel governing chirality, coherence, mass-gap structure, modular ordering, and mixing behavior. In this sense, the fiber sector may be described analogically as an “antenna”: it does not literally gather information as an independent agent, but it provides the spectral channel through which neutrino behavior can encode, transport, and deposit information into the boundary-compatible ledger structure.

16.2 Boundary-Coupled and Fiber-Coupled Evolution

The boundary, or ledger, may be represented as an operator algebra acting on the full system. Its influence on neutrino states may be modeled at an effective level by a completely positive, trace-preserving map:

$\Phi_L : \rho \rightarrow \rho'$ subject to:

- Gauge covariance,
- Compatibility with the spectral operator D_{12} ,
- Locality with respect to the boundary structure,
- Compatibility with fiber-sector phase evolution,
- And boundedness conditions ensuring admissibility.

This map may be interpreted as representing an effective interaction with an extended operator environment. It preserves total probability while allowing reduced descriptions to exhibit non-unitary features, such as phase damping or partial decoherence. Such reduced behavior should not be interpreted as fundamental information loss. Within the full Qd₁₂ operator system, evolution remains information-preserving under the stated admissibility conditions.

16.3 Sector-Dependent Sensitivity

Under admissibility constraints, different sectors of the Standard Model may couple differently to boundary and fiber-sector dynamics.

- Strongly interacting or rapidly decohering sectors tend to average out boundary-level effects.
- Electromagnetically active sectors may be screened by stronger environmental interactions.
- Weakly interacting and highly coherent sectors, such as neutrinos, may retain sensitivity over long propagation distances.

This suggests that neutrinos may serve as a particularly sensitive observational channel, though not the only one in principle. Their significance lies not in replacing standard neutrino physics, but in providing a precision probe of fiber-sector phase geometry and boundary-compatible spectral structure.

16.4 Effective Decoherence and Reduced Interaction Modes

Boundary-coupled or fiber-coupled evolution may introduce partial decoherence into neutrino propagation in reduced descriptions.

At an effective level, one may consider a decomposition:

$$H_v \approx H_{\text{active}} \oplus H_{\text{eff}}$$

where H_{active} denotes standard active neutrino behavior and H_{eff} denotes components whose interaction strength is reduced, suppressed, or weakly projecting in the effective description.

Under CPTP evolution:

- Components in H_{active} evolve approximately unitarily,
- Components in H_{eff} may exhibit reduced interaction strength,
- Fiber-sector phase shifts may modify oscillation behavior,
- And boundary-coupled effects may produce partial decoherence or apparent damping.

This may produce phenomenology that resembles “sterile-like” behavior. Within

FIT-Qd₁₂, such effects are interpreted as environment-dependent, boundary-suppressed, or weakly projecting fiber-sector modes, rather than as automatic evidence for additional independent fundamental particle species.

This distinction is important. FIT-Qd₁₂ does not require sterile-like behavior, nor does it exclude it. If sterile-like signatures are observed, the relevant question is whether they can be mapped to fiber-sector phase structure, APS-compatible boundary coupling, or weakly projecting Qd₁₂ modes.

16.5 Modified Oscillation Phenomenology

In the presence of boundary or fiber-sector coupling, neutrino evolution may be represented schematically as:

$$\rho(L) = E_v [U(L) \rho(0) U^\dagger(L)]$$

where:

- $U(L)$ is the standard unitary oscillation operator,
- E_v denotes an effective CPTP deformation arising from boundary or fiber-sector interaction.

To leading order, this may produce:

- Small deviations from standard oscillation probabilities,
- Energy-dependent modulation,
- Baseline-dependent effects,
- Phase shifts in oscillation behavior,

- Changes in coherence length,
- High-energy flavor-ratio deviations,
- And sterile-like boundary-suppressed signatures.

Such deviations are expected to be subtle and require precision experimental measurements. FIT-Qd₁₂ does not require large departures from standard three-flavor oscillation physics. Instead, the expected signal, if present, would be a small structured residual whose parameters can be linked to fiber-sector and boundary-coupling scales.

16.6 Environmental and Directional Dependence

Because boundary, fiber-sector, and intermediate-layer structure may vary across the effective spacetime description, the strength of coupling may depend on:

- Neutrino energy,
- Propagation distance,
- Local curvature environment,
- Large-scale anisotropy in the underlying configuration,
- Fiber-sector phase state,
- And boundary/ledger coupling strength.

This suggests the possibility of:

- Environment-dependent oscillation behavior,
- Weak directional modulation of propagation,
- Baseline-dependent phase residuals,
- Correlations with large-scale cosmological structure,
- And possible differences between terrestrial, solar, atmospheric, supernova, and astrophysical neutrino channels.

These effects remain to be quantified within detailed models. At the level of Canonical Series I, they are presented as observational templates rather than established signatures.

16.7 Relation to Experimental Observations

The framework provides a possible interpretation of certain deviations from standard oscillation expectations, including

- Tensions between appearance and disappearance measurements,
- Small deviations from three-flavor fits,
- Irregularities observed in short-baseline experiments,

- Energy-dependent phase residuals,
- High-energy astrophysical flavor-ratio deviations,
- And sterile-like propagation behavior.

However:

- The framework does not uniquely explain these anomalies,
- Alternative interpretations remain viable,
- Quantitative comparison requires further modeling,
- And null results constrain the fiber-ledger coupling channel rather than falsifying the full Qd₁₂ operator framework.

Future experiments, including JUNO, DUNE, Hyper-Kamiokande, IceCube, and related neutrino observatories, may provide relevant tests of these effects. The strongest support would not come from a single neutrino anomaly, but from a pattern in which neutrino-sector residuals share parameters with the broader Qd₁₂ boundary, fiber, mass-gap, dark-sector, and cosmological structure.

16.8 Connection to Cosmological Observables

Neutrino propagation occurs within the same effective structure that governs large-scale cosmological behavior.

As a result:

- Boundary and intermediate-layer effects influencing expansion and curvature may also affect neutrino propagation,
- Fiber-sector phase structure may influence oscillation and coherence behavior,
- Correlations between neutrino measurements and cosmological anisotropies may arise,
- Combined multi-domain analysis may provide stronger constraints,
- And neutrino behavior may provide an independent probe of collapse-imprinted or boundary-regulated structure.

These connections define an important direction for future investigation. In FIT-Qd₁₂, neutrino observations are most powerful when compared against CMB, large-scale structure, dark-sector lensing, expansion history, and gravitational-wave constraints. The decisive question is whether neutrino-sector behavior can be incorporated into the same shared operator-geometric parameter structure.

16.9 Summary of Neutrino Dynamics

Within the FIT-Qd₁₂ framework:

- Neutrinos are best understood as fiber-dominant projected modes rather than as a separate ontological class of information particles,
- Their weak interaction, long coherence length, oscillation behavior, and phase sensitivity make them natural probes of the fiber-boundary sector,
- The fiber sector acts analogically as a phase-sensitive channel or “antenna,” providing the spectral route through which neutrino behavior can encode information about the underlying Qd₁₂ operator geometry,
- Their evolution may include effective CPTP-type contributions arising from interaction with an extended operator environment,
- Partial decoherence or phase modification may produce sterile-like phenomenology without requiring additional independent fundamental particles,
- Observational consequences may include small, environment-dependent deviations from standard oscillation models,
- And null neutrino results constrain the fiber-ledger coupling channel rather than falsifying the full FIT-Qd₁₂operator framework.

These features provide a potential empirical window into the underlying operator structure while remaining consistent with admissibility constraints, spectral boundedness, information-preserving evolution, and current experimental uncertainty.

17. DVz Geometry, Collapse Localization, and Orientation

Within the FIT-Qd₁₂ framework, dimensional collapse is modeled as being constrained by the geometry of the Dimensional Viscosity Zone (DVz), particularly through regions where effective separation between adjacent operator domains is reduced. These regions may support enhanced spectral localization and therefore play an important role in identifying where admissible collapse transitions may occur.

The DVz thickness is not assumed to be uniform across an interface. For anisotropic or elongated operator regions, it may vary with orientation, producing direction-dependent conditions for spectral localization. These conditions may influence, but do not uniquely determine, the outcome of collapse.

17.1 DVz Neck Regions as Preferred Collapse Channels

Collapse is associated with regions where the DVz thickness function $d(x)$ approaches a local minimum. Constricted regions may support enhanced spectral localization and steeper effective gradients. Extended regions may distribute spectral structure more broadly and suppress strong localization.

Such regions may be referred to as DVz necks, representing locations where admissibility conditions for collapse are more readily approached. However, collapse is not guaranteed at every such location, and the majority of the interface remains non-collapsing under admissible dynamics.

17.2 Orientation Dependence of DVz Geometry

For elongated operator regions, DVz geometry may exhibit directional variation. More constricted orientations may correspond to stronger localization potential. More extended orientations may correspond to more distributed spectral interaction.

These geometric differences may influence how spectral modes organize during compression and may affect the likelihood of different collapse configurations. They should be interpreted as features of the operator interface, not as fixed geometric axes in emergent spacetime.

17.3 Collapse Orientation and Symmetry Outcomes

The symmetry properties of an emergent effective configuration depend primarily on the spectral organization at the time of collapse.

At an effective level, this dependence may be expressed schematically through a compression functional

$C(x) = C(\Psi_1, \Psi_2, \partial_{\square} C_{NE})$ where:

- Ψ_1 and Ψ_2 represent spectral contributions from adjacent regions,
- $\partial_{\square} C_{NE}$ encodes intermediate-layer structure.

Within this framework:

- More balanced spectral configurations are associated with approximately symmetric outcomes,
- More imbalanced configurations are associated with anisotropic structure.

DVz geometry influences this balance by shaping spectral distribution, but it does not uniquely determine the resulting configuration.

17.4 Statistical Bias from Interface Geometry

The geometry of the DVz interface may introduce a statistical bias in collapse outcomes:

- Constricted regions may favor localized, anisotropic configurations.
- Extended regions may favor more uniform, symmetric configurations.

Thus, interface geometry may influence the probability of different collapse regimes, but does not deterministically fix the outcome. At an effective level, collapse likelihood depends on spectral alignment and admissibility conditions, rather than on geometric extent alone.

17.5 Suppression of Non-Admissible Regions

Regions where DVz separation remains large may act as stabilizing domains. In such regions:

- Spectral localization may be insufficient to approach admissibility conditions,
- Effective gradients may be reduced,
- Collapse transitions are suppressed within the admissible framework.

This includes regions where multiple directions compete, producing distributed rather than localized spectral structure. As a result, collapse remains localized to specific admissible channels, and broadly distributed configurations are not generally favored.

17.6 Constraints on Multi-Region Collapse

The combined geometric and spectral constraints limit the occurrence of complex collapse configurations.

In particular:

- Simultaneous collapse across multiple independent interface regions is disfavored,
- Propagation of collapse across extended adjacency networks is not generically supported,
- Highly symmetric multi-region configurations are suppressed under typical admissible conditions.

These features are modeled as following from DVz-regulated localization and boundary compatibility, and they contribute to overall system stability.

17.7 Observational Interpretation and Limitations

Anisotropic features observed in cosmology, such as large-scale asymmetries or directional correlations, may be interpreted as consistent with collapse occurring under anisotropic interface conditions.

However:

- The framework does not uniquely identify any specific observed feature with a particular collapse orientation,
- Multiple configurations may produce similar effective signatures,
- And quantitative comparison requires detailed modeling.

Observational data therefore provide constraints on admissible configurations, rather than a unique reconstruction of collapse geometry.

17.8 Summary of DVz Geometry and Collapse Orientation

Within the FIT-Qd₁₂ framework:

- Collapse is modeled as localized to regions where DVz thickness is minimized,
- Interface geometry may influence the distribution of spectral localization,
- Symmetry outcomes depend on spectral configuration rather than geometry alone,
- Orientation introduces statistical bias but not determinism,
- And non-admissible regions are suppressed through DVz-regulated structure.

These features provide a consistent operator-geometric description of collapse localization and orientation, while remaining compatible with admissibility constraints, spectral boundedness, and observational uncertainty.

18. Collapse Orientation and Observational Cosmology

Within the FIT-Qd₁₂ framework, the spectral configuration and interface geometry at the time of dimensional collapse may imprint residual structure on the emergent effective universe. In particular, anisotropic spectral configurations may give rise to directional features in large-scale observables, while more symmetric configurations yield approximately isotropic outcomes.

These effects may be associated with the combined influence of:

- DVz-regulated collapse localization,
- Intermediate-layer NE curvature contributions,
- APS-compatible boundary/ledger dynamics,

- Fiber-sector phase structure,
- And Qd12 substrate pressure expressed through the post-collapse boundary system.

This section outlines how such imprints may manifest observationally and how they can be examined across multiple domains. The discussion is interpretive and observational. It is not required for the mathematical closure results established in this paper. The original section already framed observational cosmology in terms of collapse orientation, cross-domain alignment, and failure modes; this revision updates the language to align with the refined canonical positions on CMB interpretation,

dark-sector constraints, dark-energy behavior, neutrinos, gravitational-wave echoes, and sector-level falsification.

18.1 CMB Boundary-Imprint Signatures

Anisotropic spectral configurations at collapse may produce large-scale asymmetries or residual boundary-imprint structure in the cosmic microwave background (CMB).

However, the observed CMB should not be treated as a direct or complete image of the Qd12 boundary record.

Canonical Statement

The CMB is a slice, not the whole ledger.

Equivalently:

18.1.1 The observed CMB is a projected time-slice of boundary-imprinted radiation, not a complete image of the Qd12 boundary structure.

The observed CMB is a past-light-cone slice through the post-collapse radiation field, filtered by our four-dimensional location, last-scattering projection, line-of-sight gravitational lensing, late-time effects, foregrounds, calibration, and cosmic variance. Any Qd12 boundary imprint should therefore be treated as a projected, evolved, observationally filtered residue rather than as a one-to-one image of the original collapse boundary.

Potential signatures include:

- Hemispherical power asymmetry,
- Alignment of low-order multipoles,
- Localized temperature anomalies,
- Low-multipole phase correlations,
- Parity asymmetry,

- EB/TB polarization rotation,
- And correlations between CMB lensing and large-scale structure.

These features have been reported or discussed in observational analyses and may be consistent with anisotropic initial conditions, but they are not uniquely predicted by the framework. A single CMB anomaly is insufficient. The FIT-Qd12 CMB claim concerns correlated boundary-imprint structure across polarization, phase, parity, temperature, lensing, and large-scale-structure channels.

18.2 Large-Scale Structure and Curvature-First Dark-Sector Contributions

If dark matter-like behavior is interpreted as arising from projected, weakly projecting, or non-projecting curvature contributions, then collapse-imprinted anisotropy may influence large-scale structure.

Possible consequences include:

- Alignment of filamentary structures,
- Anisotropic clustering patterns,
- Non-spherical halo distributions,
- Directional features in void geometry,
- Weak-lensing residuals correlated with large-scale structure,
- And curvature-dominated structure that does not map cleanly onto luminous matter.

Such features are qualitatively consistent with observed cosmic web structure, though detailed quantitative comparison remains an open problem.

Within the refined canonical position, FIT-Qd12 treats dark matter as a curvature-first dark-sector explanation, not as an absolute no-particle claim. If dark-sector particles or particle-like excitations are observed, they may still be compatible with the framework if they arise as emergent, projected, semi-projecting, or residue modes of the underlying Qd12/RTF operator geometry. FIT-Qd12 would be strongly constrained only if particle dark matter fully accounts for all dark-sector phenomena without requiring non-projecting curvature, boundary effects, dimensional-collapse structure, or Qd12-sector emergence.

18.3 Boundary-Substrate Dynamics and Effective Expansion

Dark-energy-like behavior may inherit structure from both the uncollapsed Qd12 substrate and the post-

collapse boundary/ledger system. In the refined canonical position, dark energy is not merely a boundary-induced term; it is a boundary–substrate effect.

Canonical Statement

Dark energy = Qd12substrate pressure expressed through APS ledger dynamics.

Equivalently

18.3.1 Uncollapsed Qd12substrate supplies the pressure; APS ledger dynamics regulate how that pressure appears as 4D cosmic acceleration.

This may lead to

- Weak directional variation in expansion rate,
- Anisotropic contributions to late-time acceleration,
- Correlations between expansion behavior and large-scale structure,
- Λ -like leading behavior with possible small redshift dependence,
- And slow modulation or relaxation of cosmic acceleration.

Because the uncollapsed Qd12substrate supplies persistent pressure, FIT-Qd12 allows dark-energy acceleration to slow, relax, modulate, or asymptotically flatten, but not to reverse under admissible boundary–substrate dynamics.

Canonical Statement

18.3.2 FIT-Qd12 allows dark-energy acceleration to slow, but not to reverse under admissible boundary–substrate dynamics.

These effects are expected to be small and require high-precision cosmological measurements for detection. A measured slowing or mild evolution of dark-energy acceleration could be compatible with FIT-Qd12 if it can be connected to boundary–substrate dynamics. A full reversal into global contraction would strongly challenge the admissible dark-energy realization unless accompanied by a consistent mechanism involving substrate-pressure failure, APS ledger breakdown, or loss of spectral stability.

18.4 Cross-Domain Correlations

A distinguishing feature of the framework is the potential for correlated signatures across independent observational domains, arising from a common underlying operator structure.

In anisotropic configurations, one may look for correlations between:

- CMB large-scale features,
- CMB polarization and lensing structure,
- Galaxy and cluster distributions,
- Velocity fields and bulk flows,
- Expansion anisotropy,
- Dark-sector lensing residuals,
- Neutrino phase or coherence behavior,
- And gravitational-wave residual structure where measurable.

Detection of consistent correlations across independent datasets could provide stronger support than any individual observable.

The central empirical principle is:

18.4.1 FIT-Qd12 is not proven by fitting isolated anomalies. It is validated by recovering established physics while explaining otherwise disconnected experimental residuals as correlated consequences of one admissible Qd12 operator geometry.

Thus, the key question is not whether one anomaly appears, but whether CMB, large-scale structure, lensing, expansion history, neutrino observations, and gravitational-wave channels can be organized through a shared boundary, fiber, DVz, mass-gap, and projection parameter structure.

18.5 Neutrino Signatures

As discussed in Sections 11 and 16, neutrinos are best understood as fiber-dominant projected modes and phase-sensitive probes of the Qd12 fiber-boundary sector.

In the presence of anisotropic structure, possible effects include

- Direction-dependent modulation of oscillation probabilities,
- Environment-dependent decoherence,
- Baseline-dependent phase residuals,
- Energy-dependent coherence shifts,
- Sterile-like boundary-suppressed behavior,
- And correlations between neutrino behavior and large-scale geometry.

These effects provide an independent observational probe of collapse-imprinted structure. However, null

neutrino results constrain the fiber-ledger coupling channel rather than falsifying the full FIT-Qd12 operator framework. The strongest support would come from a pattern in which neutrino-sector residuals share parameters with the broader Qd12 boundary, fiber, mass-gap, dark-sector, and cosmological structure.

18.6 Gravitational-Wave Residuals and Boundary-Regulated Near-Horizon Structure

Boundary-regulated dynamics may influence gravitational-wave propagation or post-ringdown behavior under specific conditions, especially in strong-curvature regimes.

Potential signatures include:

- Late-time post-ringdown residuals,
- Inverse-mass-scaled frequency spacing,
- Spectral-comb structure,
- Small waveform deviations,
- And echo-like features under specific boundary-reflection conditions.

Gravitational-wave echoes are a conditional signature of the boundary-regulated near-horizon sector, not an unconditional requirement of the full theory. If

APS-compatible boundary response, spectral mass-gap structure, and DVZ-regulated near-horizon compression generate nonzero effective reflectivity in the observable gravitational-wave band, then post-ringdown signals may contain echo-like residuals, inverse-mass-scaled frequency spacing, or spectral-comb structure.

Canonical Statement

18.6.1 A single tentative echo candidate is insufficient, and a single null result is not fatal. The FIT-Qd12 gravitational-wave claim concerns population-level, mass-scaled, boundary-regulated residual structure.

Absence of detectable echoes constrains the boundary-reflection realization and places upper bounds on effective reflectivity, but it does not by itself falsify the full Qd12 operator framework.

18.7 Interpretation of Observational Patterns

The framework suggests that certain large-scale anomalies and directional features may be interpreted as consistent with anisotropic collapse configurations.

However:

- No single observed feature is uniquely identified with a specific collapse orientation,
- Multiple configurations may produce similar observational signatures,
- Alternative explanations within standard cosmology remain viable,
- Foregrounds and systematics must be excluded before CMB or large-scale anomalies are interpreted structurally,
- And quantitative comparison requires detailed modeling.

Thus, observational data provide constraints on admissible configurations rather than a unique reconstruction of collapse geometry. A failed or absent signature in one sector constrains the corresponding realization, parameter channel, or observational mechanism; it does not automatically falsify the full operator framework unless the failure produces global incoherence across the shared Qd12 parameter structure.

18.8 Testable Signature: Cross-Domain Consistency

A key empirical signature would be a pattern of coherent cross-domain consistency. This includes

- Alignment of directional features across independent observables,
- Consistent orientation of anisotropy across datasets,
- Shared characteristic scales of deviation from isotropy,
- Compatibility between CMB boundary-imprint parameters and lensing structure,
- Compatibility between expansion-history parameters and boundary-substrate pressure,
- Compatibility between neutrino-sector deviations and fiber-boundary coupling,
- And compatibility between gravitational-wave residuals and mass-gap/boundary parameters.

If such cross-domain consistency is established with high statistical significance, it could support the interpretation of a common underlying origin.

18.9 Symmetric and Anisotropic Outcomes

Within the framework

- Approximately symmetric spectral configurations are associated with near-isotropic cosmological behavior,

- Anisotropic configurations are associated with directional features in observables,
- Both outcomes are admissible,
- And the framework does not assume a priori which is realized.

This point is important for claim discipline. FIT-Qd₁₂ does not require anisotropy to be present. It suggests that if anisotropy exists, it should manifest consistently across domains. If observations converge toward strict isotropy, anisotropic collapse configurations are constrained, but the full operator framework is not automatically falsified.

18.10 Summary of Observational Implications

Within the FIT-Qd₁₂ framework

- Collapse orientation may imprint directional structure on cosmological observables,
- The observed CMB is a slice through boundary-imprinted radiation, not the complete Qd₁₂ boundary record,
- Large-scale structure and lensing may carry signatures of curvature-first dark-sector behavior,
- Dark-energy-like behavior is interpreted as Qd₁₂ substrate pressure expressed through APS ledger dynamics,
- Dark-energy acceleration may slow but does not reverse under admissible boundary–substrate dynamics,
- Neutrinos may provide phase-sensitive probes of fiber-boundary structure,
- Gravitational-wave echoes or spectral-comb residuals are conditional signatures rather than unconditional requirements,
- Correlations between these domains provide a key empirical test,
- And current observations may be broadly consistent with, but do not uniquely establish, this interpretation.

This perspective treats cosmological structure as a potential record of underlying operator dynamics while remaining consistent with observational uncertainty, alternative explanations, and sector-level constraints.

18.10.1 Experimental Anchor — Cross-Domain Alignment Test

The most direct empirical probe of the framework is not any single observable, but the presence or absence of statistically significant cross-domain alignment between independent datasets.

Specifically, the framework suggests that, if collapse-imprinted anisotropy or boundary-imprint structure is present, then

- Preferred directions inferred from the CMB,
- Polarization, phase, parity, and lensing features,
- Large-scale structure anisotropies,
- Bulk velocity flows,
- Dark-sector lensing residuals,
- Neutrino-sector phase or coherence deviations,
- And, where measurable, expansion anisotropy may exhibit consistent orientation and correlated statistical deviations from isotropy.

18.10.2 Failure Mode

If all datasets independently converge to strict isotropy with no statistically significant alignment, then anisotropic collapse configurations would be disfavored within the admissible solution space.

This would constrain the anisotropic collapse-realization channel. It would not automatically falsify the full FIT-Qd₁₂ operator framework, because approximately symmetric collapse configurations are also admissible.

18.10.3 Scope Clarification

The framework does not require anisotropy to be present. It suggests that if anisotropy exists, it must manifest consistently across domains.

Similarly, the framework does not require any single CMB anomaly, neutrino deviation, gravitational-wave echo, or dark-sector residual to appear. These are sector-level test channels. Their absence constrains the corresponding realization or coupling channel. The strongest test of FIT-Qd₁₂ is cross-domain parameter coherence under a shared admissible operator geometry.

19. Falsifiability and Failure Modes

A central requirement of any physically meaningful framework is that it admits clear conditions under which it can be empirically challenged, constrained, or falsified. The present work does not claim verification. Instead, it defines structural consequences and consistency conditions whose failure would challenge

specific realizations of the FIT-Qd12 framework or, in stronger cases, the admissibility of the framework as a unified operator-geometric system.

The falsifiability of FIT-Qd12 is not based on agreement with any single observable. It is based on whether multiple independent observational domains can be coherently organized under one admissible Qd12 operator geometry. A failed or absent signature in one observational sector constrains the corresponding realization, parameter channel, or coupling mechanism. It does not automatically falsify the full framework unless the failure produces global incoherence across the shared Qd12 parameter structure.

Accordingly, failure modes are organized in two levels

- Sector-level constraints, where one observational channel weakens or excludes a specific mechanism;
- And framework-level challenges, where no single admissible Qd12 configuration can jointly account for independent observations without contradiction.

This distinction is essential. FIT-Qd12 is not proven by fitting isolated anomalies, and it is not falsified by the absence of one proposed signature. It is validated or challenged by cross-domain parameter coherence.

Canonical Statement

FIT-Qd12 is not proven by fitting isolated anomalies. It is validated by recovering established physics while explaining otherwise disconnected experimental residuals as correlated consequences of one admissible Qd12 operator geometry.

19.1 Global Isotropy Across Independent Observational Domains

The framework allows both approximately isotropic and anisotropic collapse configurations. Anisotropic collapse is not required. However, if collapse-imprinted anisotropy is present, it should manifest consistently across independent datasets rather than appearing as isolated, unrelated anomalies.

19.1.1 Failure Condition

High-precision observations demonstrate strict statistical isotropy across:

- The cosmic microwave background,
- CMB polarization and lensing channels,
- Large-scale structure,
- Bulk velocity flows,

- Weak-lensing maps,
- And expansion observables,

With no statistically significant cross-domain alignment, preferred directions, or correlated deviations from isotropy.

19.1.2 Implication

This would disfavor anisotropic collapse configurations within the admissible solution space and remove one possible cross-domain signature of the framework.

However, this would not automatically falsify FIT-Qd12. Approximately symmetric collapse configurations remain admissible. The correct conclusion would be that the anisotropic collapse-realization channel is constrained or excluded, not that the full operator framework has failed.

19.2 Absence of Boundary-Induced Gravitational-Wave Signatures

Within the framework, boundary-regulated near-horizon dynamics may admit partial reflection or modification of gravitational-wave propagation under specific conditions, especially in strong-curvature regimes.

Gravitational-wave echoes are not an unconditional requirement of FIT-Qd12. They are conditional signatures of an observable boundary-reflection realization.

19.2.1 Failure Condition

Across accessible scales and sensitivities, gravitational-wave observations:

- Show no evidence of post-ringdown residuals,
- Show no mass-scaled echo-like structure,
- Show no spectral-comb behavior,
- Show no boundary-consistent deviations from classical expectations,
- And increasingly constrain effective boundary reflectivity below observationally meaningful thresholds.

19.2.2 Implication

This would place strong constraints on the boundary-reflection realization of the near-horizon sector. It may exclude specific echo-producing models or place upper bounds on effective Qd12 boundary reflectivity.

It would not, by itself, falsify the full Qd12 operator framework. The core claim is boundary-regulated,

mass-gap-protected, information-preserving near-horizon behavior. Detectable echoes arise only if that boundary response produces nonzero effective reflectivity in the gravitational-wave band.

Canonical Statement

A single tentative echo candidate is insufficient, and a single null result is not fatal. The FIT-Qd12 gravitational-wave claim concerns population-level, mass-scaled, boundary-regulated residual structure.

19.3 Fully Sufficient Particle Dark Matter Without Geometric Back-Reaction

The framework interprets dark-matter-like phenomena as arising primarily from non-projecting or weakly projecting spectral curvature associated with dimensional collapse, intermediate-layer structure, DVZ-regulated projection, and Qd12/RTF operator geometry.

This is a curvature-first position, not an absolute no-particle claim.

19.3.1 Failure Condition

A particle dark matter candidate is experimentally confirmed and shown to

- Fully account for galactic rotation curves,
- Large-scale structure formation,
- Gravitational lensing observations,
- Cluster-scale dynamics,
- Halo and void statistics,
- And cosmic-web structure,

Without requiring any non-projecting curvature, boundary contribution, dimensional-collapse residue, Qd12-sector emergence, or geometric back-reaction.

19.3.2 Implication

This would strongly challenge the FIT-Qd12 dark-sector interpretation.

However, the discovery of dark-sector particles alone would not automatically falsify FIT-Qd12. Such particles may still be compatible with the framework if they arise as emergent, projected, semi-projecting, or residue modes of the underlying Qd12/RTF operator geometry.

The stronger failure condition is not simply “dark particles exist.” The stronger failure condition is that particle dark matter fully explains all dark-sector phenomena as an independent sector unrelated to Qd12 geometry.

19.4 Dark-Energy Reversal or Incompatible Expansion History

Within the refined FIT-Qd12 position, dark energy is interpreted as Qd12 substrate pressure expressed through APS ledger dynamics. The uncollapsed Qd12 substrate supplies the pressure, while APS-compatible ledger dynamics regulate how that pressure appears as four-dimensional cosmic acceleration.

FIT-Qd12 allows dark-energy acceleration to slow, relax, modulate, or asymptotically flatten, but not to reverse under admissible boundary–substrate dynamics.

19.4.1 Failure Condition

High-precision cosmological observations establish that:

- Dark-energy acceleration reverses into global contraction,
- Or the effective dark-energy behavior requires a pressure term incompatible with persistent Qd12 substrate pressure,
- Or the expansion history requires parameters that cannot be mapped to

APS-compatible ledger dynamics, spectral trace mismatch, boundary tension, or information deposition.

19.4.2 Implication

This would strongly challenge the admissible boundary–substrate dark-energy realization.

A measured slowing, mild redshift dependence, or Λ -like leading behavior would not by itself falsify FIT-Qd12. A reversal into global contraction would be more serious because it would require failure or sign reversal of the persistent uncollapsed Qd12 substrate pressure, breakdown of APS ledger admissibility, or loss of mass-gap/spectral stability.

Canonical Statement

FIT-Qd12 allows dark-energy acceleration to slow, but not to reverse under admissible boundary–substrate dynamics.

19.5 CMB Boundary-Imprint Failure Modes

Within FIT-Qd12, the CMB is treated as a boundary-imprint test surface, but not as a direct or complete image of the Qd12 boundary record.

Canonical Statement

The CMB is a slice, not the whole ledger.

Equivalently:

The observed CMB is a projected time-slice of boundary-imprinted radiation, not a complete image of the Qd12 boundary structure.

19.5.1 Failure Condition

High-precision CMB observations demonstrate that:

- Large-scale anomalies disappear under improved foreground removal and calibration,
- EB/TB rotation or parity-violating signals are excluded at relevant sensitivity,
- Low-multipole phase structure is consistent with statistical fluctuation,
- CMB lensing and large-scale structure show no correlated boundary-imprint residue,
- And no CMB observable shares parameters with the broader Qd12 boundary, ledger, dark-sector, or spectral-gap framework.

19.5.2 Implication

This would constrain the observable CMB boundary-imprint realization.

It would not automatically falsify the full framework, because the observed CMB is only a projected and evolved slice of the post-collapse radiation field. The stronger challenge would arise if all CMB, lensing, polarization, phase, parity, and large-scale-structure channels fail to show any shared parameter structure while other domains also fail to support Qd12 coherence.

19.6 Neutrino-Sector Null Results or Incompatible Deviations

Within FIT-Qd12, neutrinos are framed as fiber-dominant projected modes and phase-sensitive probes of the fiber-boundary sector. Their importance lies in their weak interaction, long coherence length, oscillation behavior, and sensitivity to phase, chirality, mass-gap structure, and APS-compatible ledger coupling.

19.6.1 Failure Condition

Precision neutrino experiments demonstrate that:

- Standard three-flavor oscillations remain exact within increasingly tight limits,
- No baseline-dependent phase residuals are observed,
- No energy-dependent coherence shifts are observed,
- No high-energy flavor-ratio deviations are observed,
- No sterile-like boundary-suppressed behavior is supported,

- And all neutrino-sector parameters are incompatible with the Qd12 fiber-boundary coupling structure.

19.6.2 Implication

This would constrain the active fiber-ledger neutrino channel.

It would not by itself falsify the full FIT-Qd12 operator framework. Null neutrino results would place upper bounds on the coupling between neutrino propagation and fiber-boundary structure. The stronger challenge would occur if neutrino results require a structure incompatible with the Qd12 operator geometry or if neutrino-sector parameters contradict the shared parameters required by other domains.

19.7 Evidence of Fundamental Information Loss

A core structural requirement of FIT-Qd12 is global information preservation under boundary-compatible evolution. The framework treats apparent information loss in reduced descriptions as incomplete access to the full operator-boundary system.

19.7.1 Failure Condition

Definitive empirical or theoretical evidence demonstrates fundamental non-unitary evolution in physical systems, or irreversible information loss, for example in black-hole evaporation, in a manner that cannot be reconciled with boundary-mediated information encoding, global unitarity, or an admissible operator extension.

19.7.2 Implication

This would represent a framework-level challenge. Unlike a single sector-level null result, fundamental information loss would directly undermine the global information-preserving structure assumed by FIT-Qd12.

If physical information is destroyed at the deepest level, and if no boundary-compatible encoding or operator-level reconstruction is possible, then the foundational operator-theoretic construction would be invalidated.

19.8 Inconsistent Cross-Domain Parameter Reconstruction

The framework relies on the consistency of spectral parameter inference across independent observational domains.

19.8.1 Failure Condition

Independent datasets, including cosmological, gravitational, CMB, neutrino, dark-sector, and particle-scale observations, require

- Mutually incompatible parameter regimes,
- Inconsistent boundary or spectral-gap scales,
- Conflicting fiber-sector coupling parameters,
- Dark-sector parameters incompatible with expansion-history parameters,
- Or structural interpretations that cannot be embedded within a single admissible Qd12 operator configuration.

19.8.2 Implication

This would indicate that the framework lacks the internal coherence required of a unified operator-geometric system.

This is one of the strongest empirical challenges to FIT-Qd12. The theory is not expected to win by fitting isolated anomalies. It must show that multiple domains can be organized by shared boundary, fiber, DVz, mass-gap, projection, and substrate-pressure parameters.

If each sector requires unrelated parameters or mutually incompatible assumptions, the unified Qd12 interpretation fails.

19.9 Absence of Any Observable Consequence Beyond Established Frameworks

The framework must ultimately distinguish itself through observable consequences, constraints, or structural unifications beyond those already available in existing effective theories.

19.9.1 Failure Condition

All testable consequences reduce completely to those of:

- General Relativity,
- the Standard Model,
- and Λ CDM,

with no measurable deviations, no additional structural constraints, no cross-domain parameter coherence, and no explanatory gain beyond existing frameworks.

19.9.2 Implication

In this limit, FIT-Qd12 might remain mathematically consistent as an operator-geometric construction but would become physically indistinguishable from existing theories. This would eliminate its empirical relevance as a distinct physical framework.

This would not necessarily show that the mathematics is inconsistent. It would show that the theory lacks independent physical content.

19.10 Summary of Falsifiability Structure

The falsifiability of FIT-Qd12 is not tied to a single experimental outcome. It is tied to whether its structural consequences survive coordinated testing across multiple domains.

- A single null result constrains a sector.
- A failed echo search constrains boundary reflectivity.
- A null neutrino result constrains fiber-ledger coupling.
- A Λ -like expansion history constrains dark-energy modulation.
- A lack of CMB anomalies constrains observable boundary-imprint channels.
- A particle dark-matter discovery constrains the pure curvature-only dark-sector realization.

None of these alone automatically falsifies the full operator framework. The framework-level failure conditions are stronger

- Evidence of fundamental information loss,
- Loss of mathematical admissibility,
- Inability to recover established physics,
- Incompatible cross-domain parameter reconstruction,
- Or complete empirical indistinguishability from existing frameworks.

The key principle is:

The framework remains viable only if a single admissible operator-geometric structure can consistently account for independent observations without contradiction.

Failure to satisfy this condition through incompatible parameter reconstruction, evidence of information loss, loss of spectral admissibility, or absence of any independent empirical content would directly challenge the validity of the framework.

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Appendix A — Standard Model–Compatible Structure from the Qd12 Spectral Action

A.1 Structure of the Internal Algebra

Within the FIT-Qd12 framework, Standard Model–like structure may be supported by the internal sector of the operator algebra. The full algebra may be expressed schematically as:

$$A_{12} = A_4D \oplus A_RTF \oplus A_T2 \text{ where:}$$

- A_4D is associated with the emergent spacetime sector,
- A_RTF encodes internal Rope–Thread–Fiber structure,
- A_T2 represents compact fiber or modular-ordering contributions.

The internal algebra A_RTF admits a decomposition compatible with matrix algebras of the form:

$$A_RTF \simeq M_3(\mathbb{C}) \oplus M_2(\mathbb{C}) \oplus \mathbb{C}$$

Such a structure is consistent with the class of algebras appearing in noncommutative-geometric formulations of particle physics, including the Connes–Lott construction.

Within the present framework, this algebraic form is associated with constraints involving:

- Boundary compatibility,
- Spectral boundedness,
- Internal harmonic structure,
- And compactification conditions.

These constraints restrict the class of admissible algebras and support structures compatible with Standard Model–like gauge symmetry.

A.2 Emergence of Gauge Structure

Let:

- $A_3 = M_3(\mathbb{C})$,
- $A_2 = M_2(\mathbb{C})$,

- $A_1 = \mathbb{C}$.

The associated unitary groups are:

- $U(A_3) = U(3)$,
- $U(A_2) = U(2)$,
- $U(A_1) = U(1)$.

Imposing a unimodularity condition yields a gauge structure compatible with:

$$SU(3) \times SU(2) \times U(1)_Y$$

Where the hypercharge $U(1)_Y$ arises as the surviving abelian factor after quotienting by overall phase constraints.

Within this construction, the Standard Model gauge group appears as a natural symmetry associated with the internal algebra. The framework does not assume this structure a priori, but identifies it as compatible with the admissible operator geometry.

A.3 Fermionic Representations

The Hilbert space H may be decomposed into chiral components: $H = H_L \oplus H_R \oplus H_L^c \oplus H_R^c$

Under the internal symmetry structure, fermionic states transform according to representations that can be mapped onto Standard Model assignments.

Typical representation structure includes

- $SU(3)$: triplet representations for quark-like states and singlets for lepton-like states,
- $SU(2)$: doublets for left-handed components and singlets for right-handed components,
- $U(1)_Y$: hypercharge assignments determined by anomaly compatibility and algebraic constraints.

These representations are consistent with the observed fermionic structure of the Standard Model. The precise assignment of hypercharges follows from the representation theory of the internal algebra together with unimodularity constraints.

A.4 Scalar Sector and Inner Fluctuations

Scalar-sector candidates may arise from inner fluctuations of the Dirac operator:

$$D_{12} \rightarrow D_{12} + A + JAJ^{-1} \text{ where:}$$

- A is an element of the internal algebra,
- J is the real structure operator.

The finite part of this fluctuation may produce scalar degrees of freedom transforming as $SU(2)$ doublets with appropriate hypercharge.

Within this framework, a Higgs-like field may be interpreted as a geometric fluctuation of the operator system rather than as a fundamental scalar introduced independently.

The associated scalar potential may arise from the spectral action expansion: $S = \text{Tr}(f(D_{12}^2 / \Lambda^2))$ which may generate quartic and quadratic terms consistent with symmetry-breaking behavior.

A.5 Yukawa Structure and Mass Generation

Fermion mass and mixing structures may be associated with coupling terms generated in the spectral action, schematically of the form

$$L_Y = \bar{\psi}_L H Y_f \psi_R + \text{h.c.}$$

The structure of the Yukawa matrices Y_f is influenced by:

- Internal spectral geometry,
- Overlap of mode functions in the fiber sector,
- Compactification structure,
- Boundary-induced phase effects.

This provides a geometric basis for hierarchical mass structures and mixing matrices, such as CKM and PMNS, though quantitative agreement with observed values requires further specification.

A.6 Generation Structure

The presence of multiple fermion generations may be associated with distinct spectral sectors or harmonic families within the internal geometry.

Within the FIT-Qd₁₂ framework, the dimensionality and structure of the internal space constrain the number of independent spectral families. Admissibility and boundary conditions restrict the allowed configurations.

These features provide a possible explanation for generation structure, though a complete derivation of the exact number of generations requires a more detailed spectral analysis.

A.7 Anomaly Consistency

Gauge anomaly cancellation is a necessary condition for consistency. Within the operator framework, anomaly cancellation is associated with:

- Representation structure induced by the internal algebra,
- Compatibility with unimodularity constraints,
- Consistency of trace relations over the algebra.

These conditions may lead to fermionic charge assignments compatible with anomaly-free gauge symmetry.

Appendix A Summary

Within the FIT-Qd12 framework

- The internal algebra may support gauge structures compatible with the Standard Model,
- Fermionic representations may arise from Hilbert space decomposition,
- Scalar-sector candidates may emerge as inner fluctuations of the Dirac operator,
- Coupling structures may have a geometric origin in spectral data,
- Generation structure may be linked to internal spectral organization,
- And anomaly consistency may follow from algebraic constraints.

Taken together, these results show how key features of particle physics may be understood as emergent properties of an underlying operator-geometric system, while remaining consistent with admissibility conditions and spectral structure.

Appendix B — Dual-Time Compactification and Collapse-Imprinted Initial Conditions (Modeled)

Within the FIT-Qd12 framework, the operator system includes two compact temporal parameters, denoted t_1 and t_2 , which may be represented as defining an internal toroidal structure:

$$T^2 = S^1(t_1) \times S^1(t_2)$$

These compact temporal directions are not additional time coordinates in emergent four-dimensional spacetime. Instead, they form part of the internal spectral geometry and may contribute to phase structure, modular evolution, and effective mass structure.

This appendix outlines the role of this dual-time structure in shaping particle properties, boundary dynamics, and initial conditions following dimensional collapse.

B.1 Structure of the Compact Temporal Torus

The compact temporal coordinates may be parameterized as:

- $t_1 \in [0, 2\pi R_1)$
- $t_2 \in [0, 2\pi R_2)$

where R_1 and R_2 are radii associated with spectral and boundary conditions. The internal metric may be written as: $ds^2(T^2) = R_1^2 dt_1^2 + R_2^2 dt_2^2$

These coordinates act as internal spectral parameters and are not embedded as physical time directions in spacetime.

Causality Clarification

Because t_1 and t_2 are internal

- They do not generate closed timelike curves
- They do not define causal motion in spacetime
- Physical time emerges only after collapse through boundary (Ledger) evolution

B.2 Fields on the Temporal Torus

Fields may depend on both spacetime and internal coordinates: $\Phi(x, t_1, t_2)$ A representative Lagrangian may include

$$L = \text{Tr} [1/4 F^2 + 1/12 H^2 + 1/2 (\partial_{t_1} \Phi)^2 + 1/2 (\partial_{t_2} \Phi)^2 + V(\Phi)]$$

The corresponding field equation may be written as

$$(\square_{12} - \partial_{t_1}^2 - \partial_{t_2}^2 + \delta V / \delta \Phi) \Phi = 0$$

Where: $\square_{12} = \nabla_4 D^2 + \nabla R T F^2$

The compact temporal derivatives act as discrete spectral contributions, which may appear as effective mass and phase terms after collapse.

B.3 Temporal Winding Modes and Mass Structure

Compactification on T^2 is associated with integer modes: $n_1, n_2 \in \mathbb{Z}$

These may generate effective mass contributions: $m^2(n_1, n_2) \sim n_1^2 / R_1^2 + n_2^2 / R_2^2$ After collapse, these may appear as contributions to effective mass terms.

Additional contributions may arise from:

- Boundary (Ledger) phase effects,
- Spectral coupling across sectors,
- Collapse-imprinted constraints.

This suggests a geometric basis for mass hierarchy, though precise numerical matching requires further development.

B.4 Phase Structure and CP Violation

Field modes acquire phase factors: $\Phi \rightarrow \exp[i(n_1 t_1 + n_2 t_2)] \Phi$ Interference between these modes may produce:

- Complex phases in mixing matrices,
- CP-violating effects,

- Phase-dependent coupling structure.

Within this framework, CP violation may be interpreted as arising from internal phase structure on the temporal torus.

B.5 Modular Flow and Emergent Time

Physical time is not fundamental before collapse. It may be represented as emerging through boundary evolution described by modular flow: $\sigma(\tau)$

A schematic relation may be written as: $t_{\text{physical}} \approx \tau + \alpha_1 t_1 + \alpha_2 t_2$ where α_1 and α_2 depend on Ledger curvature and DVz geometry.

Thus:

- Time may emerge from boundary dynamics,
- Direction of time may correspond to ordered boundary evolution,
- Internal phase structure may contribute to temporal behavior.

B.6 Arrow of Time and Collapse Dynamics

During collapse:

- t_1 and t_2 remain compact,
- Boundary evolution becomes dominant,
- Information (entropy-like quantity) increases.

This may produce a preferred direction of time.

Within this framework, the arrow of time may be associated with:

- Boundary information accumulation,
- Irreversible projection from the full operator system,
- Asymmetry between pre- and post-collapse states.

B.7 Boundary Conditions After Collapse

After collapse, the emergent system is modeled as inheriting boundary conditions influenced by

- Spectral configuration at collapse,
- DVz interface geometry,
- Ledger encoding structure.

These conditions may influence

- Phase evolution,
- Coupling between sectors,
- Large-scale cosmological behavior.

Different collapse configurations may lead to different classes of boundary conditions.

B.8 Collapse-Imprinted Initial Conditions

Collapse may be modeled as setting initial conditions for both boundary and intermediate-layer structures.

In general

- More symmetric configurations → approximately uniform initial conditions,
- More anisotropic configurations → direction-dependent initial conditions.

These may affect:

- Boundary curvature evolution,
- Intermediate-layer curvature (NE structure),
- Large-scale dynamics.

These imprints may persist into observable cosmological features.

Appendix B Summary

Dual-time compactification on the internal torus T^2 :

- May contribute to mass structure through discrete spectral modes,
- May provide a geometric basis for phase structure and mixing,
- May support emergent time via boundary (Ledger) evolution,
- May introduce a mechanism for directional temporal behavior,
- May imprint initial conditions during collapse.

These features connect the internal operator geometry to both particle physics and cosmology within the FIT-Qd₁₂ framework, while remaining consistent with admissibility constraints and effective interpretation.

Appendix C — Collapse Geometry, NE Curvature, and Coupled PDE Structure (Representative Model)

Within the FIT-Qd₁₂ framework, dimensional collapse is modeled not as a singularity or divergence, but as a finite instability arising in a coupled system of geometric and spectral fields. The dynamics may be modeled as involving four interdependent structures:

- Ledger curvature
- Negative-energy (NE) pressure
- DVz geometry (local thickness)

- Wave-sector interference (A/B/E spectral contributions)

Collapse is associated with regions where these coupled quantities approach an admissibility boundary. This appendix outlines a representative PDE system capturing these interactions and provides a geometric interpretation within the model of NE curvature in both symmetric and anisotropic regimes.

C.1 Ledger Curvature Equation

The Ledger is modeled as a two-dimensional boundary with intrinsic coordinates (u, v). Its curvature $K_L(u, v)$ may be modeled as evolving according to a generalized elliptic relation

$$\Delta K_L(u, v) = F(T_L, P_NE, K_DVz, \Psi_waves)$$

where:

T_L = effective Ledger tension
 P_NE = NE-layer pressure

K_DVz = curvature contribution from DVz geometry
 Ψ_waves = combined spectral amplitudes (A, B, E sectors)

Qualitative Dependencies

- Increased NE pressure tends to increase boundary curvature
- Increased wave amplitude tends to increase curvature
- Increased inward DVz curvature enhances curvature
- Increased Ledger tension tends to resist curvature growth

This relation describes boundary deformation, which precedes collapse localization.

C.2 NE Pressure Evolution

The NE layer may be modeled as a compressible medium with pressure P_NE satisfying a continuity-type equation:

$$\partial_t P_NE = -\nabla \cdot (P_NE \cdot v_NE) + S_waves$$

Where:

- v_NE = effective deformation velocity field
- S_waves = source term depending on wave amplitudes Far from collapse regions:

$$P_NE \rightarrow P_0(\text{background value})$$

Localized increases in P_NE contribute to conditions under which collapse may occur.

C.3 DVz Geometry Equation

Let $d(x, y)$ denote the local DVz thickness between adjacent operator regions. A representative governing relation is

$$\Delta d - \gamma d = - (K_L(A) + K_L(B))$$

Interpretation

- Increased boundary curvature tends to reduce DVz thickness
- Regions of competing curvature may broaden the DVz
- Asymmetry in boundary curvature can produce anisotropic DVz structure Typical boundary conditions include
- $d \approx d_min$ in highly compressed regions
- d larger in regions of distributed curvature
- Symmetry conditions along selected directions

DVz minima identify candidate locations for collapse, but do not by themselves guarantee collapse.

C.4 Wave–Boundary Coupling

Wave sectors contribute to both boundary curvature and NE pressure through coupled source terms. A schematic form is:

$$C_waves = \lambda_A A^2 + \lambda_B B^2 + \lambda_E E^2 + \lambda_AB AB + \lambda_AE AE + \lambda_BE BE$$

Boundary curvature evolution may be expressed as: $\partial_t K_L = G(K_L) + C_waves$
 and NE pressure responds via: $\partial_t P_NE = H(P_NE) + \partial_t C_waves$

Constructive spectral interference may enhance both curvature and pressure, and may contribute to approach toward instability conditions.

C.5 Collapse Functional and Admissibility Condition

Define a collapse functional: $F = \alpha_1 K_L + \alpha_2 P_NE - \alpha_3 (1/d) + \alpha_4 \|\Psi_waves\|$

Interpretation

- Increased boundary curvature increases F
- Increased NE pressure increases F
- Reduced DVz thickness increases F
- Strong spectral alignment increases F
- Collapse is associated with regions where F approaches a critical admissibility regime.
- Collapse is modeled as occurring when the coupled

system can no longer maintain a stable pre-collapse configuration.

Consequences

- Collapse is localized, not global
- Collapse is finite, not singular
- Collapse reflects a coupled instability, not a divergence

C.6 Collapse Timescale

Let t_c denote the time at which the collapse condition is reached. To first approximation: $t_c \approx (F_{crit} - F(0)) / \dot{F}(0)$

where $\dot{F}(0)$ depends on:

- Rate of boundary curvature growth
- NE pressure increase
- DVz thinning rate
- Evolution of spectral amplitudes

All quantities remain finite, and collapse time may be estimated within a specified model.

C.7 NE Curvature as an Effective Geometric Contribution

NE curvature may be defined as the variation of an effective NE action with respect to the metric:

$$C_{NE}(\mu\nu) = -\delta S_{NE} / \delta g(\mu\nu)$$

This curvature may be interpreted as a geometric contribution arising from boundary–DVz interaction within the spectral framework.

In the effective four-dimensional description, such contributions may behave analogously to dark matter, influencing gravitational dynamics without requiring independent particle degrees of freedom at the fundamental level.

C.8 Symmetric and Anisotropic NE Structures

Different collapse configurations may lead to different effective curvature structures: Approximately symmetric configurations

C_{NE} is approximately isotropic Anisotropic configurations:

C_{NE} may include directional components:

$$C_{NE} \approx C^{(0)} + C^{(1)}(\hat{n}) + C^{(2)}(\hat{n}) + \dots$$

These structures may influence large-scale behavior in the effective cosmological description.

C.9 Observational Implications

The NE curvature framework suggests possible connections to

- Gravitational lensing behavior
- Large-scale structure morphology
- Halo and void anisotropy
- Correlations between curvature and large-scale geometry

These features are broadly consistent with observations, though detailed quantitative agreement requires further modeling.

Appendix C Summary

This appendix presents a representative coupled PDE framework modeling collapse dynamics in FIT-Qd₁₂:

- Ledger curvature, NE pressure, DVz geometry, and wave interference may evolve through interdependent relations
- Collapse is modeled as corresponding to a finite instability in this coupled system
- DVz minima localize collapse, while spectral and boundary conditions activate it
- NE curvature may provide a geometric contribution to effective gravitational behavior
- Symmetric and anisotropic collapse configurations may produce distinct large-scale signatures

This formulation provides a non-singular, operator-consistent and representative description of collapse and its consequences for emergent physical structure.

Appendix D — Ledger Information Theory and Directional Information Dynamics (Modeled Structure)

The two-dimensional holographic ledger (2DHL) is modeled as the boundary structure associated with information encoding in the FIT-Qd₁₂ framework. It is treated as an operator-defined boundary compatible with the underlying spectral system, rather than as an emergent or approximate construct.

Within this framework, physical processes—including quantum evolution, cosmological dynamics, and collapse behavior—may be associated with transformations that can be represented through boundary encoding.

This appendix outlines a formal structure for

- Boundary Hilbert space representation,

- Information-deposition maps,
- Modular (boundary) time evolution,
- Directional effects in anisotropic configurations,
- Neutrino–boundary coupling,
- Entanglement transfer,
- And global information consistency.

D.1 Ledger Hilbert Space and Boundary States

Let H_L denote the Hilbert space associated with the boundary (Ledger), with:

$$H_L \subset H$$

A boundary (Ledger) state may be represented by a density operator:

$$\rho_L \in B(H_L)$$

satisfying:

- $\text{Tr}(\rho_L) = 1$
- $\rho_L \geq 0$

Boundary evolution is modeled as an ordered process parameterized by a modular parameter τ .

Within this framework entropy associated with ρ_L is modeled as non-decreasing under boundary evolution. This provides a possible structural basis for an emergent arrow of time.

D.2 Ledger-Deposit Map (CPTP Structure)

Information transfer from the physical system to the boundary may be represented by a completely positive, trace-preserving (CPTP) map:

$$L_{\text{deposit}} : \rho_{\text{phys}} \rightarrow \rho_L$$

In approximately symmetric configurations, this map may be treated as isotropic. In anisotropic configurations, directional dependence may be introduced:

$$L_{\text{deposit}} = L_0 + \Delta L(\hat{n}) \text{ where:}$$

- L_0 is the isotropic component,
- $\Delta L(\hat{n})$ encodes directional variation,
- \hat{n} represents direction in the effective spacetime.

Key Structural Properties

- Distinct physical states are expected to map to distinguishable boundary encodings (up to equivalence classes)
- Boundary entropy is modeled as non-decreasing under evolution

- The map preserves normalization and boundedness
- Conserved quantities are preserved at the level of the full operator system

D.3 Direction-Dependent Decoherence

Boundary interaction may induce effective decoherence, modeled as:

$$D(\rho)(\hat{n}) = (1 - p(\hat{n})) \rho + p(\hat{n}) \text{diag}_L(\rho) \text{ where:}$$

- $p(\hat{n})$ is a direction-dependent coupling strength,
- diag_L denotes projection into a preferred boundary-compatible basis.

The compatibility condition:

$$L_{\text{deposit}} \circ D = D \circ L_{\text{deposit}}$$

is intended to ensure consistency within the model between boundary encoding and effective decoherence processes.

D.4 Modular Flow and Emergent Time

Boundary evolution may be described using Tomita–Takesaki modular flow: $\sigma_{-\tau}(A) = \Delta^{i\tau} A \Delta^{-i\tau}$

where A belongs to the boundary algebra. Properties

- $\sigma_{-\tau}$ defines, at a formal level, a one-parameter family of automorphisms
- Boundary entropy is modeled as non-decreasing with τ
- This provides a formal framework for emergent temporal ordering

In anisotropic configurations, the modular generator may include directional contributions:

$$K = K_0 + \Delta K \cdot f(\hat{n})$$

leading to small directional variation in boundary evolution.

D.5 Neutrino–Boundary Interaction

Neutrinos may serve as sensitive probes of boundary-coupled dynamics due to their weak interaction and long coherence length.

A schematic interaction map may be written as: $N : \rho_{\nu} \rightarrow \rho_{\nu}'$

Possible stages include:

- Standard oscillatory evolution
- Interaction with boundary structure
- Partial decoherence or phase modification

- Return to effective propagation

Such behavior may resemble “sterile-like” propagation modes without requiring additional particle species.

Directional Dependence

The effective coupling may depend on: $\eta = \eta(L, E, \hat{n})$ leading to:

- Direction-dependent oscillation effects
- Baseline-dependent decoherence
- Correlations with large-scale structure

D.6 Entanglement Transfer

When a composite system interacts with the boundary, information may be redistributed:

$\rho_{AB} \rightarrow \rho_A(L) \otimes \rho_B(L)$ Within the framework:

- Correlations may be preserved at the level of boundary encoding
- Entanglement measures may be represented through boundary states
- Effective decoherence in the bulk need not imply loss of information in the full operator system

D.7 Information Encoding and Completeness

Under suitable conditions on the deposit map, boundary encoding may retain the physically relevant information of bulk states.

This suggests, distinct physical configurations correspond to distinguishable boundary encodings (modulo equivalence), the boundary may provide a complete record of physically relevant information within the admissible representation.

D.8 No-Cloning and No-Erasure Constraints

Consistency of the boundary structure is consistent with

- Standard no-cloning constraints
- Distinguishability of physically distinct states

These properties align with standard quantum-information principles and support information preservation within the modeled framework.

D.9 Boundary as a State-Determination Structure

The combination of:

- Structured boundary encoding,
- Injective mapping (up to equivalence),
- And modular evolution suggests that the boundary

state may contain sufficient information to reconstruct physically relevant features of the system within the admissible framework.

D.10 Global Information Consistency

Consider a total entropy measure:

$S_{\text{total}}(t) = S_{\text{phys}}(t) + S_L(t)$ Within the framework

- Boundary entropy is modeled as non-decreasing
- Bulk evolution is consistent with unitary dynamics at the operator level
- Information transfer is encoded rather than destroyed

Together, these suggest a form of global information consistency across the system.

Appendix D Summary

Within the FIT-Qd12 framework, the Ledger

- May serve as a boundary encoding structure for spectral information,
- May support an emergent notion of time through modular evolution,
- May preserve correlations through boundary representation,
- May provide a mechanism for information transfer without loss,
- May allow directional effects in anisotropic configurations,
- And may connect quantum information structure to cosmological dynamics.

This formulation provides an information-theoretic foundation for the operator framework while remaining consistent with admissibility constraints and quantum principles.

Appendix E — Dark Sector Tensor Structure and Boundary–Substrate Evolution

Effective Representation

Within the FIT-Qd12 framework, dark-sector phenomena may be interpreted as effective geometric and boundary–substrate contributions associated with the interaction of intermediate-layer dynamics, DVz-regulated collapse, uncollapsed Qd12 substrate pressure, and APS-compatible ledger dynamics.

Two effective rank-2 tensor structures may be identified in the four-dimensional description

- An intermediate-layer curvature tensor, denoted $C_{NE}(\mu\nu)$, associated with dark-matter-like behavior;
- A boundary–substrate pressure tensor, denoted $P_{Qd12 \rightarrow ledger}(\mu\nu)$, associated with dark-energy-like behavior.

These tensors are not introduced as independent fundamental fields. Instead, they are associated with:

- NE-layer pressure and curvature,
- DVz-regulated projection,
- collapse geometry,
- uncollapsed Qd₁₂ substrate pressure,
- Ledger curvature and boundary tension,
- APS-compatible boundary dynamics,
- And projection into the effective four-dimensional regime.

This appendix outlines how these tensors may be constructed and how they may evolve within a coupled geometric framework. The original appendix framed the dark sector through an NE curvature tensor and a boundary-induced pressure tensor; this revision updates the dark-energy tensor as a boundary–substrate term and sharpens the dark-matter tensor as curvature-first rather than absolute no-particle.

E.1 NE Curvature Operator and Evolution

The intermediate NE layer may be characterized by a curvature operator K_{NE} defined on the internal operator algebra. A representative governing relation takes the form:

$$\Delta K_{NE} = G(P_{NE}, K_L, K_{DVz})$$

where:

- P_{NE} is NE pressure,
- K_L is Ledger curvature,
- K_{DVz} is curvature associated with DVz geometry.

Qualitative behavior

- K_{NE} may increase under compressive conditions associated with collapse,
- K_{NE} may evolve dynamically prior to collapse,
- DVz-regulated projection may determine which components become visible, weakly projecting, or non-projecting in the effective regime,

- and after collapse, components of this curvature may contribute to the effective geometry.

Within the refined canonical interpretation, this curvature is associated with dark-matter-like behavior only in a curvature-first sense. It does not require FIT-Qd₁₂ to deny every possible particle-like dark-sector excitation. Rather, it identifies non-projecting or weakly projecting curvature as the primary geometric origin of the effective gravitational behavior attributed to dark matter.

E.2 Projection to Effective Curvature Tensor

During collapse, the higher-dimensional operator structure is modeled as being projected into an effective four-dimensional description.

The NE curvature may contribute to a symmetric rank-2 tensor: $C_{NE}(\mu\nu) = \Pi_{collapse}(K_{NE})$

Properties

- Symmetric under index exchange compatible with conservation conditions under boundary constraints,
- May be interpreted as a geometric contribution rather than an independent particle field,
- May include projected, weakly projecting, or non-projecting components,
- And may act gravitationally in the effective description without coupling electromagnetically in the ordinary luminous sector.

This tensor may provide an effective source term in gravitational dynamics.

The important refinement is that $C_{NE}(\mu\nu)$ should be interpreted as a curvature-first dark-sector tensor. Particle-like dark-sector signatures, if observed, may still be compatible with the framework if they arise as emergent, projected, semi-projecting, or residue modes of the underlying Qd₁₂/RTF operator geometry.

E.3 Effective Gravitational Behavior

In the post-collapse regime, the tensor $C_{NE}(\mu\nu)$ may contribute to gravitational effects typically attributed to dark matter.

In this interpretation

- Energy-density-like components may contribute positively to gravitational attraction,
- Spatial components may influence structure formation,

- The tensor may support stable, extended configurations,
- Non-projecting components may contribute to lensing without ordinary electromagnetic emission,
- And weakly projecting components may appear as effective or particle-like dark-sector excitations under some conditions.

Because the primary contribution arises from curvature, it need not couple directly to electromagnetic radiation, consistent with observational constraints.

FIT-Qd12 is therefore strongly constrained only if particle dark matter fully accounts for all dark-sector phenomena without requiring non-projecting curvature, boundary effects, dimensional-collapse structure, or Qd12-sector emergence. The discovery of dark-sector particles alone would constrain the pure curvature-only realization but would not automatically falsify the full Qd12-dark-sector interpretation.

E.4 Eigenstructure and Large-Scale Geometry

The geometric influence of $C_{NE}(\mu\nu)$ can be analyzed through its eigenstructure: $C_{NE}(\mu\nu) v^\nu = \lambda v^\mu$

Interpretation:

- Larger eigenvalues may correspond to regions of enhanced curvature, such as halo-like structures;
- Anisotropic eigenvalue distributions may correspond to filamentary structure;
- Near-zero eigenvalues may correspond to low-density or void-like behavior;
- And weakly projecting modes may correspond to dark-sector behavior that appears gravitationally active but electromagnetically hidden.

This suggests a geometric mechanism for large-scale structure formation in the effective description. Quantitative comparison with lensing, halo, void, and cosmic-web datasets requires further modeling.

E.5 Symmetric and Anisotropic Configurations

The structure of $C_{NE}(\mu\nu)$ depends on the symmetry of the collapse configuration. Approximately symmetric collapse:

$C_{NE}(\mu\nu)$ is approximately isotropic. Anisotropic collapse:

$C_{NE}(\mu\nu)$ may be expanded as: $C_{NE} \approx C^{(0)} + C^{(1)}(\hat{n}) + C^{(2)}(\hat{n}) + \dots$

where directional components reflect collapse-imprinted anisotropy.

These contributions may influence large-scale alignment, filamentary structure, halo distribution, void geometry, and lensing patterns.

The framework does not require anisotropy to be present. Approximately symmetric collapse configurations remain admissible. If anisotropy is present, however, it should appear coherently across observational domains rather than as isolated unrelated anomalies.

E.6 Ledger Curvature and Boundary–Substrate Evolution

The Ledger curvature K_L may be modeled as evolving under the influence of boundary tension, coupling to NE curvature, and pressure inherited from the uncollapsed Qd12 substrate.

A schematic evolution equation may be written as:

$$\partial_t^2 K_L = F(K_L, P_{Qd12} \rightarrow \text{ledger}, C_{NE})$$

- Where time is understood in the modular or boundary sense. Initial conditions following collapse may be:
- Approximately uniform in symmetric configurations,
- Direction-dependent in anisotropic configurations,
- And influenced by the spectral trace mismatch between the full Qd12 system and the effective four-dimensional projection.

These initial conditions may propagate into effective large-scale behavior.

The refined interpretation is that Ledger curvature does not by itself define an independent dark-energy source. Instead, APS-compatible ledger dynamics regulate how the pressure of the uncollapsed Qd12 substrate appears inside the collapsed four-dimensional universe.

Canonical Statement

Dark energy = Qd12 substrate pressure expressed through APS ledger dynamics.

E.7 Boundary–Substrate Pressure Tensor

The combination of uncollapsed Qd12 substrate pressure, Ledger curvature, boundary tension, and APS-compatible projection may give rise, after collapse, to an effective tensor

$P_{Qd12 \rightarrow ledger}(\mu\nu) = \Pi_{collapse}(K_L \otimes T_L \otimes P_{Qd12})$ where:

- T_L represents boundary tension,
- K_L represents Ledger curvature,
- P_{Qd12} represents the smooth pressure contribution supplied by the uncollapsed Qd₁₂ Matrix Field.

This expression is schematic and should be understood as an effective representation, not as a closed fundamental field equation.

In the effective description

- Components of $P_{Qd12 \rightarrow ledger}(\mu\nu)$ can act as negative-pressure contributions,
- This may lead to accelerated expansion under appropriate conditions,
- The leading component may appear approximately Λ -like,
- Higher-order behavior may include redshift dependence, relaxation, or modulation,
- And directional dependence may arise in anisotropic configurations.

Canonical Statement

Uncollapsed Qd₁₂ substrate supplies the pressure; APS ledger dynamics regulate how that pressure appears as 4D cosmic acceleration.

This provides a boundary–substrate interpretation of dark-energy-like behavior without introducing a fundamental cosmological constant or independent scalar field at the operator level. Λ -like behavior, evolving dark energy, scalar-field-like equations of state, or mild redshift-dependent modulation may be treated as effective four-dimensional parameterizations of the same deeper Qd₁₂ mechanism.

E.8 Acceleration Constraint

Because the uncollapsed Qd₁₂ substrate supplies persistent pressure, the effective dark-energy contribution may slow, relax, modulate, or asymptotically flatten, but it does not naturally reverse into global contraction under admissible boundary–substrate dynamics.

Canonical Statement

FIT-Qd₁₂ allows dark-energy acceleration to slow, but not to reverse under admissible boundary–substrate dynamics.

A reversal into global contraction would require at least one of the following:

- Failure or sign reversal of the persistent uncollapsed Qd₁₂ substrate pressure,
- Breakdown of APS ledger admissibility,
- Loss of mass-gap or spectral stability,
- Or failure of the boundary–substrate coupling mechanism.

Thus, a measured slowing or mild evolution of dark-energy acceleration may be compatible with FIT-Qd₁₂. A confirmed reversal would strongly challenge the admissible dark-energy realization.

E.9 Coupling Between Curvature and Boundary–Substrate Effects

The tensors $C_{NE}(\mu\nu)$ and $P_{Qd12 \rightarrow ledger}(\mu\nu)$ may be treated as not independent within the framework.

They:

- Arise from the same underlying operator structure,
- Are influenced by collapse geometry and spectral configuration,
- Are regulated by DVz structure and APS-compatible boundary dynamics,
- And may contribute together to effective cosmological evolution.

This coupling may lead to correlated large-scale effects. For example, non-projecting curvature may influence structure formation and lensing, while boundary–substrate pressure influences expansion history. If both arise from the same collapse geometry and operator structure, their observational signatures should be tested for cross-domain coherence.

E.10 Effective Field Equations

In the effective four-dimensional regime, gravitational dynamics may be written schematically as:

$G(\mu\nu) = 8\pi G [T_{matter}(\mu\nu) + C_{NE}(\mu\nu) + P_{Qd12 \rightarrow ledger}(\mu\nu)]$ where:

- $T_{matter}(\mu\nu)$ represents standard matter and radiation,
- $C_{NE}(\mu\nu)$ provides a curvature-first dark-matter-like contribution,
- $P_{Qd12 \rightarrow ledger}(\mu\nu)$ provides a boundary–substrate dark-energy-like contribution.

These terms arise from geometric projection and boundary–substrate coupling rather than independent fundamental fields. The expression is an effective

representation of large-scale behavior, not a completed fundamental field equation.

Appendix E Summary

Within the FIT-Qd₁₂ framework:

- Intermediate-layer curvature may contribute to an effective tensor $C_{NE}(\mu\nu)$ associated with curvature-first dark-matter-like behavior;
- $C_{NE}(\mu\nu)$ may include projected, weakly projecting, or non-projecting components;
- Dark-sector particles, if discovered, would not by themselves falsify FIT-Qd₁₂ if they can be interpreted as emergent, projected, semi-projecting, or residue modes of the Qd₁₂/RTF operator geometry;
- Boundary–substrate dynamics may contribute to a tensor $P_{Qd12} \rightarrow \text{ledger}(\mu\nu)$ associated with dark-energy-like behavior;
- Dark energy is interpreted as Qd₁₂ substrate pressure expressed through APS ledger dynamics; the leading dark-energy contribution may appear Λ -like, while higher-order behavior may include small modulation, redshift dependence, or relaxation through ledger pressure, spectral trace mismatch, boundary tension, and information deposition;

FIT-Qd₁₂ allows dark-energy acceleration to slow, but not to reverse under admissible boundary–substrate dynamics;

- Both tensors arise from the same underlying geometric and spectral structure;
- Their evolution may be described by coupled relations involving NE dynamics, DVz geometry, Ledger curvature, boundary tension, and Qd₁₂ substrate pressure;
- And symmetry or anisotropy of collapse may influence their large-scale structure.

This formulation suggests a unified geometric and boundary–substrate interpretation of the dark sector while remaining consistent with admissibility constraints, spectral boundedness, information preservation, and observational uncertainty.

Appendix F — Assumptions, Stability Bounds, and Operator Constraints

Within the FIT-Qd₁₂ framework, mathematical consistency is defined through a set of structural assumptions, operator bounds, and stability conditions.

These are intended to define the admissible class of configurations under which the operator system is required to remain finite, well-defined, and dynamically stable.

This appendix summarizes

- Foundational structural assumptions
- Operator boundedness conditions
- Ledger and DVz stability requirements
- Collapse-domain constraints
- Spectral finiteness conditions
- And symmetry-related assumptions associated with collapse configurations

F.1 Foundational Structural Assumptions

F.1.1 Spectral Triple Framework

The framework is assumed to be formulated in terms of a 12-dimensional spectral triple (A_{12}, H, D_{12}) , which encodes both geometric and internal structure.

F.1.2 Boundary (Ledger) Structure

Each operator region is assumed to be associated with a boundary structure (Ledger) that is required to satisfy

- Consistent information encoding
- Compatibility with modular evolution
- Preservation of physically relevant information

This boundary is modeled as serving as the interface between bulk spectral structure and effective dynamics.

F.1.3 Intermediate and DVz Layers

Adjacency between regions is assumed to include intermediate (NE) and DVz layers, forming a structured interface that mediates interaction and regulates collapse.

F.1.4 Extended Operator Configuration

The system may be extended to multiple adjacent regions with a consistent interface structure. The global topology is not fixed, but local structural rules are assumed to be uniform.

F.1.5 Collapse as Finite Instability

Collapse is assumed to be modeled as a finite instability in a coupled system of spectral, boundary, and geometric quantities, rather than as a singular or divergent process.

F.1.6 Projection to Effective Regime

Collapse is assumed to induce a mapping from the full operator system to an effective four-dimensional description. Observable quantities depend on this projection together with boundary and curvature structure.

F.2 Symmetry and Collapse Configuration Assumptions

F.2.1 Collapse Symmetry

The symmetry of a resulting configuration depends on spectral structure at collapse. Both approximately symmetric and anisotropic outcomes are admissible.

F.2.2 Geometric Bias

Interface geometry may bias the likelihood of different collapse configurations, but does not uniquely determine the outcome.

F.2.3 Observational Interpretation

Observed large-scale features may be consistent with anisotropic configurations, but the framework does not assume a unique identification between theory and any specific observed structure.

F.3 Operator Boundedness Conditions

To ensure mathematical consistency, the following boundedness conditions are imposed:

- Commutators of the Dirac operator with algebra elements remain bounded
- Boundary curvature remains finite
- Intermediate-layer pressure remains finite
- DVz thickness remains within finite bounds
- Wave–boundary coupling remains finite

These conditions are imposed to ensure that all operators remain well-defined and to prevent divergence in the spectral system.

F.4 Ledger Stability Conditions

The boundary structure is required to satisfy:

- Positive effective tension
- Finite curvature evolution
- Absence of self-intersection under admissible evolution

These conditions are imposed to ensure that boundary dynamics remain stable and well-defined.

F.5 DVz Stability Requirements

The DVz structure is required to satisfy:

- Finite thickness bounds
- Smooth variation across interfaces
- Convexity conditions in regions of interaction

These constraints regulate interaction between regions and localize collapse.

F.6 Collapse Domain Constraints

Collapse is assumed to occur within a domain Ω defined by admissibility conditions on the coupled system.

Within this framework:

- Collapse domains are localized
- They are associated with specific interface regions
- They do not generically extend across multiple independent regions

These conditions are imposed to ensure that collapse remains a local phenomenon.

F.7 Global Stability Considerations

The extended operator system is assumed to be stable under the following conditions:

- Local instabilities do not propagate uncontrollably
- Collapse remains confined to admissible regions
- Interaction between distant regions is strongly constrained. These features support long-term consistency of the system.

F.8 Spectral Finiteness Conditions

The spectral action: $S = \text{Tr} f(D_{12}^2 / \Lambda^2)$

is required to satisfy finiteness conditions, including:

- Finite heat-kernel coefficients
- Well-defined spectral expansion
- Absence of divergences in operator traces

These conditions are imposed to support the emergence of effective physical structures.

F.9 Summary of Imposed Conditions and Purposes

- *Structural Assumptions*
- Imposed conditions:

- Spectral-triple-type framework
- Boundary structure
- Layered interfaces
- Purpose:
 - Defines the operator framework.
- **Boundary Constraints**
 - Imposed conditions:
 - Finite curvature
 - Positive effective tension
 - Purpose:
 - Ensures stability of boundary encoding.
- **Intermediate-Layer Constraints**
 - Imposed conditions:
 - Finite pressure
 - Finite curvature
 - Purpose:
 - Prevents runaway intermediate-layer behavior.
- **DV_z Constraints**
 - Imposed conditions:
 - Finite thickness
 - Smooth variation across interfaces
 - Purpose:
 - Regulates interaction and collapse localization.
- **Collapse Constraints**
 - Imposed conditions:
 - Localized admissibility conditions
 - Purpose:
 - Ensures physical consistency of collapse domains.
- **Operator Bounds**
 - Imposed conditions:
 - Bounded commutators
 - Purpose:
 - Maintains mathematical rigor and operator well-definedness.
- **Global Stability**
 - Imposed conditions:

- Suppressed propagation of instabilities
- Purpose:
 - Supports long-term consistency of the extended system.
- **Spectral Finiteness**
 - Imposed conditions:
 - Finite expansion coefficients
 - Purpose:
 - Ensures a well-defined spectral action.

Appendix F Summary

This appendix defines a consistent set of assumptions and constraints under which the FIT-Qd₁₂ framework operates:

- The operator system is required to remain finite and well-defined
- Collapse is assumed to be localized and non-singular
- Boundary and intermediate-layer structures are required to remain stable
- Spectral quantities are required to remain bounded
- And effective physical behavior may emerge from admissible configurations

These conditions provide a controlled setting in which the operator-geometric framework can be developed and analyzed.

Appendix G — Observational Diagnostics and Collapse Reconstruction

G.1 Overview

This appendix outlines a framework for relating observational data to possible underlying collapse configurations within the FIT-Qd₁₂ model. The goal is not to assign a unique origin to a given universe, nor to reconstruct the full pre-collapse Qd₁₂ boundary structure from present observations. Rather, the goal is to define diagnostic criteria by which approximately symmetric and anisotropic collapse scenarios may be distinguished, constrained, and tested.

The approach emphasizes cross-domain consistency across cosmological, gravitational, neutrino, CMB, dark-sector, and large-scale-structure observables. No single observational feature is treated as decisive. Instead, the strongest diagnostic value arises when

multiple independent datasets point toward a shared operator-geometric parameter structure.

A central caution applies to CMB-based reconstruction:

The CMB is a slice, not the whole ledger.

The observed CMB is a projected time-slice of boundary-imprinted radiation, not a complete image of the Qd₁₂ boundary structure. It is filtered by last-scattering projection, line-of-sight gravitational lensing, late-time evolution, foregrounds, calibration, cosmic variance, and our four-dimensional observational position.

Therefore, CMB signatures should be treated as projected, evolved residues of possible boundary-imprint structure, not as direct images of the original collapse boundary.

G.2 Diagnostic Criteria for Symmetric and Anisotropic Configurations

Within the framework, collapse configurations may be broadly categorized by their symmetry properties. These categories represent limiting cases within a continuous range of possible configurations.

Anisotropic Configurations

Anisotropic configurations may exhibit features such as:

- Directional variation in inferred expansion rates,
- Large-scale asymmetries in cosmic background data,
- Correlated CMB polarization, phase, parity, temperature, and lensing features,
- Alignment tendencies in filamentary structure,
- Weak directional dependence in effective dark-energy behavior,
- Possible modulation in neutrino oscillation or coherence behavior,
- Localized large-scale anomalies,
- Anisotropic lensing or multipole structure,
- And cross-domain directional correlations.

These features are not individually decisive. A single anomaly may reflect foregrounds, systematics, statistical fluctuation, or ordinary cosmological variance. The relevant FIT-Qd₁₂ test is whether anisotropic features appear coherently across independent observational channels.

Approximately Symmetric Configurations

Approximately symmetric configurations may exhibit features such as

- No preferred large-scale direction,
- Approximately isotropic expansion,
- Statistical homogeneity consistent with standard cosmological models,
- Absence of strong directional correlations across datasets,
- Λ -like leading dark-energy behavior,
- No detectable CMB boundary-imprint residue at current sensitivity,
- No observable gravitational-wave echo channel,
- And no measurable neutrino-sector deviation beyond standard oscillation behavior.

These outcomes do not automatically falsify FIT-Qd₁₂. They constrain anisotropic, strongly coupled, or observationally active realizations. Approximately symmetric collapse configurations remain admissible within the framework.

G.3 Interpreting Observations in Our Universe

Current observational data are often interpreted as showing a mixture of:

- High degrees of large-scale isotropy,
- Strong agreement with Λ CDM-like behavior in many regimes,
- And reported anomalies or directional features at large scales.

Within the FIT-Qd₁₂ framework, such observations may be interpreted as consistent with an approximately symmetric collapse configuration with possible weak anisotropic or boundary-imprint residues. However, they are not uniquely determined by that interpretation.

Relevant observational domains include

- Cosmic microwave background analyses,
- CMB polarization and lensing studies,
- Large-scale structure surveys,
- Weak and strong gravitational lensing measurements,
- Expansion-rate studies,
- Dark-energy equation-of-state constraints,
- Neutrino oscillation and flavor-ratio observations,

- Gravitational-wave ringdown and propagation studies,
- And high-energy particle or dark-sector observations.

These datasets provide constraints rather than definitive reconstruction. Their strongest value lies in testing whether independent residuals share a common Qd12 operator-geometric parameter structure.

G.4 Neutrino-Based Probes

Neutrinos may offer a potential diagnostic tool due to their sensitivity to fiber-sector and boundary-coupled dynamics. In the refined FIT-Qd12 position, neutrinos are best understood as fiber-dominant projected modes, not as a separate ontological class of “information particles.”

Their weak interaction, long coherence length, oscillation behavior, and phase sensitivity make them useful probes of:

- Fiber-sector phase geometry,
- Chirality and mixing structure,
- Mass-gap organization,
- Boundary/ledger coupling,
- And possible collapse-imprinted anisotropy.
- Possible observables include:
- Energy-dependent deviations from standard oscillation models,
- Baseline-dependent phase residuals,
- Energy-dependent coherence shifts,
- Weak directional dependence in oscillation probabilities,
- High-energy astrophysical flavor-ratio deviations,
- And sterile-like boundary-suppressed behavior.

Such effects, if confirmed, could provide constraints on:

- Fiber-sector phase structure,
- Boundary/ledger coupling,
- Intermediate-layer NE distribution,
- Large-scale anisotropy,
- And cross-domain Qd12 parameter coherence.

However, quantitative predictions require further modeling. Null neutrino results constrain the fiber-ledger coupling channel; they do not by themselves falsify the full FIT-Qd12 operator framework.

G.5 Gravitational Lensing Diagnostics

Gravitational lensing may provide an integrated probe of curvature along the line of sight. In FIT-Qd12, lensing is especially important because dark-matter-like behavior is interpreted as a curvature-first effect associated with non-projecting or weakly projecting spectral curvature.

Time-delay, weak-lensing, and strong-lensing measurements may be sensitive to combined contributions from:

- Intermediate-layer curvature,
- DVZ-regulated projection,
- Non-projecting or weakly projecting dark-sector curvature,
- Boundary–substrate effects influencing expansion history,
- And ordinary matter and radiation.

In schematic form: $\Delta t \propto \int (1 + \Phi_{\text{eff}}) dl$

Where Φ_{eff} includes both standard matter contributions and effective geometric contributions beyond luminous matter.

These observations may be used to:

- Map effective curvature distributions,
- Identify anisotropic structure,
- Test correlations with large-scale features,
- Compare halo, filament, and void behavior,
- And evaluate whether lensing residuals require curvature-first contributions beyond particle-only dark-sector models.

The discovery of dark-sector particles would not by itself falsify this interpretation. Such particles may still be compatible with FIT-Qd12 if they arise as emergent, projected, semi-projecting, or residue modes of the Qd12/RTF operator geometry. The curvature-first dark-sector interpretation would be strongly challenged only if particle dark matter fully accounts for all dark-sector phenomena without requiring non-projecting curvature, boundary effects, dimensional-collapse structure, or Qd12-sector emergence.

G.6 Dark-Energy and Expansion Diagnostics

Dark-energy behavior provides a separate but related diagnostic channel. In the refined FIT-Qd12 position:

Dark energy = Qd12 substrate pressure expressed through APS ledger dynamics.

The uncollapsed Qd12 substrate supplies the pressure, while APS ledger dynamics regulate how that pressure appears as four-dimensional cosmic acceleration.

Possible expansion-related observables include

- Λ -like leading behavior,
- Weak redshift dependence,
- Mild modulation or relaxation of acceleration,
- Directional dependence in inferred expansion rates,
- Correlations between expansion history and large-scale structure,
- And consistency between dark-energy parameters and boundary/ledger parameters.

FIT-Qd12 allows dark-energy acceleration to slow, relax, modulate, or asymptotically flatten, but not to reverse under admissible boundary–substrate dynamics. A confirmed reversal into global contraction would strongly challenge the admissible dark-energy realization unless accompanied by a consistent mechanism involving substrate-pressure failure, APS ledger breakdown, or loss of mass-gap/spectral stability.

Thus, expansion diagnostics should not ask only whether dark energy evolves. They should ask whether the observed expansion behavior can be mapped to a boundary–substrate mechanism compatible with the rest of the Qd12 parameter structure.

G.7 Gravitational-Wave Diagnostics

Gravitational-wave observations may provide diagnostic access to the boundary-regulated near-horizon sector.

Potential observables include

- Late-time post-ringdown residuals,
- Inverse-mass-scaled frequency spacing,
- Spectral-comb structure,
- Small waveform deviations,
- Direction-dependent propagation effects,
- And echo-like features under specific boundary-reflection conditions.

In FIT-Qd12, gravitational-wave echoes are conditional signatures, not unconditional requirements. They arise only if APS-compatible boundary response, spectral mass-gap structure, and DVZ-regulated near-horizon

compression generate nonzero effective reflectivity in the observable gravitational-wave band.

Canonical Statement

A single tentative echo candidate is insufficient, and a single null result is not fatal. The FIT-Qd12 gravitational-wave claim concerns population-level, mass-scaled, boundary-regulated residual structure.

Absence of detectable echoes constrains effective boundary reflectivity and the observable boundary-reflection realization. It does not by itself falsify the full Qd12 operator framework.

G.8 Cross-Domain Reconstruction Strategy

A key feature of the framework is the possibility of combining multiple observational probes:

- CMB anisotropy and polarization,
- CMB lensing and large-scale-structure correlations,
- Large-scale structure alignment,
- Weak and strong lensing data,
- Expansion-rate variation,
- Dark-energy equation-of-state constraints,
- Neutrino behavior,
- Gravitational-wave residuals,
- And dark-sector particle searches.

The goal is to search for consistent patterns across independent datasets.

Such cross-domain consistency could provide stronger support than any single observable. The decisive question is not whether FIT-Qd12 can explain one anomaly. The decisive question is whether independent observational domains can be organized through a shared operator-geometric structure involving:

- Boundary/ledger dynamics,
- Fiber-sector phase behavior,
- DVZ-regulated projection,
- Mass-gap stability,
- Non-projecting curvature,
- And Qd12 substrate pressure.

Canonical Statement

FIT-Qd12 is not proven by fitting isolated anomalies. It is validated by recovering established physics while

explaining otherwise disconnected experimental residuals as correlated consequences of one admissible Qd12 operator geometry.

G.9 Limits of Reconstruction

It is important to emphasize

- Observational data do not uniquely determine collapse geometry,
- The CMB is only a projected time-slice, not the whole boundary ledger,
- Multiple configurations may produce similar signatures,
- Standard cosmological explanations remain viable alternatives,
- Foregrounds and systematics must be excluded before anomalies are interpreted structurally,
- And quantitative predictions require further model development.

Thus, reconstruction should be treated as a constrained inference problem, not a definitive identification.

A failed or absent signature in one sector constrains the corresponding realization, parameter channel, or observational mechanism. It does not automatically falsify the full operator framework unless the failure produces global incoherence across the shared Qd12 parameter structure.

G.10 Summary of Observational Diagnostics

Within the FIT-Qd12 framework:

- Collapse configuration may leave detectable imprints across multiple observational domains,
- Anisotropic configurations may produce directional signatures,
- Symmetric configurations are associated with near-isotropic cosmology,
- The observed CMB is a slice through boundary-imprinted radiation, not the complete Qd12 boundary record,
- Dark matter-like behavior is interpreted as curvature-first and may involve non-projecting or weakly projecting spectral curvature,
- Dark-sector particles, if discovered, do not automatically falsify FIT-Qd12 if they can be interpreted as Qd12/RTF emergent modes,
- Dark energy is interpreted as Qd12 substrate pressure expressed through APS ledger dynamics,

- Dark-energy acceleration may slow but does not reverse under admissible boundary–substrate dynamics,
- Neutrinos may provide fiber-sector and boundary-coupling diagnostics,
- Gravitational-wave echoes are conditional population-level signatures, not mandatory single-event predictions,
- And combined observational data can constrain, but not uniquely determine, underlying collapse geometry.

This appendix defines a structured approach for connecting theory to observation while maintaining consistency with current data, observational uncertainty, and alternative explanations. The strongest empirical test of FIT-Qd12 is cross-domain parameter coherence under one admissible Qd12 operator geometry.

Appendix H — DVz Thickness Variation, Collapse Constraints, and Global Stability

This appendix examines the role of spatial variation in the Dimensional Viscosity Zone (DVz) thickness and its implications for collapse localization and global stability within the FIT-Qd12 framework.

The central idea is that non-uniform DVz thickness may contribute to the localization of collapse channels and the suppression of extended or multi-region instabilities.

H.1 DVz Thickness Function and Geometric Structure

Let $d(x, y)$ denote the local DVz thickness at boundary (Ledger) coordinates (x, y) .

Within the framework, different regions of the interface may exhibit distinct geometric behavior

- Constricted regions (“necks”), where $d(x, y)$ approaches a local minimum
- Extended regions, where $d(x, y)$ is comparatively larger
- Multi-directional regions, where curvature contributions from different directions interact

This variation may support

- Localization of collapse-capable regions
- Directional bias in collapse configurations
- Separation between adjacent operator regions

H.2 Hypothetical Uniform-Thickness Configuration

Consider a hypothetical configuration in which: $d(x, y) \approx d_{\min}$ for all (x, y) In such a scenario

- Geometric differentiation between regions may be reduced
- Preferred collapse channels may be less well-defined
- Curvature and spectral effects may be more uniformly distributed

This configuration provides a useful contrast to the structured case, highlighting the role of geometric variation in collapse dynamics.

H.3 Effects on Collapse Localization

In the presence of DVz thickness variation

- Collapse is modeled as being concentrated in localized regions (necks)
- Spectral compression may be enhanced in specific directions
- Multi-directional alignment may be suppressed In the uniform-thickness scenario:
- Localization mechanisms may be weakened
- Collapse-capable regions may be less well-defined
- Distributed or competing configurations may arise

This suggests that thickness variation plays a key role in maintaining localized collapse behavior.

H.4 Multi-Region Coupling and Stability

Thickness variation also affects how different regions interact. With non-uniform DVz thickness

- Interactions between adjacent regions may be constrained
- Collapse remains localized within the model
- Propagation of instabilities may be suppressed With approximately uniform thickness:
- Coupling between regions may increase
- Separation between collapse channels may be reduced
- Extended or correlated collapse behavior may become more likely

Such configurations are not generally supported within admissible conditions.

H.5 Structural Role of Thickness Variation

The preceding considerations motivate the following structural statement

DVz Thickness Variation Principle.

Spatial variation in DVz thickness contributes to

- The existence of localized collapse channels
- Suppression of multi-directional collapse configurations
- Stabilization of interactions between adjacent regions

Uniform minimal thickness may not provide the same stabilizing features.

H.6 Constraints on Diagonal and Multi-Directional Collapse

In configurations with significant thickness variation:

- Regions with larger DVz separation may tend to suppress multi-directional collapse
- Constructive alignment across multiple directions is disfavored
- Collapse tends to remain confined within the model to dominant channels In contrast, in more uniform configurations:
- Multi-directional alignment may become less constrained
- Diagonal or multi-region configurations may become more accessible
- Localization may be reduced

These observations highlight the role of DVz geometry in constraining collapse structure.

H.7 Implications for Cosmogenesis and Symmetry

DVz thickness variation may contribute to several aspects of collapse behavior:

Localization of collapse channels

Constricted regions may provide preferred locations for collapse

Bias in symmetry outcomes

Geometric variation influences the likelihood of symmetric versus anisotropic configurations

Imprinted structure in post-collapse dynamics

Variations in geometry may contribute to directional features in effective observables

Stability of extended configurations

Separation between regions may support long-term structural consistency

These effects may be associated with geometric and spectral interplay rather than externally imposed rules.

Appendix H Summary

This appendix suggests that

- DVz thickness variation plays a central role in localizing collapse
- Non-uniform geometry supports separation between collapse channels
- Multi-directional collapse configurations are suppressed under typical admissible conditions
- Uniform-thickness configurations may lack the same stabilizing features
- Collapse behavior, symmetry outcomes, and large-scale structure may be influenced by DVz geometry

Thus, DVz thickness variation is a key structural feature of the framework, supporting both localized dynamics and global stability.

Appendix I — Structural Constraints and Admissibility of the Qd₁₂ Architecture

I.1 Purpose of This Appendix

The preceding appendices (A–H) established the internal structure of the FIT-Qd₁₂ framework

- Spectral operator construction and particle-physics structure (Appendix A)
- Dual-time compactification and modular evolution (Appendix B)
- Collapse geometry and coupled PDE dynamics (Appendix C)
- Boundary information encoding (Appendix D)
- Dark-sector tensor structure (Appendix E)
- Admissibility conditions and operator bounds (Appendix F)
- Observational diagnostics (Appendix G)
- DVz geometry and stability constraints (Appendix H) This appendix addresses the central question:

Is the Qd₁₂ architecture one possible description of

reality, or is it strongly constrained by the requirements of a consistent physical framework?

The central conclusion of this appendix is:

Within a class of admissible operator-geometric theories satisfying a defined set of physical and mathematical constraints, the Qd₁₂ architecture emerges as a highly constrained and internally consistent realization.

I.2 Structural Requirements

We consider frameworks satisfying the following conditions:

- Non-singular dynamics
- Global information consistency
- Boundary-compatible evolution
- Finite spectral action
- Collapse-based cosmogenesis
- Multiregion (extended) structure
- Geometric interpretation of dark-sector phenomena

These requirements define a restricted class of admissible theories.

I.3 Dimensional Constraints

I.3.1 Lower-Dimensional Configurations

Frameworks with fewer effective dimensions face simultaneous constraints

- Limited internal algebra for gauge structure
- Insufficient capacity for boundary encoding and modular flow
- Difficulty supporting non-singular collapse
- Limited capacity to accommodate coupled dark-sector geometry

These limitations suggest that lower-dimensional constructions may not generically support the full set of required features.

I.3.2 Higher-Dimensional Configurations

In higher-dimensional constructions

- Spectral expansions require additional constraints for finiteness
- Operator domains may become over-extended

- Projection to four-dimensional effective physics may not be uniquely defined

Such theories are not excluded, but typically require additional structure beyond minimal admissibility assumptions.

1.3.3 Intermediate Result

These considerations indicate that

- Dimensionality is not arbitrary
- Admissibility conditions strongly constrain the allowed structure
- The dimensional regime associated with Qd₁₂ appears to provide a consistent balance between capacity and control

1.4 Comparison with Existing Frameworks

Major theoretical frameworks may be compared with respect to the admissibility criteria defined above. In their standard formulations, many existing approaches do not simultaneously fix boundary encoding, include collapse dynamics, enforce global information consistency, and provide a unified operator-based treatment across all sectors without additional assumptions.

This comparison is not intended as an exclusion of alternative theories. Rather, it identifies the specific structural requirements that any framework must satisfy in order to belong to the admissible class considered here.

1.5 Collapse as a Structural Constraint

If collapse is taken as a fundamental mechanism, it motivates the presence of

- A boundary capable of encoding compressed information
- An intermediate structure regulating interaction
- A geometric mechanism for localization
- Finite, non-singular instability dynamics

These requirements collectively constrain the structure of the underlying framework.

1.6 Information Consistency Requirements

Global consistency is associated with requirements such as

- Preservation of distinguishability of physical states

- Compatibility with quantum-information constraints

- Absence of uncontrolled information loss These conditions motivate:

- Structured boundary encoding
- Consistent evolution laws
- Bounded operator dynamics

1.7 Dark-Sector Constraints

Observed large-scale phenomena suggest

- Additional effective contributions to gravitational dynamics
- Non-trivial structure beyond visible matter Within an operator framework, this motivates:
- Geometric contributions arising from internal structure
- Coupling between boundary and intermediate layers

1.8 Structural Synthesis

Combining

- Dimensional constraints
- Collapse requirements
- Information consistency
- Dark-sector considerations

We are led to a highly constrained class of admissible frameworks.

Within this class

The Qd₁₂ architecture provides a coherent realization in which these requirements can be simultaneously satisfied within a single operator-geometric structure.

1.9 Interpretation of Structural Constraints

The result should be interpreted as

- Not an absolute exclusion of all alternative theories
- But a strong constraint on theories satisfying the specified conditions In this sense:

FIT-Qd₁₂ may be viewed as a fixed point (or highly constrained realization) within the space of admissible operator-geometric frameworks.

Appendix I Summary

This appendix has argued that

- Multiple independent constraints restrict the space of admissible theories
- Dimensionality, boundary structure, and collapse dynamics are interdependent
- Information consistency and dark-sector behavior impose additional conditions

- Existing theoretical frameworks do not, in their standard formulations, simultaneously satisfy all requirements without additional structure

Within this constrained space the Qd₁₂ architecture emerges as a highly constrained and structurally consistent framework within the admissible class.