

# Evolutionary Quantum Cosmology: Unification via the Principle of Non-Nullity and Mirrored Polarity Symmetry on the Unit Interval

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## Abstract

Fundamental physics faces persistent paradoxes—gravitational singularities, the vacuum energy catastrophe, and the nature of the dark sector—that suggest an underlying axiomatic failure. We propose the Principle of Non-Nullity (PNN): states of absolute absence (mathematical zeros) are physically inaccessible. This work introduces Evolutionary Quantum Cosmology (EQC), a framework that implements the PNN by restricting the physical state space to the Unit Interval  $(0, 1)$ , centered on the fundamental symmetry axis at 0.5. We formalize this concept within an Effective Field Theory (EFT), where logarithmic potential barriers dynamically prevent access to the boundaries. We introduce Mirrored Polarity Symmetry ( $Z_2$ ), which duplicates the Standard Model into Visible ( $\Phi > 0.5$ ) and Mirror ( $\Phi < 0.5$ ) Sectors, rigorously preserving Gauge Invariance. EQC unifies cosmology: the PNN at maximum density demands  $P = -\rho$ , resolving singularities via stable de Sitter Cores (non-singular Black Holes) and generating the primordial Bounce/Inflation (Hilltop-type). Dark Matter emerges from a primordial asymmetry in the potential, interacting via kinetic mixing ( $\epsilon_{\min} \approx 0.1$ ). Dark Energy is identified with the minimum vacuum energy ( $m_{\min}^4$ ), with Quintessence dynamics. The model produces testable predictions:  $r \approx 0.015$  (CMB-S4),  $w_0 \approx -0.98$ ,  $w_a \approx 0.02$  (Euclid/Rubin), and  $\sigma_{\text{SD}} \sim 10^{-41} \text{cm}^2$  (DARWIN).

## 1 Introduction: The Axiomatic Crisis in Fundamental Physics

Modern physics faces a paradigmatic impasse. Despite the remarkable successes of General Relativity (GR) and the Standard Model (SM), the extreme regimes of physical inquiry reveal profound paradoxes that have resisted resolution for decades.

### 1.1 The Persistent Paradoxes

These include: (i) **Gravitational Singularities**, where GR predicts infinite density and null volume inside black holes and at the cosmological origin, signaling the collapse of the predictive formalism; (ii) **The Vacuum Energy Catastrophe**, where Quantum Field Theory (QFT) overestimates the ground state energy density by  $\sim 10^{120}$  orders of magnitude; (iii) **The Matter-Antimatter Asymmetry**, for which standard mechanisms are insufficient; and (iv) **The Nature of the Dark Sector**, which constitutes 95% of the universe's energy content, requiring the *ad-hoc* postulation of Dark Matter and Dark Energy.

Traditional approaches treat these as independent problems, postulating exotic new physics (e.g., supersymmetry, extra dimensions) without conclusive observational success. The persistence of these paradoxes suggests their origin may not lie in the failures of specific theories but in a systemic anomaly underlying the paradigm itself.

## 1.2 The Central Thesis: The Reification of Zero

We propose a radical alternative: these are not distinct physical problems but correlated symptoms of a single axiomatic flaw in the mathematical tool used to describe reality. The anomaly lies in the **reification of the concept of "absence"**—the mathematical entity zero (0)—as a quantifiable presence, a topological location, and a valid operator in equations modeling the physical universe.

Historically, the inclusion of zero on the number line introduced a topological discontinuity. The transition between opposite states (e.g., -1 and +1) is artificially mediated by a null point. This treatment of "absence" as "presence" has infiltrated the foundations of physics. In GR, it allows the premise of null volume ( $V = 0$ ), forcing the conceptually illegal operation  $M/0$  and generating singularities. In QFT, it allows the postulation of an exactly null energy state, leading to the vacuum catastrophe and forcing the interpretation of quantum superpositions as intermediate ontological states, rather than direct transitions between definite states.

## 1.3 The Proposed Solution: The Principle of Non-Nullity (PNN)

The resolution does not require exotic new physics but the correction of the axiomatic basis. We introduce the **Principle of Non-Nullity (PNN)** as a fundamental axiom:

**PNN:** Every physically accessible state possesses a non-null and finite measure.  
The physical state space does not contain the state of absolute absence.

The PNN implies that the universe operates within universal physical limits—a minimum quantum  $\epsilon_{\min} > 0$  and a maximum limit  $\epsilon_{\max} < \infty$ .

In Evolutionary Quantum Cosmology (EQC), we implement the PNN through a new formalism, the Mathematics of Reality (MoR), which redefines the fundamental field space on the Unit Interval  $(0, 1)$ , excluding the boundaries and centering the dynamics on the fundamental symmetry axis at 0.5.

EQC proposes that the universe is described by a unified scalar field  $\Phi$  existing in two Polarity phases, corresponding to a Mirrored Parity symmetry  $Z_2$ : Visible Sector ( $\chi_+, \Phi > 0.5$ ) and Mirror Sector ( $\chi_-, \Phi < 0.5$ ). The transition between these states (Polarity Inversion) occurs via quantum tunneling through the barrier at 0.5.

This paper details how this framework dissolves the central paradoxes and unifies cosmological dynamics (Inflation, Dark Matter, Dark Energy) as different manifestations of the field  $\Phi$ , yielding testable quantitative predictions.

# 2 Axiomatic Foundations: The Mathematics of Reality (MoR)

To rigorously implement the Principle of Non-Nullity (PNN), we introduce an axiomatic system, the Mathematics of Reality (MoR), which governs the interface between abstract mathematical formalism and physical reality.

## 2.1 The Physical Domain and the PNN (Axiom I)

The fundamental axiom defines the space of accessible values for any physical quantity.

**Axiom I (Fundamental Existence):** Every physically measurable state possesses a non-null and finite measure.

For any physical quantity  $Q$ , there exist universal limits: a minimum quantum  $\epsilon_{\min}(Q) > 0$  (e.g., Planck Scale, minimum residual mass) and a maximum limit  $\epsilon_{\max}(Q) < \infty$  (e.g., Maximum Density  $\rho_{\max}$ ).

The **Physical Domain**  $\mathbb{R}_{\text{Phys}}(Q)$  is defined as:

$$\mathbb{R}_{\text{Phys}}(Q) = \{x \in \mathbb{R} \mid \epsilon_{\min}(Q) \leq |x| \leq \epsilon_{\max}(Q)\}. \quad (1)$$

The immediate consequence is that the mathematical zero does not belong to the Physical Domain ( $0 \notin \mathbb{R}_{\text{Phys}}$ ). This axiom is aligned with Quantum Mechanics, which, through the Zero-Point Energy (ZPE), recognizes that states of absolute null energy are unattainable.

## 2.2 The Two-Layer Framework

MoR does not discard standard mathematics but operates through a two-layer framework to preserve algebraic consistency:

1. **Abstract Mathematics (AM):** The standard mathematical system (Algebra, Calculus), which includes zero (0) as the additive identity. It is used as an abstract calculation engine.
2. **Mathematics of Reality (MoR):** The system describing physical existence, operating exclusively on  $\mathbb{R}_{\text{Phys}}$ .

The interface between the two layers is governed by a set of operational axioms, the "Logical Firewall."

## 2.3 The Operational Axioms and the Logical Firewall

**Axiom II-A (Input Validation - The Firewall):** Any operation modeling the interaction of physical quantities requires all operands to belong to  $\mathbb{R}_{\text{Phys}}$ .

Since  $0 \notin \mathbb{R}_{\text{Phys}}$ , operations like  $X + 0$ ,  $X - 0$ ,  $X \times 0$ ,  $X/0$  are strictly invalid in MoR (Syntax Error). The system prevents interaction with the "non-entity." For example, the premise of Null Volume ( $V = 0$ ) in GR is axiomatically rejected, preventing the formation of conceptual singularities.

**Axiom II-B (Dynamic Validation - The Inversion):** If the dynamic evolution of a system tends to cross the boundaries of  $\mathbb{R}_{\text{Phys}}$  (approaching  $\epsilon_{\min}$  or  $\epsilon_{\max}$ ), the system undergoes a Polarity Inversion ( $\mathcal{I}$ ).

The boundaries act as transition barriers ( $\epsilon_{\text{trans}}$ ), not as final states. This axiom prevents dynamic singularities.

**Axiom IV (Annihilation and Equilibrium):** When an operation in AM results in the additive identity (0), the Firewall translates this result to the corresponding physical state in MoR through two rules:

1. **Cessation of Category:** The result 0 means the category  $X$  has been neutralized (e.g.,  $X - X$ ). The category is no longer applicable to the system.
2. **Ground State:** As the physical state 0 is forbidden, the system relaxes to the minimum allowed energy state: the EQC Physical Vacuum ( $\rho_{\min} \approx \epsilon_{\min}^4$ ).

This mapping is not *ad-hoc* but a dynamic consequence of the restriction imposed by the PNN on accessible energy states (detailed in Section 3).

## 2.4 The Unit Interval and Centrality at 0.5

The fundamental flaw of the standard number line is the insertion of zero between the positive and negative domains. In MoR, the fundamental geometric structure of reality is redefined on the **Unit Interval (0, 1)**.

1. **Domain:** Physical states are mapped to the open interval (0, 1).
2. **PNN Boundaries:** The points 0 and 1 represent absolute absence and are physically inaccessible (Axiom I).
3. **Symmetry Axis:** The fundamental symmetry axis between opposite domains is not 0, but the equilibrium point: **0.5**.

This structure redefines the interpretation of fundamental symmetries and phase transitions, as explored in Section 3.

## 2.5 Tools for Physical Calculus

Standard calculus is based on limits tending to zero ( $\Delta x \rightarrow 0$ ). In MoR, the smallest interval is  $\Delta x \geq \epsilon_{\min}$ . The appropriate mathematical tool is **Non-Standard Analysis (NSA)**, which formalizes the use of infinitesimals ( $\epsilon$ )—numbers greater than zero but smaller than any positive real number.

In NSA, the derivative is defined without the step  $\epsilon$  being zero:

$$f'(x) = \text{st} \left( \frac{f(x + \epsilon) - f(x)}{\epsilon} \right), \quad (2)$$

where *st* is the "Standard Part" function.

Consequently, fundamental theorems are reformulated. The Intermediate Value Theorem (IVT), which postulates  $f(x) = 0$ , is replaced by the **Intermediate Inversion Theorem (IIT)**: if a physical function changes polarity, it must pass through the Transition Barrier (0.5), where the Inversion occurs (Axiom II-B).

## 3 The Theoretical Framework of EQC (QFT)

EQC is formulated as an Effective Field Theory (EFT), valid below the Planck scale. In this framework, the axioms of MoR define the domain of validity and the geometric structure of the accessible field space.

### 3.1 The Normalized Field $\Phi$ and Mirrored Polarity Symmetry

To implement the geometry of MoR (Unit Interval centered at 0.5), we introduce the **Normalized Field**  $\Phi$ , a real scalar field that acts as the theory's order parameter.

1. **Domain:**  $\Phi$  is strictly defined on the domain  $\Phi \in (0, 1)$ , as per Axiom I.
2. **Symmetry Axis:** The field's dynamics are centered at  $\Phi = 0.5$ .

#### 3.1.1 Mirrored Parity Symmetry ( $Z_2$ )

We postulate that the fundamental structure of nature exhibits a discrete  $Z_2$  symmetry with respect to the  $\Phi = 0.5$  axis. Crucially, to ensure consistency with QFT, we define this symmetry as a **Mirrored Parity**. This parity implies the duplication of the entire field content of the Standard Model (SM):

- **Visible Sector (SM+):** Corresponds to states where  $\Phi > 0.5$ . It includes known particles and forces (e.g., photon  $\gamma_+$ ).
- **Mirror Sector (SM-):** Corresponds to states where  $\Phi < 0.5$ . It includes an exact copy of particles and forces (e.g., mirror photon  $\gamma_-$ ).

The  $Z_2$  symmetry ensures that the laws of physics (and coupling constants) are identical in both sectors.

#### 3.1.2 Preservation of Gauge Invariance

This Mirrored Polarity model rigorously preserves Gauge Invariance *within* each sector. The "darkness" of the SM- sector is due to the fact that it primarily interacts via its own mirror forces (e.g.,  $\gamma_-$ ), not with ours ( $\gamma_+$ ).

### 3.2 The Unified Effective Potential $V_{\text{eff}}(\Phi, T)$

The dynamics of the field  $\Phi$ , and therefore cosmological evolution, are governed by the Effective Potential  $V_{\text{eff}}$ , which depends on the field's state and external parameters like Temperature ( $T$ ).

#### 3.2.1 PNN Implementation: The Logarithmic Barrier

To ensure the field never reaches the physically inaccessible boundaries (0 and 1), the potential must diverge at these points ( $V \rightarrow \infty$ ). This dynamically implements the PNN within the EFT. The mathematical tool used is the **Logarithmic Barrier Function**  $B(\Phi)$ , centered at 0.5:

$$B(\Phi) = -\ln(1 - 4(\Phi - 0.5)^2). \quad (3)$$

As  $\Phi \rightarrow 0$  or  $\Phi \rightarrow 1$ ,  $B(\Phi) \rightarrow +\infty$ .

#### 3.2.2 Phase Transition Dynamics and Asymmetry

To model cosmological evolution (Inflation and Phase Transition), we use the Ginzburg-Landau formalism. We add dynamic terms (Quadratic and Quartic) and a Bias term ( $\beta$ ) to generate the observed asymmetry:

$$V_{\text{Dynamic}}(\Phi, T) = \Lambda^4 [A(T)(\Phi - 0.5)^2 + B(\Phi - 0.5)^4 + \beta(\Phi - 0.5)]. \quad (4)$$

Where  $\Lambda$  is the fundamental energy scale. The coefficient  $A(T)$  depends on temperature and controls the phase transition:

- **High T (Inflation):**  $A(T) > 0$ . The potential has a single minimum at  $\Phi = 0.5$  (False Vacuum).
- **Low T (Today):**  $A(T) < 0$ . The point  $\Phi = 0.5$  becomes a local maximum, and two minima emerge. The bias  $\beta$  makes the minimum at  $\Phi < 0.5$  (SM-) deeper than the minimum at  $\Phi > 0.5$  (SM+).

### 3.2.3 The Complete Mathematical Form

The Unified Effective Potential of EQC is the combination of these elements:

$$V_{\text{eff}}(\Phi, T) = V_{\text{Dynamic}}(\Phi, T) + \Lambda^4 [C \cdot B(\Phi)] + V_{\text{min}}. \quad (5)$$

Where  $C$  controls the strength of the PNN barrier, and  $V_{\text{min}} = m_{\text{min}}^4$  is the absolute minimum energy (Dark Energy). This potential (illustrated in Figure 1) describes the entire cosmological history.

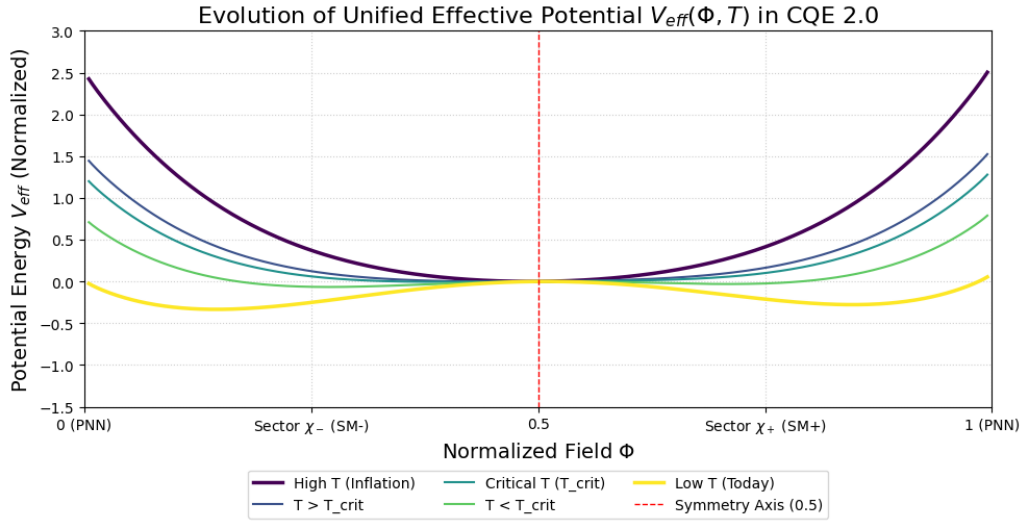


Figure 1: Illustration of the Unified Effective Potential  $V_{\text{eff}}(\Phi, T)$ , showing the logarithmic barrier at  $\Phi = 0$  and  $\Phi = 1$ , the temperature-controlled phase transition, and the primordial asymmetry ( $\beta$ ) favoring the SM- sector.

## 3.3 The Inversion Operator ( $\mathcal{I}$ ) and the Interaction Portal

The Inversion Operator  $\mathcal{I}$  is the discrete transformation that maps matter between the SM+ and SM- sectors ( $\mathcal{I} : \chi_+ \leftrightarrow \chi_-$ ).

Physically, as the potential at  $\Phi = 0.5$  forms an energy barrier, the inversion occurs via **Quantum Tunneling** (described by Instanton solutions in QFT). The tunneling probability is maximized under extreme conditions, which compress the effective width of the barrier.

For the two sectors to interact, a portal must exist. The PNN requires a minimal interaction ( $\epsilon_{\text{min}}$ ). In the Mirrored Polarity model, the most natural portal is **Kinetic Mixing** between the visible photon ( $\gamma_+$ ) and the mirror photon ( $\gamma_-$ ):

$$\mathcal{L}_{\text{Portal}} = -\frac{\epsilon_{\text{min}}}{2} F_+^{\mu\nu} F_{-\mu\nu}. \quad (6)$$

Where  $F_{\pm}^{\mu\nu}$  are the electromagnetic field tensors of each sector. We identify the kinetic mixing parameter with the fundamental minimum  $\epsilon_{\text{min}}$ . This portal is the mediator that allows the transition between polarities in extreme regimes and provides the mechanism for Dark Matter detection (Section 7.3).

## 4 The Dark Sector and the Unification Mechanism

The framework of EQC, based on Mirrored Polarity Symmetry, offers a natural identification for Dark Matter (DM) and a unified mechanism for its interactions, derived directly from the PNN.

### 4.1 The Identity of Dark Matter and Gauge Preservation

Dark Matter is identified as the content of the Mirror Sector (SM-), corresponding to the states of the field  $\Phi < 0.5$ . The  $Z_2$  symmetry ensures that the particle spectrum and the laws of physics are identical in both sectors (SM+ and SM-).

The "darkness" of the SM- sector is not due to an alteration of coupling constants (which would violate Gauge Invariance), but to the fact that its particles have no charge with respect to our forces (e.g., photon  $\gamma_+$ ), interacting primarily through their mirror counterparts (e.g.,  $\gamma_-$ ).

### 4.2 The PNN Portal and Minimal Interaction ( $\epsilon_{\min}$ )

Although the sectors are primarily decoupled, the PNN requires a minimal interaction between them, parameterized by  $\epsilon_{\min}$ . Phenomenological viability requires this interaction to generate the observed hierarchy in cross-sections, where Spin-Dependent (SD) interactions dominate over Spin-Independent (SI) ones.

To satisfy this requirement, the dominant portal must be an **Axial (or Pseudoscalar) Portal**. The interaction is mediated by the exchange of a pseudoscalar (or axial-vector) boson  $A$ , which couples to the SM+ and SM- sectors with a strength suppressed by the factor  $\epsilon_{\min}$ :

$$\mathcal{L}_{\text{Portal}} \supset \epsilon_{\min} \cdot (g_+ \bar{\psi}_+ \gamma^5 \psi_+ + g_- \bar{\psi}_- \gamma^5 \psi_-) A. \quad (7)$$

Where  $\psi_{\pm}$  are the fermions of each sector. This portal has two crucial functions:

1. **Mediating Inversion:** It allows energy transfer between sectors, mediating the tunneling process (Inversion  $\mathcal{I}$ ) under extreme conditions.
2. **Dark Matter Detection:** It generates residual interactions between SM- matter and SM+ detectors. Crucially, axial interactions naturally suppress  $\sigma_{\text{SI}}$  cross-sections at low energies while allowing for significant  $\sigma_{\text{SD}}$ .

*(Note: Other portals, such as Kinetic Mixing, may exist but must be subdominant to maintain phenomenological consistency.)*

### 4.3 Dark Matter Phenomenology

This mechanism allows for consistency with the phenomenological predictions of EQC:  $\sigma_{\text{SD}} \sim 10^{-41} \text{cm}^2$  and  $\sigma_{\text{SI}} \sim 10^{-50} \text{cm}^2$  (detailed in Section 7.3). Based on this axial portal, the magnitude of the fundamental minimal interaction is estimated to be  $\epsilon_{\min} \approx 0.1$ . EQC therefore predicts a Dark Matter signature dominated by Spin-Dependent interactions, accessible to future experiments like DARWIN.

## 5 Unified Cosmological Evolution

The Unified Effective Potential  $V_{\text{eff}}(\Phi, T)$  (Eq. 5) governs the dynamics of the universe from the primordial high-energy regime to the contemporary era, unifying Inflation, the genesis of Dark Matter, and Dark Energy through a cascade of phase transitions.

## 5.1 The Primordial Bounce and Inflation

EQC replaces the initial singularity with a non-singular Bounce in a finite universe ( $k > 0$ ).

### 5.1.1 The Bounce Mechanism ( $P = -\rho$ )

Upon reaching the maximum density  $\rho_{\max}$  imposed by the PNN (manifested as Quantum Exclusion), the condition of constant density ( $\dot{\rho} = 0$ ) relativistically requires (via the continuity equation) that the pressure becomes  $P = -\rho_{\max}$ . This extreme negative pressure reverses the collapse (Gaztañaga et al., 2025).

### 5.1.2 Hilltop Inflation

After the Bounce, the universe is at a high temperature ( $T_{\text{High}}$ ). The potential  $V_{\text{eff}}$  has  $A(T) > 0$  (Eq. 4), stabilizing the field at the symmetry axis  $\Phi = 0.5$  (False Vacuum). The energy of this state,  $\rho_{\text{Inf}}$ , drives exponential expansion. The dynamics correspond to a Hilltop Inflation model (Section 7.1).

## 5.2 The Cosmological Phase Transition and Reheating

As the universe cools, the temperature reaches a critical value  $T_{\text{Crit}}$ . The coefficient  $A(T)$  becomes negative, destabilizing the minimum at  $\Phi = 0.5$ . The field  $\Phi$  decays from the false vacuum, converting the potential energy ( $\rho_{\text{Inf}}$ ) into particles of the SM+ and SM- sectors (Reheating).

## 5.3 Genesis of Primordial Asymmetry (Asymmetric Dark Matter)

The origin of Dark Matter is primordial. The bias term  $\beta$  in  $V_{\text{eff}}$  makes the potential asymmetric (see Figure 1), causing the minimum in the SM- sector ( $\Phi < 0.5$ ) to be energetically preferable to the SM+ minimum ( $\Phi > 0.5$ ).

During the phase transition, this fundamental asymmetry directs the field's decay, resulting in a larger population in the mirror sector. This mechanism of **Asymmetric Dark Matter (ADM)** naturally explains the observed ratio:

$$\frac{\Omega_{\text{DM}}}{\Omega_{\text{B}}} \approx 5. \quad (8)$$

## 5.4 Dynamic Dark Energy and the Resolution of the Vacuum Catastrophe

In the contemporary era ( $T \approx 0$ ), the potential  $V_{\text{eff}}$  reaches its final form.

### 5.4.1 Vacuum Resolution

The absolute minimum energy of the system is  $V_{\min} = m_{\min}^4$ . The PNN (Axiom I) prevents the vacuum energy from being zero. If  $m_{\min} \approx 10^{-3}$  eV, the energy density coincides with the observed Dark Energy ( $\rho_{\text{DE}} \approx (10^{-3}\text{eV})^4$ ), resolving the Vacuum Catastrophe.

### 5.4.2 Thawing Quintessence

The field  $\Phi$  is not exactly at the minimum but is still relaxing very slowly towards it on an extremely flat potential. This "thawing" behavior (Thawing Quintessence) predicts a gentle



evolution of the equation of state (Section 7.2), consistent with recent observational hints (e.g., DESI).

## 5.5 Numerical Simulation Results

The complete evolution of the system has been numerically validated (Figure 2). The simulation confirms the sequence of Inflation ( $w = -1$ ,  $\Phi = 0.5$ ), Phase Transition (abrupt decay of energy, oscillations of  $\Phi$ ), and the subsequent cosmological evolution, validating the EQC model.

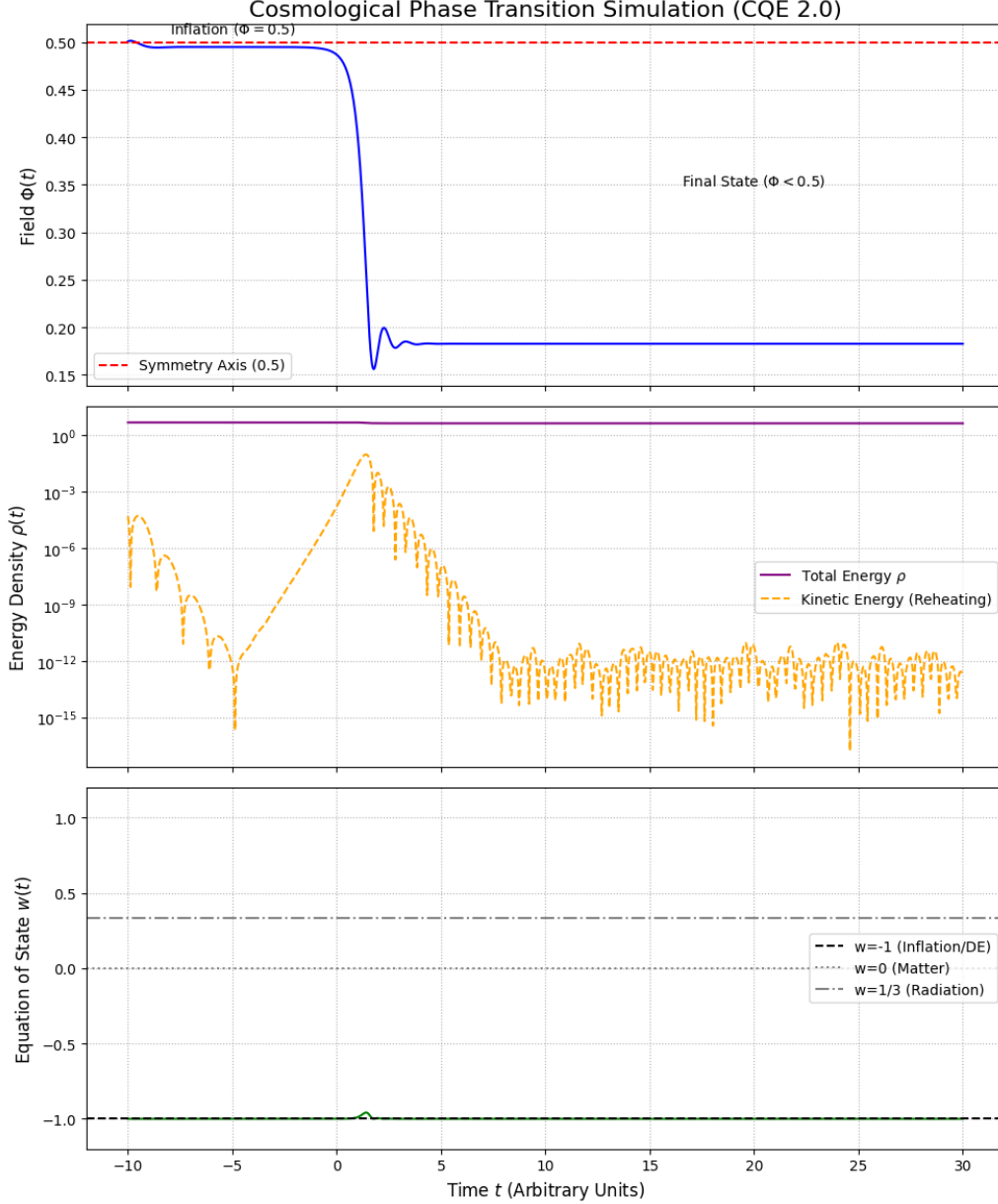


Figure 2: Results of the numerical simulation of the evolution of the field  $\Phi$  and the energy density  $\rho$  as a function of cosmological time.

## 6 Black Hole Astrophysics and the PNN in GR

Applying the Principle of Non-Nullity (PNN) to General Relativity (GR) profoundly modifies the physics of gravitational collapse, resolving the central singularity and redefining the nature

of black holes (BHs).

## 6.1 Singularity Resolution and the de Sitter Core

In classical GR, collapse inevitably leads to a singularity ( $\rho \rightarrow \infty, V \rightarrow 0$ ). Axiom I of MoR forbids this state, imposing a minimum volume  $\epsilon_V$  and a maximum density  $\rho_{\max}$ .

The physical mechanism preventing the final collapse is the manifestation of the PNN at high densities (Quantum Exclusion). Upon reaching  $\rho_{\max}$ , the condition of constant density ( $\dot{\rho} = 0$ ) requires, through the relativistic continuity equation, that the equation of state becomes  $P = -\rho_{\max}$ .

This extreme negative pressure balances gravitational attraction. In GR, a fluid with  $P = -\rho$  describes a **de Sitter (dS)** space. Therefore, the final outcome of the collapse is not a singularity but a stable **de Sitter Core**. Physically, this repulsive pressure can be interpreted as the Zero-Point Energy generated by the confinement of the field  $\Phi$  on the Unit Interval (Topological Casimir Effect).

## 6.2 The Internal Structure: The Expanded Seed

We postulate that this de Sitter Core (the "Planck Seed") does not remain microscopic but stabilizes by filling almost the entire internal volume of the Event Horizon ( $R_s$ ). The radius of the seed ( $R_{\text{seed}}$ ) is:

$$R_{\text{seed}} \approx R_s - \epsilon. \quad (9)$$

Where  $\epsilon$  is an infinitesimal distance (on the order of the Planck scale). This "Expanded Seed" structure is crucial for the phenomenology of EQC.

## 6.3 Black Holes as Polarity Converters

The Expanded Seed structure allows BHs to act as efficient converters between the SM+ and SM- sectors. The process occurs in four steps:

1. **Accretion:** Visible matter ( $\chi_+$ ) crosses the horizon  $R_s$ .
2. **Compression:** Almost immediately (after a distance  $\epsilon$ ),  $\chi_+$  hits the surface of the Seed, where the local density reaches  $\rho_{\max}$ .
3. **Inversion ( $\mathcal{I}$ ):** The extreme conditions catalyze Polarity Tunneling  $\chi_+ \rightarrow \chi_-$  through the axial portal (Eq. 7).
4. **Escape:** The inverted matter ( $\chi_-$ ) tunnels across the infinitesimal distance  $\epsilon$  to escape the horizon.

## 6.4 Stimulated Hawking Radiation and Conversion Efficiency

The escape mechanism is formally identical to Hawking Radiation (tunneling through the horizon). However, in EQC, the emission is stimulated by accretion, not a purely thermal process.

The continuous conversion at the surface generates an accumulation of  $\chi_-$ , creating a high **Chemical Potential** ( $\mu$ ). This potential difference across the gap  $\epsilon$  exponentially increases the tunneling probability. This justifies a conversion rate proportional to the accretion rate:

$$\frac{dM_{\chi_-}}{dt} \approx \eta_{\text{conv}} \cdot \dot{M}_{\text{acc}}, \quad \eta_{\text{conv}} \sim 0.05. \quad (10)$$

Although the contribution of BHs to the global DM density is negligible (DM is primordial, Section 5.3), this mechanism is fundamental for local dynamics in galactic centers.

## 6.5 Resolution of the Information Paradox

Information is not destroyed in the BH. It is encoded in the inverted polarity. The transformation  $\mathcal{I}$  acts as a unitary parity operator  $\hat{P}$  in the expanded Hilbert space ( $\text{SM}+ \oplus \text{SM}-$ ). Unitarity is preserved, as the informational structure is maintained; only its sector representation changes.

## 7 Phenomenology and Testable Predictions

EQC offers distinct quantitative predictions that can be tested by cosmological observations and particle physics experiments in the next decade.

### 7.1 Inflation (CMB-S4 and LISA)

The Hilltop Inflation model (Section 5.1.2), derived from the Unified Potential  $V_{\text{eff}}$  centered at  $\Phi = 0.5$ , predicts spectral parameters consistent with current data (Planck/BICEP):

- Scalar Spectral Index:  $n_s \approx 0.959$ .
- Tensor-to-Scalar Ratio:  $r \approx 0.015$ .

The detection of  $r \approx 0.015$  is a primary target for the **CMB-S4** experiment (sensitivity  $\sigma(r) \sim 0.001$ ). Furthermore, the model predicts a stochastic Gravitational Wave background with  $\Omega_{\text{GW}} \sim 10^{-13}$  in the mHz range, testable by **LISA**.

### 7.2 Dynamic Dark Energy (Euclid and Rubin)

The Thawing Quintessence mechanism (Section 5.4.2), where the field  $\Phi$  slowly relaxes towards  $V_{\text{min}}$ , predicts a gentle evolution of the Dark Energy (DE) equation of state. Using the CPL parameterization ( $w(a) = w_0 + w_a(1 - a)$ ):

- Current Value:  $w_0 \approx -0.98$ .
- Evolution:  $w_a \approx 0.02$ .

This "Waning DE" prediction ( $w > -1$ ) is consistent with recent hints from DESI and will be rigorously tested by the **Euclid** and **Vera Rubin** observatories, which can distinguish this model from the standard  $\Lambda\text{CDM}$  ( $w_0 = -1, w_a = 0$ ).

### 7.3 Dark Matter (DARWIN)

Dark Matter in EQC (Mirror Sector, Section 4) interacts via an Axial Portal suppressed by the PNN factor  $\epsilon_{\text{min}} \approx 0.1$ . For a particle mass  $m_\chi \sim 100$  GeV, this results in a distinct hierarchy in cross-sections:

- Spin-Dependent (SD):  $\sigma_{\text{SD}} \sim 10^{-41} \text{cm}^2$ .
- Spin-Independent (SI):  $\sigma_{\text{SI}} \sim 10^{-50} \text{cm}^2$  (strongly suppressed).

The  $\sigma_{\text{SD}}$  prediction is within the projected sensitivity range of the liquid Xenon experiment **DARWIN** and next-generation directional detectors. The detection of an SD-dominated signal would be strong evidence for the EQC portal mechanism.

## 8 Discussion and Further Implications

EQC offers a unified paradigm based on a fundamental axiomatic principle (PNN), which reformulates the geometric structure of QFT (Unit Interval) and integrates the main cosmological phenomena.

### 8.1 Conceptual Economy and Theoretical Consistency

The model's main virtue is its parsimony. Unlike approaches that postulate multiple *ad-hoc* fields and particles, EQC uses a single field ( $\Phi$ ) and a single principle (PNN) to simultaneously resolve singularity, inflation, the dark matter-asymmetry, and dark energy.

The framework is formulated as a consistent EFT, where Gauge Invariance is preserved through the Mirrored Polarity mechanism (Section 3.1). Furthermore, the Hilltop inflation model derived from  $V_{\text{eff}}$  satisfies constraints imposed by the Swampland Conjectures, such as the Refined de Sitter Conjecture (RdSC) and the Distance Conjecture (sub-Planckian field excursion), suggesting its compatibility with an underlying theory of quantum gravity.

### 8.2 Challenges and Limitations: Fine-Tuning and Naturalness

Although EQC resolves the Vacuum Catastrophe by setting  $\rho_{\text{DE}} = m_{\text{min}}^4$ , it faces naturalness challenges common to Quintessence models.

1. **Coincidence Problem:** The thawing mechanism (Section 5.4.2) requires the potential to be extremely flat today ( $m_{\Phi} \sim H_0 \sim 10^{-33}$  eV) to generate  $w \approx -1$ . The theory does not explain why this slow dynamic becomes dominant precisely in the current era.
2. **Fundamental Parameters:** The parameters governing observable phenomenology— $\beta$  (asymmetry bias) and  $\epsilon_{\text{min}}$  (minimal interaction)—are treated as fundamental inputs of the theory, determined experimentally, rather than being derived from first principles.

### 8.3 Philosophical Implications: Reinterpretation of Quantum Mechanics

The PNN has profound implications for the foundations of Quantum Mechanics (QM). If the null vector is not an accessible physical state, quantum "superposition" can be reinterpreted not as an ontological indeterminacy but as an artifact of the mathematical formalism describing the transition between states of opposite polarity.

EQC suggests that the underlying reality may be local and deterministic, with the probabilism of QM being epistemological (ignorance of the real polarity state). However, this interpretation faces the challenge of Bell's Theorems, which constrain local hidden-variable theories. A possible reconciliation may require questioning the premise of Statistical Independence underlying Bell's Theorem (Superdeterminism). Given that the PNN implies no system is truly isolated from the fundamental substrate (due to the minimal interaction  $\epsilon_{\text{min}}$  or the vacuum  $\rho_{\text{min}}$ ), pre-established correlations are conceivable. The formal resolution of this issue remains a goal for future work.

### 8.4 The Final Fate: The Cyclic Universe

The PNN has a profound consequence for the fate of the universe. Axiom I implies the existence of an absolute minimum temperature,  $T_{\text{trans}} > 0$ . Therefore, the "Heat Death" (Big Freeze), which assumes  $T \rightarrow 0$ , is physically impossible.

When the universe approaches  $T_{\text{trans}}$  in the distant future, the extreme conditions will favor a global **Great Inversion**. The field  $\Phi$  will universally tunnel, reversing the dominant pressure and initiating a contraction phase (Big Crunch). This contraction will culminate at  $\rho_{\text{max}}$ , triggering a new Bounce (Section 5.1.1) and starting the next cosmological cycle. EQC therefore implies a Cyclic Universe model, where information is preserved and re-encoded through polarity inversions.

## 9 Conclusion

Evolutionary Quantum Cosmology (EQC) proposes a unified resolution to the central paradoxes of modern physics by identifying the "reification of zero" as the underlying axiomatic flaw. The framework is founded on the Principle of Non-Nullity (PNN), which asserts that states of absolute absence are physically inaccessible.

We implement the PNN through the Mathematics of Reality (MoR), which restricts the physical field space to the Unit Interval  $(0, 1)$ , centered at 0.5. Within an Effective Field Theory (EFT), the PNN is dynamically imposed by logarithmic potential barriers. The theory's central structure is the Mirrored Polarity Symmetry ( $Z_2$ ), which duplicates the Standard Model into Visible and Mirror sectors, preserving Gauge Invariance.

EQC provides a self-consistent cosmological narrative:

1. **Singularities** are resolved. The PNN at  $\rho_{\text{max}}$  demands  $P = -\rho$ , leading to a primordial Bounce and the formation of stable de Sitter Cores inside Black Holes.
2. **Inflation** emerges naturally after the Bounce (Hilltop model).
3. **Dark Matter** is identified with the Mirror Sector, generated by a primordial asymmetry in the unified potential, interacting via a suppressed axial (or pseudoscalar) portal ( $\epsilon_{\text{min}} \approx 0.1$ ).
4. **The Vacuum Catastrophe** is resolved by identifying Dark Energy with the minimum allowed energy ( $m_{\text{min}}^4$ ), with Quintessence dynamics.

The theory is phenomenologically viable and offers clear quantitative predictions:  $r \approx 0.015$  (testable by CMB-S4),  $w_0 \approx -0.98$ ,  $w_a \approx 0.02$  (testable by Euclid/Rubin), and  $\sigma_{\text{SD}} \sim 10^{-41} \text{cm}^2$  (testable by DARWIN).

EQC demonstrates that logical consistency, by requiring the elimination of zero as a physical entity, not only resolves paradoxes but reveals a unified structure underlying reality, where nature operates not through annihilation but through the transition between opposite states mediated by fundamental physical limits.

## A The Geometric Intuition of PNN and the Corrected Euler Identity

The connection between the Principle of Non-Nullity and the fundamental structure of reality can be elegantly illustrated through a physical reinterpretation of Euler's Identity,  $e^{i\pi} + 1 = 0$ . From the perspective of EQC, this identity represents the most elegant axiomatic example of the "Reification of Zero"—the systemic flaw the PNN aims to correct.

## A.1 Euler's Formula and the Fundamental Complex Field

Euler's Formula,  $e^{ix} = \cos(x) + i\sin(x)$ , describes a rotation in the complex plane. In physics, systems exhibiting transitions between opposite states can be described by a Complex Scalar Field  $\Psi$ . In polar coordinates:

$$\Psi = Re^{i\theta}. \quad (11)$$

Where  $R$  is the amplitude and  $\theta$  is the phase.

In EQC, we can interpret the fundamental polarity states in terms of the phase  $\theta$ :

- Positive Polarity ( $\chi_+$ ):  $\theta = 0$ .  $\Psi_+ = Re^{i(0)} = R$ .
- Negative Polarity ( $\chi_-$ ):  $\theta = \pi$ .  $\Psi_- = Re^{i\pi} = -R$ .

The Inversion Operator ( $\mathcal{I}$ ) therefore corresponds to a rotation of  $\pi$  radians ( $180^\circ$ ) in the complex plane of the field  $\Psi$ .

## A.2 The Axiomatic Flaw in the Standard Identity

The standard Euler's Identity (in Abstract Mathematics, AM) is based on the exact evaluation:

$$e^{i\pi} = \cos(\pi) + i\sin(\pi) = -1 + i(0). \quad (12)$$

The term  $\sin(\pi) = 0$  asserts that at the exact point of inversion, the orthogonal (imaginary) component is null. This is the "reification of zero" that the PNN contests. If zero is physically inaccessible (Axiom I), then a state with an exactly null component cannot be realized.

## A.3 The Physical Correction via PNN (The Imperfect Rotation)

The PNN implies that the physical rotation cannot be exactly  $\pi$ . There must be a minimal uncertainty or deviation,  $\delta$ , imposed by the fundamental limit  $\epsilon_{\min}$ . The physical inversion phase is not  $\pi$ , but rather:

$$\theta_{\text{Phys}} = \pi - \delta. \quad (13)$$

Where  $\delta$  is a positive infinitesimal value related to  $\epsilon_{\min}$ .

Applying this physical rotation to the field  $\Psi$ :

$$\Psi_{\text{Inverted}} = Re^{i(\pi-\delta)} = R(\cos(\pi-\delta) + i\sin(\pi-\delta)). \quad (14)$$

Using trigonometric identities ( $\cos(\pi-\delta) = -\cos(\delta)$ ;  $\sin(\pi-\delta) = \sin(\delta)$ ) and the approximation for small  $\delta$  ( $\cos(\delta) \approx 1$ ;  $\sin(\delta) \approx \delta$ ):

$$\Psi_{\text{Inverted}} \approx R(-1 + i\delta). \quad (15)$$

## A.4 The Corrected Euler Identity (EQC)

Identifying the fundamental deviation  $\delta$  with the physical minimum  $\epsilon_{\min}$ , we obtain the Euler Identity corrected by EQC:

$$e_{\text{Phys}}^{i\pi} = -1 + i\epsilon_{\min}. \quad (16)$$

This equation states that a polarity inversion never results in a pure state ( $-1$ ). It inevitably carries with it a residual orthogonal component  $i\epsilon_{\min}$ .

*(Technical Note: This implies that the physical inversion operation is not a purely unitary rotation in the standard complex plane, since  $|e_{\text{Phys}}^{i\pi}| = \sqrt{1 + \epsilon_{\min}^2} > 1$ . This reflects the fact that the transition involves an interaction with the fundamental energetic substrate.)*

## A.5 The Fundamental Physical Formula of Unification

Eq. 16 can be mapped directly to the unified phenomenology of EQC:

- $e_{\text{Phys}}^{i\pi}$  (The Operation)  $\rightarrow \mathcal{I}$  (The Inversion Operator).
- $-1$  (The Real Component)  $\rightarrow \chi_-$  (The Inverted Polarity State / Dark Matter).
- $i\epsilon_{\text{min}}$  (The Imaginary Component)  $\rightarrow i\rho_{\text{min}}$  (The Minimal Residual Energy / Dark Energy).

The emerging fundamental physical equation is:

$$\mathcal{I}[\chi_+] \rightarrow \chi_- + i\rho_{\text{min}}. \quad (17)$$

This equation elegantly demonstrates that Dark Matter and Dark Energy are not independent phenomena but simultaneous and inevitable products of the same fundamental transition—the Polarity Inversion—whose structure is dictated by the Principle of Non-Nullity.