Quantum Information Cosmology with Scalar Field (QIC-S)
Version 7.0: Mathematical Foundation for Multi-Hamiltonian Universe

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Ver.7.0 establishes a rigorous mathematical foundation for the "Multi-Hamiltonian Universe" central to QIC-S theory. By integrating the **Conformal Interface theory** of Komatsu, Kusuki, Meineri & Ooguri (arXiv:2512.11045, December 2025), we demonstrate that regions with distinct effective Hamiltonians—individual galaxies—can coexist within a unified spacetime, smoothly connected by conformal interfaces.

This framework yields a profound reinterpretation: the Dark Matter halo is not a cloud of exotic particles, but the **physical manifestation of the conformal interface**—the stress-energy cost of transitioning between galactic and intergalactic vacuum states. We term this the **Gluing Mechanism** (Japanese: のり, *nori*).

Key Results:

1. **Mathematical Proof:** Multi-Hamiltonian structures are permitted by CFT principles and protected by the exact marginality of deformation operators ($\langle\phi\phi\phi\rangle = 0$).
2. **Positive Energy & Gravity:** The Averaged Null Energy Condition (ANEC) guarantees that the interface energy density is positive ($N_D > 0$), ensuring attractive gravity.
3. **Holographic Ansatz:** We formulate the extension from 2D CFT to 4D spacetime as a rigorous working hypothesis analogous to the Israel Junction Conditions.
4. **Unique Predictions:** The theory predicts a specific scaling law for the interface width, offering a unique signature distinct from Cold Dark Matter.

I. INTRODUCTION: THE PROBLEM OF COEXISTING LAWS

A. The Multi-Hamiltonian Challenge

QIC-S theory proposes that each galaxy possesses its own effective Hamiltonian H_{eff}, characterized by a local transport coefficient D_{eff}. This "Multi-Hamiltonian Universe" immediately raises a fundamental question:

How can different physical laws coexist in adjacent regions of spacetime without violating fundamental principles?

B. Solution via Gluing Mechanism

Recent developments in conformal field theory (CFT) provide the answer. Komatsu et al. (2025) proved that if a conformal manifold exists, nearby CFTs must be connected by **conformal interfaces**.

This theorem ensures that:

- Distinct effective theories can **coexist**.
- They are connected by a smooth interface satisfying a specific **Gluing Condition**, ensuring **Inter-Galactic Continuity**.

II. MATHEMATICAL FRAMEWORK: THE INTERFACE AS "GLUE"

A. The Gluing Condition

Consider two regions with different effective physics, CFT_L (Galaxy) and CFT_R (Intergalactic Space). At their boundary—the conformal interface—the energy-momentum tensor must satisfy the **Gluing Condition**:

$$T_L - \bar{T}_L = T_R - \bar{T}_R \tag{1}$$

where T and $\bar{T}$ denote the holomorphic and anti-holomorphic components of the stress-energy tensor, respectively.

Physical Interpretation: This equation guarantees the conservation of energy and momentum across the interface, allowing the "Multi-Hamiltonian" landscape to exist as a continuous **Conformal Manifold**.

B. The Displacement Operator and Positive Energy (ANEC)

The mismatch between adjacent regions generates a localized energy cost, quantified by the **Displacement Operator** D:

$$D \equiv T_L + \bar{T}_L - T_R - \bar{T}_R = 2(T_L - T_R) \tag{2}$$

The two-point function of this operator takes the form:

$$\langle D(z)D(w)\rangle = \frac{N_D}{(z-w)^4} \tag{3}$$

where the normalization constant is given by:

$$N_D = (2\pi\delta\lambda)^2 + O(\delta\lambda^3) > 0 \tag{4}$$

Here, $\delta\lambda$ parameterizes the difference between adjacent theories. In QIC-S terms:

$$\delta\lambda \sim D_{\text{eff},L} - D_{\text{eff},R} \tag{5}$$

Following the **Averaged Null Energy Condition (ANEC)** (Meineri et al., 2020), N_D is strictly **positive**, with the stronger bound:

$$N_D \geq 2|c_L - c_R| \tag{6}$$

where c_L and c_R are the central charges of the respective CFTs.

Physical Implication for Dark Matter:

- The interface energy density is proportional to N_D.
- Since $N_D > 0$, this energy density is **positive definite**.
- Therefore, the Gluing Mechanism always manifests as **attractive gravity** (Dark Matter), never as repulsive force.
- This is not an assumption but a **mathematical theorem** guaranteed by ANEC.

C. Exact Marginality and Quantum Stability

A critical feature of this framework is the stability of the interface against quantum corrections. In the limit where the interface vanishes ($\delta\lambda \to 0$), the normalized displacement operator becomes the exactly marginal operator:

$$\phi = \lim_{N_D \to 0} \hat{D}, \quad \text{where} \quad \hat{D} \equiv \frac{D}{\sqrt{N_D}} \tag{7}$$

Komatsu et al. proved that the three-point function of this operator vanishes identically:

$$\langle \phi(z)\phi(w)\phi(u)\rangle = 0 \tag{8}$$

Significance: The vanishing three-point function ensures that the Multi-Hamiltonian structure is **quantum mechanically stable**. It is not an unstable configuration that decays, but a **robust vacuum solution** protected at the leading order of perturbation theory.

III. PHYSICAL REALIZATION: FROM 2D TO 4D SPACETIME

A. Ansatz: Holographic Dimensional Extension

While the proofs by Ooguri et al. rely on 2D CFT, we postulate their validity in our 3+1 dimensional spacetime based on the **Holographic Principle**.

Core Ansatz (Dimensional Extension):

> *We postulate that the mechanism of conformal interfaces and domain walls, proven in 2D, extends to 4D spacetime as 3-dimensional hypersurfaces (membranes). Specifically, we treat the galaxy as a "bubble" of a specific vacuum on the Conformal Manifold, bounded by a domain wall.*

The 2D Gluing Condition generalizes to 4D as:

$$\int_\Sigma d^3x\sqrt{h}\,(T^{\mu\nu}n_\mu n_\nu)\big|_L = \int_\Sigma d^3x\sqrt{h}\,(T^{\mu\nu}n_\mu n_\nu)\big|_R \tag{9}$$

where Σ is the interface hypersurface (3D membrane), h is the induced metric, and n_μ is the normal vector.

Note: This ansatz is conceptually analogous to the **Israel Junction Conditions** in General Relativity, but applied here to the stress-energy tensor of the Conformal Interface within the context of the Swampland program.

B. The Galactic Halo as a Thick Interface

In cosmological reality, the mathematical interface is not infinitely thin but acquires **finite thickness** due to coarse-graining of the information field.

The region where D_{eff} transitions from the galactic value ($D_{\text{eff,gal}}$) to the cosmic background value ($D_{\text{eff,cosmic}}$) corresponds to the **Galactic Halo**:

$$r_{\text{inner}} < r < r_{\text{outer}}: \quad D_{\text{eff}}(r) \text{ transitions smoothly} \tag{10}$$

C. Scaling Law

The characteristic width of the interface ($\ell_{\text{interface}}$) scales with the normalization constant N_D:

$$\ell_{\text{interface}} \sim \frac{1}{\sqrt{N_D}} \sim \frac{1}{|\delta\lambda|} \sim \frac{1}{|D_{\text{eff,gal}} - D_{\text{eff,cosmic}}|} \tag{11}$$

Important Note: This prediction concerns the **intrinsic width** of the transition zone, not necessarily the total virial extent.

IV. CONNECTION TO SWAMPLAND PROGRAM

This framework aligns QIC-S with the **Swampland Program** (Vafa et al.), specifically **Conjecture 0**:

"There are no free parameters in quantum gravity; all parameters are expectation values of scalar fields."

QIC-S Achievement: The transport coefficient D_{eff} is not a "fitting parameter" but the **expectation value of the exactly marginal operator** ϕ. QIC-S satisfies Conjecture 0.

V. TESTABLE PREDICTIONS

The Gluing Mechanism framework generates specific, falsifiable predictions that distinguish QIC-S from standard Cold Dark Matter models:

1. **Interface Width Scaling:** $\ell_{\text{interface}} \propto 1/|\Delta D_{\text{eff}}|$. The sharpness of the halo boundary should correlate with the contrast between galactic and intergalactic environments.

2. **No Negative Mass Dark Matter:** $N_D > 0$ (guaranteed by ANEC) implies that repulsive "Dark Matter" is **mathematically impossible** in this framework.

3. **Environmental Signature:** The interface width should anti-correlate with environmental isolation. Isolated galaxies (large contrast) should have sharper transition zones than cluster galaxies (small contrast), distinct from tidal stripping effects.

4. **Universal Chiral Invariant:** Following the theorem that $(c - \bar{c})$ is invariant on the conformal manifold, some analogous quantity should be **universal across all galaxies**, independent of mass or morphology.

VI. CONCLUSION

Ver.7.0 elevates QIC-S to a theory grounded in the deepest structures of high-energy theoretical physics.

Summary:

- **Gluing Mechanism:** Galaxies are local domains connected by conformal interfaces (Japanese: のり), ensuring Inter-Galactic Continuity.
- **Dark Matter:** Identified as positive interface energy ($N_D > 0$, via ANEC).
- **Quantum Stability:** Guaranteed by $\langle\phi\phi\phi\rangle = 0$.
- **4D Extension:** Holographic Ansatz analogous to Israel Junction Conditions.

VII. FUTURE DIRECTIONS

1. **Quantitative rotation curves** derived from interface action.
2. **Validation** of 4D Ansatz via AdS/CFT correspondence.
3. **Connection** to hydrodynamic limit of interacting particle systems (Prof. Sasada's framework).
4. **Observational tests** of Predictions 1-4.

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GLOSSARY

- **Conformal Manifold:** Space of CFTs connected by exactly marginal deformations.
- **Conformal Interface:** Boundary connecting two CFTs; the "glue" (Japanese: のり).
- **Gluing Condition:** $T_L - \bar{T}_L = T_R - \bar{T}_R$.
- **Displacement Operator:** $D = 2(T_L - T_R)$; interface energy.
- **ANEC:** Averaged Null Energy Condition; guarantees $N_D > 0$.
- **Exactly Marginal Operator:** ϕ with $\langle\phi\phi\phi\rangle = 0$; generator of D_{eff} variation.
- **Israel Junction Conditions:** GR analog for domain wall matching.
- **Holographic Ansatz:** 2D→4D extension postulate.