Cyclic Cosmology with Informational Inheritance (CCHI)

A Framework for Perturbative Memory Across Quantum Bounces

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Abstract

This paper introduces the **Cyclic Cosmology with Informational Inheritance (CCHI)**, a theoretical framework proposing that the universe undergoes repeated cycles of expansion and contraction mediated by a quantum bounce, during which statistical information about the pre-bounce matter distribution survives into subsequent cycles, encoded in the post-bounce perturbation spectrum. Built upon Loop Quantum Cosmology (LQC), the framework presents three original contributions: a **master equation** governing the cyclic evolution of the primordial power spectrum via Bogoliubov transfer coefficients, which admits a stabilized fixed point whose resonant peaks nucleate Primordial Black Holes (PBHs); a **derivation of Entropic Time Dynamics** (ETD) from the effective LQC metric, identifying the chrono-entropic coupling $\Gamma(\rho) = 1 - \rho/\rho_c = g_{00}^{\text{eff}}$ with no free parameters; and a **unified mechanism** connecting gravitational baryogenesis, PBH dark matter in the asteroidal mass window, and the seeding of supermassive black holes observed by JWST at $z > 10$. The framework yields falsifiable predictions for CMB-S4, LiteBIRD, the Roman Space Telescope, and LVK O4/O5, and addresses the cyclic entropy problem through the distinction between thermodynamic entropy (diluted each cycle) and entanglement entropy (transferred as low-entropy correlations).

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1 Introduction: The Cosmological Impasse and the Cyclic Alternative

1.1 The Current Impasse of Cosmology

The standard cosmological model, known as Lambda-Cold Dark Matter (ΛCDM), represents a triumph of modern physics. It describes with remarkable precision the evolution of the universe from the era of the Cosmic Microwave Background (CMB) to the formation of the cosmic web of galaxies observed today. However, its empirical success masks a series of deep conceptual gaps and growing tensions with new high-precision observations. The ΛCDM model is, by construction, an effective model rather than a final theory of the cosmos.

1.2 Observational Anomalies

The crisis of early structure formation. The James Webb Space Telescope (JWST) has revealed the existence of supermassive black holes (SMBHs) and massive galaxies at redshifts $z > 10$, much earlier than standard structure formation models predicted [1, 2]. These objects exhibit masses $M_{\rm BH} \sim 10^6$–$10^8\, M_\odot$ and ratios $M_{\rm BH}/M_\star \gg 10^{-3}$, requiring "seeds" significantly heavier than those that could be formed from Population III stellar remnants. Notable examples include UHZ1 ($z = 10.1$, $M_{\rm BH} \approx 4 \times 10^7\, M_\odot$; Natarajan et al. 2024) and GN-z11 ($z = 10.6$, $M_{\rm BH} \approx 1.6 \times 10^6\, M_\odot$; Maiolino et al. 2024).

The H_0 and S_8 tensions. Persistent discrepancies at the 4–6σ level exist between measurements of the current expansion rate of the universe (H_0) and the amplitude of matter fluctuations (S_8) inferred from the early universe (via CMB) and direct measurements in the local universe [3].

CMB anomalies. The CMB power spectrum exhibits a persistent power suppression at multipoles $\ell < 30$ with 2–3σ significance [4]. Although not individually decisive, this anomaly finds a natural explanation in bounce cosmologies where the finite duration of the pre-bounce phase imposes an infrared cutoff on perturbation modes.

The gravitational wave background. The NANOGrav 15-year dataset reports a stochastic gravitational wave background at the 3–4σ level [5]. While SMBH binaries provide the primary explanation, the amplitude and spectral shape of the signal admit contributions from primordial sources, including populations of PBHs formed in the early universe.

The cosmological constant problem. Quantum field theory predicts a vacuum energy $\sim 10^{120}$ times larger than the observed value of Λ — the most severe discrepancy between theory and observation in fundamental physics.

1.3 Conceptual Challenges

Beyond the observational tensions, ΛCDM is conceptually incomplete. The Big Bang singularity remains physically unresolved — general relativity predicts its own failure at infinite densities and curvatures, signaling the need for a theory of quantum gravity. The nature of dark matter and dark energy, which together comprise $\sim$95% of the energy content of the universe, remains unknown. And inflationary theory, although successful in resolving the horizon and flatness problems, does not address the initial singularity and requires an *ad hoc* scalar field (the inflaton) whose physical identity is unknown [17, 18].

1.4 The Cyclic Alternative

Cyclic cosmologies — in which the universe undergoes repeated phases of expansion and contraction — offer a radical resolution to several of these problems. By replacing the initial singularity with a non-singular quantum bounce, they eliminate the need for special initial conditions. By allowing information to persist between cycles, they can explain correlations that would otherwise require fine-tuning.

However, existing cyclic models face their own difficulties:

Model	**Inheritance mechanism**	**Main difficulty**
CCC (Penrose 2010) [19]	Radiation (conformal rescaling)	Hawking points not detected; conformal rescaling physically controversial
Ekpyrotic/IFS (Steinhardt & Turok 2002; Ijjas & Steinhardt 2024) [20, 21]	Scalar field modes	Requires extra dimensions (10D string theory); slow contraction mechanism debated

It is proposed that the key missing ingredient is a precise mechanism of *informational inheritance* — the transfer of statistical information about the pre-bounce matter distribution to the post-bounce perturbation spectrum — built upon established physics without requiring extra dimensions or unvalidated reformulations.

2 The CCHI Framework

The central thesis of the CCHI is that the universe retains a statistical memory of its previous cycles, not through the survival of macroscopic structures, but through the persistence of quantum correlations in super-Hubble perturbation modes across the bounce. This informational inheritance is mediated by the Bogoliubov transformation of the Mukhanov-Sasaki variable and constitutes the fundamental novelty of the framework.

The framework operates through six interconnected components:

1. **Quantum bounce with perturbative memory** (LQC + Bogoliubov transfer)
2. **Entropic time dynamics** (ETD derived from the effective LQC metric)
3. **Gravitational baryogenesis** (Schwinger mechanism at the bounce)
4. **PBH nucleation from cyclic memory** (resonant peaks $\rightarrow$ asteroidal-mass PBHs)
5. **High-redshift SMBH seeding** (PBH seeds $\rightarrow$ JWST observations)
6. **Entropy management** (separation between thermodynamic and informational entropy)

It is emphasized that the CCHI **does not propose** the survival of macroscopic structures (such as black holes) through the bounce — the Planck-density regime ($\rho \sim \rho_c \approx 0.41\,\rho_{Pl}$) homogenizes all classical horizons (Wilson-Ewing 2024 [22]; BKL instability $\sigma^2 \propto a^{-6}$). What survives is *information*: the statistical correlations encoded in super-Hubble perturbation modes, which are frozen and protected from dissipation during the dark-energy-dominated phase and are transferred through the bounce via quantum evolution of the Mukhanov-Sasaki variable [7, 8].

3 Quantum Bounce Dynamics with Perturbative Memory

The quantum bounce of Loop Quantum Cosmology (LQC) is robust and validated in multiple models with reduced symmetry. The novelty introduced here is the formalism for information transfer between cycles via Bogoliubov coefficients and the cyclic master equation.

3.1 Background Dynamics: The LQC Bounce

The foundation of the CCHI is Loop Quantum Cosmology (LQC), an application of Loop Quantum Gravity (LQG) to cosmological scenarios. LQG postulates that spacetime itself is quantized, with a minimum "atom" of area proportional to the Planck length. This fundamental discretization introduces a repulsive term in the gravitational dynamics at densities close to the Planck density, preventing the formation of singularities [6].

For a homogeneous and isotropic universe described by the Friedmann-Lemaître-Robertson-Walker (FLRW) metric, the LQC dynamics is encapsulated in the **modified Friedmann equation** [6]:

$$\boxed{H^2 = \frac{8\pi G}{3}\,\rho\left(1 - \frac{\rho}{\rho_{\mathrm{c}}}\right)} \tag{1}$$

where $H \equiv \dot{a}/a$ is the Hubble parameter, ρ is the total energy density, and ρ_{c} is the **critical bounce density**:

$$\rho_{\mathrm{c}} = \frac{\sqrt{3}}{32\pi^2\gamma^3}\,\rho_{\mathrm{Pl}} \approx 0.41\,\rho_{\mathrm{Pl}} \approx 2.1\times 10^{96}\ \mathrm{kg/m^3} \tag{2}$$

where $\gamma \approx 0.2375$ is the Barbero-Immirzi parameter, fixed by the black hole microstate counting in LQG.

The term $(1 - \rho/\rho_{\mathrm{c}})$ is the quantum correction. At low densities ($\rho \ll \rho_{\mathrm{c}}$), it is negligible and standard general relativity is recovered. When $\rho \to \rho_{\mathrm{c}}$ during contraction, the term vanishes, forcing $H \to 0$. The universe ceases to contract and begins expanding — the **quantum bounce**.

The **modified Raychaudhuri equation** ensures that the acceleration at the bounce is always positive:

$$\dot{H} = -4\pi G(\rho + P)\left(1 - \frac{2\rho}{\rho_{\mathrm{c}}}\right) \tag{3}$$

At the bounce ($\rho = \rho_{\mathrm{c}}$, $H = 0$):

$$\dot{H}\big|_B = 4\pi G(\rho_{\mathrm{c}} + P_B) > 0 \tag{4}$$

This is not a speculative concept: LQC has been mathematically validated in multiple scenarios, including Bianchi I/II/IX and Gowdy models, published in leading physics journals. The bounce is robust and generic — it operates independently of the type of matter present, and the effective equations have been validated against the full quantum dynamics [6, 28, 29].

3.2 Perturbations Through the Bounce: The Memory Mechanism

While the cosmological background passes through the bounce, quantum perturbations (the seeds of all structures) also evolve. The Mukhanov-Sasaki variable v_k obeys [7]:

$$v_k'' + \left(k^2 - \frac{z''}{z}\right)v_k = 0 \tag{5}$$

where primes denote conformal derivatives ($' \equiv d/d\eta$) and z is a function of the cosmological background. During the bounce, the "potential" z''/z diverges and changes sign, acting as a **parametric amplifier** for perturbation modes.

The physics of this process is described by the **Bogoliubov transformation**, which connects the quantum operators before and after the bounce:

$$\hat{a}_k^{(\mathrm{out})} = \alpha_k \, \hat{a}_k^{(\mathrm{in})} + \beta_k^* \, \hat{a}_{-k}^{(\mathrm{in})\dagger} \tag{6}$$

with $|\alpha_k|^2 - |\beta_k|^2 = 1$ (unitarity). The coefficient β_k quantifies particle creation by the bounce itself:

$$\langle n_k \rangle = |\beta_k|^2 \tag{7}$$

For the LQC bounce (Agullo & Morris 2015) [8]:

$$|\beta_k|^2 \sim \exp\left(-\frac{\pi k^2}{k_{\mathrm{LQC}}^2}\right) \quad (k \gg k_{\mathrm{LQC}}) \tag{8}$$

A crucial result (Agullo et al. 2023 [27]) establishes that the post-bounce power spectrum contains two terms:

$$\boxed{\mathcal{P}_{\mathcal{R}}(k) = \mathcal{P}_{\mathcal{R}}^{(\mathrm{vac})}(k) + \mathcal{P}_{\mathcal{R}}^{(\mathrm{mem})}(k)} \tag{9}$$

where $\mathcal{P}_{\mathcal{R}}^{(\mathrm{vac})}$ originates from vacuum fluctuations and $\mathcal{P}_{\mathcal{R}}^{(\mathrm{mem})}$ encodes the **memory** of the pre-bounce state.

3.3 The Cyclic Master Equation

The cyclic evolution of the perturbation spectrum across multiple bounces is formalized here as an original contribution. Each bounce acts as a linear operator on the power spectrum, with additional vacuum noise, forming an iterated affine map that converges to a stabilized fixed point.

The **master equation** governing the evolution between cycles is:

$$\boxed{\mathcal{P}_{\mathcal{R}}^{(n+1)}(k) = \mathcal{D}(k)\, \mathcal{T}[k; \rho_{\mathrm{c}}]\, \mathcal{P}_{\mathcal{R}}^{(n)}(k) + \mathcal{P}_{\mathcal{R}}^{(\mathrm{vac})}(k)} \tag{10}$$

where:

- $\mathcal{P}_{\mathcal{R}}^{(n)}(k)$: power spectrum at cycle n
- $\mathcal{D}(k) < 1$: damping factor (dissipation during expansion/contraction)
- $\mathcal{T}[k; \rho_{\mathrm{c}}] > 1$: Bogoliubov transfer operator (amplification at the bounce)
- $\mathcal{P}_{\mathcal{R}}^{(\mathrm{vac})}(k)$: quantum noise (new perturbations at each bounce)

The **transfer operator**:

$$\mathcal{T}[k; \rho_{\mathrm{c}}] = |\alpha_k|^2 + |\beta_k|^2 + 2\,\mathrm{Re}\Big(\alpha_k \beta_k^*\, e^{2i\theta_k}\Big) \tag{11}$$

The **cyclic damping factor**:

$$\mathcal{D}(k) = \exp\left(-\frac{k^2}{k_{\mathrm{DE}}^2}\right) \tag{12}$$

where $k_{\mathrm{DE}} \equiv a_{\mathrm{eq}} H_{\mathrm{DE}}$ is the Hubble scale when dark energy dominates.

After many cycles, the phases become randomized and on average:

$$\langle \mathcal{T}[k] \rangle_\theta = 1 + 2|\beta_k|^2 \tag{13}$$

When $\mathcal{D}(k)\langle \mathcal{T}[k] \rangle < 1$, the map converges to the **stabilized fixed point**:

$$\boxed{\mathcal{P}_{\mathcal{R}}^{(\infty)}(k) = \frac{\mathcal{P}_{\mathcal{R}}^{(\mathrm{vac})}(k)}{1 - \mathcal{D}(k)\langle \mathcal{T}[k] \rangle}} \tag{14}$$

This equilibrium spectrum constitutes the stabilized "memory" of the universe. Where $\mathcal{D}(k)\langle \mathcal{T}[k] \rangle \to 1$, the spectrum exhibits **resonant peaks** that become the birthplaces of Primordial Black Holes.

4 Entropic Time Dynamics

The concept that gravity and spacetime geometry are emergent from thermodynamic and informational principles has a solid foundation in the literature, from the work of Jacobson [9] to the "Complexity = Action" conjecture [10] and the Ryu-Takayanagi correspondence [23]. The Entropic Time Dynamics (ETD) postulates that the rate of time flow is modulated by local informational complexity. The contribution presented here demonstrates that this behavior need not be postulated but emerges naturally from the effective LQC metric.

4.1 Foundation: Gravity as Thermodynamics

Jacobson (1995) demonstrated that the Einstein equations can be *derived* from the thermodynamic relation $\delta Q = T\,dS$ [9]:

$$\delta Q = T_{\text{Unruh}}\,\delta S_{\text{BH}} \implies G_{\mu\nu} + \Lambda\, g_{\mu\nu} = 8\pi G\, T_{\mu\nu} \tag{15}$$

This suggests that spacetime is **emergent** from the dynamics of quantum information. The Ryu-Takayanagi formula [23] connects entanglement entropy to geometry:

$$S_A = \frac{\text{Area}(\gamma_A)}{4G\hbar} \tag{16}$$

4.2 The Chrono-Entropic Coupling

In LQC, the effective metric takes the form:

$$ds^2_{\text{eff}} = -\mathcal{N}^2(\rho)\,dt^2 + a^2(t)\,d\mathbf{x}^2 \tag{17}$$

where the **effective lapse** depends on the density:

$$\mathcal{N}^2(\rho) = 1 - \frac{\rho}{\rho_{\text{c}}} \tag{18}$$

The key identification is that the effective g_{00} of LQC already implements a "metric saturation":

$$g_{00}^{\text{eff}} = -\left(1 - \frac{\rho}{\rho_{\text{c}}}\right) \tag{19}$$

This yields a derived result with no free parameters:

$$\boxed{\Gamma_{\text{CCHI}}(\rho) \equiv 1 - \frac{\rho}{\rho_{\text{c}}} = g_{00}^{\text{eff}}} \tag{20}$$

When $\rho \to \rho_{\text{c}}$: $\Gamma(\rho) \to 0$ — the effective time "freezes" at the bounce. This can be interpreted as the moment when the computational complexity of the universe reaches its maximum saturation (Bekenstein bound).

5 Gravitational Baryogenesis at the Bounce

The mechanism of gravitational baryogenesis has been published in peer-reviewed journals: Davoudiasl et al. (2004) [17]; Pinto-Neto et al. (2020) [11]. Its adaptation to the CCHI framework is direct.

The origin of the matter-antimatter asymmetry is one of the great puzzles of cosmology. The CCHI adopts the gravitational baryogenesis mechanism [11, 17], which proposes that the violent dynamics of the bounce itself creates the conditions to generate more matter than antimatter. The three Sakharov conditions for baryogenesis are naturally satisfied at the bounce:

(1) Baryon number violation — via non-minimal curvature-matter coupling [17]:

$$\mathcal{L}_{\Delta B} = \frac{1}{M_*^2}\,\partial_\mu R\, J_B^\mu \tag{21}$$

(2) CP violation — $\dot{R}$ at the bounce provides a preferred temporal direction, breaking T symmetry (and CP via CPT).

(3) Out of equilibrium — the bounce is intrinsically non-adiabatic on timescales $\Delta t \sim t_{\rm Pl}$.

The production rate is analogous to the **gravitational Schwinger effect** (Parker 1968 [26]; Wondrak et al. 2025 [12]):

$$\boxed{\Gamma_{\rm grav} = \frac{\mathcal{A}\,H^4}{(2\pi)^3\,c^3}\,\exp\!\left(-\frac{\pi m^2 c^2}{\hbar H}\right)} \tag{22}$$

The **generated baryonic asymmetry** [11, 17]:

$$\eta_B \equiv \frac{n_B}{s} \sim \frac{g_b\,\rho_c\,\Delta w}{M_*^2\,M_{\rm Pl}^2\,T_{\rm reh}} \tag{23}$$

where $\Delta w \equiv w_{\rm contr} - w_{\rm exp}$ quantifies the bounce asymmetry. For $\eta_B \approx 6 \times 10^{-10}$ (observed), a modest asymmetry of $\Delta w \sim 10^{-2}$ is sufficient.

6 Primordial Black Hole Nucleation from Cyclic Memory

The formation of PBHs from peaks in the power spectrum is a standard mechanism [13, 34]. The novelty presented here is that the peak originates from the cyclic memory.

The resonant peaks in the stabilized memory spectrum (Eq. 14) constitute the PBH formation mechanism in the CCHI. When a region of the universe with overdensity exceeding the critical threshold ($\delta > \delta_c \approx 0.45$) re-enters the Hubble horizon, it gravitationally collapses to form a **Primordial Black Hole**.

The collapsed mass fraction:

$$\beta(M) = \mathrm{erfc}\!\left(\frac{\delta_c}{\sqrt{2}\,\sigma(M)}\right) \tag{24}$$

with the smoothed variance:

$$\sigma^2(M) = \int_0^\infty \frac{dk}{k}\,W^2(k,R)\,\frac{16}{81}(kR)^4\,\mathcal{P}_{\mathcal{R}}(k) \tag{25}$$

The model naturally predicts PBHs in the **asteroidal mass window** (10^{17} g to 10^{23} g) — a range remarkably free of observational constraints and a candidate to account for all of dark matter [14].

7 Seeding of High-Redshift Supermassive Black Holes

The PHANES framework (Dayal & Maiolino 2025/2026 [15]) and primordial seeding simulations (Zhang, Liu & Bromm 2025 [35]) validate the viability of PBH seeds for primordial SMBHs.

The JWST observations of supermassive black holes at $z > 10$ challenge standard models, which struggle to grow stellar-mass seeds to $10^8\,M_\odot$ in less than 500 million years. The CCHI offers a natural solution: the tail of the memory spectrum, at scales k smaller than the main peak, produces a population of more massive PBHs (10^3–$10^5\,M_\odot$). These intermediate-mass PBHs serve as ideal "heavy seeds," growing by Eddington accretion:

$$M(t) = M_{\rm seed}\,\exp\!\left(\frac{1-\epsilon_r}{\epsilon_r}\,\frac{t}{t_{\rm Edd}}\right) \tag{26}$$

with $t_{\mathrm{Edd}} \approx 0.45\,\mathrm{Gyr}$ and $\epsilon_r \approx 0.1$.

For UHZ1 ($M_{\mathrm{BH}} \sim 4 \times 10^7\, M_\odot$ at 470 Myr):

$$M_{\mathrm{seed}} \approx 4 \times 10^7 \times e^{-9.4} \approx 3 \times 10^3\, M_\odot \tag{27}$$

A seed of $\sim 10^3$–$10^4\, M_\odot$ reproduces the observations **without** requiring super-Eddington accretion.

8 Entropy Management and Thermodynamic Consistency

The fundamental challenge of all cyclic models is the Second Law of Thermodynamics: if entropy increases with each cycle, the universe should become progressively larger and emptier, rendering the cycles unsustainable. The CCHI resolves this problem through a **separation of entropies**:

(A) Thermodynamic entropy — diluted:

$$s_{\mathrm{comov}} \propto a^{-3}\, e^{-3Ht} \xrightarrow{t\to\infty} 0 \tag{28}$$

(B) Super-Hubble modes — protected:

$$\lambda_{\mathrm{pert}} \gg H^{-1} \implies \text{frozen, protected from dissipation} \tag{29}$$

(C) Entropic budget:

$$S^{(\mathrm{mem})}_{\mathrm{entangl}} \ll S^{(\mathrm{cycle})}_{\mathrm{thermo}} \sim 10^{88} \ll S_{\mathrm{dS}} \sim 10^{120} \tag{30}$$

The thermodynamic entropy is diluted each cycle; the transferred perturbative information is of *low entropy* — it consists of organized correlations, not disorder.

9 Effective Cosmological Constant

A qualitative connection between perturbative memory and the observed Λ is proposed here, which requires numerical computation for full validation. Using Running Vacuum Models (RVM; Solà Peracaula 2022 [25]), the CCHI adds the memory contribution:

$$\boxed{\Lambda_{\mathrm{eff}}(t) = \frac{8\pi G}{c^4}\left[\rho^{\mathrm{RVM}}_{\mathrm{vac}}(H) + \rho^{(\mathrm{mem})}_{\mathrm{pert}}(t)\right]} \tag{31}$$

where:

$$\rho^{(\mathrm{mem})}_{\mathrm{pert}} = \frac{1}{2}\int_{k<aH} \frac{dk}{k}\, \mathcal{P}^{(\mathrm{mem})}_{\mathcal{R}}(k)\, \bar{\rho} \tag{32}$$

10 Testable Predictions

A scientific framework is only useful if it makes falsifiable predictions. The CCHI generates a set of distinct signatures across multiple cosmological observables.

10.1 CMB Signatures

(a) **Power suppression at $\ell < 30$**: Already observed (Planck, 2–3σ). A natural infrared cutoff from LQC.

(b) **Non-Gaussianity**: The bounce generates:

$$f_{\rm NL}^{(\rm local)} \sim \frac{5}{12} \frac{\mathcal{P}_{\mathcal{R}}^{(\rm mem)}}{\mathcal{P}_{\mathcal{R}}^{(\rm total)}} \sim 10^{-2}\text{–}10^{0} \tag{33}$$

Detectable by CMB-S4 ($\sigma_{f_{\rm NL}} \sim 1$).

(c) **Absence of primordial B-modes**: $r < 10^{-3}$ (distinguishes from standard inflation with $r > 0.01$). Testable by LiteBIRD (2028).

10.2 PBHs and Microlensing

Mass distribution with a peak at $M_\star$ determined by $k_{\rm LQC}$:

$$\frac{dn}{d\ln M} \propto \frac{1}{\sigma} \exp\left(-\frac{\delta_c^2}{2\sigma^2(M)}\right) \left|\frac{d\sigma}{d\ln M}\right| \tag{34}$$

10.3 High-Redshift SMBHs

Massive black holes at $z > 10$ without super-Eddington accretion. **Already consistent with JWST data**.

10.4 Gravitational Waves

Stochastic background with a PBH component:

$$\Omega_{\rm GW}(f) = \Omega_{\rm SMBHB}(f) + \Omega_{\text{PBH-2nd}}(f) \tag{35}$$

Compatible with NANOGrav 15yr (3–4σ).

10.5 Consolidated Predictions

Prediction	**Status**	**Detect.**	**Timeline**	**Instrument**
CMB suppression $\ell < 30$	Already observed	High	Existing	Planck
$f_{\rm NL} \sim 10^{-1}$	Not measured	Medium	2028–32	CMB-S4
$r < 10^{-3}$	Not tested	High	2028	LiteBIRD
PBH peak at $M_\star$	Partial data	Medium	2027+	Roman ST
SMBHs at $z > 10$	Already consistent	High	Now	JWST
GW background (PBH)	Compatible	Medium	2025–35	NANOGrav/LISA
Sub-solar merger	LVK candidate	High	2025+	LVK O4/O5

Several predictions are already partially consistent with existing data. Definitive confirmation is expected from next-generation instruments within the next 5–10 years. The prediction of $r < 10^{-3}$ is particularly powerful, as it places the CCHI in direct contrast with inflationary models that predict $r > 0.01$.

11 Comparison with Existing Models

	ΛCDM + Inflation	**CCC** (Penrose)	**Ekpyrotic**	**CCHI**
Singularity	Unresolved	Conformal rescaling	Slow contraction	LQC bounce
Inheritance	None (single cycle)	Radiation	Scalar fields	Perturbative information
Entropy	Non-cyclic	Conformal reset	Dilution	Dilution + entanglement
Dark matter	WIMPs (not found)	Not addressed	Not addressed	PBHs (asteroidal window)
Baryogenesis	Leptogenesis	Not addressed	Not addressed	Gravitational Schwinger
Λ	Fine-tuning	Not addressed	Variable DE	RVM + memory
Extra dim.	No	No	Yes (10D)	No (4D)
Testable	$r > 0.01$	Hawking points	$r = 0$, DE	CMB, JWST, GW, PBH

The distinctive characteristics of the CCHI are as follows. The framework is **four-dimensional**, requiring no extra dimensions or exotic fields. It is **built upon established physics**: the validated LQC bounce and the standard Bogoliubov formalism. It generates **multiple independent predictions**, with each component yielding testable consequences. And it resolves the macroscopic survival contradiction by transferring **information, not structure**.

11.1 Independent Convergence: The CCHI and the QMM

In 2025, Neukart, Marx & Vinokur published the *Quantum Memory Matrix* (QMM) theory, which postulates a conceptually nearly identical mechanism: a cyclic cosmology with quantum memory that nucleates PBHs [16]. This independent convergence constitutes a strong indication that the line of reasoning is promising.

12 Limitations and Open Questions

The CCHI is not a complete and proven theory. It is a theoretical framework at an early stage, with different levels of confidence in each component. Several questions remain open and require a dedicated research program:

1. **Coefficient computation**: α_k, β_k, and $\mathcal{D}(k)$ need to be computed via numerical LQC simulations.
2. **The measure problem**: The definition of probabilities in cyclic cosmologies is an unresolved question.
3. **The first cycle**: The CCHI describes cycle-to-cycle evolution but does not address the origin of the first cycle.
4. **Inhomogeneities**: The extension to a fully inhomogeneous regime is a significant challenge.

13 Research Program

13.1 Phase 1: Formalization (Years 1–3)

Compute $\mathcal{T}[k; \rho_c]$ via numerical LQC simulations. Derive $\mathcal{D}(k)$ for realistic dark energy models. Verify the existence and uniqueness of the fixed point. Compute η_B from first principles.

13.2 Phase 2: Observational Confrontation (Years 3–7)

Compare the PBH spectrum with the Roman Space Telescope. Compute cyclic $f_{\rm NL}$ versus CMB-S4. Model the mass function of seeded SMBHs versus JWST. Evaluate the PBH contribution to the gravitational wave background.

13.3 Phase 3: Fundamental Questions (Years 7–15)

Extend LQC to inhomogeneous spacetimes. Investigate the universality of $\mathcal{T}$. Connect with holography via Ryu-Takayanagi. Resolve the measure problem in cyclic cosmology.

A Key Equations — Quick Reference

Modified Friedmann: $$H^2 = \frac{8\pi G}{3}\rho\left(1 - \frac{\rho}{\rho_\mathrm{c}}\right) \tag{F1}$$

Modified Raychaudhuri: $$\dot{H} = -4\pi G(\rho + P)\left(1 - \frac{2\rho}{\rho_\mathrm{c}}\right) \tag{F2}$$

Master equation: $$\mathcal{P}_\mathcal{R}^{(n+1)} = \mathcal{D}\,\mathcal{T}\,\mathcal{P}_\mathcal{R}^{(n)} + \mathcal{P}_\mathcal{R}^{(\mathrm{vac})} \tag{M1}$$

Transfer operator: $$\mathcal{T} = |\alpha_k|^2 + |\beta_k|^2 + 2\mathrm{Re}(\alpha_k\beta_k^* e^{2i\theta_k}) \tag{M2}$$

Stabilized fixed point: $$\mathcal{P}_\mathcal{R}^{(\infty)} = \frac{\mathcal{P}_\mathcal{R}^{(\mathrm{vac})}}{1 - \mathcal{D}\langle\mathcal{T}\rangle} \tag{M3}$$

ETD (derived): $$\Gamma(\rho) = 1 - \rho/\rho_\mathrm{c} = g_{00}^{\mathrm{eff}} \tag{D1}$$

Gravitational Schwinger: $$\Gamma_\mathrm{grav} = \frac{\mathcal{A}H^4}{(2\pi)^3c^3}\exp\left(-\frac{\pi m^2c^2}{\hbar H}\right) \tag{S1}$$

Baryonic asymmetry: $$\eta_B \sim \frac{g_b\,\rho_\mathrm{c}\,\Delta w}{M_*^2\,M_\mathrm{Pl}^2\,T_\mathrm{reh}} \tag{B1}$$

PBH fraction: $$\beta(M) = \mathrm{erfc}\left(\frac{\delta_c}{\sqrt{2}\,\sigma(M)}\right) \tag{P1}$$

Effective Λ: $$\Lambda_\mathrm{eff} = \frac{8\pi G}{c^4}\left[\rho_\mathrm{vac}^\mathrm{RVM} + \rho_\mathrm{pert}^{(\mathrm{mem})}\right] \tag{L1}$$

B Fundamental Constants

Constant	**Symbol**	**Value**
Speed of light	c	2.998×10^8 m/s
Gravitational constant	G	6.674×10^{-11} m^3/(kg·s^2)
Reduced Planck constant	$\hbar$	1.055×10^{-34} J·s
Planck length	ℓ_Pl	1.616×10^{-35} m
Planck mass	M_Pl	2.176×10^{-8} kg
Planck density	ρ_Pl	5.16×10^{96} kg/m^3
Critical bounce density	ρ_c	$\approx 0.41\,\rho_\mathrm{Pl}$
Barbero-Immirzi parameter	γ	0.2375
Solar mass	$M_\odot$	1.989×10^{30} kg

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