Guided Potential Collapse: A Hybrid Framework for Classical Space–Time Emergence and Multiverse Map Attempt

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Abstract

We introduce the *Guided Potential Collapse* (GPC) framework—a hybrid interpretation of quantum cosmology that integrates Bohmian trajectory realism with context-sensitive collapse dynamics, inspired by the Wheeler–DeWitt (WDW) approach. In GPC, the guiding potential is fundamentally quantum and enables smoother navigation through superspace. Collapse fields are seeded by multiversal interactions, where external universes act as contextual observers that suppress non-classical branches and preferentially stabilize Friedmann–Robertson–Walker (FRW) geometries. These geometries serve as classical reference beacons, facilitating the inference and mapping of multiversal space–time structures across distinct minisuperspaces. We distinguish between two probabilistic regimes: Born-rule-like probabilities that emerge across intersuperspace interactions—mediated by entanglement and decoherence between universes—and standard Born probabilities confined within individual minisuperspaces. This dual structure allows for deterministic Bohmian evolution locally, while enabling classical emergence and multiversal inference globally. The framework resonates with recent efforts to clarify the empirical and ontological foundations of collapse dynamics [8], and is reinforced by pilot-wave analogs that converge toward Bohmian behavior under specific coupling conditions [7], offering a classical substrate for quantum trajectory realism.

1 Introduction

The emergence of classical space–time from an underlying quantum substrate remains one of the central challenges in theoretical physics [27, 2]. The Wheeler–DeWitt (WDW) framework offers a foundational approach to quantum cosmology, describing the universe via a timeless wave functional $\Psi[h_{ij}, \phi]$ over superspace—the configuration space of all three-geometries and matter fields [3, 17]. In this formalism, the Hamiltonian constraint $\hat{H}\Psi = 0$ replaces the conventional Schrödinger equation, reflecting the absence of an external time parameter [5]. Time must instead be reconstructed relationally, using semiclassical degrees of freedom as internal clocks [2, 6]. Despite its background independence and conceptual elegance, the WDW approach struggles to explain how definite classical trajectories emerge from a single, timeless wave function [9, 10].

Collapse models such as Ghirardi–Rimini–Weber (GRW) introduce spontaneous, stochastic reductions of the wave function to address this issue [11, 12, 41]. In GRW, microscopic systems collapse infrequently, preserving quantum coherence, while macroscopic systems collapse rapidly, suppressing superpositions [41]. Applied to cosmology, such collapse events may correlate with early-universe density fluctuations, leading to localization in superspace and dynamically favoring homogeneous and isotropic Friedmann–Robertson–Walker (FRW) geometries [5, 14, 17].

The *Guided Potential Collapse* (GPC) framework extends this paradigm by integrating Bohmian pilot-wave determinism with a dynamically generated collapse potential [15]. Within a single universe, latent collapse fields—seeded by entanglement and decoherence—suppress non-classical branches and stabilize classical attractors such as FRW space–time [37, 9]. These emergent geometries serve as internal reference beacons, enabling collapse without invoking external observers.

Crucially, GPC generalizes to a multiverse superspace partitioned into minisuperspaces (individual universes) and intersuperspaces (relational domains between universes). Intersuperspaces, governed by WDW evolution, host probabilistic density perturbations shaped by decoherence-weighted entanglement across universes. These interactions yield Born-rule-like probabilities for geometric selection at the multiversal level, distinct from standard Born probabilities confined within single-universe minisuperspaces. The resulting probabilistic structure guides deterministic Bohmian trajectories locally, linking quantum selection to classical evolution across the multiverse.

In this way, GPC reconciles Bohmian clarity with WDW timelessness, offering a unified mechanism for classical space–time emergence and multiversal inference [12, 6].

2 FRW Metric and Classical Background

A natural starting point for cosmological modeling is the Friedmann–Robertson–Walker (FRW) metric, which describes a spatially homogeneous and isotropic universe [17, 14]. Its line element is given by

$$ds^2 = -dt^2 + a(t)^2 \left[\frac{dr^2}{1 - kr^2} + r^2 d\Omega^2 \right], \qquad (1)$$

where $a(t)$ is the scale factor, $k = 0, \pm 1$ denotes the spatial curvature, and $d\Omega^2$ is the metric on the unit 2-sphere [21]. When Einstein's field equations are applied to this metric, they yield the Friedmann equations, which govern the evolution of $a(t)$ in terms of the universe's matter content, radiation density, and cosmological constant [22, 23].

In quantum cosmology, the FRW metric plays a dual role: it serves both as a classical solution to Einstein's equations and as a geometric attractor within superspace. In the Guided Potential Collapse (GPC) framework, FRW geometries emerge as dynamically favored configurations—stabilized by latent collapse fields seeded through entanglement and decoherence. These geometries act as internal reference structures, guiding the suppression of non-classical branches and facilitating the transition from quantum indeterminacy to classical determinism [41, 15]. Thus, the FRW background is not merely a classical starting point, but a beacon for collapse-driven emergence across minisuperspaces.

3 Bohmian Mechanics and the Action Formalism

The de Broglie–Bohm interpretation of quantum mechanics offers a deterministic account of quantum evolution, wherein particles follow well-defined trajectories guided by the wave function [34, 25, 26]. Recent work has demonstrated that classical pilot-wave systems can converge to Bohmian dynamics under specific coupling conditions, reinforcing the plausibility of trajectory realism even outside standard quantum regimes [7]. For a single-particle system, the wave function can be expressed in polar form as

$$\Psi(x,t) = R(x,t)\, e^{iS(x,t)/\hbar}, \qquad (2)$$

where $R(x,t)$ is the amplitude and $S(x,t)$ is the phase function, often interpreted as a quantum action. The Bohmian guidance equation then takes the form

$$p = \nabla S(x,t), \qquad (3)$$

linking particle momentum directly to the gradient of the phase. This formulation embeds classical-like trajectories within the quantum formalism, offering ontological clarity and avoiding measurement-induced discontinuities. For a single-particle system, the wave function can be expressed in polar form as

$$\Psi(x,t) = R(x,t)\, e^{iS(x,t)/\hbar}, \qquad (4)$$

where $R(x,t)$ is the amplitude and $S(x,t)$ is the phase function, often interpreted as a quantum action. The Bohmian guidance equation then takes the form

$$p = \nabla S(x,t), \qquad (5)$$

linking particle momentum directly to the gradient of the phase. This formulation embeds classical-like trajectories within the quantum formalism, offering ontological clarity and avoiding measurement-induced discontinuities.

In field-theoretic and cosmological contexts, the phase function S generalizes to a functional over field configurations or metric components. For example, in quantum cosmology, $S[h_{ij}, \phi]$ governs the evolution of three-geometries and matter fields within superspace. Bohmian mechanics thus provides a trajectory-based interpretation of the Wheeler–DeWitt equation, allowing one to define deterministic paths through configuration space even in the absence of external time.

However, Bohmian mechanics alone does not resolve the problem of branch selection or classical emergence. Without a collapse mechanism, all branches of the wave function persist, and the theory lacks a natural way to suppress non-classical configurations. The *Guided Potential Collapse* (GPC) framework addresses this limitation by introducing dynamically seeded collapse potentials—driven by multiversal entanglement and decoherence—that selectively stabilize classical trajectories. In this way, Bohmian determinism is preserved while collapse dynamics are embedded into the cosmological evolution.

4 Wheeler–DeWitt Framework and Hamiltonian Constraint

In canonical quantum gravity, the Wheeler–DeWitt (WDW) equation governs the wave function of the universe [27, 33]:

$$\hat{H}\Psi[h_{ab}, \phi] = 0, \tag{6}$$

where h_{ab} denotes the three-metric and ϕ the matter fields. The Hamiltonian constraint $\hat{H}$ encapsulates both kinetic contributions from superspace and potential terms arising from spatial curvature and matter interactions. This equation replaces the conventional Schrödinger evolution, reflecting the absence of an external time parameter in a fully covariant theory.

The wave functional $\Psi[h_{ab}, \phi]$ is often expressed in polar form:

$$\Psi[h, \phi] = R[h, \phi]\, e^{iS[h,\phi]/\hbar}, \tag{7}$$

where R is the amplitude and S is the phase functional, interpreted as a generalized quantum action. Substituting into the WDW equation yields a Hamilton–Jacobi-like equation for S:

$$\frac{\delta S}{\delta h_{ab}} + H_{\text{matter}}\left[\phi, \frac{\delta S}{\delta \phi}\right] + V[h_{ab}, \phi] = 0, \tag{8}$$

which governs the evolution of geometries and fields in superspace. This formalism provides a timeless, background-independent description of quantum cosmology, where classical space–time must be reconstructed relationally through semiclassical variables acting as internal clocks.

Despite its elegance, the WDW framework leaves unresolved the mechanism by which specific classical geometries—such as the FRW metric—emerge from the full wave functional. Without a selection principle or collapse dynamics, all branches of Ψ coexist, and the theory lacks a natural pathway to classicality. The *Guided Potential Collapse* (GPC) framework addresses this gap by introducing multiverse-seeded collapse potentials that dynamically suppress non-classical branches and stabilize FRW-like attractors. In this way, GPC complements the WDW formalism with a mechanism for classical emergence grounded in Bohmian determinism and multiversal decoherence.

5 Guided Potential Collapse Framework

The *Guided Potential Collapse* (GPC) framework preserves the realist clarity of Bohmian mechanics [15] while extending it to cosmological and multiversal domains. Its central innovation is the introduction of a *collapse potential*, a scalar field $C(x, t)$ that modulates amplitudes in response to entanglement and decoherence [37, 41]. Unlike abrupt projection models, this potential acts as a gradient-driven suppression mechanism, steering trajectories toward classical attractors while preserving Bohmian guidance through the phase S.

Within a single universe, this mechanism explains how classical space–time geometries—such as the Friedmann–Robertson–Walker (FRW) metric—can emerge naturally [17, 14]. Collapse potentials seeded by decoherence grow most strongly in anisotropic and highly entangled regions of superspace [9, 5], leading to their suppression. Homogeneous and isotropic configurations, by contrast, remain dynamically stable. As a result, FRW-like trajectories are statistically favored, offering a concrete example of collapse-driven classicality without invoking external observers [11, 12]. This emergence functions as a torch—a guiding reference case for the quantum-to-classical transition [6].

This reference case sets the stage for a multiverse extension. In the Wheeler–DeWitt picture [27, 2], where no external observer collapses the universal wave function, the multiverse itself acts as an ensemble of interacting systems. Neighboring universes, through subtle correlations or entanglement, serve as effective observers contributing to the collapse potential [37]. In this extended framework, intersuperspaces—regions between minisuperspaces—are governed by WDW evolution and host probabilistic density perturbations shaped by decoherence-weighted entanglement. These regions yield Born-rule-like probabilities for geometric selection, which then seed deterministic Bohmian trajectories within minisuperspaces.

Using the FRW torch as a baseline, one can map how the distribution of collapse potentials and probabilistic amplitudes shapes the statistical occurrence of classical geometries across the multiverse [10]. Regions of superspace with low collapse pressure—defined by minimal entanglement gradients and high entropy uniformity—tend to favor FRW attractors. Universes that resist collapse may populate alternative basins such as Bianchi-type or eternal de Sitter states [14]. In this way, GPC bridges the gap between single-universe emergence and multiversal inference, offering a systematic method for deducing cosmological outcomes across the ensemble [15, 41].

5.1 Quantum Potential in WDW-GPC Formalism

To formalize collapse dynamics within the Wheeler–DeWitt framework, we extend the Bohmian quantum potential to field configurations space. Given a universal wave function

$$\Psi[h, \phi] = R[h, \phi]\, e^{-\Phi_{\text{total}}(h,\phi)}\, e^{iS[h,\phi]/\hbar}, \tag{9}$$

the quantum potential in the GPC formalism becomes

$$Q_{\text{GPC}}[h, \phi] = -\frac{\hbar^2}{2R[h, \phi]} \left(G^{ab} \frac{\delta^2 R}{\delta h_{ab}^2} + G^{\phi\phi} \frac{\delta^2 R}{\delta \phi^2} \right), \tag{10}$$

where G^{ab} is the DeWitt supermetric and $G^{\phi\phi}$ encodes scalar field dynamics. This potential governs collapse pressure across superspace, selectively suppressing high-curvature or highly entangled configurations.

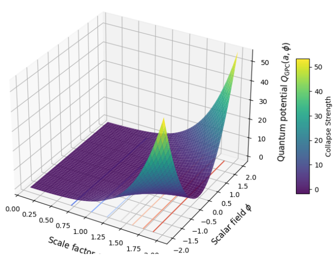

Figure 1: Quantum potential for hybrid WDW-GPC Bohmian-like trajectories.

5.2 Generalized Quantum Action in GPC

The Bohmian trajectories in the Guided Potential Collapse (GPC) framework are derived from a generalized quantum action that incorporates both classical dynamics and collapse-modified influences:

$$S_{\text{GPC}}[q] = \int dt \left[\frac{1}{2} \mathcal{G}_{AB} \dot{q}^A \dot{q}^B - V(q) - Q_{\text{GPC}}(q) \right], \tag{11}$$

where $q^A = \{h_{ab}, \phi\}$ are minisuperspace variables, $\mathcal{G}_{AB}$ is the superspace metric, $V(q)$ is the classical potential, and Q_{GPC} is the quantum potential derived previously. This action yields deterministic guidance equations modified by collapse-induced drift:

$$v^A(t) = \mathcal{G}^{AB} \left(\frac{\partial S}{\partial q^B} - \frac{\partial \Phi_{\text{total}}}{\partial q^B} \right), \tag{12}$$

ensuring that Bohmian evolution is biased toward classical attractors while preserving phase coherence. Here, t indexes the evolution of minisuperspace variables $q^A = \{h_{ab}, \phi\}$ and serves as an emergent relational time—not a fundamental coordinate—allowing us to describe how configurations evolve along Bohmian paths, even though the Wheeler–DeWitt framework itself lacks a preferred temporal parameter.

5.3 Minisuperspace Supermetric with Scalar Field

In the Wheeler–DeWitt formulation, the supermetric governing minisuperspace dynamics includes both gravitational and scalar field sectors. The full supermetric is

$$\mathcal{G}^{AB} = \begin{pmatrix} G^{ab\,cd}(x) & 0 \\ 0 & G^{\phi\phi}(x) \end{pmatrix}$$

where

$$G^{ab\,cd}(x) = \frac{1}{2\sqrt{h}} \left(h^{ac}h^{bd} + h^{ad}h^{bc} - h^{ab}h^{cd} \right), \quad G^{\phi\phi}(x) = \sqrt{h}.$$

Here:

- h_{ab} is the 3-metric on spatial slices
- $h = \det(h_{ab})$
- $G^{ab\,cd}$ governs the kinetic term for geometry
- $G^{\phi\phi}$ governs the kinetic term for the scalar field

Entanglement-production rate $\Gamma(t)$. Let $\rho_S(t) = \mathrm{Tr}_E\, \rho_{SE}(t)$ be the reduced state of the system (geometry plus relevant matter modes), obtained by tracing out the environment. Define the purity $\mathcal{P}(t) = \mathrm{Tr}\, \rho_S(t)^2$ and the linear entropy $S_{\text{lin}}(t) = 1 - \mathcal{P}(t)$. Then,

$$\Gamma(t) \equiv \dot{S}_{\text{lin}}(t) = -\frac{d}{dt} \mathrm{Tr}\, \rho_S(t)^2. \tag{13}$$

For a Lindblad master equation

$$\dot{\rho}_S = -\frac{i}{\hbar}[H_S, \rho_S] + \sum_k \gamma_k \left(L_k \rho_S L_k^\dagger - \frac{1}{2}\{L_k^\dagger L_k, \rho_S\} \right),$$

one obtains the operational form

$$\begin{aligned} \Gamma(t) &= 2 \sum_k \gamma_k\, \mathrm{Var}_{\rho_S(t)}(L_k) \\ &= 2 \sum_k \gamma_k \left(\langle L_k^\dagger L_k \rangle - \langle L_k^\dagger \rangle \langle L_k \rangle \right), \end{aligned} \tag{14}$$

so $\Gamma(t)$ grows with the environment's information gain about system observables $\{L_k\}$ [38, 39].

Decoherence factor $D(x,t)$. The decoherence factor $D(x,t)$ quantifies how strongly the environment distinguishes alternative branches separated at x by a configuration displacement $\Delta x(x,t)$. Two standard models are:

(i) Collisional / Joos–Zeh form. For gas or photon scattering with differential number density $n(\mathbf{p})$, speed $v(\mathbf{p})$, and cross section $\sigma(\mathbf{p})$,

$$D_{\rm JZ}(x,t) = \int d^3p\, n(\mathbf{p})\, v(\mathbf{p})\, \sigma(\mathbf{p}) \times \left[1 - \mathrm{sinc}\left(\frac{\mathbf{p}\cdot\Delta\mathbf{x}(x,t)}{\hbar}\right)\right], \tag{15}$$

which reduces for small separations to

$$D_{\rm JZ} \approx \Lambda(t)\, \|\Delta\mathbf{x}(x,t)\|^2/\ell_c^2,$$

with $\Lambda(t) = \int d^3p\, nv\sigma$ and coherence length $\ell_c = \hbar/\bar{p}$ [35, 37].

(ii) Quantum Brownian motion / Caldeira–Leggett (high-T) form. For Ohmic friction γ at temperature T,

$$D_{\rm CL}(x,t) = \frac{2m\gamma k_B T}{\hbar^2}\, \|\Delta\mathbf{x}(x,t)\|^2. \tag{16}$$

This describes thermal decoherence in continuous-variable systems [36, 39].

GRW/CSL augmentation. To incorporate explicit GRW-like localization with characteristic length r_C and rate $\lambda_{\rm GRW}$, we add

$$D_{\rm GRW}(x,t) = \lambda_{\rm GRW}\left[1 - \exp\left(-\frac{\|\Delta\mathbf{x}(x,t)\|^2}{4r_C^2}\right)\right], \tag{17}$$

which behaves quadratically for small separations and saturates for large ones [40, 41].

The Joos–Zeh form captures discrete scattering events, while the Caldeira–Leggett model describes continuous thermal environments. Both yield quadratic suppression for small displacements, consistent with GRW-like behavior. These models collectively define the collapse pressure landscape across superspace, shaping the evolution of the wave function toward classical geometries.

6 Bubbles vs. Branches in Multiverse Collapse Dynamics

In quantum cosmology—particularly within Wheeler–DeWitt and collapse-based multiverse models—it is essential to distinguish between **bubbles** and **branches**, as they represent fundamentally distinct structures in both geometry and quantum evolution.

Bubbles refer to spatially disconnected regions of spacetime, typically nucleated via tunneling events, scalar field transitions, or vacuum decay processes. Each bubble evolves with its own internal geometry—often FRW or de Sitter—and hosts independent collapse potentials $\Phi_i(x,y)$ and decoherence kernels $D_i(x,y)$. Decoherence suppresses cross-bubble interference, effectively isolating each bubble's quantum evolution. Born-rule-like amplitude selection governs the probability of bubble nucleation and geometric stabilization, with multiversal entanglement contributing to interbubble correlations.

Branches, by contrast, represent decohered quantum histories within a single bubble. These arise from superpositions of field configurations, observer states, or semiclassical trajectories, all sharing the same underlying spacetime geometry. Decoherence kernels $D(x,x')$ suppress interference between branches, and collapse sharpening—via the GPC potential—selects dominant outcomes. Probabilities across branches follow Born-rule weights derived from $|\Psi|^2$, modulated by the collapse dynamics encoded in $\Phi_{\rm total}(x,t)$.

This distinction is crucial for modeling multiverse dynamics: bubbles define the ensemble structure across disconnected spacetime domains, while branches encode the internal quantum histories within each domain. The GPC framework accommodates both levels, enabling a unified treatment of classical emergence and probabilistic inference across the multiverse.

Feature	**Bubble**	**Branch**
Geometry	Distinct spacetime regions (e.g., FRW, dS)	Shared geometry, differing quantum states
Decoherence Kernel	$D_i(x,y)$ localized per bubble	$D(x,x')$ across field configurations
Collapse Potential	$\Phi_i(x,y)$ per bubble	$\Phi(x,y)$ modulating branches
Interference	Suppressed across bubbles	Suppressed within bubble
Visualization	Separate basins in amplitude landscape	Contours within a basin
Probability Selection	Born-like across bubbles	Born-like across branches

Table 1: Formal comparison between bubbles and branches in multiverse collapse dynamics.

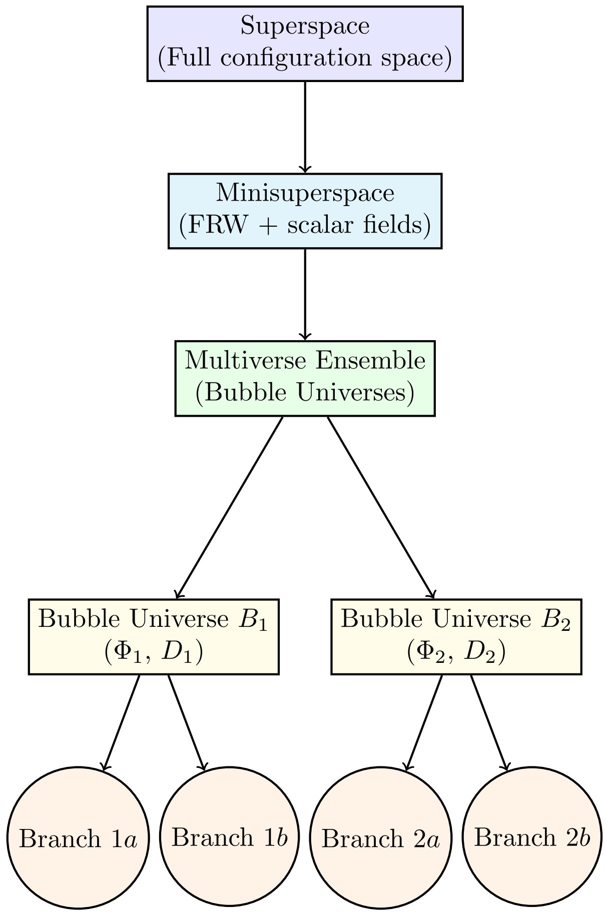

Figure 2: Superspace: Full quantum gravity configuration space; Minisuperspace: FRW + scalar field truncation; Bubble Universes: Spatially disconnected sectors; Branches: Decohered quantum histories within each bubble.

7 Hybrid GPC–WDW Dynamics in Inter-Minisuperspace and Classical Geometry Selection

In the hybrid framework, the Wheeler–DeWitt (WDW) wave functional is extended to an ensemble of minisuperspace configurations $\{h_{ij}^{(n)}, \phi^{(n)}\}$, indexed by n, representing distinct quantum branches across the multiverse. Each branch evolves under a Guided Potential Collapse (GPC) mechanism [27, 35, 36, 40, 41], which combines Bohmian guidance with context-sensitive collapse dynamics. This hybridization reflects a growing effort to reconcile deterministic evolution with classical emergence, while maintaining ontological clarity and empirical testability — themes emphasized in recent reviews of collapse-based quantum foundations [8]. The resulting wave function for branch n takes the form

$$\Psi_n[h_{ij}^{(n)}, \phi^{(n)}] = R_n \, e^{-\Phi_n} \, e^{iS_n/\hbar}, \tag{18}$$

where $\Phi_n = \Phi_{\text{total}}[h_{ij}^{(n)}, \phi^{(n)}]$ is the collapse potential for branch n, and S_n is the Hamilton–Jacobi phase functional guiding Bohmian trajectories.

The total wave functional over inter-minisuperspace is then given by the superposition

$$\Psi_{\text{multi}} = \sum_n \alpha_n \Psi_n[h_{ij}^{(n)}, \phi^{(n)}], \tag{19}$$

where the complex amplitudes α_n encode initial weighting and entanglement structure across branches.

Multiversal Decoherence and Geometry Selection

The inter-branch decoherence structure defines a geometry-weighted probability distribution:

$$P[h_{ij}, \phi] \propto \sum_n \delta(h_{ij} - h_{ij}^{(n)})\delta(\phi - \phi^{(n)})\, P_n, \tag{20}$$

which governs the statistical emergence of classical spacetimes. Branches with high decoherence and low collapse potential are dynamically favored, yielding a multiverse populated by FRW and de Sitter attractors.

Practical Implementation in Multiversal Minisuperspace

In the multiverse framework, each branch n evolves under a collapse potential $\Phi_n(x,t)$ computed via a kernel blend:

$$\Phi_n(x,t) = \lambda \int_0^t dt' \, \Gamma_n(t') \Big[\alpha \, D_{\text{JZ}}^{(n)}(x,t') + \beta \, D_{\text{CL}}^{(n)}(x,t') + \mu \, D_{\text{GRW}}^{(n)}(x,t')\Big], \tag{21}$$

with weights $\alpha + \beta + \mu = 1$. Each kernel quantifies branch distinguishability and environmental imprinting:

- $D_{\text{JZ}}^{(n)}$: collisional decoherence (Joos–Zeh) [35]
- $D_{\text{CL}}^{(n)}$: thermal decoherence (Caldeira–Leggett) [36]
- $D_{\text{GRW}}^{(n)}$: spontaneous localization (GRW) [40, 41]

The entanglement production rate $\Gamma_n(t)$ reflects how rapidly branch n becomes environmentally encoded.

Born-Weighted Branch Probabilities

Each branch n contributes to the multiversal ensemble with a decoherence-weighted Born-like probability:

$$P_n = |\alpha_n|^2 \, e^{-2\Phi_n} \, \mathcal{D}_n, \tag{22}$$

where:

- α_n is the WDW amplitude for branch n
- Φ_n is the collapse potential from Eq. (21)
- $\mathcal{D}_n$ is the decoherence factor measuring inter-branch distinguishability

This probability governs the statistical emergence of classical geometries across the multiverse.

Trajectory Selection and Classical Attractors

Branch separations Δa_n and $\Delta \phi_n$ are extracted from competing Bohmian histories. Collapse dynamics suppress branches with large Φ_n and low $\mathcal{D}_n$, favoring those with minimal quantum interference and maximal environmental imprinting. In particular, branches that stabilize toward FRW or de Sitter trajectories exhibit:

$$\Delta a_n \to 0, \quad \Delta \phi_n \to 0, \tag{23}$$

$$D^{(n)}(x,t) \to 0, \quad \Phi_n(x,t) \to \min. \tag{24}$$

In homogeneous and isotropic configurations, the effective Hamilton–Jacobi equation becomes:

$$-\frac{\kappa}{12 a_n}\left(\frac{\partial S_n}{\partial a_n}\right)^2 + \frac{1}{2a_n^3}\left(\frac{\partial S_n}{\partial \phi_n}\right)^2 + a_n^3 V(\phi_n) = 0. \tag{25}$$

For vacuum-dominated branches ($V(\phi_n) \approx \Lambda/\kappa$), the guidance equation reduces to:

$$\dot{a}_n \simeq \sqrt{\frac{\Lambda}{3}}\, a_n - \frac{\delta \Phi_n}{\delta a_n}, \tag{26}$$

yielding exponential expansion:

$$a_n(t) \sim a_0^{(n)} \, e^{\sqrt{\Lambda/3}\, t}. \tag{27}$$

Branches with minimal Φ_n and maximal $\mathcal{D}_n$ dominate the ensemble, leading to emergent classical geometries. These conditions amplify the probability P_n, making classical attractors statistically dominant in the multiversal ensemble.

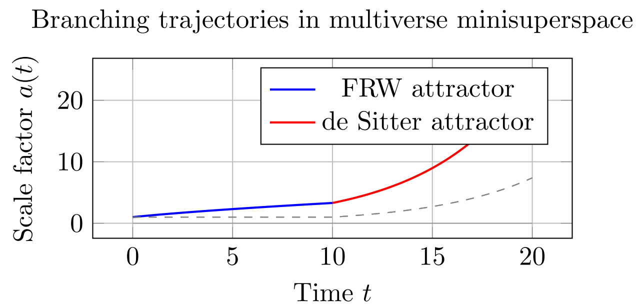

Figure 3: Multiverse branching under WDW+GPC dynamics. Decoherence-weighted trajectories evolve from quantum spread to classical attractors. FRW dominates early-time emergence; de Sitter emerges as a vacuum-driven attractor. Dashed branches represent suppressed alternatives with lower Born-like amplitude.

8 FRW Geometry as a Diagnostic of Neighboring Universe Distribution

In the multiverse framework governed by Wheeler–DeWitt–Generalized Potential Collapse (WDW-GPC) dynamics, the geometry of a single Friedmann–Robertson–Walker (FRW) universe encodes statistical information about the surrounding ensemble of universes. This diagnostic role arises from the interplay between local curvature, matter content, and collapse-modulated decoherence.

8.1 Fractal Classicality Cycle and WDW–GPC Embedding

The recursive cycle of quantum spread, decoherence localization, collapse sharpening, and classical emergence unfolds within the constraint surface defined by the Wheeler–DeWitt (WDW) equation. Rather than being confined to isolated sectors, each cycle manifests within decoherence-weighted regions of the multiverse wave functional, where classicality emerges locally but remains globally entangled through WDW amplitudes. Transitions between regions are governed by Born-like selection rules, with amplitudes modulated by collapse-weighted decoherence kernels, forming a fractal tapestry of classical trajectories across the multiverse landscape:

$$\begin{aligned} \text{Quantum spread} &\to \text{Decoherence localization} \\ \text{Collapse sharpening} &\to \text{Classical trajectory} \\ \text{Re-entanglement} &\to \text{Quantum spread} \cdots \end{aligned}$$

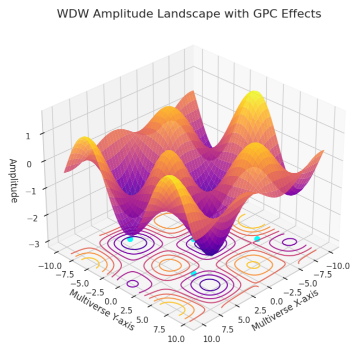

Figure 4: WDW amplitude landscape focused on dominant collapse basin. Trimmed margins isolate FRW attractor zone and suppress peripheral decoherence wells.

8.2 FRW Background and Collapse Dynamics

In the FRW context, the scale factor $a(t)$ evolves according to the Friedmann equation:

$$\left(\frac{\dot{a}}{a}\right)^2 = \frac{8\pi G}{3}\rho - \frac{k}{a^2} + \frac{\Lambda}{3} \tag{28}$$

Collapse dynamics sharpen trajectories toward FRW-like attractors, with decoherence kernels $D(x, x')$ and collapse potentials $\Phi(x, y)$ suppressing quantum interference and selecting dominant outcomes.

8.3 Estimating Neighboring Universe Density

Let n_u denote the estimated density of neighboring universes in minisuperspace. We propose the following diagnostic relation:

$$n_u \approx \frac{\alpha(|k| + \beta\rho)}{\Phi^2} \tag{29}$$

where:

- k is the spatial curvature of the observed FRW universe,
- ρ is the local matter density,
- Φ is the collapse potential amplitude from the GPC framework,
- α, β are model-dependent constants encoding tunneling and decoherence scaling.

This formula reflects the idea that stronger curvature and higher matter density signal more active inter-bubble dynamics, while stronger collapse suppresses fragmentation and reduces distinguishability.

8.4 Spatially Varying Collapse and Matter Fields

For spatially varying collapse potentials $\Phi_i(x, y)$ and matter distributions $\rho_i(x, y)$ across minisuperspace sectors, a refined version becomes:

$$n_u(x, y) \approx \frac{\alpha(|k(x, y)| + \beta\rho_i(x, y))}{\langle \Phi_i(x, y)^2 \rangle} \tag{30}$$

where $\langle \cdot \rangle$ denotes averaging over neighboring sectors.

This formulation links observable FRW geometry to multiverse structure via collapse-modulated decoherence and Born-like amplitude selection, consistent with inter-bubble space dynamics and tunneling gradients.

8.5 Torch-Like Entanglement and Bubble Pairing

Beyond its role as a classical attractor, the FRW geometry functions as a torch that reveals entanglement structure across the multiverse. Within the Wheeler–DeWitt–Generalized Potential Collapse (WDW-GPC) formalism, bubble nucleation and collapse bifurcations often produce entangled pairs of universes with mirrored geometric and matter properties.

Let (k_1, ρ_1) and (k_2, ρ_2) denote the spatial curvature and matter density of two entangled bubbles. Then, under symmetric collapse bifurcation and Born-like amplitude balancing, we expect:

$$k_1 \approx -k_2, \quad \rho_1 \approx \rho_2 \tag{31}$$

This symmetry arises from conservation-like constraints in the inter-bubble space and the structure of the decoherence kernel $D_i(x, y)$ across sectors. Collapse sharpening selects complementary outcomes, while decoherence suppresses cross-interference between paired bubbles.

The FRW geometry of a single bubble thus acts as a diagnostic torch: by analyzing its curvature and matter distribution, one can infer the statistical properties of its entangled counterpart. This insight supports the construction of multiverse maps where entangled sectors are paired via mirrored geometric signatures.

8.6 Relating Entanglement Pairing $\mathcal{E}(x, y)$ to Collapse Potential $\Phi(x, y)$

In the Wheeler–DeWitt–Generalized Potential Collapse (WDW-GPC) formalism, the entanglement pairing function $\mathcal{E}(x, y)$ quantifies the symmetry and correlation between bubble sectors x and y across minisuperspace. Meanwhile, the collapse potential $\Phi(x, y)$

governs the strength and directionality of decoherence-induced collapse between these sectors.

We propose the following correspondence:

$$\mathcal{E}(x, y) \propto \exp\left[-\Phi(x, y)\right] \tag{32}$$

This relation reflects that stronger collapse potential $\Phi(x, y)$ suppresses entanglement between sectors, reducing $\mathcal{E}(x, y)$. Conversely, low collapse strength allows entangled bubble pairs to retain mirrored curvature and matter distributions.

This formulation shows that $\Phi(x, y)$ acts as a collapse-modulated entanglement barrier: it encodes how geometric and matter asymmetries suppress quantum correlations across bubble sectors.

In the WDW–GPC formalism, we distinguish between two formulations of the collapse potential:

- $\Phi_n(x, t)$: governs local collapse evolution within a bubble, integrating decoherence diagnostics over time and modulated by a collapse rate $\Gamma_n(t')$.
- $\Phi(x, y)$: a coarse-grained projection of the time-integrated collapse potentials across sectors, encoding inter-bubble decoherence geometry.

The inter-sector collapse potential is defined as:

$$\Phi(x, y) = \int_0^T dt' \, \Gamma_{xy}(t') \Big[\alpha \, \Delta D_{\mathrm{JZ}}(x, y, t') + \beta \, \Delta D_{\mathrm{CL}}(x, y, t') + \mu \, \Delta D_{\mathrm{GRW}}(x, y, t')\Big] \tag{33}$$

where $\Delta D(x, y, t') = D^{(x)}(x, t') - D^{(y)}(y, t')$ captures decoherence asymmetry, and $\Gamma_{xy}(t')$ is a relational collapse rate.

Assuming decoherence diagnostics are dominated by geometric observables, we approximate:

$$\Phi(x, y) \approx \gamma \left(k(x) + k(y)\right)^2 + \delta \left(\rho(x) - \rho(y)\right)^2 \tag{34}$$

where γ and δ are parameters modulating curvature and matter contributions, respectively. This equation allows comparison of two bubble sectors x and y, encoding entanglement suppression based on geometric and matter asymmetries.

These curvature values are illustrative and reflect symmetry assumptions in entangled pairs. Sectors 3 and 4 are flat and stable, consistent with FRW attractors. Sectors 1 and 2 show mirrored curvature, while 5 and 6 may represent asymmetric or metastable geometries.

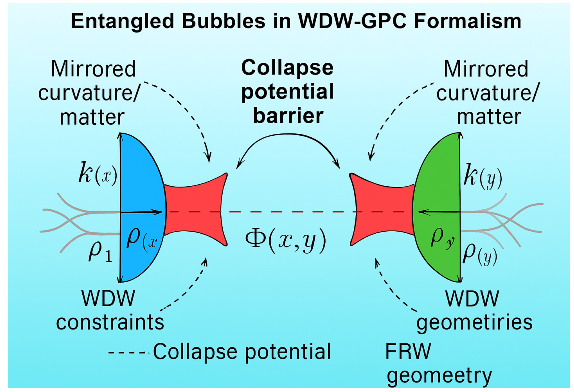

Figure 5: Schematic diagram of two entangled FRW bubbles with mirrored curvature and matter parameters. A potential collapse $\Phi(x, y)$ in red separates them, with WDW constraint surfaces anchoring the branches, emphasizing that all trajectories lie on the timeless quantum constraint manifold.

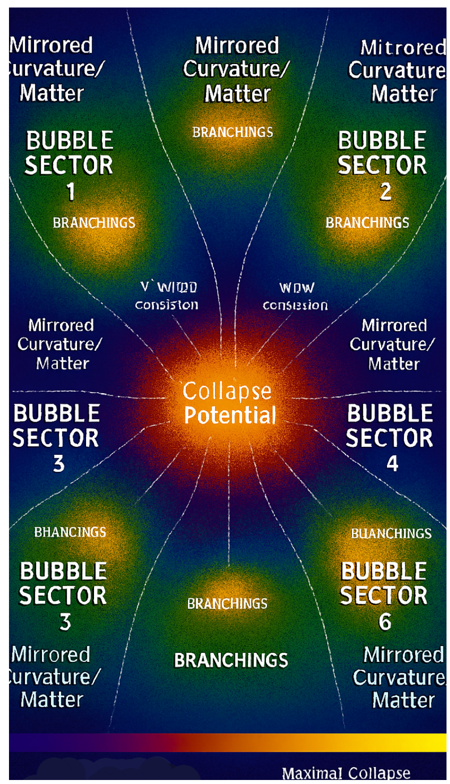

Figure 6: Schematic of six entangled bubble sectors within the WDW–GPC framework. Each bubble exhibits mirrored curvature and matter distributions, branching trajectories, and Wheeler–DeWitt constraint surfaces. The central collapse potential modulates decoherence and entanglement, guiding classical emergence across minisuperspace.

Bubble	FRW-like	Entangled With	ρ (kg/m^3)	k
Sector 1	No	Sector 2	—	+1
Sector 2	No	Sector 1	—	−1
Sector 3	Yes	Sector 4	9.2×10^{-27}	0
Sector 4	Yes	Sector 3	$\approx \rho_3$	0
Sector 5	No	—	—	−0.8
Sector 6	No	—	—	+0.8

Table 2: FRW Classification, Entanglement Pairing, and Estimated Parameters

9 Discussions and Conclusions

The Generalized Potential Collapse (GPC) framework offers a holistic approach that bridges theories traditionally viewed as distinct, such as Bohmian mechanics and the Wheeler–DeWitt (WDW) equation. While multiverse theory continues to establish its foundational concepts and remains niche outside quantum gravity circles, we propose a draft method to approximate matter density and curvature in universes neighboring a flat bubble.

In this context, FRW space–time serves as a beacon to infer entangled universes. The quantum behavior of GPC enables us to model external observers as nearby universes, allowing us to navigate both deterministic and stochastic elements. By extending the timeless constraints of WDW with GPC formalism, we create a framework that traverses quantum histories without relying on conventional parameters like space or time, which are intrinsic to a single universe.

The multiverse wave functional encodes a fractal ensemble of classical branches, suggesting cycles of classicality and quantum conformity. These cycles are shaped by collapse dynamics and selected through decoherence-weighted Born-like amplitudes, offering a pathway to unify quantum and classical regimes across the minisuperspace network.

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