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A Three-Dimensional Reformulation of Bohmian Mechanics

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Abstract

We propose a reinterpretation of Bohmian mechanics in which the single–particle wave functions defined in ordinary three–dimensional space—usually treated as conditional or derived quantities—are elevated to ontological primitives. In this formulation, particle positions and their associated three–dimensional wave functions jointly constitute the fundamental ontology, while the universal wave function on configuration space is retained as part of the formal structure generating their dynamics. Each particle is associated with a wave function in three–dimensional space, conditioned on the actual positions of the others, yielding an exact reformulation of standard Bohmian dynamics. Within a ψ–ontic framework supported by the Pusey–Barrett–Rudolph theorem, we argue that the ontological status of the wave function need not be tied to configuration space, but may instead be realized through interacting wave fields defined directly in physical space. This reinterpretation preserves the full empirical and dynamical content of Bohmian mechanics while restoring a spatially grounded ontology. Although no new testable predictions are introduced, the proposed framework secures three conceptual gains: ontological clarity, pedagogical accessibility, and extension potential. The novelty lies in providing an exact, spatially grounded reformulation that clarifies the ontological role of wave functions without committing to configuration space as the fundamental arena of physical reality.

Keywords: quantum mechanics; ontology; 3D; Bohmian mechanics; deBroglie-Bohm; trajectories; 3D wave

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1. Introduction

The ontology of quantum mechanics remains one of its most contested features. Bohmian mechanics offers a realist alternative to standard interpretations by positing particles with definite positions guided by a universal wave function [1]. However, this wave function, $\Psi(x_1, \ldots, x_N, t)$, is a field on the high-dimensional configuration space $\mathbb{R}^{3N}$, not on the three-dimensional physical space we inhabit. This raises a central interpretative challenge: how much are we to read our mathematical 'maps' as a literal description of the physical 'territory'? The fact that alternative, empirically equivalent formulations exist—such as the Heisenberg picture, which suggests a different ontology of evolving operators rather than evolving states—underscores that a given formalism is not a given reality.

This paper represents a realist project that adopts the Schrödinger picture as the most intuitive foundation for an ontology of beables evolving in time. From this starting point, we suggest that the standard interpretation, by reifying configuration space, conflates the mathematical 'map' with the physical territory. In contrast, we propose a reinterpretation of Bohmian mechanics in which single-particle wave functions—traditionally treated as technical derivatives and referred to as "conditional wave functions"—are elevated to *ontological primitives*, referred to here as 3D wave functions.

In this framework, each particle is associated with a wave function in real three-dimensional space, conditioned on the actual positions of the others. Consequently, the guiding equation is naturally expressed in 3D space, while the full dynamical content of the theory is preserved. It is important to emphasize that this proposal does not yield new empirical predictions; the formal dynamics remain

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those of standard Bohmian mechanics. The novelty lies instead in the ontological shift: by relocating the wave function from configuration space to a family of interacting 3D fields, we achieve conceptual clarity, pedagogical accessibility.

Recent no–go results in the foundations of quantum mechanics sharpen the ontological stakes of these questions. In particular, the Pusey–Barrett–Rudolph (PBR) theorem rules out a broad class of epistemic interpretations of the quantum state [2], supporting the conclusion that the wave function corresponds to physical reality rather than mere information . Importantly, however, the PBR theorem is neutral with respect to the spatial representation of that reality: it constrains the ontological status of the quantum state, but not the space in which it is realized. Configuration–space realism is therefore one possible response to ψ–ontology, but it is not forced by it. The present work explores an alternative resolution of this underdetermination, in which the ontic content required by PBR is carried by wave–like fields defined directly in three–dimensional space. By elevating the conditional (or "3D") wave functions of Bohmian mechanics to ontological primitives, we show how ψ–ontology can be maintained without committing to configuration space as the fundamental arena of physical reality.

In what follows, we use the term *ontological primitives* to denote those entities posited as elements of physical reality (beables) that are not reducible to other dynamical variables within the theory. In the present framework, these primitives consist of particle positions together with the associated single–particle wave functions defined in ordinary three–dimensional space.

2. Standard Bohmian Formalism

Bohmian mechanics describes an N-particle quantum system using:

- A universal wave function $\Psi(x_1, \ldots, x_N, t) \in \mathbb{C}$, defined on configuration space $\mathbb{R}^{3N}$.
- A set of particle positions $x_i(t) \in \mathbb{R}^3$, evolving according to the guiding equation

$$\frac{dx_i}{dt} = v_i(t) = \frac{\hbar}{m_i} \operatorname{Im}\left(\frac{\nabla_{x_i} \Psi(x_1, \ldots, x_N, t)}{\Psi(x_1, \ldots, x_N, t)} \right)\Bigg|_{x_j = x_j(t)}. \tag{1}$$

- Schrödinger evolution of Ψ:

$$i\hbar \frac{\partial \Psi}{\partial t} = \hat{H}\Psi. \tag{2}$$

This formalism is deterministic, nonlocal, and empirically equivalent to standard quantum mechanics [3]. Yet its reliance on configuration space as the domain of the wave function has motivated various proposals for reformulation or reinterpretation [4,5]. While it is standard to say that the universal wave function $\Psi(x_1, \ldots, x_N, t)$ "lives" on the $3N$-dimensional configuration space $\mathbb{R}^{3N}$, this is not a necessary view. An equivalent reformulation associates to each particle its own wave function in 3D space, with these wave functions interacting through their dependence on the actual positions of the others. Developing this alternative perspective is the aim of the present paper.

3. The 3D Wave Function

We now derive the exact evolution equation for the 3D wave function, demonstrating how the familiar single-particle Schrödinger equation is modified by a non-local quantum potential. This derivation is not an approximation but an exact reformulation of the standard Bohmian dynamics.

3.1. Defining the 3D Wave Function

We begin with the universal wave function $\Psi(x_1, \ldots, x_N, t)$ on configuration space $\mathbb{R}^{3N}$ obeying the standard Schrödinger equation, $i\hbar\partial_t\Psi = \hat{H}\Psi$. From the Bohmian trajectories $X_j(t)$ for each particle, we define the 3D wave function for particle i by evaluating the configuration–space wave function at the actual positions of all particles except i, leaving the coordinate of particle i as the only spatial argument:

$$\psi_i(x,t) := \Psi(X_1(t), \ldots, X_{i-1}(t),\, x,\, X_{i+1}(t), \ldots, X_N(t), t). \tag{3}$$

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This object, typically called the *conditional wave function* [3], is a genuine field on physical three–dimensional space. For our ontological proposal, we elevate its status from a mere technical construct to a primitive beable, referring to it simply as the *3D wave function*.

3.2. The Evolution Equation and the Quantum Potential

The evolution of $\psi_i(x,t)$ is determined by the universal Schrödinger equation. To reveal the physical nature of the interactions between the 3D wave functions, we employ a derivation that makes the coupling terms explicit, following the detailed formalism presented in authoritative texts on the subject [6,7]. The evolution law for ψ_i can be written as:

$$i\hbar\frac{\partial\psi_i}{\partial t} = \left(-\frac{\hbar^2}{2m_i}\nabla_x^2 + V_i\right)\psi_i + K_i(x,t)\,\psi_i, \tag{4}$$

where $K_i(x,t)$ is a complex potential that couples particle i to all other particles in the system. By performing a polar decomposition of the universal wave function ($\Psi = Re^{iS/\hbar}$) and applying the Bohmian guiding law, this potential can be separated into three distinct parts:

$$K_i(x,t) = \underbrace{\sum_{j\neq i} Q_j(x,t)}_{\mathcal{Q}_{-i}(x,t)} - \underbrace{\sum_{j\neq i}\frac{1}{2}m_j|v_j(t)|^2}_{\mathcal{T}(t)} \underbrace{-i\frac{\hbar}{2}\sum_{j\neq i}\nabla_{x_j}\cdot v_j(t)}_{\mathcal{D}(t)}. \tag{5}$$

Here, $Q_j(x,t) = [-\frac{\hbar^2}{2m_j}\frac{\nabla_{x_j}^2 R}{R}]_{x_{-i}=X_{-i}(t)}$ is the quantum potential associated with particle j. The crucial insight is that the coupling consists of a position-dependent quantum potential, $\mathcal{Q}_{-i}(x,t)$, and two terms, $\mathcal{T}(t)$ and $\mathcal{D}(t)$, that depend only on time. These time-dependent terms can be absorbed into a physically irrelevant phase factor via a gauge transformation, $\psi_i(x,t) = e^{\Lambda(t)}\Phi_i(x,t)$. This yields the final, tidy evolution equation for the rescaled 3D wave function Φ_i:

$$i\hbar\frac{\partial\Phi_i}{\partial t} = \left(-\frac{\hbar^2}{2m_i}\nabla_x^2 + V_i(x,X_{-i}(t))\right)\Phi_i + \mathcal{Q}_{-i}(x,t)\,\Phi_i. \tag{6}$$

This equation captures the dynamical content of the proposed 3D ontology. It shows that each particle's wave function Φ_i evolves via a local Schrödinger equation, plus a single, non-local quantum potential $\mathcal{Q}_{-i}(x,t)$. This term precisely encodes the influence of all other particles, mediated by the curvature of the universal wave function's amplitude at their actual positions.

Although the conditional wave function $\psi_i(x,t)$ and the transformed field $\Phi_i(x,t)$ are mathematically distinct, they represent the same underlying physical structure at different descriptive levels. The conditional wave function provides the direct link to the universal wave function Ψ, whereas $\Phi_i(x,t)$ is the dynamically autonomous representation that makes the three-dimensional field ontology explicit.

3.3. Guidance, Equivariance, and the Axiomatic View

The particle's motion is guided by its associated 3D wave function. Since the gauge transformation is spatially uniform, the guiding law can be expressed equivalently using ψ_i or Φ_i:

$$\dot{X}_i(t) = \frac{\hbar}{m_i}\mathrm{Im}\left[\frac{\nabla_x\Phi_i(x,t)}{\Phi_i(x,t)}\right]_{x=X_i(t)} = \frac{1}{m_i}\nabla_x S_i(x,t)\Big|_{x=X_i(t)}. \tag{7}$$

The non-local term $\mathcal{Q}_{-i}(x,t)$ in the evolution equation (6) is precisely what is needed to ensure that the dynamics of the 3D fields and particles preserves the quantum equilibrium distribution $|\Psi|^2$, a property known as equivariance. This naturally leads to an alternative, but fully equivalent, axiomatic formulation of Bohmian mechanics:

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1. **Ontology:** The ontological primitives consist of particles with positions $X_i(t) \in \mathbb{R}^3$ together with a set of corresponding fields $\{\Phi_i(x,t)\}$ on $\mathbb{R}^3$.
2. **Guidance Postulate:** Each particle is guided by its field via Equation (7).
3. **Evolution Postulate:** The fields evolve according to the coupled evolution equation (6), where the non-local coupling is given by the quantum potential $\mathcal{Q}_{-i}$.

This axiomatic presentation makes the conceptual advantage of the 3D formalism explicit: the fundamental dynamics occur in ordinary 3D space, with non-locality manifesting as an explicit potential in the fields' evolution equations.

4. Conceptual Features of the 3D Ontology

The 3D wave function formalism, while empirically equivalent to the standard model, offers a distinct physical and philosophical perspective. To sharpen its conceptual profile, we emphasize a **two-level ontology**:

- **Ontological Primitives:** The manifest beables are particles with definite positions in 3D space, together with their associated 3D wave functions $\psi_i(x,t)$. These fields are ontological primitives, guiding particle motion via Equation (7).
- **Nomological Structure:** The universal wave function Ψ on configuration space is retained, but only as a compact generator of nonlocal quantum potentials $Q_{-i}(x,t)$. It encodes the global dynamical constraints without being itself a material field.

This hierarchy clarifies the metaphysical stance: reality consists of particles and their guiding 3D fields, while the universal wave function plays a law-like role analogous to the Hamiltonian in classical mechanics.

4.1. Born Rule and Quantum Equilibrium

Since the theme of the present Special Issue concerns Born's rule, it is important to emphasize explicitly that the proposed 3D ontology preserves the full statistical structure of standard Bohmian mechanics. In Bohmian mechanics, the Born rule arises through the quantum equilibrium hypothesis: for an ensemble of systems with universal wave function $\Psi(x_1,\ldots,x_N,t)$, the distribution of particle configurations is given by:

$$\rho(x_1,\ldots,x_N,t) = |\Psi(x_1,\ldots,x_N,t)|^2$$

and this distribution is preserved under the dynamics (equivariance). The present reformulation retains this structure exactly.

When expressed in terms of 3D wave functions, the equilibrium distribution on configuration space induces a corresponding statistical measure over particle positions together with their associated conditional wave functions $\psi_i(x,t)$. In this sense, Born's rule may be understood as a statistical law governing ensembles of particles and 3D fields rather than as a primitive postulate about configuration space amplitudes. The 3D ontology thus reproduces all quantum statistics while rendering their physical basis more transparent: probabilities reflect equilibrium properties of spatially grounded beables evolving under deterministic, nonlocal dynamics.

Accordingly, the Born rule is neither weakened nor reinterpreted in a way that alters its empirical content. Its role is clarified rather than revised, appearing as a natural consequence of quantum equilibrium within a fully three-dimensional ontology.

4.2. Collapse and Conditionalization

In standard Bohmian mechanics, collapse is not a fundamental physical process but an effective one, occurring at the level of subsystem conditional wave functions once environmental degrees of freedom are taken into account. The present framework does not modify the dynamics or empirical content of the theory; it differs only in ontology. The same conditional wave functions that already appear in standard Bohmian mechanics are here treated as ontological primitives in physical space, so

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that effective collapse is understood as the conditional updating of real-space fields upon the actual configuration of the environment. Expressed in this way, collapse involves no departure from unitary dynamics and no appeal to measurement postulates or consciousness, but becomes a transparent feature of the real-space description.

4.3. Physical Transparency vs. Mathematical Compactness

One might note that the N coupled equations of motion for the 3D wave functions (Equation (6)) are more complex than the single Schrödinger equation on configuration space. This reflects a deliberate choice: prioritizing physical transparency over mathematical compactness. The additional term $Q_{-i}(x,t)$ is not mere mathematical clutter, but the explicit representation of non-local quantum interaction in ordinary three-dimensional space. In contrast, the configuration–space formulation provides a compact global encoding of the same dynamics. The two descriptions are mathematically equivalent, but emphasize different aspects of the theory.

5. Philosophical Positioning and Relation to Alternative Approaches

Having established the dynamics and conceptual features of the 3D ontology, we now position it with respect to rival interpretations, including configuration-space realism, the nomological view, and other approaches that seek to ground quantum mechanics in 3D space.

5.1. The Choice of Formalism: Realism vs. Anti-Realism

Any realist interpretation of quantum mechanics is implicitly rooted in the **Schrödinger picture**, where reality is composed of 'beables' (like particles and fields) that have a state and evolve in time. This choice is deliberate.

The primary alternative, the **Heisenberg picture**, is more naturally aligned with the anti-realist Copenhagen interpretation. In the Heisenberg picture, the state vector is static, and the 'observables' (represented by operators) evolve. This formalism is philosophically suited to an instrumentalist view, where physics is only about the *outcomes of measurements* (observables) and not an underlying 'story' of reality. The concept of a 'beable' fits awkwardly, if at all.

Our framework, in contrast, is fundamentally realist. By choosing the Schrödinger picture, we accept that there *is* a 'story' of reality evolving in spacetime. The central question for us is not *if* there are beables, but *what* they are. The standard Bohmian answer is 'particles and a global Ψ'. This paper argues for a more coherent answer: 'particles and their 3D fields ψ_i'.

Having established our realist foundations in the Schrödinger picture, we now position our 3D ontology with respect to other realist approaches.

5.2. Configuration-Space Realism and the 3D Ontology

Proponents of configuration-space realism argue that the universal wave function Ψ represents a genuine physical field on the high-dimensional space $\mathbb{R}^{3N}$ [8–10]. On this view, the fundamental ontology of quantum theory is not the familiar three-dimensional world, but a vast configuration space in which the wave function "lives," with ordinary 3D reality treated as emergent or derivative. While this interpretation has the virtue of literalism, it is often argued to incur a substantial metaphysical cost: it reifies an abstract mathematical representation and requires a radical reconceptualization of physical space as non-fundamental.

The present framework offers an alternative that preserves the full empirical and dynamical content of Bohmian mechanics without this ontological commitment. The same dynamics encoded in the configuration-space Schrödinger equation can be expressed exactly in terms of interacting wave functions defined on ordinary three-dimensional space. Each particle is associated with a 3D wave function evolving according to Equation (6), with nonlocal correlations encoded explicitly through the quantum potential $Q_{-i}(x,t)$. In this formulation, configuration space remains a powerful mathematical tool, but it is no longer interpreted as a physically real arena.

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This perspective directly addresses recent critiques of Bohmian ontology. Esfeld and Lazarovici argue that configuration-space realism imposes unnecessary metaphysical burdens while leaving unresolved the problem of how the manifest 3D world arises from high-dimensional structure [5,11]. By relocating the ontology into ordinary space—particles together with their guiding 3D wave functions—the present framework avoids this difficulty. The theory is formulated entirely in terms of entities in physical space, while remaining exactly equivalent to standard Bohmian mechanics at the level of dynamics and empirical content.

In short, the mathematical use of configuration space does not force an ontological commitment to configuration-space realism. The same physics can be represented through a spatially grounded ontology of particles and interacting 3D wave functions.

6. PBR, ψ–Ontology, and Conditional Wave Functions

Recent no–go results in the foundations of quantum mechanics sharpen the ontological stakes of interpretations of the wave function. In particular, the Pusey–Barrett–Rudolph (PBR) theorem shows that, under natural assumptions such as preparation independence, distinct quantum states cannot correspond to overlapping distributions over the same underlying physical states. The theorem is therefore widely taken to support a ψ–ontic reading of quantum mechanics, according to which the wave function represents an element of physical reality rather than mere epistemic information.

In the context of Bohmian mechanics, the implications of the Pusey–Barrett–Rudolph (PBR) theorem require careful interpretation. If the ontic state is taken to consist of the pair (Q, Ψ), where Q denotes the configuration of particle positions and Ψ the universal wave function, then ψ–ontology is effectively built into the formalism and the PBR conclusion adds no new constraint. If, by contrast, the universal wave function Ψ is treated as nomological, the question of how the ontic content required by PBR is realized at the level of subsystems becomes nontrivial.

In Bohmian mechanics, the quantum state of a subsystem is represented by its conditional wave function. When effective dynamical decoupling conditions hold, this conditional wave function evolves autonomously and plays exactly the same role as the standard wave function in ordinary quantum mechanics. In the present framework, this effective subsystem wave function is represented by the single–particle conditional wave function $\psi_i(x, t)$ defined on ordinary three–dimensional space and associated with the particle position $X_i(t)$. In this sense, the conditional wave function is not an alternative to the configuration–space wave function, but its effective realization for subsystems.

PBR–type considerations apply to conditional wave functions insofar as they play the role of effective quantum states for subsystems. When independently prepared subsystems are dynamically decoupled, distinct conditional wave functions cannot correspond to overlapping underlying physical states without contradicting quantum predictions. In this sense, the conditional wave function cannot be interpreted as purely epistemic in such regimes, although this does not by itself determine its precise ontological status.

Accordingly, PBR–type arguments constrain how ψ–ontology may be implemented within Bohmian mechanics, but they do not require the universal wave function Ψ to be reified as a physical field on configuration space. They are fully compatible with an ontology in which the ontic content of the quantum state is carried by particle positions together with their associated three–dimensional conditional wave functions, as proposed here.

6.1. Nomological View

Dürr, Goldstein, and Zanghì have argued that the universal wave function Ψ in Bohmian mechanics is best understood as nomological, functioning as a global generator of particle motion rather than as a physical field in its own right [12]. A common objection to this view is that Ψ is explicitly time–dependent, whereas fundamental laws are often taken to be static. However, time dependence alone does not preclude a nomological role: in classical mechanics, a time–dependent Hamiltonian $H(t)$ can encode a changing dynamical constraint without being regarded as a physical component of the system.

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Our proposal adopts this nomological reading of the universal wave function, but supplements it with additional ontological structure in ordinary three–dimensional space. While Ψ provides a compact, global encoding of the dynamics, the conditional wave functions associated with individual particles are taken to be ontic.

6.2. Relation to Multi-Field Ontology

Recent work has proposed so–called "multi–field" interpretations, in which the universal wave function is reinterpreted as a single field on three–dimensional space whose values depend on tuples of spatial points [13]. While this avoids treating configuration space as fundamental, it retains a single global object with inherently relational dependence and does not introduce distinct single–particle wave functions.

By contrast, the present framework assigns to each particle its own wave function defined on ordinary three–dimensional space, with an exact (though coupled) evolution equation derived from the universal dynamics. The resulting 3D wave functions are genuine particle–indexed fields that enter directly into the guiding equation. In this sense, our approach replaces a global relational ontology with a local field ontology in physical space, rather than merely reinterpreting the domain of the universal wave function.

6.3. Norsen's Local Beables Program

Norsen's local beables approach [4] seeks to reconstruct quantum theory using exclusively real-space entities, thereby discarding configuration space. In contrast, the present approach retains the universal wave function as part of the formal machinery but translates its content into exact evolution laws for 3D wave functions. Equation (6) is not a postulate but a derivation from the universal Schrödinger dynamics together with the actual Bohmian configuration. This guarantees that the ontology of 3D wave functions is mathematically equivalent to standard Bohmian mechanics, while providing an explicit wave function ontology in 3D space. Unlike Norsen's program, no additional dynamical assumptions or supplementary equations are required.

6.4. A Limited Analogy with Special Relativity

In a limited sense, our conceptual strategy bears comparison with Einstein's 1905 reformulation of kinematics. In that case, the central mathematical structures of the theory—the Lorentz transformations—were already known from the work of Lorentz [14] and Poincaré [15], and Einstein's contribution lay both in a conceptual reorganization and in providing a simpler derivation of the same equations from new physical principles [16].

The present work is more modest. We do not propose new principles or a new derivation of the fundamental equations. Rather, starting from the standard Bohmian formalism, we reorganize the ontology so that the theory is expressed in terms of entities defined in ordinary three–dimensional space, while remaining mathematically equivalent to the original description.

7. Conceptual Payoffs of the 3D Ontology

The statistical structure of the theory, including the recovery of Born's rule via quantum equilibrium, has been discussed in detail in Section 4.1. Here we focus instead on the conceptual advantages of the proposed 3D ontology, which arise independently of any new empirical predictions.

Conceptual Clarity

The two-level ontology introduced in this work resolves a central tension in standard Bohmian mechanics: the coexistence of particles in ordinary three-dimensional space with a guiding wave function defined on configuration space. In the present framework, both particles and their guiding wave functions reside in physical space, while the universal wave function is relegated to a nomological role. This sharpens the distinction between mathematical representation and physical ontology, restoring transparency to the relation between formalism and reality.

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Pedagogical Accessibility

Because the guiding wave functions are defined in ordinary space, the dynamics of Bohmian mechanics become more intuitive and accessible. Phenomena such as effective collapse, entanglement, and nonlocal interaction are represented as processes involving spatially extended fields rather than abstract high-dimensional objects. This opens the door to visualization, simulation, and didactic tools that can make the theory more approachable for students and non-specialists without sacrificing rigor.

8. Classical Potentials and Holistic Dynamics

Before turning to a classical analogy, it is useful to recall the role of potentials in Bohmian mechanics. The guiding equation can be derived from a modified Hamilton–Jacobi formulation in which the quantum potential appears,

$$Q(x_1, \ldots, x_N, t) = -\sum_i \frac{\hbar^2}{2m_i} \frac{\nabla^2_{x_i} |\Psi|}{|\Psi|}. \tag{8}$$

This potential depends on the full configuration of the system and is therefore inherently nonlocal. It provides a concrete expression of how Bohmian dynamics encode holistic dependencies while remaining formulated in terms of variables associated with physical space.

A useful classical point of comparison is provided by vortex dynamics in incompressible fluids. For N point vortices in a two–dimensional ideal (inviscid, incompressible) fluid, the velocity of the ith vortex at position $\mathbf{r}_i$ is given by the Biot–Savart law,

$$\frac{d\mathbf{r}_i}{dt} = \sum_{j \neq i} \frac{\Gamma_j}{2\pi} \frac{\hat{z} \times (\mathbf{r}_i - \mathbf{r}_j)}{|\mathbf{r}_i - \mathbf{r}_j|^2}, \tag{9}$$

where Γ_j denotes the circulation strength of the jth vortex and $\hat{z}$ is the unit vector perpendicular to the plane [17]. In this idealized incompressible setting, the motion of each vortex depends nonlocally, through a long–range kernel, on the positions of all others, yielding a holistic, non-factorizable dependence encoded entirely in ordinary physical space.

The instructive point of this analogy is not merely that holistic interactions can be formulated in real space, but how ontology is naturally assigned within such a formulation. In vortex dynamics, the interaction kernel appearing in the equations of motion is not regarded as a physical entity; rather, the vortices themselves are taken to be the beables, even though their motion is determined by a collective interaction structure. The Biot–Savart term functions as a generator of motion, not as an object in the ontology.

The present framework invites a similar ontological reading. Although the dynamics of the 3D wave functions involve nonlocal coupling terms derived from the universal wave function, it is the particles and their associated three–dimensional wave fields that naturally present themselves as physical entities in space. The configuration–space wave function plays a role analogous to that of the interaction kernel in vortex dynamics: it encodes the structure of the coupling, but it is not itself the primary bearer of ontological commitment.

9. Conclusions

By elevating 3D wave functions to ontological primitives, we reinterpret Bohmian mechanics as a realist, dynamically nonlocal, yet spatially grounded theory. This shift restores the ontology to ordinary three–dimensional space, where both particles and their guiding wave fields reside, without altering the empirical content or predictive structure of the theory.

The contribution of the present work is not new dynamics or new predictions, but a clarified ontological picture. By treating the universal wave function Ψ as nomological while assigning ontic status to particle positions and their associated 3D wave functions, the framework avoids the metaphysical commitments of configuration–space realism while remaining fully equivalent to standard Bohmian mechanics.

What distinguishes this approach from earlier real–space proposals is that the 3D wave functions obey an exact and constructive evolution equation, Equation (6), derived directly from the universal Schrödinger dynamics together with the actual Bohmian configuration. This result shows that a spatially grounded ontology can be formulated in precise mathematical terms, without supplementary postulates or modifications of the theory.

Taken together, these results establish the internal coherence and viability of an ontology based on particles and three–dimensional wave functions. The resulting formulation is ontologically transparent while remaining mathematically and empirically equivalent to the standard Bohmian framework.

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