THE INCOMPLETENESS OF OBSERVATION
Why Quantum Mechanics and General Relativity Cannot Be Unified From Within

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Abstract

This paper argues that the incompatibility between quantum mechanics and general relativity is a structural consequence of embedded observation. Any observer that is part of the universe it measures must access their reality through projections which discard information about causally inaccessible degrees of freedom. Using Wolpert's (2008) physics-independent impossibility theorems for inference devices, a Complementarity Theorem is introduced: the quantum-mechanical and gravitational descriptions of vacuum energy correspond to variance and mean estimations of a hidden sector, and Wolpert's mutual inference impossibility prohibits their simultaneous determination by any embedded observer. The 10^{120} cosmological constant discrepancy is not an error but the quantitative signature of this structural incompleteness. It is shown that tracing out any dynamical hidden sector with temporal correlations generically produces indivisible stochastic processes, which are mathematically equivalent to quantum mechanics (Barandes 2023). Interpreting the 10^{120} value as a variance-to-mean ratio, $N \sim 10^{240}$ hidden-sector degrees of freedom are extracted—equal to S_{dS}^2, the square of the Bekenstein-Hawking entropy of the cosmological horizon—converting the cosmological constant problem from a mystery into a measurement. Specific experimental predictions are offered, including near-term null predictions for beyond-Standard-Model particles and longer-term frequency-dependent scaling relations for gravitational wave echoes and a stochastic noise floor quantitatively anchored to the 10^{120} ratio.

1 THE PROBLEM

1.1 The Incompatibility

Quantum mechanics and general relativity are extraordinarily successful yet incompatible. The dominant assumption has been that this incompatibility is a deficiency—that a deeper theory will eventually unify them. This paper proposes the opposite: **the incompatibility is a structural feature of embedded observation.**

1.2 The 10^{120} ratio

The sharpest manifestation of the QM-GR incompatibility is the **cosmological constant problem ?**. It concerns the single quantity that both frameworks predict: the energy density of empty space.

Quantum mechanics computes the vacuum energy by summing the zero-point fluctuations of all quantum field modes up to a cutoff. At the Planck scale:

$$\rho_{\mathrm{QM}} \sim \frac{c^7}{\hbar G^2} \sim 10^{110} \ \mathrm{J/m^3} \tag{1}$$

General relativity measures the vacuum energy through its gravitational effect—the accelerated expansion of the universe:

$$\rho_{\text{grav}} \sim 6 \times 10^{-10} \text{ J/m}^3 \tag{2}$$

The ratio:

$$\frac{\rho_{\text{QM}}}{\rho_{\text{grav}}} \sim 10^{120} \tag{3}$$

is the largest quantitative disagreement in all of physics. The standard interpretation is that one or both calculations must be wrong—that some unknown mechanism cancels the QFT contribution down to the observed value. Decades of effort have failed to find such a mechanism **??**.

A different interpretation is proposed: **neither calculation is wrong. They disagree because they are answering fundamentally different questions about the same thing.**

2 THE ARGUMENT

2.1 Observers Are Embedded

Observers are part of the universe that they observe. This assertion has both physical and mathematical consequences. Wolpert (2008) proved that any physical device performing observation, prediction, or recollection—an "inference device"—faces fundamental limits on what it can know about the universe it inhabits **?**. These limits hold **independent of the laws of physics**:

(a) There exists at least one function of the universe state that the inference device cannot correctly compute—regardless of its computational power or the determinism of the underlying physics.

(b) No two distinguishable inference devices can fully infer each other's conclusions (the "mutual inference impossibility").

These are physics-independent analogues of the Halting theorem, extended to physical devices embedded in physical universes **?**. The key mathematical structure is the **setup function** $\pi : \Omega \to S_C$ that maps the full universe state space Ω to the device's state space S_C. Wolpert's impossibility theorem requires only that π is surjective and many-to-one. This is assumed to be trivially satisfied by any observer.

2.2 The Hidden Sector

Regardless of what specific theory describes the microscopic world, **there exist degrees of freedom that observers cannot directly access.**

Let $\Omega = (X, \Phi)$ denote the full state space, where X represents degrees of freedom accessible to observers and Φ represents the hidden sector. The projection that discards the hidden sector defines a map:

$$\pi : (X, \Phi) \mapsto \rho(X) \tag{4}$$

This map is many-to-one: many distinct configurations Φ yield the same $\rho(X)$. It therefore satisfies the requirements of a Wolpert setup function. **There exist properties of the universe that no observer confined to X can determine.**

It is not necessary to specify what Φ is. The argument requires only that it exists and that π is many-to-one.

The hidden sector consists not of exotic particles but of standard degrees of freedom rendered causally inaccessible by the structure of spacetime: (i) trans-horizon modes beyond the cosmological horizon, (ii) sub-Planckian degrees of freedom below the observer's resolution limit, and (iii) black

hole interiors. In each case, the mechanism enforcing hiddenness is the causal structure of spacetime. The partition between X and Φ is a property of the observer's position, not of the hidden sector's content.

2.3   Two Projections of the Same Thing

Vacuum energy is the energy density of the hidden sector. When physicists measure or calculate it, they are attempting to characterize Φ from within X. There is more than one way to do this, and the different ways are not equivalent.

Projection 1: Fluctuation statistics (QM). Quantum mechanics characterizes the hidden sector through its fluctuation structure. The QFT vacuum energy calculation sums these fluctuations—the total variance of the hidden sector's influence on observables:

$$\rho_{\text{QM}} \sim \int_0^\Lambda \frac{d^3k}{(2\pi)^3} \frac{1}{2}\hbar\omega_k \sim \frac{\Lambda^4}{16\pi^2} \tag{5}$$

Projection 2: Mean-field pressure (gravity). Gravity characterizes the hidden sector through its net mechanical effect—the aggregate pressure that the hidden degrees of freedom exert on spacetime:

$$\rho_{\text{grav}} = \langle T_{00}\rangle_{\text{eff}} \sim 6 \times 10^{-10} \text{ J/m}^3 \tag{6}$$

The physical reason for the divergence is that gravity acts as an **adiabatic probe**, averaging over Planck-scale fluctuations and seeing only the mean energy density. Quantum mechanics probes the **correlation structure**—summing over propagators to measure how much the medium fluctuates, not how heavy it is.

The key identification. These two projections compute different statistical quantities of the same distribution:

- ρ_{QM}: total fluctuation content (related to variance / second moment)

- ρ_{grav}: net mechanical effect (related to mean / first moment)

This identification has precise mathematical content. The QFT vacuum energy is a sum over zero-point energies $\frac{1}{2}\hbar\omega_k$, one for each field mode k. Each mode contributes positively regardless of any relative phase or sign. Formally, the QFT zero-point sum

$$\rho_{\text{QM}} \sim \sum_k \frac{1}{2}\hbar\omega_k \sim \int_0^\Lambda \frac{d^3k}{(2\pi)^3} \frac{1}{2}\hbar\omega_k \tag{7}$$

has the structure of $\text{Tr}[\hat{H}_{\text{vac}}] = \sum_k \langle 0|\hat{a}_k^\dagger \hat{a}_k + \frac{1}{2}|0\rangle \cdot \hbar\omega_k$, where the vacuum expectation value of each mode's energy is its zero-point fluctuation amplitude—a variance-type quantity that is always positive. Note that $\langle 0|x_k|0\rangle = \langle 0|p_k|0\rangle = 0$ for every mode, so $\langle 0|H_k|0\rangle = \frac{1}{2}\text{Var}(p_k) + \frac{1}{2}\omega_k^2 \text{Var}(x_k)$: the zero-point energy is identically the sum of the canonical variances. In the classical ground state both variances vanish and the vacuum energy is zero—the entire $\frac{1}{2}\hbar\omega_k$ is fluctuation content.

To see how the divergence arises concretely, consider N modes each contributing energy $\pm\mu$ with random sign. The unsigned sum—the fluctuation content—is $N\mu$. The signed sum—the net mechanical effect—is a random walk of N steps, whose expectation scales by the central limit theorem as $\sqrt{N}\,\mu$. The ratio is $\sqrt{N}$, which grows without bound. For the vacuum, N is set by the number of hidden-sector degrees of freedom; §4 shows that the observed ratio of 10^{120} implies $N \sim 10^{240}$.

2.4 The Complementarity Theorem

This incompatibility is not merely conceptual. Because the two operations extract independent statistical moments of Φ (variance and mean respectively), Wolpert's mutual inference impossibility provides a quantitative bound on their simultaneous determination, which is now stated formally.

Theorem 1 (Complementarity Theorem). *Let $\pi : (X, \Phi) \to \rho(X)$ be the projection that traces out the hidden sector Φ. Define two inference targets:*

- $f_1 : \Phi \to \rho_{QM}$ *(fluctuation projection: total variance)*

- $f_2 : \Phi \to \rho_{grav}$ *(mechanical projection: mean)*

If both targets are independently configurable—that is, if distributions exist with the same mean but different variances, and vice versa—then Wolpert's mutual inference impossibility guarantees that no pair of inference devices sharing the same setup function π can simultaneously determine both f_1 and f_2 with certainty. In the stochastic generalization, the product of their success probabilities is bounded:

$$\epsilon_1 \cdot \epsilon_2 \leq c < 1 \tag{8}$$

where c is a constant determined by the setup function π and the independence of the targets.

Application of the impossibility theorem. Wolpert's mutual inference impossibility (result (b) in §2.1) applies when the two targets are independently configurable—when distributions exist with the same mean but different variances, and vice versa. This is manifestly the case. To obtain a quantitative bound, the stochastic extension of Wolpert's Theorem 1 **?** is applied, which generalizes the deterministic impossibility result to probabilistic inference devices. In the stochastic setting, each device's "correctness" is measured by the probability ϵ that its conclusion function matches the target. Wolpert shows that for two inference devices sharing the same setup function π and targeting independently configurable functions of the universe state, the product of their success probabilities is bounded:

$$\epsilon_{QM} \cdot \epsilon_{grav} \leq c < 1 \tag{9}$$

The constant c depends on the cardinality of the conclusion spaces and the structure of π. The theorem guarantees that perfect simultaneous knowledge of both projections is impossible. The 10^{120} ratio is a manifestation of this bound.

Remark on the inference-ontology bridge. Wolpert's theorem bounds inference accuracy, not physical quantities directly. The bridge is this: the values called ρ_{QM} and ρ_{grav} are not observer-independent properties of the hidden sector. They are outputs of specific measurement procedures—QFT mode-summation and gravitational coupling—each constituting an inference operation in Wolpert's sense. There is no "true" vacuum energy behind both measurements. The two values are the best answers that two structurally different inference procedures can extract from the same hidden sector, and Wolpert's theorem guarantees they cannot converge. The 10^{120} is not the gap between two estimates of one quantity; it is the gap between two quantities that embeddedness forces to be distinct.

3 THE QUANTUM PROJECTION IS NOT ARBITRARY

3.1 Tracing Out a Hidden Sector Generically Yields Quantum Mechanics

The argument thus far has shown that quantum mechanics and general relativity are fundamentally incompatible projections. A natural objection is: why should the fluctuation projection take the specific form of quantum mechanics? Why not some other statistical description?

Barandes (2023–2025) proved a powerful result: **any indivisible stochastic process is mathematically equivalent to quantum mechanics ??**. This means that if the traced-out dynamics of a system cannot be written as a sequence of independent intermediate steps, the system's behavior is exactly captured by the Schrödinger equation, interference, superposition, entanglement, and the Born rule. Quantum mechanics is not an axiom—it is the unique description of indivisible stochastic evolution.

The question becomes: when does tracing out a hidden sector produce indivisible dynamics?

3.2 Generic Indivisibility from Temporal Correlations

Consider a classical system with degrees of freedom (X, Φ) evolving under a joint Hamiltonian. The Nakajima-Zwanzig projection formalism gives the exact reduced dynamics of X after tracing out Φ **??**:

$$\frac{d\rho(t)}{dt} = -i\mathcal{L}\rho(t) - \int_0^t d\tau \, \mathcal{K}(t, \tau)\rho(\tau) \tag{10}$$

where $\mathcal{K}(t, \tau)$ is the memory kernel encoding the hidden sector's influence at time t due to the system's state at earlier time τ. The argument is model-independent. The only requirements are that: **(a)** Φ exists, **(b)** Φ has dynamics, and **(c)** Φ has temporal correlations.

If the memory kernel vanishes ($\mathcal{K} = 0$), the reduced dynamics are Markovian and can be divided into arbitrary intermediate steps—the evolution is *divisible*. The system behaves classically.

However, such cancellations are non-generic in the following precise sense: they require that $\mathcal{L}$ and $\mathcal{K}$ conspire to produce a completely positive, trace-preserving (CPTP) intermediate map $T(t_f, t_m) = T(t_f, t_i) \cdot T(t_m, t_i)^{-1}$ for *every* intermediate time t_m and *every* initial state simultaneously. This is a measure-zero condition in the space of memory kernels. The Nakajima-Zwanzig formalism generates CP-indivisible dynamics whenever system-environment correlations are non-negligible **??**. Since the traced-out hidden sector constitutes the vast majority of the universe's degrees of freedom, these correlations are dominant rather than perturbative, and the indivisibility condition is robustly satisfied.

Conclusion: Tracing out any dynamical hidden sector with temporal correlations generically produces indivisible dynamics. By Barandes' theorem, such dynamics are mathematically equivalent to quantum mechanics. The quantum projection is not an ad-hoc choice—it is the inevitable result of projecting reality through a setup function that discards a temporally correlated environment.

3.3 Quantum Phenomena as Projection Artifacts

This derivation reinterprets the core features of quantum mechanics:

- **Interference:** The memory kernel introduces phase relationships between paths that appear distinct in the reduced description but share common hidden-sector histories.

- **Superposition:** Multiple hidden-sector microstates project onto the same observable state; the reduced description represents this ambiguity as a linear combination.

- **Entanglement:** Two systems that have interacted share correlations in Φ that the projection cannot represent locally.

- **The Born rule:** Probabilities arise from coarse-graining over the hidden sector's measure space.

In this framework, quantum mechanics is not fundamental—it is what the universe looks like when observed from inside a projection that hides most of reality.

4 QUANTITATIVE IMPLICATIONS

4.1 Extracting the Hidden Sector's Dimensionality

The central limit theorem provides a direct route from the observed 10^{120} ratio to the number of hidden-sector degrees of freedom.

If the hidden sector consists of N independent fluctuating modes, each contributing energy with zero mean and variance σ^2, then:

- Total fluctuation (variance sum): $\rho_{\mathrm{QM}} \sim N\sigma^2$

- Net mechanical effect (mean of sum): $\rho_{\mathrm{grav}} \sim \sqrt{N}\,\sigma$ (by CLT)

The ratio:
$$\frac{\rho_{\mathrm{QM}}}{\rho_{\mathrm{grav}}} \sim \frac{N\sigma^2}{\sqrt{N}\sigma} = \sqrt{N} \tag{11}$$

Setting this equal to the observed 10^{120}:

$$\sqrt{N} \sim 10^{120} \quad \Rightarrow \quad N \sim 10^{240} \tag{12}$$

This is the number of hidden-sector degrees of freedom accessible to an observer.

4.2 Connection to the Cosmological Horizon

Remarkably, $N \sim 10^{240}$ equals S_{dS}^2, the square of the Bekenstein-Hawking entropy of the cosmological horizon **?**:

$$S_{\mathrm{dS}} = \frac{A}{4\ell_P^2} \sim 10^{122} \tag{13}$$

where A is the horizon area and ℓ_P is the Planck length. Thus:

$$N \sim S_{\mathrm{dS}}^2 \sim (10^{122})^2 = 10^{244} \tag{14}$$

This relationship was independently predicted by Sorkin's causal set approach to quantum gravity **?**, which derives dark energy from fluctuations in the number of spacetime atoms. The coincidence is striking: three independent routes—the CLT analysis, the Bekenstein-Hawking formula, and causal set theory—all point to the same number.

The cosmological constant problem, in this reading, is not a problem. It is a *measurement*—the most precise measurement available of the dimensionality of the parts of reality that cannot be seen.

5 EXPERIMENTAL PREDICTIONS

5.1 Gravitational Wave Echoes

The event horizon is the limit of the mechanical projection. The framework predicts that future gravitational wave observations of binary black hole mergers should detect **post-merger echoes** **?**—repeating signals from wave reflections at the effective boundary of the hidden sector. The

distinguishing signature is that echo amplitude should scale with the ratio of probe frequency to the hidden sector's relaxation frequency: $A_{\text{echo}}/A_{\text{signal}} \sim (f/f_{\text{relax}})^{\beta}$. This frequency-dependent slope distinguishes mean-field breakdown from static surface models, which predict frequency-independent reflectivity.

5.2 Stochastic Gravitational Noise Floor

Since gravity is the mean of a high-variance distribution, it should exhibit statistical fluctuations at high frequencies. The framework predicts a **stochastic gravitational wave background** in the MHz–GHz band ?, with a $1/f^{\alpha}$ spectrum ($\alpha \approx 2$) satisfying the fluctuation-dissipation relation. The strain noise power at frequency f would be $S_h(f) \sim 10^{-78}(1 \text{ GHz}/f)^2 \text{ Hz}^{-1}$, yielding $h_{\text{rms}} \sim 10^{-39} \text{ Hz}^{-1/2}$ at 1 GHz—beyond current detectors but within projected reach of next-generation sensors ?. This amplitude is anchored to the 10^{120} ratio and is falsifiable.

5.3 Null Prediction

The framework predicts a **null result** for searches for supersymmetric partners or inflaton particles invoked to solve the cosmological constant problem. The continued absence of these particles serves as confirming evidence for the Complementarity framework.

6 BROADER IMPLICATIONS

Beyond the formal results, the framework suggests several broader reinterpretations that are noted briefly below without claiming to have proven them.

The framework also suggests reinterpretations of several topics treated at length in the companion explainer ?. These include: **the arrow of time** as the one-directional flow of information from the observable sector into the vastly larger hidden sector; **quantization** as a sampling artifact of the finite-bandwidth projection rather than a fundamental property of reality; **dark matter** as spatial correlations in the mean-field residual rather than an undiscovered particle; and **String Theory** as a successful characterization of the hidden sector whose failure to make observable predictions reflects the Complementarity Theorem's prohibition on simultaneously capturing both projections. These reinterpretations are consistent with the formal framework but go beyond what it rigorously derives; they are presented as directions for future investigation rather than established results.

6.1 Open Problems

The most important open problems include: (1) a fully continuous formulation of the Complementarity Theorem via the multi-parameter quantum Cramér-Rao bound; (2) whether the $N \sim S_{\text{dS}}^2$ relationship can be derived rather than observed; (3) whether special relativity can be derived from the hidden sector's propagation structure; (4) whether gauge symmetry can be derived from the projection structure; and (5) whether the Einstein field equations can be derived as the mean-field equation governing the mechanical projection.

7 CONCLUSION

The argument proceeds in three steps.

First, it is established that embedded observers face irreducible inference limits (Wolpert), that quantum mechanics and general relativity represent two structurally incompatible projections of the same hidden sector (the Complementarity Theorem), and that the 10^{120} cosmological constant discrepancy is the quantitative signature of this incompleteness.

Second, it is shown that the quantum projection is not arbitrary. Via the Barandes stochastic-quantum correspondence, tracing out any dynamical hidden sector with temporal correlations generically produces indivisible stochastic processes equivalent to quantum mechanics. Interference, superposition, entanglement, and the Born rule follow from the projection structure.

Third, the 10^{120} is converted from a problem into a measurement. The central limit theorem yields $N \sim 10^{240}$ hidden-sector degrees of freedom—equal to S_{dS}^2—independently corroborated by Sorkin's causal-set prediction.

If this argument is correct, the incompatibility between quantum mechanics and gravity is not a bug to be fixed. It is the physical analogue of Gödel incompleteness in formal systems—the universe telling observers, in the starkest numerical terms available, that they are inside the system they are trying to describe.

DECLARATION OF AI-ASSISTED TECHNOLOGIES

During the preparation of this work, the author used **Claude Opus 4.6 (Anthropic)** and **Gemini Pro 3 (Google)** in order to assist in drafting specific sections, refining the argumentation structure, and verifying the bibliographic details of cited references. After using these tools/services, the author reviewed and edited the content as needed and takes full responsibility for the content of the publication.

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