# A Bohmian Reformulation of the Gravitational Collapse Model of Hossenfelder

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**Abstract**

A recent proposal [1] introduces a local, parameter-free mechanism in which gravitational effects dynamically suppress macroscopic quantum superpositions by enforcing a product-state constraint between matter and geometry. In this note I present a Bohmian reformulation of this proposal. The reformulation replaces the product-state constraint with a clear ontology consisting of particle positions and gravitational configuration variables guided by a joint wavefunctional.

Collapse arises dynamically from gravitationally induced phase instability, rather than from a teleological action-minimisation principle. The resulting framework is deterministic, nonlocal, and ontologically transparent, while preserving the central physical insight that gravity destabilises superpositions of distinct mass distributions, but without requiring teleological dynamics.

The Born rule is recovered through standard Bohmian equivariance on the joint matter–geometry configuration space, without introducing an additional stochastic collapse law.

## 1 Introduction

A recent proposal [1] aims to explain wavefunction collapse as a consequence of the requirement that matter and geometry remain unentangled. Because the Schrödinger equation generically produces matter–geometry entanglement, the physical evolution must deviate from it. The model introduces a residual functional and selects physical histories by minimising an action constructed from this residual. This leads to a teleological, all-at-once dynamics that violates measurement independence but preserves locality.

Bohmian mechanics, by contrast, provides a clear ontology and a first-order, nonlocal dynamics. The purpose of this note is to construct a Bohmian version of Hossenfelder's model that retains her physical intuition while avoiding the teleological structure and the product-state constraint.

# 2 Ontology and State Space

The Bohmian ontology consists of:

- particle positions $Q(t) = (x_1(t), \ldots, x_N(t))$,
- gravitational configuration variables $G(t)$, taken here as a 3-metric or a reduced set of gravitational degrees of freedom,
- a joint wavefunctional $\Psi[Q, G, t]$.

The wavefunctional evolves according to a Schrödinger-type equation

$$i\hbar\partial_t \Psi[Q, G, t] = \hat{H}\Psi[Q, G, t], \tag{1}$$

with Hamiltonian

$$\hat{H} = \hat{H}_{\mathrm{matter}}[Q, G] + \hat{H}_{\mathrm{grav}}[G] + \hat{H}_{\mathrm{int}}[Q, G]. \tag{2}$$

The precise form of the gravitational Hamiltonian is left unspecified here, as the present discussion focuses on the general structure of the coupled matter-geometry dynamics.

This replaces the product-state constraint with a unified configuration space on which the wavefunctional lives.

# 3 Guidance Equations

Writing $\Psi = Re^{iS/\hbar}$, the Bohmian velocities follow from the phase $S$.

## 3.1 Matter Guidance

$$\dot{x}_k(t) = \frac{1}{m_k}\nabla_{x_k} S(Q, G, t)\Big|_{Q=Q(t),\, G=G(t)}. \tag{3}$$

### 3.2 Geometry Guidance

For the gravitational degrees of freedom:

$$\dot{G}(t) = \frac{\delta S(Q, G, t)}{\delta G}\bigg|_{Q=Q(t),\, G=G(t)}. \tag{4}$$

These equations guarantee equivariance of the $|\Psi|^2$ measure. This property will be used below to recover the Born rule.

# 4 Gravitational Phase Instability and Effective Collapse

Consider a superposition of two macroscopically distinct branches:

$$\Psi = \alpha\Psi_1[Q, G] + \beta\Psi_2[Q, G]. \tag{5}$$

The gravitational interaction induces a phase difference

$$\Delta\phi(t) = \phi_1(t) - \phi_2(t), \tag{6}$$

analogous to Hossenfelder's Penrose-type phase $\tau m|\Phi_{12}|$.

When $|\Delta\phi(t)| \gg 1$, the interference term oscillates rapidly and the guidance field decomposes into disjoint bundles. The actual configuration $(Q(t), G(t))$ becomes dynamically confined to one branch. The other branch becomes an empty wave. This constitutes effective collapse in the Bohmian sense, in which the wavefunctional remains a superposition while the configuration is confined to a single branch.

# 5 Born Rule and Equivariance

The Bohmian reformulation does not require an additional stochastic collapse postulate in order to recover the Born rule. Instead, the Born rule follows from the standard Bohmian equivariance argument applied to the enlarged matter–geometry configuration space.

Let the full configuration be denoted by

$$Y = (Q, G), \tag{7}$$

where $Q$ denotes the particle configuration and $G$ denotes the gravitational configuration. The wavefunctional is then written as

$$\Psi(Y,t) = \Psi[Q,G,t]. \tag{8}$$

The Bohmian guidance equations define a flow on this configuration space. If the initial distribution of actual configurations satisfies quantum equilibrium,

$$\rho(Y,t_0) = |\Psi(Y,t_0)|^2, \tag{9}$$

This assumption corresponds to the standard quantum equilibrium hypothesis in Bohmian mechanics. The status of this assumption has been extensively discussed in the Bohmian literature, for example in terms of typicality or dynamical relaxation. Under this assumption, equivariance implies

$$\rho(Y,t) = |\Psi(Y,t)|^2 \tag{10}$$

for all later times.

Now consider a measurement-like branching state

$$\Psi(Y,t) = \sum_i \alpha_i \Psi_i(Y,t), \tag{11}$$

where the branch wavefunctionals $\Psi_i$ have macroscopically disjoint support in the joint matter–geometry configuration space:

$$\mathrm{supp}(\Psi_i) \cap \mathrm{supp}(\Psi_j) \approx \varnothing \qquad \text{for } i \neq j. \tag{12}$$

The probability that the actual configuration lies in branch $i$ is therefore

$$P_i = \int_{\mathrm{supp}(\Psi_i)} |\Psi(Y,t)|^2 \, dY. \tag{13}$$

Because the branch supports are disjoint, the interference terms vanish upon integration over configuration space, and hence

$$P_i = |\alpha_i|^2 \int_{\mathrm{supp}(\Psi_i)} |\Psi_i(Y,t)|^2 \, dY. \tag{14}$$

For normalised branches this gives

$$P_i = |\alpha_i|^2. \tag{15}$$

Thus the gravitationally induced phase instability explains the dynamical separation of branches, while the Born probabilities follow from equivariance of the $|\Psi|^2$ measure on the enlarged matter–geometry configuration space. This is a key distinction from Hossenfelder's original model [1], where an additional probabilistic hidden-variable distribution is introduced to recover Born's rule. In the Bohmian reformulation, no such additional probability law is required: the Born rule is inherited from quantum equilibrium in Bohmian mechanics, i.e. the assumption that initial configurations are distributed according to $|\Psi|^2$.

# 6 Comparison with Hossenfelder's Model

The Bohmian reformulation:

- removes the product-state constraint,
- eliminates teleology and future-dependent dynamics,
- preserves the gravitational mechanism for suppressing macroscopic superpositions,
- provides a clear ontology and deterministic dynamics.

The key physical intuition of the original model is retained: gravity destabilises superpositions of distinct mass distributions. The Bohmian version achieves this through phase instability rather than action minimisation.

# 7 Testability

Hossenfelder's model is notable for being parameter-free and for making explicit, quantitative predictions about when gravitationally induced collapse should occur. The key prediction is that collapse happens when the accumulated gravitational phase difference between two branches, $\tau m|\Phi_{12}|$, becomes of order unity [1]. This leads to concrete experimental thresholds: collapse is unobservable for elementary particles or quantum computers, but potentially observable for nanogram-scale mechanical oscillators displaced by femtometres, with current experiments lying within one to two orders of magnitude of the required regime [1].

The Bohmian reformulation developed in this note preserves the same physical trigger for collapse—gravitationally induced phase instability— but replaces the teleological action-minimisation mechanism with a dynamical separation of Bohmian trajectories in configuration space. Because the phase difference between branches enters the Bohmian guidance equations in the same way as in the original model, the timescale for effective collapse is governed by the same quantity, $\Delta\phi(t) \sim \tau m|\Phi_{12}|$. Consequently, the Bohmian version predicts that macroscopic superpositions of distinct mass distributions become dynamically unstable at precisely the same mass–displacement thresholds as in the original model.

There are, however, two important differences in testability:

1. **Absence of teleological early collapse.** In Hossenfelder's model, collapse may occur *before* the system reaches the detector, because the action functional depends on both initial and final states. In the Bohmian version, collapse occurs only when the gravitational phase instability actually develops along the realised trajectory. Experiments that could reveal early-onset collapse in the original model would not show such behaviour in the Bohmian reformulation.

2. **Matter–geometry entanglement.** Hossenfelder's model forbids matter–geometry entanglement by construction, whereas the Bohmian version allows it. Experiments designed to detect matter–gravity entanglement—for example, through gravitationally mediated entanglement witnesses—would therefore falsify the original model but remain compatible with the Bohmian reformulation.

Despite these differences, both models agree on the central empirical prediction: superpositions of nanogram-scale masses displaced by femtometres should not remain coherent for longer than approximately one second. The Bohmian reformulation is therefore testable in the same experimental window as the original model, and forthcoming experiments on macroscopic quantum oscillators [1] provide a promising opportunity to distinguish between the two approaches.

# 8 Novelty and Contribution

The Bohmian reformulation developed in this work introduces several conceptual and dynamical elements that are absent from Hossenfelder's model

[1], while preserving its central physical intuition that gravity destabilises macroscopic superpositions. The key novelties are as follows.

## (1) A new ontology for matter–geometry dynamics

Hossenfelder's model assumes that matter and geometry are ultimately the same underlying quantum state, and that only product states between matter and geometry are physically allowed [1]. This leads to a reduced Hilbert space and forbids matter–geometry entanglement. In contrast, the Bohmian reformulation introduces a clear ontology consisting of particle positions $Q(t)$ and gravitational configuration variables $G(t)$, guided by a joint wavefunctional $\Psi[Q, G, t]$. Matter–geometry entanglement is allowed and plays a natural role in the dynamics. This constitutes a fundamentally different ontological framework.

## (2) A dynamical collapse mechanism without teleology

In Hossenfelder's model, collapse arises from minimising a residual functional over product-state paths, leading to an all-at-once, future-dependent (teleological) dynamics [1]. The Bohmian version replaces this with a first-order, local-in-time guidance law. Collapse occurs when the gravitationally induced phase difference between branches causes the Bohmian velocity field to split into disjoint bundles. This mechanism is non-teleological and does not require superdeterministic constraints on future detector settings.

## (3) A reinterpretation of the Penrose phase

Hossenfelder identifies the accumulated quantity $\tau m|\Phi_{12}|$ as the relevant measure of gravitational instability [1]. In the Bohmian reformulation, this same quantity appears as a phase-gradient instability in the guidance field. The Penrose phase is thus reinterpreted as a dynamical driver of trajectory separation rather than as a term in a residual action. This provides a new physical interpretation of the same underlying estimate.

## (4) Distinct empirical predictions

Although both models predict loss of coherence for nanogram-scale masses displaced by femtometres, the Bohmian reformulation differs in two experimentally relevant ways:

- It does not predict early collapse triggered by future detector amplification, a feature that follows from the teleological structure of Hossenfelder's model.
- It allows matter–geometry entanglement, whereas Hossenfelder's model forbids it. Experiments designed to detect gravitationally mediated entanglement would therefore falsify the original model but not the Bohmian reformulation.

These differences imply that the Bohmian version is empirically distinguishable from the original proposal, despite sharing the same scaling for gravitational phase instability.

### (5) A unified and ontologically transparent framework

By embedding gravitationally induced collapse into Bohmian mechanics, the reformulation provides a deterministic, nonlocal, and ontologically explicit alternative to the superdeterministic, product-state-based model of [1]. The resulting framework preserves the parameter-free nature of the collapse criterion while avoiding the conceptual costs associated with teleology and the prohibition of matter–geometry entanglement.

In summary, this work contributes a new theoretical framework that retains the physical motivation of Hossenfelder's model while replacing its core assumptions with a Bohmian ontology and a dynamical, non-teleological collapse mechanism. The resulting theory is both conceptually distinct and experimentally distinguishable.

## 8.1 Relation to the Diósi–Penrose criterion

The collapse condition used in Hossenfelder's model,

$$\tau \, m \, |\Phi_{12}| \sim 1, \tag{16}$$

is closely related to the Diósi–Penrose (DP) criterion for the instability of superpositions of distinct mass distributions. In the DP framework, the relevant quantity is the gravitational self-energy of the difference between the two mass configurations,

$$E_G = -\frac{G}{2} \int d^3r \, d^3r' \, \frac{\big(\rho_1(\mathbf{r}) - \rho_2(\mathbf{r})\big)\big(\rho_1(\mathbf{r}') - \rho_2(\mathbf{r}')\big)}{|\mathbf{r} - \mathbf{r}'|}, \tag{17}$$

and the superposition becomes unstable on a timescale

$$\tau_{\mathrm{DP}} \sim \frac{\hbar}{E_G}. \tag{18}$$

To connect the two formulations, note that the gravitational potential difference $\Phi_{12}$ appearing in Hossenfelder's expression is, up to numerical factors, the potential generated by the mass-density difference $\rho_1 - \rho_2$. Consequently,

$$m\,|\Phi_{12}| \;\propto\; \frac{E_G}{\hbar}, \tag{19}$$

so that her collapse condition

$$\tau\, m\,|\Phi_{12}| \sim 1 \tag{20}$$

is equivalent to the Diósi–Penrose condition

$$\frac{E_G\,\tau}{\hbar} \sim 1. \tag{21}$$

Thus the gravitational phase used in Hossenfelder's model is a reparametrisation of the DP phase $\phi(t) = E_G t/\hbar$, and both approaches identify the same physical trigger for collapse: the accumulation of a gravitationally induced relative phase of order unity between the two branches of the superposition. Unlike stochastic collapse models, the present framework remains fully deterministic.

# 9 Conclusion

The Bohmian reformulation presented here offers a conceptually cleaner and dynamically transparent version of Hossenfelder's collapse model. It preserves the central idea that gravity suppresses macroscopic superpositions while avoiding the teleological structure and the product-state constraint. The Born rule is recovered through equivariance of the $|\Psi|^2$ measure on the joint matter–geometry configuration space, rather than through an additional stochastic collapse law. This suggests that gravitationally induced collapse can be formulated as a fully dynamical, non-teleological process within a Bohmian framework.

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## References


[1] S. Hossenfelder, *How Gravity Can Explain the Collapse of the Wavefunction*, arXiv:2510.11037 (2025).