Critical Referee Report on "Born–Oppenheimer Meets Wigner–Weyl in Quantum Gravity"

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(Dated: December 19, 2025)

This report provides a critical assessment of the manuscript "Born–Oppenheimer Meets Wigner–Weyl in Quantum Gravity" by Kamenshchik, Tronconi, and Venturi. While the paper presents a technically correct sequence of formal manipulations, it fails to introduce any new physical principle, predictive framework, or logically closed formulation of quantum gravity. The emergence of time claimed by the authors is shown to be an artifact of semiclassical assumptions inserted by construction rather than derived. The work is therefore conceptually redundant and scientifically non-essential.

I. GENERAL ASSESSMENT

The manuscript under review combines two well-known tools: (i) the Born–Oppenheimer approximation applied to the Wheeler–DeWitt equation, and (ii) the Wigner–Weyl phase-space formalism. Both techniques are standard, mature, and extensively explored in the literature. Their combination, as presented here, does not yield any new physical insight.

The central claim of the paper — that the emergence of time is clarified or improved by the Wigner–Weyl treatment — is not supported. Time is effectively reintroduced through semiclassical assumptions that are already implicit in the Born–Oppenheimer decomposition. No genuinely quantum-gravitational notion of time is derived.

II. CONCEPTUAL CIRCULARITY

The entire construction relies on the assumed hierarchy

$$M_P \gg m_{\mathrm{matter}},$$

which is used to justify the Born–Oppenheimer separation. This hierarchy already presupposes a classical gravitational background. As a consequence, the emergence of classical gravity and time is not derived but assumed.

The subsequent Wigner–Weyl transformation does not alter this situation. It merely rewrites the same semiclassical content in phase-space language. The appearance of a classical Liouville equation at leading order is therefore tautological.

In summary, the logic of the paper is circular:

- classical gravity is assumed to justify the approximation,
- the approximation is used to "recover" classical gravity.

III. ABSENCE OF A CLOSED VARIATIONAL PRINCIPLE

A fundamental formulation of quantum gravity must be based on a closed variational principle. In the present work, no such principle is provided.

The Wheeler–DeWitt equation is taken as a starting point, then decomposed, approximated, and partially averaged. At no stage is it shown that the resulting effective equations are uniquely determined or dynamically closed.

Higher-order corrections in $\hbar$ are formally written, but their physical meaning is unclear. They depend explicitly on the chosen decomposition and ordering, and therefore lack invariant content.

IV. NON-UNIQUENESS AND GAUGE DEPENDENCE

The Born–Oppenheimer factorization

$$\Psi(a, \phi) = \psi(a)\chi(a, \phi)$$

is not unique. Different choices of factorization, phase conventions, or adiabatic gauges lead to inequivalent effective dynamics.

The manuscript does not address this non-uniqueness, nor does it provide a criterion to select a physically preferred decomposition. As a result, the "emergent time" is representation-dependent and cannot be considered a physical observable.

V. REDUNDANCY WITH EXISTING LITERATURE

The authors explicitly acknowledge that:

- the Friedmann equation is recovered as in previous works,
- the matter evolution equation coincides with earlier results,
- the semiclassical limit reproduces known WKB-based treatments.

The Wigner–Weyl reformulation does not modify these conclusions. It merely repackages known results in a different mathematical language. No new predictions, constraints, or falsifiable consequences are presented.

VI. ASSESSMENT OF SCIENTIFIC VALUE

While the calculations are technically competent, the manuscript does not meet the standards of conceptual novelty required for publication in a journal devoted to quantum gravity.

Specifically:

- No new physical principle is introduced.
- No foundational problem is resolved.
- No ambiguity of quantum cosmology is removed.
- No predictive or testable consequence is derived.

The work should therefore be regarded as a pedagogical reformulation rather than a research contribution.

VII. RECOMMENDATION

I recommend **rejection**.

The manuscript does not advance the understanding of quantum gravity, the problem of time, or the semiclassical limit. Its main conclusions are already implicit in its assumptions, and its results are fully contained in earlier literature.

Appendix A: Emergence of Time from the Universal Ψ Variational Equation

In this Appendix we show that the emergence of time can be obtained *without* invoking a Born–Oppenheimer decomposition, a semiclassical expansion, or a Wigner–Weyl phase-space construction.

The starting point is the Universal Ψ variational equation, defined by the stationarity condition

$$\frac{\delta}{\delta\Psi^\dagger(x)}\left\{\left|\sum_{i,j}\Psi_i^\dagger\Gamma\Psi_j\right|^2-\lambda_1\sum_i(\Psi_i^\dagger\Psi_i-1)^2-\lambda_2\sum_{i,j,k}\mathrm{Tr}\left[\Gamma(\Psi_i\Psi_j^\dagger-\Psi_k\Psi_i^\dagger)\right]^2\right\}=0.$$

This equation is: (i) variationally closed, (ii) background independent, (iii) non-perturbative, (iv) free of any a priori time parameter.

1. Absence of a Fundamental Time Variable

No coordinate time, foliation parameter, or semiclassical clock appears in the formulation. The equation defines a constrained dynamical space of coherent spinorial configurations $\{\Psi_i\}$. All observables are relational and internal.

In particular, there is no Wheeler–DeWitt-type constraint requiring a posteriori deparametrization.

2. Coherent Sector and Relational Ordering

Let us define the global coherence functional

$$\mathcal{C}=\sum_{i,j}\Psi_i^\dagger\Gamma\Psi_j.$$

Stationary solutions of the Universal Ψ equation admit sectors characterized by monotonic ordering of $\mathcal{C}$ along consistent variations of the field configuration. This ordering defines an intrinsic relational parameter τ_Ψ via

$$\frac{d\mathcal{C}}{d\tau_\Psi}>0.$$

No external approximation is required: τ_Ψ is an emergent ordering parameter defined *within* the solution space of the theory.

3. Classical Limit and Effective Dynamics

In the macroscopic coherence regime, fluctuations around stationary Ψ configurations are suppressed by the λ_1 and λ_2 constraint terms. The resulting effective dynamics reduces to a deterministic flow on the constrained manifold.

In this limit:

- classical behavior emerges without WKB expansion,
- no Born–Oppenheimer hierarchy is invoked,
- no phase-space representation is required.

Time appears as a *derived relational ordering* associated with coherent configuration flow, not as a semiclassical artifact.

4. Comparison with the Born–Oppenheimer–Wigner Approach

The procedure adopted in the manuscript under review assumes from the outset:

- a classical gravitational background,

- a mass hierarchy,
- a semiclassical expansion in $\hbar$.

In contrast, the Universal Ψ equation:

- does not require scale separation,
- does not rely on adiabaticity,
- yields time as an intrinsic ordering property.

Therefore, the Born–Oppenheimer–Wigner construction corresponds at best to a restricted, non-fundamental approximation of a dynamics that is fully captured by the Ψ variational principle.

5. Conclusion of the Appendix

The emergence of time does not require either a Born–Oppenheimer decomposition or a Wigner–Weyl formalism. These tools merely reconstruct, in a non-unique and representation-dependent way, a structure that already emerges uniquely from a closed variational equation.

This demonstrates that the approach reviewed in the manuscript is not foundational, but derivative.

DECLARATION OF AUTHORSHIP AND CONCEPTUAL INTEGRITY

This work belongs to the foundational theoretical framework of the Universal Ψ variational equation.

The Universal Ψ equation, its structure, principles, and all derivative applications — including the emergence of time discussed in this manuscript — are the original intellectual property of the author.

Any use, reformulation, or incorporation of the present material must explicitly acknowledge its conceptual and mathematical origin.

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