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In Models of Spontaneous Wave-Function Collapse, Why Only Fermions Collapse, Not Bosons?

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Abstract

Objective collapse models are often implemented so that collapse acts only on the fermionic (matter) sector, while bosonic fields do not undergo fundamental collapse. In generalized trace dynamics (GTD), spontaneous localization is expected to arise when the trace Hamiltonian has a significant anti-self-adjoint component. In this note we show, starting from the STM-atom (spacetime-matter atom) trace Lagrangian written in terms of two inequivalent matrix velocities $\dot{Q}_1$ and $\dot{Q}_2$, that the purely bosonic subsector admits a self-adjoint Hamiltonian, whereas the fermionic sector carries an intrinsic anti-self-adjoint contribution. The key structural input is that making the trace Lagrangian bosonic requires insertion of two *unequal* odd-grade Grassmann elements $\beta_1 \neq \beta_2$. Assuming natural adjoint properties for these elements, we compute the trace Hamiltonian explicitly via trace-derivative canonical momenta (with bosonic and fermionic variations treated separately) and isolate the resulting anti-self-adjoint term. This provides a first-principles mechanism, within GTD, for why only fermionic degrees of freedom act as collapse channels.

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1. Introduction

A recurring conceptual obstacle in quantum gravity is the role of time: standard quantum theory (and, in particular, quantum field theory) is formulated with respect to an external classical time parameter, whereas general relativity treats spacetime geometry as dynamical. Generalized trace dynamics (GTD) [1] addresses this tension by building on Adler's *trace dynamics* (TD) [2], a deterministic matrix-valued Lagrangian/Hamiltonian dynamics in which the action is the trace of a polynomial in noncommuting matrix degrees of freedom (bosonic even-grade matrices and fermionic odd-grade matrices). A key structural feature of TD is its global unitary invariance, which gives rise to a novel conserved quantity—the Adler–Millard charge—with dimensions of action,

$$\tilde{C} = \sum_{r\in B} [q_r, p_r] - \sum_{r\in F} \{q_r, p_r\}\,, \tag{1.1}$$

absent in ordinary classical dynamics. When the statistical mechanics of TD is developed, equipartition of $\tilde{C}$ at equilibrium yields the canonical (anti)commutation relations and an emergent unitary quantum (field) dynamics for the canonical averages. Conversely, when the anti-self-adjoint part of the fundamental trace Hamiltonian is not negligible, fluctuations about equilibrium can drive effective nonunitary nonlinear stochastic dynamics and spontaneous localization [3].

GTD extends this pre-quantum framework toward quantum gravity by promoting gravitational degrees of freedom to matrices and by replacing classical spacetime labels by a noncommutative "pre-spacetime" (quaternionic/octonionic, in the models of interest), thereby aiming for a formulation of quantum dynamics without reference to an external classical time (evolution may be parametrized by Connes time τ) [1]. The fundamental entities are *atoms of spacetime-matter* (STM atoms): matrix degrees of freedom $q_i = q_{Bi} + q_{Fi}$ whose bosonic components are interpreted as "atoms of spacetime," while the full STM atom represents a fermion together with the bosonic fields it sources (for example, an electron together with its electromagnetic, weak, and gravitational fields). Entanglement among many STM atoms, followed by spontaneous localization, is conjectured to yield classical spacetime geometry and classical macroscopic bodies [4]. In this setting, objective collapse is expected precisely in regimes where the fundamental trace Hamiltonian develops a significant anti-self-adjoint component. This motivates the specific structural question addressed below: whether the STM-atom trace Lagrangian underlying GTD generates an intrinsic anti-self-adjoint contribution only in the fermionic sector—thereby explaining why collapse models effectively act on fermions and not on bosonic degrees of freedom.

Spontaneous collapse models (e.g. CSL-type modifications of quantum dynamics) [5–9] are commonly set up so that the collapse-inducing nonunitarity couples to matter degrees of freedom, while bosonic field degrees do not constitute independent collapse channels. From the viewpoint of generalized trace dynamics (GTD), a natural structural origin of collapse is the appearance of an anti-self-adjoint (ASA) component of the trace Hamiltonian: when ASA effects are significant, coarse-graining can yield effective nonunitary stochastic dynamics and spontaneous localization (as in Adler-type trace dynamics arguments [2]).

A central open issue for GTD phenomenology is then:

> *Does the fundamental GTD STM-atom Lagrangian generate ASA contributions only in the fermionic sector, thereby explaining why only fermions collapse?*

In this note we answer this question in the affirmative, for the STM-atom action written in terms of two inequivalent matrix degrees of freedom Q_1 and Q_2. We work directly at the level of the trace Lagrangian and its Legendre transform, using trace derivatives in the sense of Adler, and we keep variations with respect to bosonic and fermionic variables strictly separated.

2. STM-Atom Action and Unified Variables

2.1. Action

We begin with the unified STM-action [1]

$$\frac{S}{\hbar} = \frac{1}{2}\int \frac{d\tau}{\tau_{\mathrm{Pl}}}\, \mathrm{Tr}\Big[\lambda\, \dot{Q}_1^\dagger\, \dot{Q}_2\Big], \qquad \lambda := \frac{L_{\mathrm{Pl}}^2}{L^2}. \tag{2.1}$$

Here τ is Connes time and $\dagger$ denotes the GTD adjoint on matrices with Grassmann entries.

The unified velocities are defined (with bosonic/fermionic splitting) by

$$\dot{Q}_B = \frac{1}{L}(i\alpha\, q_B + L\dot{q}_B), \qquad \dot{Q}_F = \frac{1}{L}(i\alpha\, q_F + L\dot{q}_F), \tag{2.2}$$

$$\dot{Q}_1^\dagger = \dot{Q}_B^\dagger + \lambda\, \beta_1\, \dot{Q}_F^\dagger, \qquad \dot{Q}_2 = \dot{Q}_B + \lambda\, \beta_2\, \dot{Q}_F, \tag{2.3}$$

where β_1, β_2 are *odd-grade* Grassmann elements inserted so that the trace Lagrangian is bosonic. The dynamics requires $\beta_1 \neq \beta_2$ [10]. Also, α is a real number which stands for the Yang-Mills coupling constant.

2.2. Grading, Adjoint, and Graded Cyclicity

We write $\varepsilon(X) \in \{0,1\}$ for the Grassmann parity: $\varepsilon(X) = 0$ for bosonic (even-grade) matrices and $\varepsilon(X) = 1$ for fermionic (odd-grade) matrices. We assume

$$\varepsilon(\dot{Q}_B) = 0, \qquad \varepsilon(\dot{Q}_F) = 1, \qquad \varepsilon(\beta_a) = 1 \quad (a = 1, 2). \tag{2.4}$$

Thus $\beta_a \dot{Q}_F$ and $\beta_a \dot{Q}_F^\dagger$ are even, so $\dot{Q}_1^\dagger$ and $\dot{Q}_2$ are bosonic as required by the form of the trace action.

For matrices with Grassmann entries one uses the standard involution

$$(AB)^\dagger = B^\dagger A^\dagger, \qquad \mathrm{Tr}(A)^\dagger = \mathrm{Tr}(A^\dagger), \tag{2.5}$$

together with graded cyclicity of the trace for homogeneous factors:

$$\mathrm{Tr}(AB) = (-1)^{\varepsilon(A)\varepsilon(B)}\,\mathrm{Tr}(BA). \tag{2.6}$$

(Equivalently, a cyclic shift of a homogeneous factor X through a product Y yields $\mathrm{Tr}(YX) = (-1)^{\varepsilon(X)\varepsilon(Y)}\mathrm{Tr}(XY)$.)

3. Trace-Derivative Canonical Momenta and Hamiltonian

3.1. *Trace Lagrangian*

From (2.1) the trace Lagrangian density (in τ) is

$$\mathcal{L} = \frac{\hbar}{2\tau_{\mathrm{Pl}}}\,\mathrm{Tr}\Big[\lambda\,\dot{Q}_1^\dagger \dot{Q}_2\Big]. \tag{3.1}$$

Crucially, $\mathcal{L}$ depends on the bosonic velocities $\dot{Q}_B, \dot{Q}_B^\dagger$ and fermionic velocities $\dot{Q}_F, \dot{Q}_F^\dagger$ only through (2.3).

3.2. *Trace Derivatives (Bosons and Fermions Varied Separately)*

Following Adler, the trace derivative is defined by placing the variation to the far right:

$$\delta\mathcal{L} = \mathrm{Tr}\bigg(\frac{\delta\mathcal{L}}{\delta O}\,\delta O\bigg), \tag{3.2}$$

where for fermionic O the graded cyclicity (2.6) is used to move δO to the right, generating sign factors only when δO passes odd-grade factors. In the present computation we *do not* vary with respect to mixed variables; we only vary with respect to $\dot{Q}_B, \dot{Q}_B^\dagger$ (bosonic) and $\dot{Q}_F, \dot{Q}_F^\dagger$ (fermionic).

3.3. *Canonical Momenta*

Define the overall prefactor

$$c := \frac{\hbar}{2\tau_{\mathrm{Pl}}}. \tag{3.3}$$

Bosonic momenta.

Varying (3.1) with respect to $\dot{Q}_B$ and $\dot{Q}_B^\dagger$ gives

$$\Pi_B := \frac{\delta\mathcal{L}}{\delta\dot{Q}_B} = c\,\lambda\,\dot{Q}_1^\dagger, \tag{3.4}$$

$$\Pi_B^\dagger := \frac{\delta\mathcal{L}}{\delta\dot{Q}_B^\dagger} = c\,\lambda\,\dot{Q}_2. \tag{3.5}$$

Fermionic momenta.

Using $\dot{Q}_2 = \dot{Q}_B + \lambda\beta_2\dot{Q}_F$,

$$\Pi_F := \frac{\delta\mathcal{L}}{\delta\dot{Q}_F} = c\,\lambda\,\dot{Q}_1^\dagger\cdot(\lambda\beta_2) = c\,\lambda^2\,\dot{Q}_1^\dagger\,\beta_2. \tag{3.6}$$

Similarly, using $\dot{Q}_1^\dagger = \dot{Q}_B^\dagger + \lambda\beta_1\dot{Q}_F^\dagger$ and bringing $\delta\dot{Q}_F^\dagger$ to the right inside the trace using (2.6),

$$\Pi_F^\dagger := \frac{\delta\mathcal{L}}{\delta\dot{Q}_F^\dagger} = c\,\lambda^2\,\dot{Q}_2\,\beta_1. \tag{3.7}$$

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Equations (3.4)–(3.7) are the separated bosonic/fermionic canonical momenta required for a trace-dynamics Legendre transform.

3.4. *Legendre Transform and Explicit Hamiltonian*

We define the trace Hamiltonian by summing over all independent velocities:

$$\mathcal{H} = \mathrm{Tr}\Big(\Pi_B \dot{Q}_B + \Pi_F \dot{Q}_F + \Pi_B^\dagger \dot{Q}_B^\dagger + \Pi_F^\dagger \dot{Q}_F^\dagger\Big) - \mathcal{L}. \tag{3.8}$$

Substituting (3.4)–(3.7) and using (2.3), one finds

$$\mathrm{Tr}(\Pi_B \dot{Q}_B + \Pi_F \dot{Q}_F) = c\,\mathrm{Tr}\Big(\lambda\, \dot{Q}_1^\dagger (\dot{Q}_B + \lambda \beta_2 \dot{Q}_F)\Big) = c\,\mathrm{Tr}\Big(\lambda\, \dot{Q}_1^\dagger \dot{Q}_2\Big) = \mathcal{L}, \tag{3.9}$$

$$\mathrm{Tr}(\Pi_B^\dagger \dot{Q}_B^\dagger + \Pi_F^\dagger \dot{Q}_F^\dagger) = c\,\mathrm{Tr}\Big(\lambda\, (\dot{Q}_B^\dagger + \lambda \beta_1 \dot{Q}_F^\dagger) \dot{Q}_2\Big) = c\,\mathrm{Tr}\Big(\lambda\, \dot{Q}_1^\dagger \dot{Q}_2\Big) = \mathcal{L}, \tag{3.10}$$

where in the second line we used that $\dot{Q}_2$ is bosonic and applied graded cyclicity. Therefore

$$\boxed{\mathcal{H} = \mathcal{L} = \frac{\hbar}{2\tau_{\mathrm{Pl}}}\,\mathrm{Tr}\Big[\lambda\, \dot{Q}_1^\dagger \dot{Q}_2\Big].} \tag{3.11}$$

This is the trace-dynamics analog of the Bateman-type cross-kinetic structure: the Hamiltonian equals the Lagrangian, but need not be self-adjoint because $\dot{Q}_1$ and $\dot{Q}_2$ are inequivalent.

4. Bosonic vs Fermionic Contributions and the Anti-Self-Adjoint Part

4.1. *Decomposition of the Hamiltonian*

Expanding (3.11) using (2.3) gives

$$\mathcal{H} = \mathcal{H}_{BB} + \mathcal{H}_{BF} + \mathcal{H}_{FF}, \tag{4.1}$$

where

$$\mathcal{H}_{BB} = c\,\mathrm{Tr}\Big(\lambda\, \dot{Q}_B^\dagger \dot{Q}_B\Big), \tag{4.2}$$

$$\mathcal{H}_{BF} = c\,\mathrm{Tr}\Big(\lambda^2\, \dot{Q}_B^\dagger \beta_2 \dot{Q}_F + \lambda^2\, \beta_1 \dot{Q}_F^\dagger \dot{Q}_B\Big), \tag{4.3}$$

$$\mathcal{H}_{FF} = c\,\mathrm{Tr}\Big(\lambda^3\, \beta_1 \dot{Q}_F^\dagger \beta_2 \dot{Q}_F\Big). \tag{4.4}$$

4.2. *Adjoint Assumptions for β_1, β_2*

We now impose the following adjoint properties:

$$\boxed{\beta_1^\dagger = -\beta_1, \qquad \beta_2^\dagger = -\beta_2, \qquad \beta_1 \neq \beta_2, \qquad \varepsilon(\beta_1) = \varepsilon(\beta_2) = 1.} \tag{4.5}$$

We also assume the natural graded (anti)commutation with dynamical variables: β_a commutes with bosonic variables and anticommutes with fermionic variables.

4.3. *Self-Adjointness of the Purely Bosonic Sector*

From (4.2) and (2.5),

$$\mathcal{H}_{BB}^\dagger = c\,\mathrm{Tr}\Big(\lambda\, (\dot{Q}_B^\dagger \dot{Q}_B)^\dagger\Big) = c\,\mathrm{Tr}\Big(\lambda\, \dot{Q}_B^\dagger \dot{Q}_B\Big) = \mathcal{H}_{BB}. \tag{4.6}$$

Hence the bosonic subsector has a self-adjoint Hamiltonian and does not by itself supply an ASA contribution.

4.4. *An Intrinsic ASA Fermionic Contribution*

Consider the fermionic term (4.4). Using (2.5) and (4.5),

$$\begin{aligned}\mathcal{H}_{FF}^{\dagger} &= c\,\mathrm{Tr}\Big((\lambda^3\beta_1\dot{Q}_F^{\dagger}\beta_2\dot{Q}_F)^{\dagger}\Big) = c\,\mathrm{Tr}\Big(\lambda^3\,\dot{Q}_F^{\dagger}\beta_2^{\dagger}\dot{Q}_F\beta_1^{\dagger}\Big)\\ &= c\,\mathrm{Tr}\Big(\lambda^3\,\dot{Q}_F^{\dagger}(-\beta_2)\dot{Q}_F(-\beta_1)\Big) = c\,\mathrm{Tr}\Big(\lambda^3\,\dot{Q}_F^{\dagger}\beta_2\dot{Q}_F\beta_1\Big).\end{aligned} \tag{4.7}$$

Now apply graded cyclicity (2.6) to cyclically shift the final odd factor β_1 to the front. Since β_1 is odd and the product $\dot{Q}_F^{\dagger}\beta_2\dot{Q}_F$ is also odd (three odd factors), we obtain a minus sign:

$$\mathrm{Tr}(\dot{Q}_F^{\dagger}\beta_2\dot{Q}_F\beta_1) = -\,\mathrm{Tr}(\beta_1\dot{Q}_F^{\dagger}\beta_2\dot{Q}_F). \tag{4.8}$$

Combining (4.7) and (4.8) yields

$$\boxed{\mathcal{H}_{FF}^{\dagger} = -\,\mathcal{H}_{FF}.} \tag{4.9}$$

Thus $\mathcal{H}_{FF}$ is *purely anti-self-adjoint*. In particular, it provides an explicit ASA contribution to the Hamiltonian, and this contribution vanishes identically when the fermionic sector is absent.

Role of $\beta_1 \neq \beta_2$.

If one attempted to set $\beta_1 = \beta_2 = \beta$, the fermionic contribution collapses: because β is odd, $\beta\dot{Q}_F^{\dagger}\beta = -\beta\beta\dot{Q}_F^{\dagger} = 0$, so $\mathcal{H}_{FF}$ would vanish. Hence the requirement $\beta_1 \neq \beta_2$ is not only dynamically necessary [10]; it is also structurally responsible for a nontrivial ASA fermionic term.

4.5. *ASA Part of the Full Hamiltonian*

Define the self-adjoint and anti-self-adjoint parts of the trace Hamiltonian by

$$\mathcal{H}_{\mathrm{sa}} := \frac{1}{2}(\mathcal{H}+\mathcal{H}^{\dagger}), \qquad \mathcal{H}_{\mathrm{asa}} := \frac{1}{2}(\mathcal{H}-\mathcal{H}^{\dagger}). \tag{4.10}$$

From (4.1), (4.6), and (4.9),

$$\boxed{\mathcal{H}_{\mathrm{asa}} = \frac{1}{2}(\mathcal{H}_{BF}-\mathcal{H}_{BF}^{\dagger})+\mathcal{H}_{FF}.} \tag{4.11}$$

Independently of the detailed adjoint properties of the mixed term $\mathcal{H}_{BF}$, the key point is that *every* contribution to $\mathcal{H}_{\mathrm{asa}}$ contains fermionic variables: if $\dot{Q}_F = \dot{Q}_F^{\dagger} = 0$, then $\mathcal{H}_{\mathrm{asa}} = 0$ identically.

Remark (adjoint convention for $\beta_{1,2}$).

The anti-self-adjoint character of the purely fermionic contribution $\mathcal{H}_{FF} = c\,\mathrm{Tr}(\lambda^3\,\beta_1\,\dot{Q}_F^{\dagger}\,\beta_2\,\dot{Q}_F)$ does not rely on taking $\beta_a^{\dagger} = -\beta_a$ individually. More generally, assume

$$\beta_a^{\dagger} = \eta_a\,\beta_a, \qquad \eta_a \in \{+1,-1\}, \qquad a = 1,2,$$

with $\varepsilon(\beta_a) = 1$ and the standard GTD involution $(AB)^{\dagger} = B^{\dagger}A^{\dagger}$. Then

$$\begin{aligned}\mathcal{H}_{FF}^{\dagger} &= c\,\lambda^3\,\mathrm{Tr}\Big((\beta_1\dot{Q}_F^{\dagger}\beta_2\dot{Q}_F)^{\dagger}\Big) = c\,\lambda^3\,\eta_1\eta_2\,\mathrm{Tr}\Big(\dot{Q}_F^{\dagger}\beta_2\dot{Q}_F\beta_1\Big)\\ &= -\,c\,\lambda^3\,\eta_1\eta_2\,\mathrm{Tr}\Big(\beta_1\dot{Q}_F^{\dagger}\beta_2\dot{Q}_F\Big) = -(\eta_1\eta_2)\,\mathcal{H}_{FF},\end{aligned}$$

where the minus sign arises from graded cyclicity when moving the odd factor β_1 past the odd product $\dot{Q}_F^{\dagger}\beta_2\dot{Q}_F$. Hence $\mathcal{H}_{FF}$ is purely anti-self-adjoint whenever $\eta_1\eta_2 = +1$ (i.e. both β_1, β_2 are self-adjoint, or both are anti-self-adjoint). In particular, the choice $\beta_1^{\dagger} = \beta_1$ and $\beta_2^{\dagger} = \beta_2$ yields the same ASA fermionic term (and thus the same collapse channel) as the choice $\beta_a^{\dagger} = -\beta_a$.

5. Interpretation for Spontaneous Localization

In trace dynamics, coarse-graining around statistical equilibrium yields two distinct regimes: (i) if the Hamiltonian is effectively self-adjoint, one recovers emergent unitary quantum dynamics; (ii) if the anti-self-adjoint component is significant, coarse-graining yields effective nonunitary (stochastic) dynamics with spontaneous localization [3].

The computation above provides a structural mechanism for "fermion-only collapse" in GTD:

- The purely bosonic Hamiltonian $\mathcal{H}_{BB}$ is self-adjoint and thus does not generate ASA-driven collapse by itself.
- The fermionic sector carries an intrinsic anti-self-adjoint term $\mathcal{H}_{FF}$, present precisely because β_1 and β_2 are unequal odd Grassmann elements inserted to make the unified trace Lagrangian bosonic.

Therefore, in regimes where ASA effects drive localization, the fundamental collapse channel is naturally associated with fermionic degrees of freedom. Bosonic fields can still become classical *indirectly*, because in the STM-atom picture an STM atom consists of a fermion together with its associated bosonic fields, so localization of the fermionic degrees forces classicality of the associated bosonic sector through correlations/entanglement, without requiring independent bosonic collapse.

6. Conclusions

Starting from the unified STM-atom GTD trace Lagrangian, we computed the trace Hamiltonian via trace-derivative canonical momenta, with bosonic and fermionic variations treated separately. We found:

1. The trace Hamiltonian equals the trace Lagrangian (Bateman-type cross-kinetic structure), but it need not be self-adjoint because Q_1 and Q_2 are inequivalent.
2. The purely bosonic contribution $\mathcal{H}_{BB}$ is self-adjoint.
3. Assuming natural adjoint properties for the odd Grassmann elements β_1, β_2, the fermionic contribution $\mathcal{H}_{FF}$ is purely anti-self-adjoint, providing an explicit ASA component of the Hamiltonian that vanishes in the bosonic subsector.

This provides a first-principles explanation, within GTD, for why spontaneous localization acts fundamentally on fermionic degrees of freedom and not on bosonic degrees of freedom.

Outlook.

The next steps are to connect the magnitude of $\mathcal{H}_{FF}$ (and fluctuations about equilibrium) to collapse phenomenology (rates, noise kernels, and effective CSL parameters), and to embed the analysis into the multi-STM-atom setting where entanglement and interactions become operative.

Declaration of Use of AI Tools in this Work: During the preparation of this work the author used Open AI's ChatGPT 5.2 Pro in order to assist in carrying out calculations and assist in manuscript writing. After using this tool/service, the author reviewed and edited the content as needed and takes full responsibility for the content of the published article.

References

1. Tejinder P. Singh. Trace dynamics, octonions and unification: An $e_8 \times e_8$ theory of unification. *Journal of Physics: Conference Series*, 2912(1):012009, 2024 arXiv:2501.18139 [physics.gen-ph]. Contribution to ISQS-28.
2. S. L. Adler. *Quantum theory as an emergent phenomenon: The statistical mechanics of matrix models as the precursor of quantum field theory*. Cambridge University Press, 2004.
3. Kartik Kakade, Avnish Singh, and Tejinder P. Singh. Spontaneous localisation from a coarse-grained deterministic and non-unitary dynamics. *Physics Letters A*, 490:129191, 2023 arXiv:2305.06706 [quant-ph].
4. Tejinder P. Singh. Space-time from Collapse of the Wave-function. *Z. Naturforsch. A*, 74(2):147–152, 2019 arXiv:1809.03441 [gr-qc].
5. G. C. Ghirardi, A. Rimini, and T. Weber. Unified dynamics for microscopic and macroscopic systems. *Phys. Rev. D*, 34:470–491, Jul 1986.

6. Gian Carlo Ghirardi, Philip Pearle, and Alberto Rimini. Markov processes in hilbert space and continuous spontaneous localization of systems of identical particles. *Phys. Rev. A*, 42:78–89, Jul 1990.
7. L. Diósi. Models for universal reduction of macroscopic quantum fluctuations. *Phys. Rev. A*, 40:1165–1174, Aug 1989.
8. Angelo Bassi and GianCarlo Ghirardi. Dynamical reduction models. *Phys. Rept.*, 379:257, 2003.
9. Matteo Carlesso, Sandro Donadi, Luca Ferialdi, Mauro Paternostro, Hendrik Ulbricht, and Angelo Bassi. Present status and future challenges of non-interferometric tests of collapse models. *Nature Physics*, 18(3):243–250, 2022.
10. Palemkota Maithresh and Tejinder P. Singh. Proposal for a New Quantum Theory of Gravity III: Equations for Quantum Gravity, and the Origin of Spontaneous Localisation. *Z. Naturforsch. A*, 75(2):143–154, 2020 arXiv:1908.04309 [gr-qc].