GLOBAL JOURNAL
OF SCIENCE FRONTIER RESEARCH - A: PHYSICS & SPACE SCIENCE
Volume 26 | Issue 1 | 2026 | Article ID: GJSFR-257434 | Language: English

CATALOGING
PACS • 04.60.-m, 95.36.+x, 04.60.Bc | ARXIV • gr-qc | MSC • 83C45

Quantum Superposition Effect of Gravitational Field, Negative Pressure and Dark Energy

Article Record

Dr. Gang Lee[§*]
*Corresponding Author

§ Independent Researcher china, China

RECEIVED	REVISED	ACCEPTED	PEER REVIEW
2026-05-15	2026-05-18	2026-05-25	Double Blind

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Noncommutative quantum gravity | Dark energy | Quantum superposition | Negative pressure | Gravitational field | Feynman path integral | Energy-momentum field

AI USE STATEMENT
No generative AI was used for analysis or results.

FUNDING
No external funding was declared for this work.

CONFLICT OF INTEREST
The authors declare no conflict of interest.

DATA AVAILABILITY
Not applicable for this article.

ETHICS
No ethics committee approval was required for this article type.

CONSENT
Not applicable for this article.

TRIAL REG.
Not applicable.

Crossref DOI: 10.34257/GJSFRA257434

How to Cite: Lee (2026). Quantum Superposition Effect of Gravitational Field, Negative Pressure and Dark Energy. Global Journal of Science Frontier Research, 26(1), 1-15. DOI: 10.34257/GJSFRA257434

AR Experience Web Page DOI

Print ISSN 0975-5896
9 770975 589008

Online ISSN 2249-4626
9 772249 462017

Under the strict compliance and defined process of

METADATA CONTINUATION

AUTHOR CONTACT QR LEDGER

Dr. Gang Lee§*

ARCHIVAL RECORD

GJSFR · Vol 26 · Issue 1 · 2026

Article ID GJSFR-257434 · DOI 10.34257/GJSFRA257434

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Global Journal of Science Frontier Research - Section A
GJSFR Volume 26 Issue 1

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Dr. Gang Lee§*

Affiliations
§ Independent Researcher china, China

Abstract

This paper explains how dark energy is generated through a simplified model based on noncommutative quantum gravity.

Keywords: *Noncommutative quantum gravity, Dark energy, Quantum superposition, Negative pressure, Gravitational field, Feynman path integral, Energy-momentum field*

* **Corresponding Author**
Dr. Gang Lee

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1. Introduction

In the paper [1],[2],[3],[4],[5],[6] and [7], we introduce the noncommutative quantum gravity and its applications. In this paper, from a simplified model based on the theory of noncommutative quantum gravity, we have found a mechanism that can cause negative pressure in a system and generate dark energy.

2. Quantum Superposition effect of Gravitational Field, Negative Pressure and Dark Energy

In the paper [1] and [2] we introduce a wave packet approximate to the Dirac δ-function which can be explained as a semiclassical graviton. It can be written as follows

$$\xi^i(x,r) = \begin{cases} \xi^r &= r + C^r(x)\exp(-\frac{r}{l_P}) \\ \xi^\theta &= \theta(x) \\ \xi^\phi &= \phi(x) \\ \xi^t &= t + C^t(x)\exp(-\frac{|t|}{t_P}) \end{cases} \tag{2.1}$$

The dynamic variables of ξ^i are $C^i(x) = \left(C^r(x), \theta(x), \phi(x), C^t(x)\right)$. Quantization only quantizes the dynamic variable $\dot{C}^i(x)$. Therefore, in this paper, for the sake of brevity, we directly consider $C^i(x)$ as the fundamental state function of gravitational field.

From the paper [1] we have the Lagrangian density of graviton is

$$\mathcal{L} = -\frac{\eta^{\mu\nu}}{2}\frac{\partial \xi^i(x,r)}{\partial x^\mu}\frac{\partial \xi^j(x,r)}{\partial x^\nu}\eta_{ij} \tag{2.2}$$

For simplicity, assume that the initial state has two gravitational fields $C^i_{(1)}$ and $C^i_{(2)}$, and $C^i_{(2)} = k \cdot C^i_{(1)}, k > 0, k \in \mathbb{R}$. Let the gravitational source of $C^i_{(1)}$ and $C^i_{(2)}$ be $j^i_{(1)}$ and $j^i_{(2)}$, respectively. If the gravity between $j^i_{(1)}$ and $j^i_{(2)}$ neglect as negligible, the joint propagator $K_{(1+2)}$ of $C^i_{(1)} + C^i_{(2)}$ in the Feynman path integral form can be written as follows

$$\begin{aligned} K_{(1+2)} &= \int \mathcal{D}[C^i_{(1)} + C^i_{(2)}] e^{i\left(S[C^i_{(1)}] + S[C^i_{(2)}]\right)/\hbar} \\ &= \int \mathcal{D}[C^i_{(1)} + C^i_{(2)}]\left(e^{iS[C^i_{(1)}]/\hbar} \cdot e^{iS[C^i_{(2)}]/\hbar}\right) \end{aligned} \tag{2.3}$$

If $C^i_{(2)} = k \cdot C^i_{(1)}$, for the Lagrangian density (2.2), we have

$$S[C_{(2)}] = k^2 \cdot S[C_{(1)}] \tag{2.4}$$

Then

$$\begin{aligned} K_{(1+2)} &= \int \mathcal{D}[C^i_{(1)} + C^i_{(2)}]\left(e^{iS[C^i_{(1)}]/\hbar} \cdot e^{iS[C^i_{(2)}]/\hbar}\right) \\ &= \int \mathcal{D}[C^i_{(1)} + C^i_{(2)}]\left(e^{i(1+k^2)S[C^i_{(1)}]/\hbar}\right) \end{aligned} \tag{2.5}$$

The final state $\tilde{C}^i_{(1+2)}$ of $C^i_{(1)} + C^i_{(2)}$ is

$$\tilde{C}^i_{(1+2)} = \int d^4x K_{(1+2)} \cdot \left(C^i_{(1)} + C^i_{(2)}\right) \tag{2.6}$$

Consider the case where there is gravity between sources $j^i_{(1)}$ and $j^i_{(2)}$ of the initial state $C^i_{(1)} + C^i_{(2)}$. In this case, the Feynman path integral should be written as follows

$$K_{(1\oplus 2)} = \int \mathcal{D}[C^i_{(1)} + C^i_{(2)}]\left(e^{iS[C^i_{(1)} + C^i_{(2)}]/\hbar}\right) \tag{2.7}$$

where $\oplus$ denotes the quantum superposition of states.

For the Lagrangian density (2.2), if $C^i_{(2)} = k \cdot C^i_{(1)}$,we have

$$S[C^i_{(1)} + C^i_{(2)}] = (1+k)^2 \cdot S[C^i_{(1)}] \tag{2.8}$$

Then Eq. (2.7) can be written as follows

$$K_{(1\oplus 2)} = \int \mathcal{D}\left[C^i_{(1)} + C^i_{(2)}\right]\left(e^{iS[C^i_{(1)}+C^i_{(2)}]/\hbar}\right)$$
$$= \int \mathcal{D}\left[C^i_{(1)} + C^i_{(2)}\right]\left(e^{i(1+k)^2 S[C^i_{(1)}]/\hbar}\right) \tag{2.9}$$

The propagator $K_{(1\oplus 2)}$ is not equal to $K_{(1+2)}$. Then the final states will be different

$$\tilde{C}^i_{(1\oplus 2)} \neq \tilde{C}^i_{(1+2)} \tag{2.10}$$

Therefore the sources of the final states will be different

$$j^i_{(1\oplus 2)} \neq j^i_{(1+2)} \tag{2.11}$$

Now let's analyze the meaning of Eq. (2.11). Recall Eq. (2.9), it can be written as

$$K_{(1\oplus 2)} = \int \mathcal{D}\left[C^i_{(1)} + C^i_{(2)}\right]\left(e^{iS[C^i_{(1)}+C^i_{(2)}]/\hbar}\right)$$
$$= \int \mathcal{D}\left[C^i_{(1)} + C^i_{(2)}\right]\left(e^{i(1+k)^2 S[C^i_{(1)}]/\hbar}\right)$$
$$= \int \mathcal{D}\left[C^i_{(1)} + C^i_{(2)}\right]\left(e^{iS[C^i_{(1)}]/\hbar}\right)^{(1+k^2+2k)} \tag{2.12}$$
$$= \int \mathcal{D}\left[C^i_{(1)} + C^i_{(2)}\right]\left(e^{iS[C^i_{(1)}]/\hbar} \cdot e^{iS[C^i_{(2)}]/\hbar} \cdot e^{iS[C^i_{(3)}]/\hbar}\right)$$

where $C^i_{(3)} = \sqrt{2k} \cdot C^i_{(1)}$. The source of $C^i_{(3)}$ can be written as $j^i_{(3)}$. The measure of the Feynman path integral can be written as

$$\int \mathcal{D}\left[C^i_{(1)} + C^i_{(2)}\right] = \frac{1+k}{1+k+\sqrt{2k}} \int \mathcal{D}\left[C^i_{(1)} + C^i_{(2)} + C^i_{(3)}\right] \tag{2.13}$$

Factor $\frac{1+k}{1+k+\sqrt{2k}}$, as an overall constant factor, is independent of field configurations and external sources, so it can be reduced and eliminated via functional integration when calculating all physical observables, such as correlation functions, scattering cross sections. This factor has no observable physical effects. While it may perturb vacuum fluctuations, among other effects, we do not consider it in this paper. By comparing Eq. (2.5) and Eq. (2.12), we can see that $K_{(1+2)} \neq K_{(1\oplus 2)}$, therefore Eq. (2.12) isn't an algebraic rewriting of the same two-field system, a new physical degree of freedom is introduced in Eq. (2.12). Eq. (2.12) implies that there is an additional energy-momentum field $j^i_{(3)}$ in the final state, which is similar to the sources $j^i_{(1)}$ and $j^i_{(2)}$. And Eq. (2.12) also implies that the gravity between $j^i_{(1)}$, $j^i_{(2)}$ and $j^i_{(3)}$ can be neglected as negligible, indicating that the spacetime in the final state has expanded sufficiently.

The addition of energy-momentum field $j^i_{(3)}$ indicates an increase in total energy of the system, and the space is expanding, it means that the quantum superposition of the gravitational field does negative work during the expansion process, therefore the corresponding pressure p is a negative value. Written the energy density of the system as ρ. According to the Friedman acceleration equation and the Raychaudhuri equation, if $p < -\frac{\rho}{3}$, the negative pressure will cause gravitational repulsion. The negative pressure are rarely occurs, it is precisely the characteristic of dark energy, therefore the energy-momentum fields such as $j^i_{(3)}$ can be regarded as dark energy. So that dark energy is continuously generated by the quantum superposition effect of the gravitational fields, until the space expands to a sufficiently large final state where the gravity between the gravitational sources neglect as negligible.

According to the model proposed in this paper, dark energy originates from the conversion induced by the quantum superposition effect of the gravitational field. Therefore, it can be reasonably conjectured that dark energy only participates in gravitational interaction.

3. Conclusion

This paper calculate the quantum effects of gravitational fields by the Feynman path integration. The calculation results indicate that the quantum superposition of the gravitational fields will be converted into the additional energymomentum fields. The quantum superposition of gravitational fields produces negative work, increasing the energy of the system and resulting in a negative pressure in the system. When the negative pressure reaches a certain strength, it will cause gravitational repulsion, so the energy-momentum fields converted through quantum superposition can be understood as dark energy.

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