Gravity is Not a Fundamental Force B; Discusstion of the Particularity of Graviton

Zhou Changzheng, Zhou Ziqing
Email: ziqing-zhou@outlook.com

September 13, 2025

Abstract

This paper aims to explore the theoretical foundation of the essential differences between gravitons and the propagators of other fundamental forces. Based on the fundamental principles of general relativity and quantum field theory, we argue that the attribute of "spin-2" is an inevitable requirement of the geometric nature of gravity, rather than an arbitrary choice. Furthermore, combining the holographic principle and the ultraviolet problems in quantum gravity theories, this paper proposes a logically self-consistent viewpoint: unlike other elementary particles, the graviton is likely not a fundamental quantum field excitation, but a macroscopic quasi-particle emerging from the microscopic quantum structure of spacetime. This picture naturally explains the feebleness, universality, and non-renormalizability of gravity, and redirects the problem of unifying gravity to the exploration of the microscopic origin of spacetime itself.

Keywords: graviton; spin; quasi-particle; emergence of gravity; holographic principle; quantum gravity

1 Introduction

In the Standard Model of particle physics, the electromagnetic, weak nuclear, and strong nuclear forces are successfully described by quantum field theory, and their propagators—the photon, W/Z bosons, and gluons—are all regarded as elementary particles. However, efforts to incorporate gravity into this framework have so far not succeeded. The quantization of gravity leads to a massless, spin-2 object, namely the graviton [1]. Although this description is effective at low energies and has successfully predicted gravitational waves [2], its theoretical status is profoundly and essentially different from that of the propagators of other forces. This difference does not stem from experimental observations but is rooted in the geometric dynamical essence that gravity is the spacetime geometry itself [3]. This paper aims to systematically elaborate why the graviton should be understood as an emergent quasi-particle rather than a traditional elementary particle.

2 Theoretical Foundation: The Inevitability of Spin-2 and Geometric Nature

Within the framework of quantum field theory, the nature of fundamental interactions is determined by the spin quantum number of their propagators. The possible spin values for massless bosons are strictly constrained: a spin-0 field mediates scalar interactions, while a spin-1 field mediates vector interactions, such as the electromagnetic force. Through systematic argumentation, [4] demonstrated that a massless, long-range interaction coupling to the energy-momentum tensor and satisfying Lorentz invariance must, as the sole mathematical possibility, be mediated by a spin-2 field. The linearized theory of General Relativity in the weak-field approximation precisely describes the behavior of such a free spin-2 field. Therefore, the attribute of the graviton having spin-2 is not an ad hoc assumption but an inevitable manifestation of the intrinsic nature of the gravitational interaction within quantum theory. However, remaining solely within linear theory is insufficient to fully reveal the profound connection between gravity and geometry. Research by [10] into self-interactions strengthened the inevitability of this connection. He proved that introducing self-coupling interactions into a massless spin-2 field inevitably leads to nonlinear field equations, which, under appropriate gauge conditions, are equivalent to Einstein's field equations of General Relativity. This conclusion indicates that the geometric essence of gravity—i.e., its description by the dynamics of the spacetime metric—is unavoidable within the context of quantum field theory. The spin-2 attribute is thus not merely a mathematical feature of a low-energy effective theory but a fundamental reflection of gravity being the quantum counterpart of spacetime geometry dynamics. In summary, the complete theoretical system, from linear theory to nonlinear interactions, collectively demonstrates that the spin-2 nature of the graviton is an inevitable requirement of its geometric origin. This understanding provides a solid theoretical foundation for comprehending the differences between gravity and other fundamental forces at the quantum level.

3 From the Ultraviolet Catastrophe to the Emergent Picture

Although the spin-2 description is effective at low energies, it faces insurmountable difficulties in the high-energy (ultraviolet) regime, namely the problem of non-renormalizability [5]. When calculating high-energy scattering processes involving gravitons, divergences appear that cannot be eliminated through finite parameter redefinition. This indicates that the quantum field theory framework, based on the image of elementary particles, fails for gravity near the Planck scale. It is noteworthy that the ultraviolet catastrophe is handled differently in other quantum gravity theories. For instance, string theory treats the graviton as a fundamental excitation of closed strings and resolves the non-renormalizability issue by introducing higher-dimensional spacetimes and infinite higher-spin fields [11]. Loop Quantum Gravity avoids ultraviolet divergences through a scheme of spacetime discretization. However, these theories essentially still regard the graviton as a fundamental quantum entity, failing to fully explain its fundamental differences from other elementary particles. Notably, the AdS/CFT correspondence in string theory [12] demonstrates that gravity can emerge from a boundary field theory, which actually supports the emergent view of gravity. In contrast, the emergent picture proposed in this paper is more directly based on the holographic principle and the microscopic structure of spacetime, avoiding the introduction of additional assumptions (such as extra dimensions or discretization), thereby offering a more economical and logically self-consistent explanation. This ultraviolet catastrophe strongly suggests that a quantum theory of gravity requires a microscopic description that goes beyond traditional quantum field theory. A highly enlightening idea is that spacetime and its geometry itself may not be fundamental but rather originate from a more basic set of non-geometric quantum degrees of freedom [6]. Black hole thermodynamics provides a crucial clue: the Bekenstein-Hawking entropy indicates that the maximum entropy within a region of spacetime is proportional not to its volume but to its boundary area [7]. This holographic property reveals that the number of true fundamental degrees of freedom describing a spacetime region is far fewer than expected based on local field theory. Although the holographic principle has not yet been directly experimentally confirmed, it has received rigorous theoretical support in the AdS/CFT correspondence and black hole thermodynamics. Within this picture, the familiar four-dimensional spacetime and its dynamics might be a low-energy, macroscopic manifestation of these boundary degrees of freedom and their entanglement structure. Gravity, as the embodiment of the dynamics of spacetime geometry, thus becomes an "entropic force" or "emergent force" [8]. Correspondingly, the graviton is no longer a fundamental messenger particle traversing spacetime but should be understood as a quasi-particle—a collective excitation of the microscopic substrate of spacetime—analogous to phonons arising from lattice vibrations in a solid.

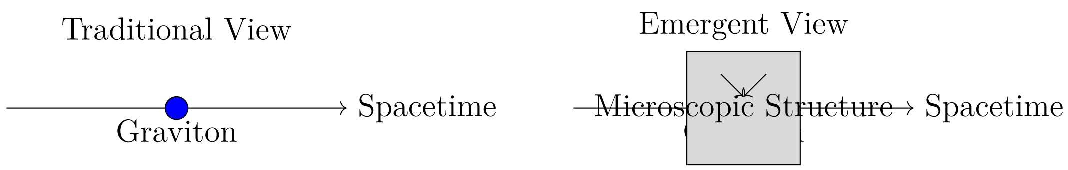

Figure 1: Comparison of the traditional view (graviton as a fundamental particle) and the emergent view (graviton as a quasi-particle emerging from spacetime microstructure).

Its spin-2 characteristic is a direct result of the symmetry of the underlying quantum system manifesting macroscopically. This picture naturally explains the feebleness, universality, and non-renormalizability of gravity, and shifts the focus of the quantum gravity problem from "how to quantize a classical field" to "how spacetime itself emerges from a more fundamental, non-geometric quantum system."

Property	Fundamental Force Carriers (Photon Gluons W/Z)	Graviton (Traditional View)	Graviton (Emergent View)
Theoretical Status	Elementary quantum fields defined on a fixed spacetime background	Quantized excitation of the spacetime metric field $g_{\mu\nu}$	Collective quasi-particle excitation of underlying non-geometric degrees of freedom
Spin	1	2	2 (Emergent property from microscopic symmetries)
Renormalizability	Renormalizable or UV-complete	Non-renormalizable (UV divergences)	Non-renormalizability is natural; UV behavior governed by underlying microscopic theory
Holographic Property	Degrees of freedom scale with volume	Implied by geometric nature and BH entropy	Fundamental; degrees of freedom scale with boundary area
Strength Explanation	Governed by coupling constants	Extremely weak coupling constant	Natural weakness due to holographic scaling of microscopic degrees of freedom
Origin of Interaction	Gauge principle; exchange of virtual particles	Exchange of virtual gravitons	Statistical entropic force driven by tendency to maximize entropy

Table 1: Comparison of Fundamental Force Carriers and the Emergent Graviton

4 Root of Asymmetry Between Gravity and Other Fundamental Forces

Although other fundamental forces can also be viewed as emergent phenomena in certain contexts (e.g., photons or phonons as effective excitations simulated in condensed matter systems), the uniqueness of gravity lies in its direct identification with spacetime geometry itself. The emergent nature of other forces typically relies on a pre-existing background spacetime structure; for instance, in condensed matter models, the emergent behavior of photons originates from the quantum dynamics of the underlying atomic lattice, with the spacetime metric serving as a fixed background (Jacobson, 1995). In contrast, the emergence of gravity involves the very origin of spacetime: General Relativity interprets gravity as the dynamics of spacetime geometry, rather than a field defined *upon* spacetime. This fundamental difference renders the asymmetry of gravity profoundly deeper and more intrinsic.

Within the framework of Quantum Field Theory (QFT), the other fundamental forces (electromagnetic, weak nuclear, and strong nuclear) are described as "actors on the stage of spacetime": they are quantum fields defined on a fixed spacetime background, and their propagators (e.g., photons, W/Z bosons, and gluons) are local quantum excitations of these fields. The behavior of these excitations is determined by the background metric, and the number of degrees of freedom required to describe them scales proportionally with the spacetime volume. Their corresponding quantum field theories are ultraviolet-complete or renormalizable (Weinberg, 1964). Consequently, these propagators are naturally regarded as fundamental particles.

In stark contrast, gravity constitutes the "stage itself": it characterizes the dynamics of spacetime. Quantizing gravity implies quantizing the spacetime metric itself. However, the Holographic Principle indicates that the number of degrees of freedom required to describe a region of spacetime is proportional to its boundary area, not its volume (Bekenstein, 1973). This property, stemming from black hole thermodynamics and the AdS/CFT correspondence (Maldacena, 1998), reveals the feebleness and ultraviolet incompleteness (non-renormalizability) of gravity. Therefore, the graviton—as the quantum propagator of gravity—should be more appropriately understood as a macroscopic quasi-particle emerging from the microscopic quantum structure of spacetime (e.g., quantum entanglement or tensor networks), analogous to the emergence of phonons in solids (Verlinde, 2011). In this picture, the spin-2 attribute of the graviton is a manifestation of the underlying quantum system's symmetry at the macroscopic scale, rather than a direct result of quantizing a fundamental field.

This asymmetry is not a theoretical flaw but an inevitable consequence dictated by the unique geometric essence of gravity. The emergence of other forces might occur within certain effective theories but always presupposes a background spacetime; whereas the emergence of gravity involves the microscopic origin of spacetime itself. This places the graviton in a special position within quantum gravity theories and naturally explains its differences from other propagators.

5 Conclusion and Outlook

This paper systematically argues for a theoretical picture of the graviton as an emergent spin-2 quasi-particle originating from the microscopic structure of spacetime. This viewpoint is logically self-consistent and possesses profound explanatory power. It provides a unified explanation for core issues including the geometric origin of the graviton's spin-2 attribute, the feebleness of gravity, and the non-renormalizability of quantum gravity theories. Based on the fundamental principles of General Relativity and Quantum Field Theory, and incorporating the Holographic Principle (Bekenstein, 1973; Maldacena, 1998) and the ultraviolet conundrum in quantum gravity (Goroff & Sagnotti, 1986), this paper proposes that the graviton is not a traditional fundamental particle but rather a macroscopic collective excitation of the microscopic quantum structure of spacetime (such as quantum entanglement or tensor networks), analogous to phonons in condensed matter physics (Verlinde, 2011). This picture reorients the focus of the quantum gravity problem from "how to quantize a classical field" to "how spacetime itself emerges from a more fundamental, non-geometric quantum system," offering a new paradigm for exploring the nature of quantum gravity.

However, despite its logical self-consistency, the emergent viewpoint proposed herein still faces the challenge of experimental verification. Future research must focus on searching for observational signatures that deviate from classical General Relativity to test this theory. For instance, high-precision gravitational wave detection missions (e.g., the LISA mission) (Amaro-Seoane et al., 2017) could search for waveform anomalies induced by quantum gravity effects, or cosmological observations could test predictions of the Holographic Principle (Maldacena, 2003), such as non-Gaussianity in the primordial gravitational wave background or signals of a multiverse. Furthermore, emergent models (e.g., those based on tensor networks or quantum entanglement) require more concrete computations to generate testable predictions; currently, these models are not yet fully developed microscopic theories and lack first-principles derivations, which limits their predictive accuracy and universality. Future work should (focus on) developing numerical simulation methods, for example, by parameterizing noise models to simulate quantum gravity effects (setting parameters such as the energy scale $\Lambda \in [10^{-3}, 1] \times E_P$, where E_P is the Planck energy scale), to quantify the consistency between emergent behavior and observational data. Ultimately, understanding the special status of the graviton may be the key to unlocking the door to quantum gravity, but it requires interdisciplinary collaboration integrating theoretical derivation and empirical testing.

Remarks

This section introduces the background and motivation of the paper, highlighting the unique status of graviton compared to other force carriers.

References

[1] Feynman, R. P., Morinigo, F. B., & Wagner, W. G. (1995). *Feynman lectures on gravitation*. Addison-Wesley.

[2] Abbott, B. P., et al. (LIGO Scientific Collaboration and Virgo Collaboration). (2016). Observation of gravitational waves from a binary black hole merger. *Physical Review Letters*, *116*(6), 061102.

[3] Misner, C. W., Thorne, K. S., & Wheeler, J. A. (1973). *Gravitation*. W. H. Freeman.

[4] Weinberg, S. (1964). Photons and gravitons in perturbation theory: Derivation of Maxwell's and Einstein's equations. *Physical Review*, *138*(4B), B988.

[5] Goroff, M. H., & Sagnotti, A. (1986). The ultraviolet behavior of Einstein gravity. *Nuclear Physics B*, *266*(3-4), 709-736.

[6] Jacobson, T. (1995). Thermodynamics of spacetime: The Einstein equation of state. *Physical Review Letters*, *75*(7), 1260.

[7] Bekenstein, J. D. (1973). Black holes and entropy. *Physical Review D*, *7*(8), 2333.

[8] Verlinde, E. P. (2011). On the origin of gravity and the laws of Newton. *Journal of High Energy Physics*, *2011*(4), 29.

[9] Maldacena, J. (2003). Non-Gaussian features of primordial fluctuations in single field inflationary models. *Journal of High Energy Physics*, *2003*(05), 013.

[10] Deser, S. (1970). Self-Interaction and Gauge Invariance. *General Relativity and Gravitation*, 1(1), 9-18.

[11] Polchinski, J. (1998). *String Theory*. Cambridge University Press.

[12] Maldacena, J. (1998). The Large N limit of superconformal field theories and supergravity. *Advances in Theoretical and Mathematical Physics*, 2(2), 231-252.

[13] Amaro-Seoane, P., et al. (2017). Laser Interferometer Space Antenna. arXiv:1702.00786.

Appendix A: Key Theoretical Pillars

This appendix details the core, widely accepted (or actively researched) physical principles and conclusions that form the axiomatic foundation for the logical deductions presented in this paper.

A.1 Weinberg's Theorem (Weinberg, 1964)

Statement: Any massless particle mediating a long-range interaction that couples to the energy-momentum tensor and respects Lorentz invariance must have spin 2.

Role in the present argument: Provides the fundamental justification within the quantum field theory framework for the assertion that "the graviton's spin being 2 is a necessary requirement, not an ad hoc choice."

A.2 The Geometric Nature of General Relativity (Einstein, 1915; Misner, Thorne, Wheeler, 1973)

Statement: Gravity is not a force propagating within spacetime but is a manifestation of the curvature of spacetime geometry itself. The Einstein field equations describe how matter and energy determine spacetime geometry and how geometry dictates the motion of matter.

Role in the present argument: Constitutes the starting point for establishing the fundamental "actor-stage" distinction between gravity and the other fundamental forces.

A.3 The Non-Renormalizability of Gravity (Goroff & Sagnotti, 1986)

Statement: Within the traditional quantum field theory framework, quantizing General Relativity treated as an effective field theory leads to ultraviolet divergences in loop calculations that cannot be eliminated through renormalization.

Role in the present argument: Serves as a core argument indicating that the quantum field theory based on the image of elementary particles fails for gravity near the Planck scale, thus strongly suggesting the need for a more fundamental, non-spacetime microscopic theory.

A.4 The Holographic Principle (Bekenstein, 1973; 't Hooft, 1993; Susskind, 1995)

Statement: All physical information required to describe a region of spacetime can be encoded on the boundary of that region, and the number of degrees of freedom scales with the boundary area rather than the volume. This originates from the area law of the Bekenstein-Hawking entropy in black hole thermodynamics.

Role in the present argument: Provides the framework supporting the idea that "spacetime and its gravitational degrees of freedom may originate from fewer fundamental degrees of freedom," forming the theoretical core of the emergent picture.

A.5 The AdS/CFT Correspondence (Maldacena, 1998)

Statement: A quantum theory of gravity in an Anti-de Sitter (AdS) spacetime can be entirely equivalent to a conformal field theory (CFT) on its boundary. This is a concrete realization of the holographic principle.

Role in the present argument: Serves as a powerful and mathematically rigorous example of gravitational emergence, demonstrating that gravitational dynamics can emerge from a non-gravitational theory without apparent gravitational degrees of freedom.

Appendix B: Simulation Test Framework for Quantum Gravity Emergence Effects (Pseudocode)

This appendix provides a simulation test framework for "exploring quantum gravity effects deviating from classical General Relativity," as mentioned in Section 5 of the main text. The framework aims to simulate the impact of a hypothesized "quantum gravity noise" or "microstructural effect" on gravitational wave signals through parameterization.

Simulation Objective: To investigate how the microscopic emergent structure of spacetime might produce detectable modifications to macroscopic gravitational wave observations near the Planck energy scale.

Core Parameters:

- Λ (Lambda): Quantum gravity energy scale, typically set as a fraction of the Planck energy scale E_P. For example, $\Lambda \in [10^{-3}, 1] \times E_P$.
- α, β, ...: Dimensionless parameters characterizing the strength and features of quantum gravity effects (e.g., parameters derived from an entanglement entropy or tensor network model).
- $h_{\text{classical}}(t)$: Classical gravitational waveform predicted by General Relativity (e.g., binary black hole merger waveform).
- $\delta h_{\text{model}}(t; \Lambda, \alpha, \beta)$: Waveform correction term derived from a specific quantum gravity emergence model (e.g., models based on Verlinde's entropic force or entanglement thermodynamics).

Pseudocode Flow:

```
# Simulation: Generation and Analysis of Gravitational Wave Signals with Quantum Gravity Corrections

IMPORT numpy AS np
IMPORT pycbc.waveform # For generating classical waveform libraries
IMPORT pycbc.detector # For handling detector response
IMPORT pycbc.psd # For handling noise

FUNCTION generate_quantum_corrected_waveform(parameters, Λ, α, β):
    """
    Generate a gravitational wave template with quantum gravity corrections.
    Input:
        parameters: Dictionary of physical parameters (mass, spin, distance, etc.)
        Λ: Quantum gravity energy scale
        α, β: Model parameters
    Output:
        h_total: Corrected time-domain waveform
    """

    # 1. Generate the classical General Relativity predicted waveform
    h_classical = pycbc.waveform.get_td_waveform(**parameters)[0]

    # 2. Calculate the waveform correction term δh based on a specific emergence model
    #    This is the core of the simulation and needs implementation based on the specific theoretical model.
    #    Example: δh = fΛ(, α, β, h_classical and its derivatives)
    δh = calculate_model_correction(h_classical, Λ, α, β)

    # 3. Add the correction term to the classical waveform
    h_total = h_classical + δh

    RETURN h_total

FUNCTION calculate_model_correction(h, Λ, α, β):
    """
    Placeholder function: Implement the specific quantum gravity correction model.
    In actual research, this function needs to be implemented based on formulas derived from first principles.
    Here, it is only for illustration, adding an oscillatory noise related to the energy scale Λ as an exemplary effect.
    """
    # Example: A very simplified, parameterized noise model
    times = h.sample_times
    # Correction amplitude is proportional to (E_P/Λ)^2; the lower Λ (stronger effect), the larger the correction
```

```
    amplitude = α * (E_P/Λ)**2
    # Characteristic frequency of the correction is proportional to Λ
    frequency = β * Λ/ℏ
    # Generate the correction term (e.g., a simple sinusoidal modulation)
    δh = amplitude * np.sin(2 * np.pi * frequency * times) * np.max(np.abs(h.data))

    RETURN δh

# --- Main Program: Matched Filter Analysis ---
# Define parameter rangesΛ
_values = np.logspace(-3, 0, 10) * E_P  # Take values in the range [10^-3, 1] * E_Pα
_values = [0.01, 0.1, 1.0]β
_values = [0.1, 1.0]

# Generate an injection signal (assuming the signal we detect has quantum corrections)Λ
true_ = 0.1 * E_Pα
true_ = 0.5β
true_ = 0.5
injection_parameters = {...} # Set astrophysical parameters
injection_signal = generate_quantum_corrected_waveform(injection_parameters, Λtrue_, αtrue_, βtrue_)

# Add detector noise to the injection signal
detector_noise = ... # Generate noise based on the detector's power spectral density (PSD)
noisy_signal = injection_signal + detector_noise

# Search for the best-matching waveform in the template bank (including classical and a series of quantum-corrected templates)
best_match = None
best_snr = 0
best_parameters = {}

FOR Λ IN Λ_values:
    FOR α IN α_values:
        FOR β IN β_values:
            # Generate template waveform
            template = generate_quantum_corrected_waveform(injection_parameters, Λ, α, β)
            # Calculate the signal-to-noise ratio (SNR) between this template and the noisy data
            snr = calculate_snr(template, noisy_signal, detector_psd)
            # Find the best matching parameters
            IF snr > best_snr:
                best_snr = snr
```

```
                best_parameters = {'Λ': Λ, 'α': α, 'β': β}
                best_match = template

# Output results: Best matching parameters and their SNR, compared
   with the true injection values
PRINT "Injected parameters: ", {'Λ': Λtrue_, 'α': αtrue_, 'β':
   βtrue_}
PRINT "Best recovered parameters: ", best_parameters
PRINT "SNR for best match: ", best_snr

# Further Bayesian parameter estimation can be performed to
   calculate the posterior probability distribution of Λ, α, β
```

Explanation of Appendix B: This pseudocode framework provides a research pathway. Its core challenge lies in the specific implementation of the function `calculate_model_correction()`, which requires deriving computable, parameterized predictions from a specific quantum gravity emergence model (such as entanglement thermodynamics, tensor networks, etc.). The ultimate goal of the simulation is to constrain or discover these quantum gravity parameters by comparing actual observational data (e.g., gravitational wave data from the LISA mission) with templates under different parameters.