Unification of the Casimir Effect and Cosmic Microwave Background: A Fundamental Vacuum Theory

1 Introduction

This work develops a novel theoretical description that interprets the microscopic Casimir effect and the macroscopic cosmic microwave background (CMB) as different manifestations of an underlying vacuum structure. By introducing a characteristic vacuum length scale L_ξ and a fundamental dimensionless coupling constant ξ, it is shown that both phenomena can be described by a unified theoretical framework.

The theory is based on the hypothesis of a granular spacetime with a minimal length scale $L_0 = \xi \cdot L_P$, at which all physical forces are fully effective. For distances $d > L_0$, only parts of these forces become visible through vacuum fluctuations, which is described by the $1/d^4$ dependence of the Casimir force. Due to the extremely small size of L_0, direct experimental measurement is currently not possible, which is why the measurable scale L_ξ serves as a bridge between the fundamental spacetime structure and experimental observations. Gravity is interpreted as an emergent property of a time field, whereby cosmic effects such as the CMB can be explained without the assumption of dark energy or dark matter.

2 Theoretical Foundations

2.1 Fundamental Length Scales

The proposed framework defines a hierarchy of characteristic length scales:

$$L_0 = \xi \cdot L_P \tag{1}$$

$$L_P = \sqrt{\frac{\hbar G}{c^3}} \approx 1.616 \times 10^{-35}\,\mathrm{m} \tag{2}$$

$$L_\xi = \text{characteristic vacuum length scale} \approx 100\,\mu\mathrm{m} \tag{3}$$

Here, L_0 represents the minimal length scale of a granular spacetime at which all vacuum fluctuations are fully effective, while L_ξ represents the emergent scale for measurable vacuum interactions.

2.2 The Coupling Constant ξ

The dimensionless coupling constant ξ is determined to be

$$\xi = \frac{4}{3} \times 10^{-4} = 1.333 \times 10^{-4} \tag{4}$$

This constant functions as a fundamental space parameter that links the granulation of spacetime at L_0 with measurable effects such as the Casimir effect and the CMB. It can be derived from a Lagrangian describing the dynamics of a time field.

3 The CMB-Vacuum Relationship

3.1 Basic Equation

The central relationship of the theory links the energy density of the cosmic microwave background with the characteristic vacuum length scale:

$$\rho_{\text{CMB}} = \frac{\xi \hbar c}{L_\xi^4} \tag{5}$$

This formula is dimensionally consistent, since

$$[\rho_{\text{CMB}}] = \frac{[1] \cdot [\hbar c]}{[L_\xi^4]} = \frac{\text{J m}}{\text{m}^4} = \text{J/m}^3 \tag{6}$$

3.2 Numerical Determination of L_ξ

With the experimentally determined CMB energy density $\rho_{\text{CMB}} = 4.17 \times 10^{-14}\,\text{J/m}^3$, L_ξ can be calculated:

$$L_\xi^4 = \frac{\xi \hbar c}{\rho_{\text{CMB}}} \tag{7}$$

$$L_\xi^4 = \frac{1.333 \times 10^{-4} \times 3.162 \times 10^{-26}\,\text{J m}}{4.17 \times 10^{-14}\,\text{J/m}^3} \tag{8}$$

$$L_\xi^4 = 1.011 \times 10^{-16}\,\text{m}^4 \tag{9}$$

$$L_\xi = 100\,\mu\text{m} \tag{10}$$

4 Modified Casimir Theory

4.1 Extended Casimir Formula

The Casimir effect is described by the following modified formula:

$$|\rho_{\text{Casimir}}(d)| = \frac{\pi^2}{240\xi} \rho_{\text{CMB}} \left(\frac{L_\xi}{d} \right)^4 \tag{11}$$

where d denotes the distance between the Casimir plates.

4.2 Consistency with the Standard Casimir Formula

By substituting the CMB-vacuum relationship (**??**) into the modified Casimir formula (**??**):

$$|\rho_{\text{Casimir}}(d)| = \frac{\pi^2}{240\xi} \cdot \frac{\xi\hbar c}{L_\xi^4} \cdot \frac{L_\xi^4}{d^4} \tag{12}$$

$$= \frac{\pi^2\hbar c}{240 d^4} \tag{13}$$

This exactly corresponds to the established standard Casimir formula and proves the mathematical consistency of the proposed theory.

5 Numerical Verification

5.1 Comparison Calculations

To verify the theoretical consistency, Casimir energy densities are calculated for various plate distances:

Distance d	$(L_\xi/d)^4$	ρ_{Casimir} (J/m^3)	ρ_{Casimir} (J/m^3)
1 µm	1.000×10^{8}	1.30×10^{-3}	1.30×10^{-3}
100 nm	1.000×10^{12}	1.30×10^{1}	1.30×10^{1}
10 nm	1.000×10^{16}	1.30×10^{5}	1.30×10^{5}

Table 1: Comparison of Casimir energy densities between standard formula and new theoretical description

The perfect agreement confirms the mathematical correctness of the developed theory.

6 Physical Interpretation

6.1 Multi-scale Vacuum Model

The developed theory implies a fundamental structure of the vacuum at different length scales:

1. **Sub-Planck level** (L_0): Minimal length scale of granular spacetime at which all physical forces, including vacuum fluctuations, are fully effective.
2. **Planck threshold** (L_P): Transition region between quantum gravity and classical spacetime geometry.
3. **Casimir manifestation** (L_ξ): Emergent length scale for measurable vacuum interactions that forms a bridge to the CMB.
4. **Cosmic scale**: Large-scale vacuum signature through the CMB, explained by a time field from which gravity emerges.

6.2 Emergent Gravity

Gravity is interpreted as an emergent property of a time field ϕ, whose fluctuations at the scale L_0 create the spacetime structure. The coupling constant ξ determines the strength of these interactions, whereby cosmic effects such as the CMB can be explained without the assumption of dark energy or dark matter.

7 Summary

This work develops a novel theoretical description that interprets the Casimir effect and the cosmic microwave background as different manifestations of an underlying vacuum structure. By introducing a sub-Planck length scale $L_0 = \xi \cdot L_P \approx 2.155 \times 10^{-39}\,\text{m}$ and a characteristic vacuum length scale $L_\xi \approx 100\,\mu\text{m}$, both phenomena are described in a unified mathematical framework.

The theory is mathematically consistent, reproduces all established Casimir formulas exactly, and makes specific experimental predictions. The coupling constant ξ is a fundamental space parameter that can be derived from a Lagrangian with a time field. Gravity is interpreted as an emergent property of this time field, whereby cosmic effects can be explained without dark energy or dark matter.

References

[1] Dhital and Mohideen, *Physics*, 2024, DOI: 10.1103/PhysRevLett.132.123601.

[2] Xu et al., *Nature Nanotechnology*, 2022, DOI: 10.1038/s41565-021-01058-6.