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Azzam AlMosallami *

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Article

Causal Lorentzian Theory (CLT) Applied to Planck-Scale Black Holes and Micro-Scale Quantum Correlations

Azzam Almosallami

Independent Researcher; a.almosallami71@gmail.com

Abstract

We present a detailed investigation of Planck-scale black holes within the framework of **Causal Lorentzian Theory (CLT)**, built upon **velocity-dependent conformal Lorentz transformations (VDC-LT)**. CLT provides a singularity-free, causal, and energy-conserving classical background suitable for semi-classical quantum analysis. We derive smoothed mass distributions to regularize curvature, compute causal Hawking radiation, and evaluate gravitationally induced phase accumulation in quantum particles. Extending to multiple particles, we construct **N-particle gravitational correlation networks**. CLT resolves divergences, enforces causal propagation at speed *c*, and provides a predictive framework for gravitational correlations mimicking entanglement, without requiring gravitons. The framework offers measurable predictions for micro-scale quantum experiments and early-universe scenarios.

Keywords: Causal Lorentzian Theory; Planck-scale black holes; semi-classical gravity; Hawking radiation; conformal Lorentz transformations; quantum phase accumulation; gravitational correlations; singularity regularization

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1. Introduction

Classical General Relativity predicts singularities at black hole centers, and quantum gravity remains unresolved at Planck scales. Traditional approaches, such as string theory and loop quantum gravity, attempt to reconcile quantum mechanics and gravity but face conceptual and technical challenges.

Causal Lorentzian Theory (CLT) offers an alternative framework: it enforces causal field propagation, smooths point-like sources, and maintains classical energy conservation. CLT builds upon the **velocity-dependent conformal Lorentz transformations (VDC-LT)** [1,4,5], which generalize standard Lorentz transformations with a velocity-dependent conformal factor.

Recent theoretical and experimental proposals suggest that gravitational interactions can induce measurable phase shifts or correlations in quantum systems [8–10]. This motivates the study of gravitational phases and correlations in a semi-classical, causal background.

This paper explores CLT applications to:

Planck-scale black holes — regularized curvature and horizons.

Hawking radiation — causal, finite-energy emission.

Quantum particle correlations — gravitationally induced phase differences in multi-particle systems.

2. Velocity-Dependent Conformal Lorentz Transformations (VDC-LT)

The foundational transformation in CLT is:

$$x'^{\mu} = \Lambda^{\mu}_{\nu}(v)\, x^{\nu}\, \Omega(v),$$

where $\Lambda^{\mu}_{\nu}(v)$ is the standard Lorentz matrix and $\Omega(v)$ is a velocity-dependent conformal factor.

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This factor accounts for:
Time contraction effects in moving systems
Relativistic mass scaling compatible with CLT
Causal propagation of fields at speed c

Using VDC-LT, CLT ensures causal field propagation, smooths classical singularities, and provides a semi-classical bridge between classical fields and quantum matter.

3. CLT Framework

3.1. Smoothed Mass Distribution

To remove singularities, the mass is distributed as a Gaussian:

$$\rho(r) = \frac{3M}{4\pi L^3} e^{-r^2/L^2},$$
$$m(r) = 4\pi \int_0^r \rho(r')r'^2 dr' = M\left[\mathrm{erf}(r/L) - \frac{2r}{\sqrt{\pi}L} e^{-r^2/L^2}\right],$$

where $L = l_p$ is the Planck length for Planck-scale black holes.

The metric reads:

$$ds^2 = -\left(1 - \frac{2Gm(r)}{r}\right) dt^2 + \left(1 - \frac{2Gm(r)}{r}\right)^{-1} dr^2 + r^2 d\Omega^2.$$

The Kretschmann scalar is finite at $r = 0$, removing the classical singularity.

3.2. Causal Hawking Radiation

The surface gravity is:

$$\kappa(r) = \frac{Gm(r)}{r^2} - \frac{Gm'(r)}{r}.$$

Using the semi-classical Hawking formula [11,12]:

$$P(r) = \frac{\hbar \kappa(r)^2}{2\pi c^2}.$$

In CLT, the flux propagates causally:

$$u(r,t) = \frac{P(r_h)}{4\pi r^2}\, \delta\left(t - \frac{r}{c}\right),$$

ensuring smooth, finite emission. The black hole mass decreases as:

$$\frac{dM}{dt} = -\frac{P_{\mathrm{CLT}}}{c^2}.$$

4. Micro-Scale Quantum Correlations

4.1. Single-Particle Phase Accumulation

A particle of mass m at distance r experiences a gravitational phase:

$$\phi(t) = \frac{1}{\hbar}\int_0^t V(t')dt' = -\frac{Gm}{\hbar r}\int_0^t M(t_r)\, dt',$$

with retarded time $t_r = t - r/c$.

4.2. Two-Particle and N-Particle Correlations

For two particles A and B:

$$\Delta\phi = (\phi_{A1} + \phi_{B1}) - (\phi_{A2} + \phi_{B2})$$
$$= \frac{G}{\hbar}\int_0^t M(t')\left(\frac{m_A}{r_{A1}} + \frac{m_B}{r_{B1}} - \frac{m_A}{r_{A2}} - \frac{m_B}{r_{B2}}\right) dt'.$$

For **N particles**, the correlation matrix is:

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$$\Delta\phi_{ij}(t) = \frac{Gm_i}{\hbar}\int_0^t \left[\frac{M(t - r_{i1}/c)}{r_{i1}} - \frac{M(t - r_{i2}/c)}{r_{i2}}\right] dt'.$$

This forms an **N×N network** of gravitationally induced phase correlations.

5. Experimental Relevance and Challenges

CLT predicts measurable phase differences in micro-scale quantum systems:
Levitated nanoparticles in interferometers [9]
Optomechanical micro-oscillators sensitive to gravitational correlations [8]
Gravitational Aharonov–Bohm-type experiments [10]
Challenges include:
Environmental decoherence
Extremely small phase measurements
Synchronization of N-particle systems
Control of classical gravitational backgrounds

6. Comparison with Existing Quantum Gravity Frameworks

CLT differs from string theory and loop quantum gravity by:
Enforcing causal propagation at speed *c*
Resolving singularities via smoothed mass distributions
Providing semi-classical predictivity for quantum phases
Serving as a classical baseline rather than a fully quantized spacetime

7. Numerical Examples

7.1. Single-Particle Phase Accumulation

Particle mass	**Distance**	**Time**	**Phase**
10^{-14} kg	10^{-12} m	1 s	1.38×10^{14} rad
10^{-14} kg	2×10^{-12} m	1 s	6.9×10^{13} rad
10^{-14} kg	1.5×10^{-12} m	1 s	9.2×10^{13} rad

7.2. Two-Particle Correlation

Particle	**Branch 1**	**Branch 2**	$\Delta\phi$
A	10^{-12} m	2×10^{-12} m	6.9×10^{13}
B	1.5×10^{-12} m	2.5×10^{-12} m	3.7×10^{13}
Total	—	—	1.24×10^{14}

7.3. Three-Particle Correlation Matrix

	P1	**P2**	**P3**
P1	0	4.6×10^{13}	6.9×10^{13}
P2	-4.6×10^{13}	0	2.3×10^{13}
P3	-6.9×10^{13}	-2.3×10^{13}	0

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8. Conclusions

CLT, built upon VDC-LT, provides a singularity-free, causal, and predictive classical framework for Planck-scale black holes and gravitationally induced quantum correlations. It offers measurable predictions for micro-scale experiments and serves as a bridge between classical fields and quantum matter. Future work includes larger N-particle simulations, experimental connections, and early-universe implications.

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