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Article

Causal Lorentzian Theory (CLT) Applied to Planck-Scale Compact Objects and Micro-Scale Quantum Correlations

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Abstract

We investigate Planck-scale compact objects and gravitationally induced quantum correlations within the framework of **Causal Lorentzian Theory (CLT)**, a flat-spacetime, Lorentz-invariant field theory of gravitation with explicit causal propagation and localized gravitational field energy. In CLT, gravitational phenomena arise from conformal time dilation rather than spacetime curvature, eliminating event horizons and curvature singularities. Point-like sources are regularized through smooth mass distributions, yielding finite gravitational fields at all scales. We analyze Planck-scale compact objects, derive a finite horizon-free gravitational energy emission mechanism, and compute gravitationally induced quantum phase shifts arising from conformal time dilation. Extending the analysis to multi-particle systems, we construct causal gravitational phase-correlation networks that mimic entanglement-like signatures without quantizing gravity or introducing gravitons. The framework provides concrete, testable predictions for micro-scale interferometry and optomechanical experiments, offering a consistent semi-classical bridge between gravitation and quantum mechanics.

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

General Relativity (GR) successfully describes gravitation in weak-field and astrophysical regimes, yet it generically predicts curvature singularities and event horizons in strong-field scenarios. At Planck scales, the classical theory loses predictive power, while a fully consistent quantum theory of gravity remains elusive.

Most approaches attempt to quantize spacetime itself, leading to conceptual difficulties such as nonlocality, loss of causality, and ambiguities in energy localization. An alternative strategy is to preserve flat spacetime while modifying the physical description of gravitation.

Causal Lorentzian Theory (CLT) adopts this approach. Gravity is described as a physical field propagating causally at speed c, carrying local, positive-definite energy. Gravitational effects arise from **conformal time dilation**, not spatial curvature. This permits a consistent treatment of strong fields, removes singularities, and allows controlled semi-classical coupling to quantum matter.

Recent experimental advances motivate the study of gravitationally induced quantum phases and correlations in micro-scale systems. CLT provides a natural framework for such investigations.

This paper applies CLT to:

1. Planck-scale compact objects,
2. finite horizon-free gravitational energy emission,

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3. gravitationally induced quantum phase correlations in multi-particle systems.

2. Velocity-Dependent Conformal Lorentz Transformations

The kinematical foundation of CLT is the **velocity-dependent conformal Lorentz transformation**

$$x'^{\mu} = \Omega(v^2)\Lambda^{\mu}_{v}(v)x^{v}$$

where $\Lambda^{\mu}_{v}(v)$ is the standard Lorentz transformation and Ω is a conformal factor determined by gravitational field energy.

Unlike GR, spacetime remains Minkowskian. The conformal factor modifies physical clocks and rulers, producing gravitational time dilation while preserving Lorentz invariance and causality.

3. CLT Framework for Planck-Scale Compact Objects

3.1. Smoothed Mass Distribution

To eliminate point singularities, matter sources are modeled by smooth distributions. We adopt a Gaussian profile

$$\rho(r) = \frac{3M}{4\pi L^3} e^{-r^2/L^2},$$

with enclosed mass

$$m(r) = M\left[\operatorname{erf}\left(\frac{r}{L}\right) - \frac{2r}{\sqrt{\pi}L} e^{-r^2/L^2}\right].$$

For Planck-scale objects, $L = \ell_p$.

This regularization ensures finite gravitational fields and finite field energy everywhere.

3.2. Conformal Gravitational Field (No Curved Space)

In CLT, gravity enters through a conformal scaling of flat spacetime:

$$ds^2 = \Omega^2(r)(c^2dt^2 - dr^2 - r^2 d\Omega^2),$$

We define the inverse conformal factor as

$$\Omega^{-1}(r) = 1 - \frac{GM}{c^2 r}.$$

This choice ensures agreement with the standard weak-field gravitational time dilation at first order.

Squaring immediately gives

$$\Omega^{-2}(r) = \left(1 - \frac{GM}{c^2 r}\right)^2 = 1 - \frac{2GM}{c^2 r} + \frac{G^2M^2}{c^4 r^2}.$$

Thus, the metric reproduces the correct Newtonian limit while providing a well-defined second-order correction in strong gravitational fields, without invoking spacetime curvature or horizons.

There is:

- no spatial curvature,
- no event horizon,
- no curvature singularity.

Time dilation remains finite for all r.

4. Horizon-Free Gravitational Energy Emission

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CLT does not admit Hawking radiation in the thermodynamic sense, as event horizons do not exist. Instead, compact objects emit a **finite, causal gravitational energy flux** arising from time-dependent gravitational field energy.

The effective potential is

$$\Phi_{\text{eff}}(r) = -\frac{Gm(r)}{r}.$$

A representative expression for the emitted power is

$$P_{\text{CLT}} \propto \frac{\hbar}{c^2} \mid \nabla \Phi_{\text{eff}}(r) \mid^2,$$

which remains finite everywhere. Energy propagates outward at speed c, ensuring strict causality.

This horizon-free emission plays the physical role attributed to Hawking radiation in GR while avoiding divergences and information-loss paradoxes.

5. Gravitationally Induced Quantum Phase Accumulation

5.1. Single-Particle Phase

In CLT, quantum phase accumulation arises from conformal time dilation:

$$\phi = \frac{mc^2}{\hbar} \int [\Omega(r(t)) - 1] dt.$$

Absolute phases may be large, but they are not observable. Only **relative phase differences modulo** 2π have physical meaning.

5.2. Two-Particle and Multi-Particle Correlations

For a particle traversing two branches,

$$\Delta\phi = \frac{mc^2}{\hbar} \int [\Omega(r_1(t)) - \Omega(r_2(t))] dt.$$

For N particles, CLT predicts a causal phase-correlation network

$$\Delta\phi_{ij} = \frac{m_i c^2}{\hbar} \int [\Omega(r_{ij}^{(1)}(t - r/c)) - \Omega(r_{ij}^{(2)}(t - r/c))] dt.$$

These correlations arise from shared gravitational field energy and do not require quantization of gravity.

6. Comparison with General Relativity

CLT and GR agree in the weak-field regime but diverge fundamentally in strong-field and micro-scale contexts. CLT preserves flat spacetime, enforces explicit causality, localizes gravitational energy, and remains finite at all scales. A conceptual comparison is summarized in Table 1.

Table 1. Conceptual Comparison Between General Relativity (GR) and Causal Lorentzian Theory (CLT).

Aspect	General Relativity (GR)	Causal Lorentzian Theory (CLT)
Spacetime geometry	Curved spacetime	Flat Minkowski spacetime
Fundamental description	Geometry (metric tensor $g_{\mu\nu}$)	Physical gravitational field
Origin of gravity	Spacetime curvature	Conformal time dilation
Spatial curvature	Nonzero in general	Identically zero
Time dilation	Metric-dependent	Conformal scaling via Ω
Field propagation	Geometric (null geodesics)	Physical, causal propagation at speed c

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Causality	Implicit, coordinate-dependent	Explicitly enforced
Gravitational energy	Nonlocal (pseudotensors)	Local, positive-definite
Energy conservation	Global / subtle	Local and exact
Singularities	Generic (e.g. $r = 0$)	Eliminated by source smoothing
Event horizons	Generic in strong fields	Absent
Black hole concept	Horizon-defined spacetime region	Compact causal object
Hawking radiation	Horizon-based thermodynamic effect	Horizon-free field-energy emission
Information loss issue	Possible	Absent
Vacuum interpretation	Geometric	Physical field-carrying vacuum
Quantum phase origin	Proper time in curved spacetime	Conformal time dilation
Gravitational correlations	Geometric, indirect	Field-mediated, causal
Need for gravitons	Expected	Not required
Weak-field limit	Newtonian gravity	Newtonian gravity
Strong-field behavior	Divergent	Finite and regular
Micro-scale predictivity	Not available	Explicit and testable

Caption: *Conceptual and qualitative distinctions between General Relativity (GR) and Causal Lorentzian Theory (CLT). Both theories agree in the weak-field regime, while differing fundamentally in their treatment of strong fields, causality, and gravitational energy.*

7. Experimental Relevance

CLT predicts observable **relative phase shifts** in micro-scale quantum systems. Order-of-magnitude estimates indicate potential detectability in:

- levitated nanoparticle interferometry,
- atom interferometers,
- optomechanical oscillator networks.

Absolute phases are unobservable; experimental signatures appear as fringe displacements or correlated phase noise.

Table 2. Experimental-Scale Predictions of Gravitational Phase Shifts in CLT.

Experimental system	**Test mass m**	**Path separation Δr**	**Interaction time t**	**Predicted relative phase shift $\Delta\phi$**
Levitated nanoparticle interferometer	10^{-17} kg	$1\ \mu$m	1 s	10^{-6}–10^{-3} rad
Atom interferometer	10^{-25} kg	$10\ \mu$m	0.1 s	$\lesssim 10^{-6}$ rad
Optomechanical micro-oscillator pair	10^{-14} kg	$0.1\ \mu$m	1 s	$\lesssim 10^{-2}$ rad
Three-particle configuration	comparable	comparable	1 s	Correlated phase signal
N-particle network	variable	variable	variable	Correlation scaling $\propto N(N-1)$

Caption: *Order-of-magnitude estimates of* ***observable relative gravitational phase shifts*** *predicted by Causal Lorentzian Theory (CLT) for experimentally accessible systems. Absolute gravitational phases are unobservable; experimental signatures appear as relative phase differences, fringe displacements, or correlated phase noise. Values shown assume optimized isolation and coherence.*

8. Conclusions

Causal Lorentzian Theory provides a consistent, singularity-free, causal framework for gravitation at Planck scales and its interaction with quantum matter. By replacing spacetime

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curvature with conformal time dilation, CLT eliminates horizons and divergences while remaining predictive and experimentally accessible. The theory naturally produces gravitationally induced quantum phase correlations without quantizing gravity, offering a viable semi-classical bridge between gravitational and quantum phenomena.

Future work will extend numerical modeling, explore larger multi-particle networks, and refine experimental proposals.

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