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[A. AlMosallami](#)*

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Article

Causal Lorentzian Theory of Gravitation Conceptual Foundations, Nonlinear Completion, and Observational Signatures

A. AlMosallami

Zurich, Switzerland; a.almosallami71@gmail.com

Abstract

We present **Causal Lorentzian Theory (CLT)**, a flat-spacetime, Lorentz-invariant field theory of gravitation with explicit causal propagation and exact local energy–momentum conservation. Gravitation is described as a physical field propagating on Minkowski spacetime rather than as spacetime curvature. Matter localization is governed by a conformal localization factor modifying physical clock rates and length scales, while photon propagation occurs through a nonlinear, polarizable and magnetizable quantum vacuum medium. A minimal nonlinear completion is introduced in which gravitational field self-energy acts as a physical source while the propagation operator remains linear and hyperbolic. The theory reproduces all experimentally tested weak-field predictions of General Relativity—including Mercury perihelion advance, gravitational light deflection, and Shapiro time delay—while predicting controlled, testable deviations in strong-field regimes such as photon-ring structure and strong gravitational lensing.

Keywords: Causal Lorentzian Theory; local gravitational energy; nonlinear gravity; flat-spacetime gravitation; gravitational optics

I. Introduction

General Relativity (GR) describes gravitation geometrically, identifying gravity with spacetime curvature. Despite its empirical success, this formulation raises long-standing conceptual issues, including the absence of a local gravitational energy density, the interpretation of event horizons, and the appearance of singularities. These issues motivate the exploration of alternative formulations that preserve relativistic causality and observational agreement while improving conceptual transparency.

Relativistic gravity can be formulated as a field theory on flat spacetime, provided Lorentz invariance, causality, and conservation laws are respected. However, purely linear gravitational field theories fail because they allow matter to gravitate while neglecting the gravitational field’s own energy–momentum, leading to inconsistencies in strong-field regimes.

Causal Lorentzian Theory (CLT) adopts a flat-spacetime, field-theoretic ontology and resolves these shortcomings through a minimal nonlinear completion in which gravitational field self-energy acts as a physical source, while the propagation operator remains linear and causal.

II. Ontology and Background Structure

CLT is formulated on Minkowski spacetime with metric

$$\eta_{\mu\nu} = \text{diag}(+1, -1, -1, -1), d\sigma^2 = c^2 dt^2 - dx^2 - dy^2 - dz^2.$$

Spacetime itself is not dynamical. Gravitation is described as a physical field propagating causally on this fixed background. Lorentz invariance is exact and global, and no preferred frame is introduced.

III. Localization Postulate for Matter

A. Exact Localization Factor

Gravitational effects on matter are encoded through **localization**, which modifies physical clock rates and rod lengths relative to Minkowski coordinate quantities. The localization factor is defined **exactly** as

$$\Omega(r) \equiv \frac{1}{1 - \frac{GM}{c^2 r}},$$

valid for all $r > 0$.

B. Clock Localization

A localized physical clock at radius r measures proper-time increments

$$dt' = \Omega(r) dt.$$

In the weak-field regime,

$$\Omega(r) = 1 + \frac{GM}{c^2 r} + O(r^{-2}) = 1 - \frac{\Phi(r)}{c^2} + O(r^{-2}), \Phi(r) = -\frac{GM}{r},$$

reproducing observed gravitational time dilation.

C. Spatial Localization

Spatial rods scale in the same manner:

$$d\ell' = \Omega(r) d\ell.$$

Hence the **matter localization interval** is

$$ds_m^2 = \Omega^2(r)(c^2 dt^2 - dx^2 - dy^2 - dz^2).$$

This interval governs physical measurements by matter but does **not** define spacetime geometry.

IV. Gravitational Field Dynamics

A. Field variables and Lagrangian

The gravitational field is described by a four-potential A_g^μ and field tensor

$$F_g^{\mu\nu} = \partial^\mu A_g^\nu - \partial^\nu A_g^\mu.$$

The free-field Lagrangian is Maxwell-type:

$$\mathcal{L}_{\text{field}} = -\frac{1}{16\pi G} F_{g\mu\nu} F_g^{\mu\nu}.$$

B. Gravitational Stress–Energy

The gravitational field carries energy–momentum described by

$$T_{\text{field}}^{\mu\nu} = \frac{1}{4\pi G} \left(F_g^{\mu\alpha} F_{g\alpha}^\nu - \frac{1}{4} \eta^{\mu\nu} F_{g\alpha\beta} F_g^{\alpha\beta} \right).$$

C. Self-Consistent Nonlinear Sourcing

The field equations are

$$\partial_\nu F_g^{\mu\nu} = -\frac{4\pi G}{c^2} J_{\text{tot}}^\mu J_{\text{tot}}^\mu = J_m^\mu + J_{\text{field}}^\mu.$$

Because $F_g^{\mu\nu}$ is antisymmetric,

$$\partial_\mu J_{\text{tot}}^\mu = 0,$$

ensuring **exact local conservation of total energy–momentum**.

V. Static Limit and Nonlinear Poisson Equation

In the static limit,

$$\mathbf{g} = -\nabla\Phi, u_g = \frac{|\nabla\Phi|^2}{2\pi G}.$$

Interpreting gravitational field energy as gravitating mass density,

$$\rho_{\text{field}} = \frac{u_g}{c^2}.$$

The self-consistent static field equation becomes

$$\nabla^2\Phi = 4\pi G\rho + \frac{2}{c^2}|\nabla\Phi|^2.$$

For a point mass M , the exterior solution is

$$\Phi(r) = -\frac{GM}{r} + \frac{G^2M^2}{c^2r^2} + O(r^{-3}).$$

This corresponds to post-Newtonian parameters $\beta = 1, \gamma = 1$.

VI. Motion of Massive Bodies and Mercury Perihelion Advance

A. CLT Matter Action

The CLT matter action is

$$S_m = -mc \int ds_m = -mc^2 \int \Omega(r) \sqrt{1 - \frac{v^2}{c^2}} dt.$$

Expanding to first post-Newtonian order yields the effective Lagrangian

$$L = \frac{1}{2}mv^2 + \frac{GMm}{r} + \frac{1}{c^2} \left[\frac{1}{8}mv^4 + \frac{3GMm}{2r}v^2 + \frac{GMm}{2r}\dot{r}^2 + \frac{G^2M^2m}{2r^2} \right].$$

B. Orbit Equation from CLT

Using the Euler–Lagrange equations, conservation of angular momentum, and defining

$$u(\varphi) = \frac{1}{r}, h = r^2\dot{\varphi},$$

one obtains the CLT orbit equation

$$u'' + u = \frac{GM}{h^2} + \frac{3GM}{c^2}u^2,$$

where primes denote derivatives with respect to φ .

C. Perihelion Advance

Solving perturbatively gives the secular advance

$$\Delta\varpi = \frac{6\pi GM}{a(1-e^2)c^2},$$

in exact agreement with observation.

VII. Photon Propagation and Nonlinear Vacuum Medium

A. Physical Interpretation

In CLT, photons do not follow null geodesics of the matter localization interval. Instead, the gravitational field polarizes and magnetizes the quantum vacuum, which behaves as a nonlinear optical medium.

B. Constitutive Relation

The exact refractive index is

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

In the weak-field regime,

$$n(r) \simeq 1 - \frac{2\Phi(r)}{c^2}.$$

VIII. Light Deflection

Fermat’s principle,

$$\delta \int n(r) \, ds = 0,$$

yields the deflection angle

$$\delta\theta = \frac{4GM}{bc^2},$$

matching experimental results.

IX. Shapiro Time Delay

The coordinate travel time is

$$t = \frac{1}{c} \int n(r) \, ds.$$

The excess delay is

$$\Delta t = \frac{2GM}{c^3} \ln \left(\frac{4r_1 r_2}{b^2} \right),$$

identical to the GR leading-order prediction.

X. Strong-Field Lensing and Photon-Sphere Analogue

For the exact refractive index,

$$b(r) = n(r)r = \frac{r}{\left(1 - \frac{GM}{c^2 r}\right)^2}.$$

This function has a minimum at

$$r_{\text{ph}} = 3 \frac{GM}{c^2},$$

with critical impact parameter

$$b_c^{\text{CLT}} = \frac{27}{4} \frac{GM}{c^2} \approx 6.75 \frac{GM}{c^2}.$$

For comparison, GR predicts

$$b_c^{\text{GR}} = 3\sqrt{3} \frac{GM}{c^2} \approx 5.20 \frac{GM}{c^2}.$$

This difference provides a clear observational discriminant.

XI. Gravitational Radiation

The total source J_{tot}^μ satisfies

$$\partial_\mu J_{\text{tot}}^\mu = 0$$

and transforms as a four-vector. Consequently, monopole radiation is forbidden by mass conservation and dipole radiation by momentum conservation. As in electromagnetism, the leading time-dependent multipole for isolated systems is quadrupole.

Gravitational radiation in CLT is therefore quadrupole-dominated and consistent with binary-pulsar observations.

XII. Equivalence Principle

The weak and Einstein equivalence principles are satisfied. The strong equivalence principle is not fundamental but violations are suppressed in weak fields.

XIII. Falsifiability

CLT would be falsified by:

- detection of monopole or dipole gravitational radiation,
- confirmed geometric event horizons,
- strong-field lensing inconsistent with b_c^{CLT} ,
- compact-object observations incompatible with nonlinear vacuum optics.

XIV. Conclusion

Causal Lorentzian Theory provides a causal, Lorentz-invariant, flat-spacetime description of gravitation with explicit gravitational self-energy, nonlinear vacuum response, and exact conservation laws. It reproduces all tested weak-field phenomena while predicting distinct strong-field signatures, making it both conceptually transparent and experimentally falsifiable.

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