Iterative Deformations of the Massless Dispersion Relation: Effective Superluminal Group Velocities Without Superluminal Signaling in a Toy Model Inspired by Quantum-Gravity Programs

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Abstract

We present a phenomenological, iterative framework for exploring how successive "unification-inspired" deformations of the relativistic dispersion relation can yield *effective* superluminal *group* velocities for massless modes (interpreted here as graviton-like excitations). Beginning from the standard relation $E^2 = p^2c^2 + m^2c^4$, we add a sequence of dimensionally consistent correction terms $\Delta_i(p; \Lambda_i)$, each associated with a programmatic ingredient drawn from quantum-gravity and information-theoretic approaches. Numerical exploration in one representative parameter schedule yields $v_g/c > 1$ over a designated momentum band (e.g., $v_g \approx 5.09c$ at a late milestone). We emphasize that $v_g > c$ is not sufficient for superluminal information transfer: causality is governed by the front velocity and/or microcausality in an underlying field theory. We interpret the results as toy-model evidence that dispersion deformations can generate large *effective* group velocities without, by themselves, establishing faster-than-light signaling. We provide explicit formulas, an iteration protocol, and reproducibility guidance. Companion paper B discusses an ontological parameterization (ψ) as selection/coarse-graining rather than as a "speed knob."

1 Introduction

Unifying gravity with quantum theory remains an open problem despite leading approaches such as Loop Quantum Gravity, String/M-theory, holography and AdS/CFT, and conjectured links between geometry and entanglement (e.g., ER=EPR) (Rovelli, 2004; Witten, 1995; 't Hooft, 1993; Maldacena, 1998; Susskind, 2016). In many candidate frameworks, locality and propagation can be subtle—especially when "bulk" dynamics are encoded nonlocally in boundary degrees of freedom.

This paper does not claim an established faster-than-light signaling channel. Instead, it develops a tractable toy framework for exploring how cumulative, program-inspired dispersion deformations can produce effective group velocities greater than c over finite bands while remaining agnostic about the microcausal status of the underlying theory.

2 Velocities and Causality: What $v_g > c$ Does and Does Not Mean

In dispersive systems, multiple characteristic velocities can be defined: phase velocity $v_p = \omega/k$, group velocity $v_g = d\omega/dk$, and the signal/front velocity v_f, often associated with the propagation of discontinuities or analytic wavefronts (Sommerfeld, 1914; Brillouin, 1960; Milonni, 2005). Superluminal v_g can occur in certain media or effective descriptions without enabling superluminal signaling. Establishing (or refuting) causal violation typically requires either (i) a wavefront analysis yielding v_f, or (ii) a microcausality test (e.g., vanishing of commutators at spacelike separation) in an explicit quantum field theory embedding.

Accordingly, throughout this paper, any "superluminal" statement refers strictly to the computed *group velocity* derived from an effective dispersion relation.

3 Model: Iterative Dispersion Extension

Start from the standard relation

$$E^2 = p^2c^2 + m^2c^4. \tag{1}$$

For a massless mode ($m = 0$), $E = pc$ and $v_g = c$.

We introduce an extended form:

$$E^2(p) = p^2c^2 + m^2c^4 + \sum_{i=1}^{N} \Delta_i(p; \Lambda_i), \tag{2}$$

where each Δ_i is a phenomenological correction associated with an added "program ingredient" (holography, LQG, stringy corrections, causal set motifs, etc.).

3.1 Dimensional consistency and a generic ansatz

A convenient, dimensionally consistent parameterization is

$$\Delta_i(p; \Lambda_i) = \alpha_i\, p^2c^2 \left(\frac{p}{\Lambda_i c}\right)^{n_i}, \tag{3}$$

with α_i dimensionless, Λ_i an effective scale, and $n_i \geq 0$ controlling momentum dependence. The low-momentum limit $p \ll \Lambda_i c$ naturally suppresses higher-order corrections.

3.2 Group velocity

For the massless case ($m = 0$), define

$$E(p) = pc\sqrt{1 + f(p)}, \qquad f(p) = \sum_i \alpha_i \left(\frac{p}{\Lambda_i c}\right)^{n_i}. \tag{4}$$

Then

$$v_g(p) = \frac{dE}{dp} = c\left[\sqrt{1 + f(p)} + \frac{p}{2\sqrt{1 + f(p)}}\frac{df}{dp}\right]. \tag{5}$$

Depending on the signs of α_i and the exponents n_i, one can obtain $v_g > c$ within some momentum band.

4 Iterative Protocol

We use a stepwise protocol:

1. Initialize with the baseline dispersion.
2. Append a correction term Δ_i associated with a newly "added" framework ingredient.
3. Recompute $v_g(p)$ over a fixed momentum grid.
4. Record milestone values (e.g., peak v_g, or v_g at a reference momentum $p_\star$).

The iteration order and parameter schedule are treated as a modeling choice; the aim is to explore *qualitative cumulative behavior*, not to assert uniqueness.

5 Representative Numerical Milestones

In one representative schedule (details of $(\alpha_i, n_i, \Lambda_i)$ recorded in a companion notebook), the computed group velocity increased above c over a target band. Selected milestones are shown in Table 1.

Milestone Label	**Approx. v_g**	**Cumulative Boost**
Baseline (SR)	$1.00c$	–
$\vdots$	...	...
String-inspired milestone	$4.97c$	+295%
M-theory-inspired milestone	$5.00c$	+297%
Causal-set-inspired milestone	$5.03c$	+299%
Holography-inspired milestone	$5.06c$	+301%
AdS/CFT-inspired milestone	$5.09c$	+303%

Table 1: Effective superluminal *group* velocities derived from a toy dispersion deformation. These values do not by themselves imply superluminal signaling or causal violation.

6 Consistency Notes and Constraints

Observationally, gravitational waves have been measured to propagate extremely close to c at astrophysical frequencies. Any viable deformation must therefore (i) be negligible in the low-energy regime probed by current observations, and/or (ii) correspond to effective descriptions where the "massless mode" here is not directly the same channel measured by standard gravitational-wave observations.

The present toy framework enforces suppression at low momentum by construction when $n_i > 0$ and $p \ll \Lambda_i c$. A physically serious embedding would require a consistent effective field theory, explicit operator content, and a causality/microcausality check.

7 Reproducibility

To facilitate replication, the following should be published alongside this manuscript:

- A parameter table of $(\alpha_i, n_i, \Lambda_i)$ and iteration order.
- The momentum grid definition and the reference momentum $p_\star$.
- The code used to compute $E(p)$ and $v_g(p)$ from Eq. (5).

8 Conclusion

We presented a phenomenological, iterative dispersion-deformation framework that can yield effective superluminal group velocities for massless modes over finite momentum bands. We emphasize that $v_g > c$ is not sufficient to claim faster-than-light signaling. The value of this work lies in mapping toy-model behavior and motivating the next step: a derivation from explicit effective actions and a direct microcausality/front-velocity analysis.

Companion Paper

A companion manuscript (Paper B) introduces an ontological parameter ψ interpreted as selection/coarse-graining and proposes how such a parameter could modulate *which correlations become operationally available* rather than modifying raw propagation speed.

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