Frequency-Dependent Phase Rigidity in Gravitational Waves from Global Phase Coherence Constraints

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Abstract

In the Global Constraint Framework (GCF/MT), gravity emerges as the minimal spacetime deformation required to preserve global phase coherence in the presence of localized energy–momentum. Gravitational waves (tensor perturbations) carry phase information; the coherence constraint implies a small frequency-dependent phase velocity correction to maintain consistency over long baselines. We propose a toy dispersion relation of the form $\omega^2 = c^2k^2\left(1+\eta\left(\frac{k}{k_c}\right)^{\alpha}\right)$, where $\eta \approx 10^{-20}$ to 10^{-15} (from vacuum stiffness and relic scale), k_c corresponds to a coherence cutoff (e.g., relic channel or Planck-suppressed), and $\alpha \approx -1$ to -2 (from relic phase modulation or gradient penalty). This predicts tiny phase residuals $\Delta\phi \approx (\eta k_c D)/2$ over baseline D, potentially detectable in high-SNR events with long baselines (LIGO O5 $\rightarrow$ LISA overlap, multi-messenger BNS). The 255° vacuum lock could induce weak polarization mixing or echo-like residuals at preferred frequencies ($f_{\mathrm{res}} \approx$ 50–150 Hz). Current O4 data (GW170817, GW190425) provide a baseline; O5 (design sensitivity $\sim 2\times$ better at high f, 2027+) offers improved constraints. Absence of residuals bounds η; detection would support global coherence over standard GR propagation.

1 Introduction

The Global Constraint Framework (GCF/MT) posits that physical laws emerge from global admissibility under coherence constraints rather than local postulates. Gravity is the minimal spacetime deformation required to preserve universal phase transport when localized energy–momentum is present. Curvature is the lowest-cost mechanism to maintain consistency across all admissible paths. This note quantifies a testable consequence for gravitational-wave (GW) propagation.

2 Dispersion Relation from Phase Coherence

GW are phase-carrying tensor perturbations. The coherence constraint implies a small frequency-dependent phase velocity correction to keep total phase admissible over long baselines. We propose the toy dispersion relation

$$\omega^2 = c^2 k^2 \left(1 + \eta \left(\frac{k}{k_c}\right)^\alpha\right), \tag{1}$$

where

- $\eta \approx 10^{-20}$ to 10^{-15} (strength from vacuum stiffness and relic scale),
- $k_c = 2\pi f_c$ with f_c a coherence cutoff (e.g., relic channel or Planck-suppressed),
- $\alpha \approx -1$ to -2 (from relic phase modulation or gradient penalty).

This predicts phase velocity $c_{\mathrm{ph}} \approx c\,(1 + \eta/2 \cdot (k_c/k)^\alpha)$ and group velocity $c_{\mathrm{gr}} \approx c\,(1 - \eta/2 \cdot (k_c/k)^\alpha)$. Cumulative phase delay over baseline D is

$$\Delta\phi \approx \frac{\eta k_c D}{2}. \tag{2}$$

3 Detectable Signatures in LIGO O5

LIGO O5 (2027+) achieves design sensitivity $\sim 2\times$ better than O4 at high f ($f \gtrsim 100$ Hz) with longer observing runs and multi-messenger capability.

3.1 Frequency-dependent phase residuals

Phase mismatch between inspiral (low f) and ringdown (high f) in high-SNR events (SNR > 30). O5 resolution $\sim 10^{-6}$ rad over 10 ms signals at 100 Hz. Threshold for detection: $\eta > 10^{-15}$ (or lower f_c).

3.2 Phase-locking or echo residuals

Weak phase steps or post-merger echoes at preferred frequencies $f_{\mathrm{res}} \approx 50$–150 Hz (from relic minima or 255° bias). Search for narrow features in ringdown spectra (LIGO-Virgo-KAGRA joint analysis).

3.3 Multi-messenger baselines

BNS with EM counterpart $\to D \sim$ Gpc $\to \Delta\phi \sim 10^{-3}$ rad for $\eta \sim 10^{-20}$. Joint LIGO-LISA arrival time / phase residuals.

4 Comparison with GW170817

GW170817 (BNS, high-f content) provides a baseline. Re-analysis with custom dispersion templates can constrain η or detect residuals in inspiral–ringdown mismatch.

5 Conclusion

The GCF predicts small frequency-dependent phase rigidity in GW propagation. O5 sensitivity offers a near-term test via phase residuals in high-SNR or multi-messenger events. Absence constrains η; detection would support global coherence over pure geometry.

References