Echo Formation in Toroidal Curvature Structures under Universal Motion Theory

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Abstract

Universal Motion Theory (UMT) predicts that post-merger gravitational geometries may form toroidal curvature structures capable of supporting gravitational wave echoes. This addendum derives the timing, damping, and harmonic structure of gravitational wave echoes from curvature activation principles, compares toroidal trapping mechanisms to traditional black hole ringdowns, and quantifies predictions for events such as GW150914. The derivation strengthens the observational structure of UMT without altering its core framework.

1 Introduction

Standard general relativity predicts a rapid ringdown of gravitational waves post-merger, typically modeled as a damped sinusoid corresponding to the quasinormal modes of a perturbed black hole. Universal Motion Theory (UMT) introduces an alternative post-merger structure: toroidal curvature traps formed by incomplete activation zones. These structures allow gravitational waves to reverberate, producing delayed echoes that are observable under favorable conditions.

2 Toroidal Curvature Structures and Activation

UMT predicts that curvature activation gradients ($\nabla(\Phi\kappa)$) near merger remnants can produce stable or metastable toroidal geometries. The curvature activation function is:

$$\Phi(\rho) = \frac{1}{1 + e^{-k(\rho - \rho_{th})}} \tag{1}$$

where k is the steepness parameter and ρ_{th} the curvature density threshold.

Toroidal regions with incomplete activation ($\Phi \lesssim 1$) act as partially reflective boundaries for gravitational waves, enabling echo formation.

3 Echo Timing Derivation

The round-trip travel time Δt_{echo} for gravitational waves trapped in a toroidal region of effective radius R_τ is given by:

$$\Delta t_{echo} = \frac{2\pi R_\tau}{c} \tag{2}$$

where c is the speed of light.

Thus, the effective toroidal radius can be estimated from observed echo time delays:

$$R_\tau = \frac{c\Delta t_{echo}}{2\pi} \tag{3}$$

4 Damping and Harmonic Structure

The amplitude $A(t)$ of successive echoes decays exponentially as:

$$A(t) = A_0 e^{-\lambda t} \cos(\omega_r t + \delta) \tag{4}$$

where:

- λ is the damping constant, dependent on the activation sharpness (related to k).
- ω_r is the ringdown frequency corresponding to the dominant mode of the toroidal trap.
- δ is a phase offset.

The standing wave modes within the torus satisfy:

$$\omega_{r,n} = n\omega_{r,1} \tag{5}$$

where n is an integer indicating the harmonic index.

5 Comparison to Black Hole Ringdown

In classical GR, ringdowns arise from the horizon's quasinormal modes, with little or no echo structure. In UMT, by contrast:

- Echoes result from physical curvature traps, not horizon quantum structures.
- Activation gradients $(1 - \Phi)$ allow partial reflectivity without requiring Planck-scale modifications.
- The persistence and decay of echoes are governed by Φ-mediated trapping efficiency.

6 Application to GW150914

For the GW150914 event, observed potential echo delays of $\Delta t_{echo} \sim 0.1 - 0.2$ seconds correspond to effective toroidal radii:

$$R_\tau \sim (5 \times 10^3 \text{km}) - (10^4 \text{km}) \tag{6}$$

consistent with expected post-merger curvature trapping scales for stellar mass black holes under UMT.

Future detections of echo signals with consistent Δt_{echo} and decay profiles can serve as empirical tests of toroidal activation structures predicted by Universal Motion Theory.

7 Conclusion

This addendum formalizes the derivation of gravitational wave echoes within Universal Motion Theory, highlighting the role of toroidal curvature activation structures. It provides specific, falsifiable predictions for echo timing, damping behavior, and harmonic patterns, offering a direct observational test for UMT's post-merger geometry predictions.

References

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