A Testable Signature of Black Hole Horizon Quantization in Gravitational Wave Ringdown

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The quantization of black hole horizon area remains without direct observational evidence. We propose a testable prediction: if the horizon area is discrete, the ringdown spectrum must exhibit a frequency comb with spacing $\Delta f = (c^3 \ln k)/(16\pi^2 GM)$. For the bit hypothesis ($k = 2$), this gives $\Delta f \approx 896$ Hz $\cdot(M_\odot/M)$, detectable by current LIGO/Virgo detectors.

I. INTRODUCTION

For half a century, the quantization of black hole horizon area has been a cornerstone of quantum gravity research. Bekenstein and Mukhanov proposed that the horizon area is discrete, with fundamental step $\Delta A = 4 \ln k \cdot L_P^2$ [1]. We propose a direct observational test using gravitational wave ringdown.

If the horizon area is quantized, the emission spectrum should exhibit a frequency comb with constant step size Δf inversely proportional to mass. For the physically motivated bit hypothesis ($k = 2$), we derive:

$$\Delta f \approx 896 \text{ Hz} \cdot \frac{M_\odot}{M} \tag{1}$$

For a 30 solar mass black hole, this predicts $\Delta f \approx 30$ Hz. For GW150914 ($62M_\odot$), the prediction is $\Delta f \approx 14.5$ Hz, within LIGO's sensitive band.

II. THEORETICAL FRAMEWORK

The Bekenstein-Mukhanov area quantization proposal is [1]:

$$\Delta A = 4 \ln k \cdot L_P^2 \tag{2}$$

where $L_P^2 = \hbar G/c^3$ is the Planck area.

For a Schwarzschild black hole:

$$A = \frac{16\pi G^2 M^2}{c^4} \tag{3}$$

The minimal energy quantum corresponding to area change ΔA is:

$$\Delta E = \frac{c^6 \Delta A}{32\pi G^2 M} \tag{4}$$

Using the Planck relation $\Delta E = 2\pi\hbar\Delta f$ and substituting, we obtain:

$$\Delta f = \frac{c^3 \ln k}{16\pi^2 GM} \tag{5}$$

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III. OBSERVATIONAL PREDICTIONS

For $k = 2$, equation (5) gives:

$$\Delta f \approx 896.1 \text{ Hz} \cdot \left(\frac{M_\odot}{M}\right) \tag{6}$$

Table I shows predictions for LIGO events [2, 3].

TABLE I. Predicted frequency step for $k = 2$.

Event	Mass ($M_\odot$)	Δf (Hz)
GW150914	62.0	14.5
GW190521	142	6.3
GW170104	48.7	18.4
Hypothetical	30.0	29.9

IV. ANALYSIS PROTOCOL

We propose a two-stage search protocol:

Stage 1: Stack ringdown spectra rescaled by mass ($f' = f \cdot M/M_{\text{ref}}$) to find universal comb spacing.

Stage 2: Measure $\ln k$ from slope of Δf vs $1/M$.

Falsifiability: If ≥ 50 events with total ringdown SNR ≥ 200 show no comb with amplitude $\geq 1\%$ at predicted frequency, the $k = 2$ hypothesis is disfavored.

V. DISCUSSION

A positive detection would provide first direct evidence for horizon quantization, supporting the holographic principle [4, 5].

Our test differs from echo searches [6] by probing intrinsic quantum properties rather than near-horizon modifications.

Future detectors (Einstein Telescope, Cosmic Explorer, LISA) will increase sensitivity below 0.1% amplitude.

VI. CONCLUSIONS

We presented a testable prediction: black hole ringdown should contain a frequency comb with spacing $\Delta f \approx 896$ Hz $\cdot(M_\odot/M)$ for $k = 2$. This offers a direct test of quantum spacetime using current gravitational wave data.

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