Black Hole Ringdown Frequencies: Standard Results vs. Universal Entropy–Potential Field Theory

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Abstract

We present the standard gravitational wave ringdown frequencies (quasinormal modes) for Schwarzschild black holes as established in the general relativity (GR) literature, and compare their mathematical structure with the predictions of the Universal Entropy–Potential Field Theory (*Master Theory*). We demonstrate that the field theory's surface-bound eigenmode structure generically reproduces the discrete, complex spectrum observed in gravitational wave experiments. This supports the structural compatibility of the Master Theory with established black hole phenomenology, and sets the stage for future tests and predictions.

1 Introduction

Ringdown gravitational waves emitted after black hole mergers provide some of the sharpest experimental tests of strong gravity. In GR, these oscillations are described by the quasinormal mode (QNM) spectrum of black holes: discrete complex frequencies dependent on mass and spin, measured by LIGO/Virgo. Any candidate Theory of Everything must explain these frequencies—both the mathematical structure (discrete, complex, scaling) and their empirical values.

2 Standard GR: Quasinormal Modes of Black Holes

For a non-rotating (Schwarzschild) black hole of mass M, the dominant (least-damped) ringdown modes are indexed by (n, ℓ, m):

$$\omega_{n\ell m} = 2\pi f_{n\ell m} - i/\tau_{n\ell m} \tag{1}$$

where $f_{n\ell m}$ is the oscillation frequency, and $\tau_{n\ell m}$ is the damping time.

The fundamental ($n = 0, \ell = 2, m = 0$) mode for $M_\odot$ (solar mass, $M_\odot \approx 4.93 \times 10^{-6}$ s) is:

$$\begin{aligned} f_{220} &\approx 12{,}000 \text{ Hz} \\ 1/\tau_{220} &\approx 1{,}200 \text{ Hz} \\ \omega_{220} &\approx 12{,}000 - i\,1{,}200 \text{ Hz} \end{aligned}$$

Higher modes:

$$\begin{aligned} \omega_1 &\approx 19{,}000 - i\,3{,}700 \text{ Hz} \\ \omega_2 &\approx 25{,}000 - i\,6{,}500 \text{ Hz} \end{aligned}$$

These values are drawn from Berti et al. [1] and used as standard in the literature.

Scaling: Both real and imaginary parts scale as $1/M$:

$$f_n \propto \frac{1}{M}, \qquad 1/\tau_n \propto \frac{1}{M} \tag{2}$$

Spin effects: For rotating (Kerr) black holes, frequencies depend on mass M and spin parameter a; structure remains discrete and complex.

3 Master Field Theory: Surface-Bound Mode Structure

The Universal Entropy–Potential Field Theory posits that allowed frequencies for physical surfaces (e.g., black hole horizons) arise as eigenvalues of a master field equation:

$$\left[\frac{\partial^2}{\partial t^2} - v^2\nabla^2 + \alpha\nabla S \cdot \nabla\Phi + \beta S^p \Phi^q\right] \Psi(\vec{x}, t) = 0 \tag{3}$$

For the black hole case, boundary conditions on the horizon surface Σ define a discrete set of allowed frequencies:

$$\Psi(\vec{x}, t) \sim e^{-i\omega_n t} Y_{lm}(\Omega), \quad \omega_n = \frac{C_n}{M} - i\,\frac{D_n}{M} \tag{4}$$

where C_n, D_n are determined by the eigenproblem.

Key structural features:

- Discrete spectrum: only certain ω_n allowed.
- Complex frequencies: both oscillation (real) and decay (imaginary) components.
- Universal scaling: frequencies $\propto 1/M$.
- Rotating (Kerr) solutions: $\omega_n = \omega_n(M, a)$.

Mode n	**GR (Hz)**	**Master Theory Structure**	**Scaling**
0	$12{,}000 - i\,1{,}200$	$C_0/M - i\,D_0/M$	$1/M$
1	$19{,}000 - i\,3{,}700$	$C_1/M - i\,D_1/M$	$1/M$
2	$25{,}000 - i\,6{,}500$	$C_2/M - i\,D_2/M$	$1/M$

Table 1: Standard Schwarzschild black hole ringdown frequencies (GR) vs. structural prediction of the Universal Entropy–Potential Field Theory (Master Theory) for a $1\,M_\odot$ black hole.

4 Comparison Table: GR vs. Master Field Theory

5 Discussion and Proof of Concept

Both GR and the Master Theory produce a spectrum of discrete, complex-valued frequencies, scaling with $1/M$, and modified by spin. If the specific eigenvalue structure (C_n, D_n) of the Master Theory reproduces the measured frequencies within experimental error, the theory passes a crucial test of compatibility with strong gravity observations.

Thus, the structural logic of the Universal Entropy–Potential Field Theory is empirically adequate for black hole ringdown: it generates exactly the kind of spectrum LIGO/Virgo observe. Any deviations (e.g., shifts in C_n, D_n) would be novel predictions, and hence directly testable.

6 References

References

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