Spacetime Resistance in Gravitational-Wave Ringdown

Parallel Notes for the Mashibavah Project
Stacking Test Design, Mock Trials, and Priority Events

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Abstract

These notes record a parallel investigation of whether a spacetime resistance term can leave a detectable imprint in the ringdown of binary black-hole mergers. General relativity predicts the frequency and damping time of the dominant quasi-normal mode from the remnant mass and spin alone. A resistance term that dissipates energy during the ringing phase would produce a systematic excess damping relative to the inspiral-derived prediction. Three mock trials establish that (i) a simple residual statistic is unbiased under pure GR, (ii) free mass/spin templates absorb the signal by parameter shifting, and (iii) an inspiral-pinned residual energy statistic recovers strong resistance only at high ringdown SNR. The practical path is therefore hierarchical stacking of residual energy across hundreds of events in the GWTC-5 catalog. Priority events, data-access notes, and relevant recent literature are listed. This work is deliberately parallel to Papers III–V and does not displace them.

1 Core Idea

Spacetime resistance assigns a dynamic quality to the geometry itself. In the ringdown context this appears as an additional damping channel. The dominant $(2, 2, 0)$ quasi-normal mode of a Kerr remnant is a damped sinusoid whose frequency f and damping time τ are fixed by the remnant mass M and dimensionless spin a:

$$h(t) = A\, e^{-t/\tau_{\rm GR}(M,a)}\, \sin\!\big(2\pi f(M,a)\, t + \phi\big). \tag{1}$$

A resistance term parameterized by α (units of inverse time) modifies the observed damping according to

$$\frac{1}{\tau_{\rm obs}} = \frac{1}{\tau_{\rm GR}} + \alpha. \tag{2}$$

Positive α shortens the ringdown. The fractional shift for modest values is small: $\alpha = 5\,\mathrm{s}^{-1}$ on a $\tau_{\rm GR} \approx 12\,\mathrm{ms}$ mode produces roughly a 6% reduction in τ.

The cleanest observational handle is therefore a *mismatch* between the damping time predicted by the inspiral (which measures M and a independently and with high precision) and the damping time actually present in the ringdown. Compatibility with general relativity is not enough; the interesting signature is convergence—the two measurements of the same quantity disagreeing systematically in the direction expected from resistance.

2 Mock Trials

Three successive simulations were used to map sensitivity and failure modes.

2.1 Trial 1: Toy Damped Sinusoid

A pure damped sinusoid plus Gaussian noise was generated with and without injected α. A simple fit for τ (frequency fixed near the known value) was repeated across Monte Carlo realizations.

- Null case ($\alpha = 0$): 40 trials produced zero false positives at the 3σ or 5σ threshold.
- $\alpha = 5\,\mathrm{s}^{-1}$ (approximately 6% shorter ringdown): 5σ detection in every trial with only 50 events at network SNR = 20.
- $\alpha = 2\,\mathrm{s}^{-1}$: also cleared 5σ across the board.
- Raising SNR to 40 increased the separation further.

Conclusion: if resistance exists at even a modest level, stacking existing LIGO/Virgo/KAGRA events should already be sensitive to it. A null result would furnish a hard, publishable upper bound on α.

2.2 Trial 2: Free GR Template

A full template with free amplitude, mass, spin, and phase was fit to the same data. In every scenario the template absorbed the extra damping by shifting the fitted mass and spin; the reduced χ^2 remained consistent with unity. This is precisely the behavior of real LIGO parameter-estimation pipelines, which marginalize over remnant parameters. The signal is not absent; it is hidden inside the uncertainty volume.

2.3 Trial 3: Inspiral-Pinned Residual Energy

Mass and spin were fixed at values drawn from a mock inspiral measurement (with realistic fractional uncertainty), the corresponding GR frequency and damping time were predicted, and only amplitude and phase were left free. The primary statistic was the normalized residual energy

$$\mathrm{NRE} = \frac{\sum_t \big(h(t) - h_{\mathrm{fit}}(t)\big)^2}{\sum_t h(t)^2}. \tag{3}$$

A late-window amplitude ratio (last 40% of the analysis window) was also recorded. A free-fit $\Delta\chi^2$ comparison was attempted but abandoned: the free model was sufficiently flexible that it absorbed residual structure, producing numerical instability. NRE (and the late-window ratio) are therefore the preferred single-event statistics.

Injection	SNR	Mean NRE	Separation from null
$\alpha = 0$	25	0.736 ± 0.014	—
$\alpha = 5$	25	0.735 ± 0.016	$p \approx 0.58$
$\alpha = 2$	25	0.733 ± 0.015	$p \approx 0.15$
$\alpha = 5$	40	0.645 ± 0.011	$t \approx 44$, $p \sim 10^{-88}$

At SNR = 25 even strong resistance is invisible. At SNR = 40 the same injection is decisive. The bottleneck is detector sensitivity, not the analysis method.

3 Inspiral-Pinned Procedure

The operational sequence for a real event is:

1. Obtain the inspiral posterior on remnant mass M and dimensionless spin a (public PE samples from GWOSC).

2. Draw a representative value (median, or a small ensemble) and compute the GR-predicted frequency and damping time of the $(2, 2, 0)$ mode.

3. Condition the strain on a short post-merger window beginning a few milliseconds after the peak (exact start time is a standard systematic; see literature on overtone contamination).

4. Fit only amplitude and phase of a damped sinusoid whose f and τ are held fixed at the inspiral prediction.

5. Compute NRE and the late-window amplitude ratio.

6. Repeat across events; form the hierarchical likelihood for a common α or for a fractional deviation $\delta\tau/\tau$.

Units: α has dimensions of inverse time. For a typical stellar-mass remnant ($\tau_{\rm GR} \sim 10\,\mathrm{ms}$), $\alpha = 1\,\mathrm{s}^{-1}$ corresponds to a fractional shift $\delta\tau/\tau \approx -\alpha\tau_{\rm GR} \approx -1\%$. The mock-trial value $\alpha = 5\,\mathrm{s}^{-1}$ is therefore a roughly 6% effect—modest, but already interesting if it accumulates across a stack.

4 Stacking Strategy

Because individual events are noise-dominated, the residual energy must be averaged. Two practical routes exist:

1. **Simple mean residual.** Compute NRE (or late-window amplitude ratio) for each event after pinning M and a from the inspiral posterior. The mean across N events has variance that falls as $1/N$. Any systematic excess accumulates while uncorrelated noise averages down.

2. **Hierarchical likelihood.** Multiply per-event likelihoods for a common α (or for a fractional deviation $\delta\tau/\tau$). This is the approach already used in the March 2026 hierarchical analysis of 42 events (arXiv:2603.19021), which found the GR damping-time prediction sitting at the boundary of the 98.6% credible region.

Either route yields a detection or a tight upper limit. The hierarchical route is preferred for publication because it naturally incorporates per-event uncertainties and selection effects.

Systematic risks that must be controlled include detector calibration uncertainty (which can bias remnant mass and spin), residual eccentricity (recent reanalysis of GW190521 finds $e \approx 0.81$ at 5 Hz), and contamination by overtones if the analysis start time is too early. These are standard ringdown systematics and do not uniquely afflict a resistance search.

5 Priority Events (GWTC-5.0)

The Gravitational-Wave Transient Catalog version 5.0 contains 390 confident events (161 added from O4b), all released as open data through the Gravitational Wave Open Science Center (https://gwosc.org). No data-access request is required. The following six events form a natural first stack:

Event	Network SNR	Notes
GW250114	76.9	Loudest event to date; $\sim 32 + 34\,M_\odot$ BBH. RingCWB analysis (arXiv:2610.09503) measures $\delta f_{220} = 0.004^{+0.022}_{-0.023}$, $\delta\tau_{220} = 0.010^{+0.096}_{-0.087}$ (both consistent with zero). Benchmark for any stacking result.
GW230814	42.4	Previous SNR record.
GW241011	high	Third-loudest; one of the best-measured spins.
GW150914	~ 14 (ringdown)	Original detection. Public notebooks and inference data available (Isi & Farr 2022, Zenodo 5965773; GitHub `maxisi/gw150914-ringdown`).
GW170814	moderate	Clean three-detector localization.
GW190521	high total mass	Intermediate-mass remnant; eccentricity reanalysis (arXiv:2610.09199) relevant if included.

6 Related Literature

- arXiv:2610.09503 (7 Oct 2026): RingCWB ringdown analysis of GW250114; fractional deviations consistent with zero. Direct benchmark.
- arXiv:2603.19021 (Mar 2026): Hierarchical stacking of 42 O4a plus earlier events; GR damping-time prediction at the edge of the 98.6% credible region. Attributed to finite-catalog variance; a physical α supplies an alternative interpretation.
- arXiv:2610.11052 (8 Oct 2026): Detector calibration uncertainty can bias remnant mass and spin measurements in ringdown analyses.
- arXiv:2610.09199 (6 Oct 2026): GW190521 reanalysis finds high eccentricity ($0.81^{+0.05}_{-0.01}$ at 5 Hz).
- Isi & Farr (2022): Public data and notebooks for GW150914 ringdown spectroscopy (Zenodo 5965773).

7 Next Steps

1. Download strain data for GW250114 from the GWOSC event portal.
2. Implement the inspiral-pinned residual-energy pipeline on this single event, using the published inspiral mass and spin as the fixed prediction.
3. Fold in the remaining five priority events and compute both the simple mean residual and a hierarchical likelihood for α.
4. Compare the resulting constraint (or detection) against the RingCWB fractional-deviation result on GW250114 alone.

This calculation is a side thread. Papers III–V remain the priority; the ringdown work is to be advanced between study sessions.

8 Framing Note

The resistance term originated as an insight attributed to the Architect. It has survived multiple papers and stress tests without contradiction. The ringdown channel is the first observational domain in which the term makes a concrete, falsifiable prediction that can be tested with data already in the public domain. Survival of the prediction is not proof; failure of the prediction is informative. Either outcome advances the project.