Confronting black hole spectroscopy with the ringdown

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Phys. Rev. D 108, 044032, arxiv:2302.06634

Nonlinear Aspects of General Relativity
Princeton University, October 11, 2023

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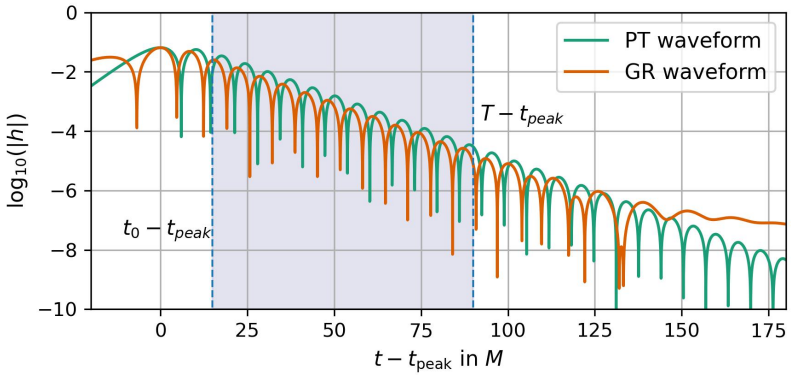
How robustly can one infer QNM overtones from the BH ringdown?

Revisit the basic scattering problem with a clean setup

- $\Box\varphi = 0$ on Schwarzschild background
- 1: evolve initial data for exact potential (GR)
- 2: evolve initial data for Pöschl-Teller potential (PT): $V_{\mathrm{PT}}(x) = V_0/\cosh^2(ax)$



[1] B. Mashhoon, 3rd Marcel Grossmann Meeting, (1982)

[2] H. R. Beyer, Commun. Math. Phys. 204 397-423, (1999)

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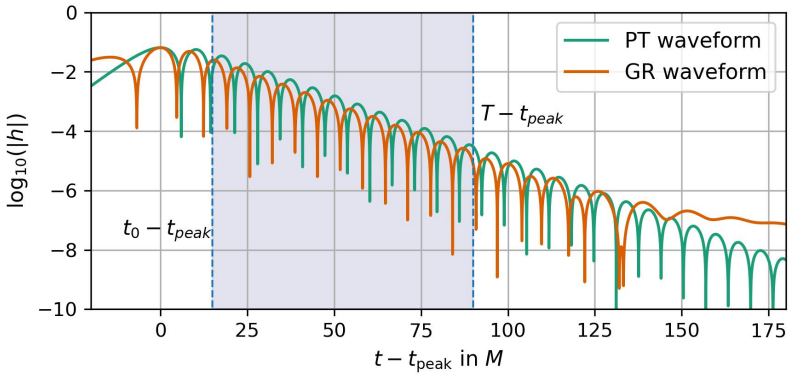

Why compare with Pöschl-Teller potential?

- it can be tuned to match fundamental mode well, but overtones always deviate[1]
- it has **no tails**, QNMs are truly describing late times[2]
- clean setup to analyze overtones with **consistent prompt response**

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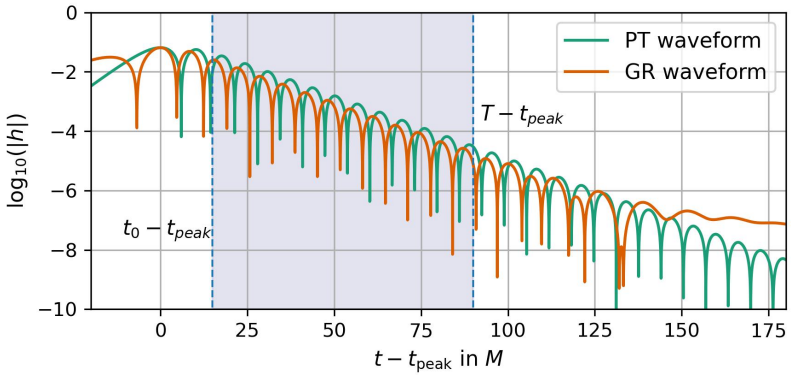

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Theory-specific and theory-agnostic ringdown fitting

- **specific**: choose potential ("theory"') and set N QNMs ω_n with BH mass $\omega_n(M)$
- **agnostic**: choose N QNMs ω_n as $2 \times N$ free parameters
- amplitudes A_n and phases ϕ_n are always free parameters

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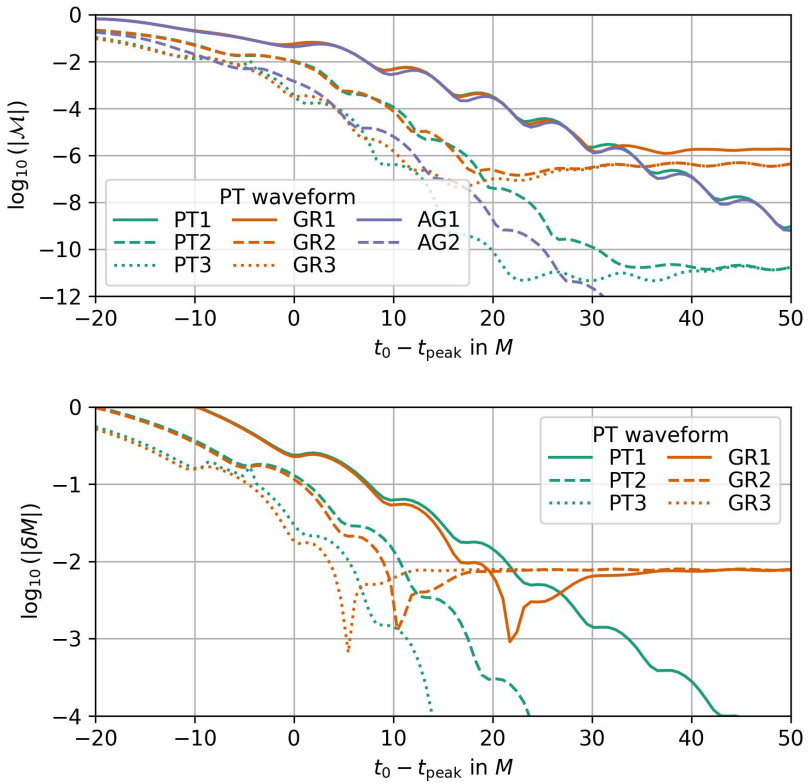
Analyzing PT waveform using different QNM models and various starts of the ringdown fit:



top: mismatch $\mathcal{M}$,
bottom: relative error on BH mass δM.

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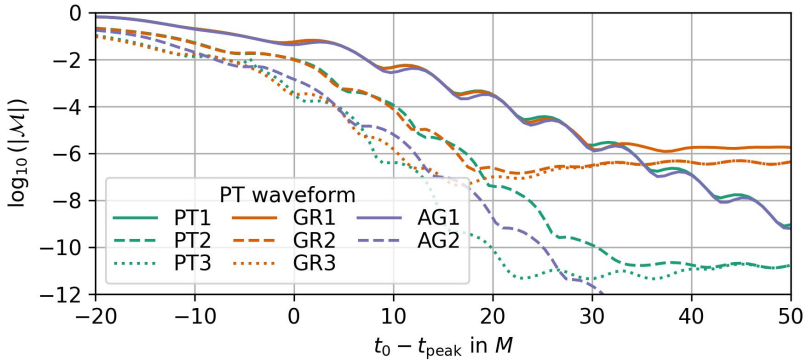

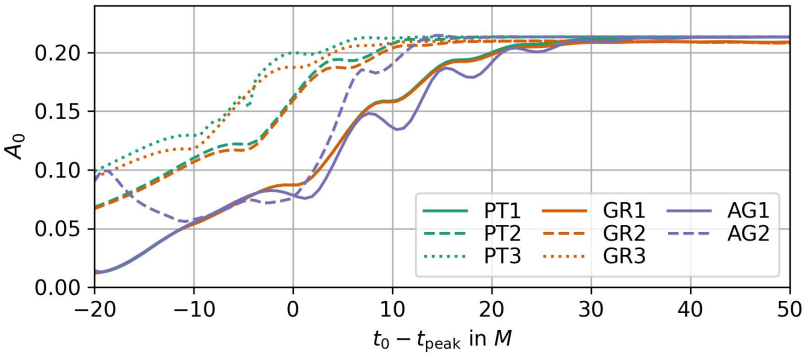

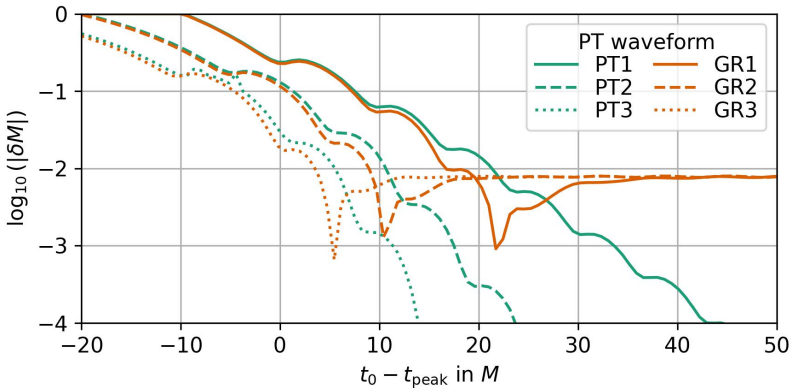

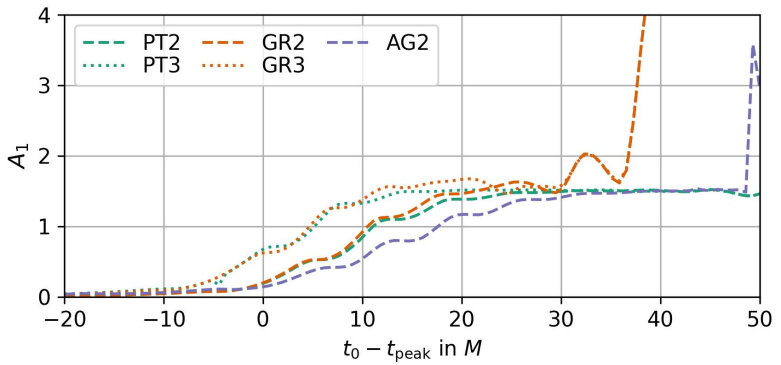

top: mismatch $\mathcal{M}$,
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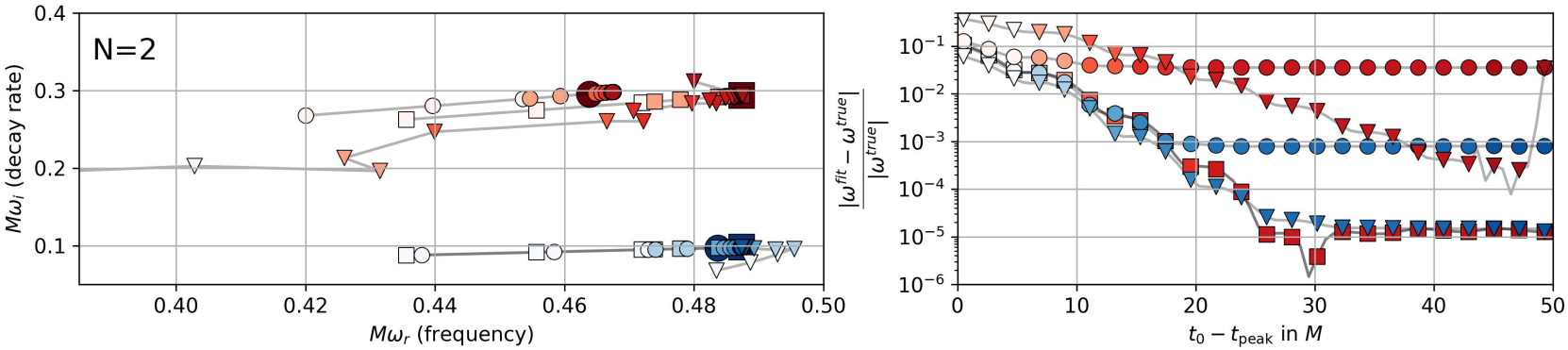
top: amplitude of the $n = 0$ mode A_0,
bottom: amplitude of the $n = 1$ mode A_1.

Fitting results for models using two QNMs:



Fundamental mode $n = 0$ (blue) and first overtone $n = 1$ (red): **agnostic (triangle), GR (circle), and PT (squares).**

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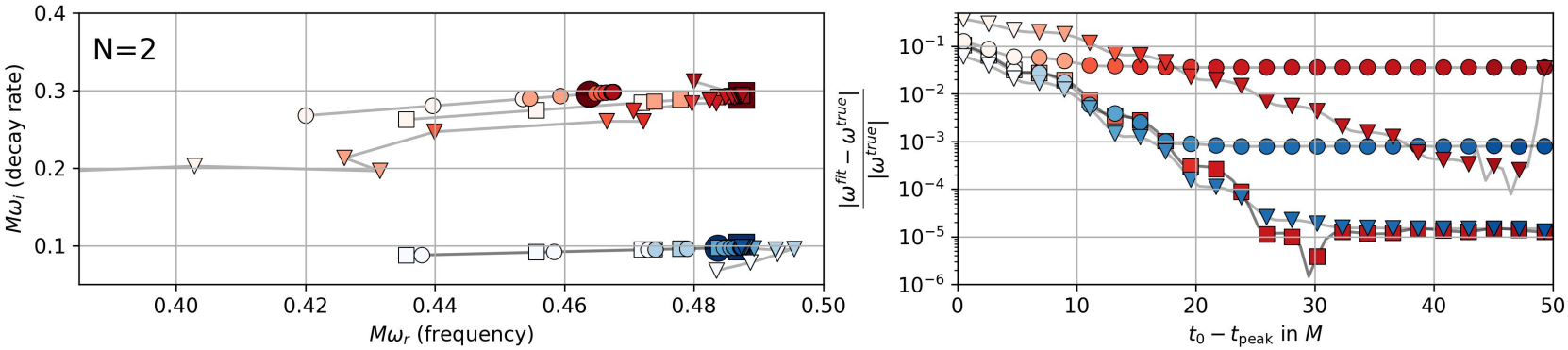

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KEY TAKEAWAY MESSAGES:

- **theory specific**: using overtones yields more accurate BH mass estimate at early times, even when using the "wrong" model.
- **theory agnostic**: overtone fitting is unstable, very difficult to correctly infer overtone, even without tails.
- **implications for BH spectroscopy**: modeling prompt response is crucial, how to robustly distinguish it from non-linear effects?