Searching higher-derivative extensions to GR in black holes' ringdown

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[based on arXiv:2110.11378]

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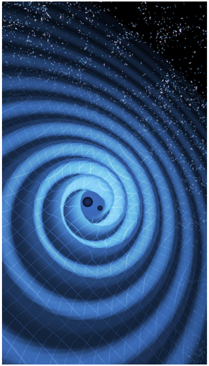


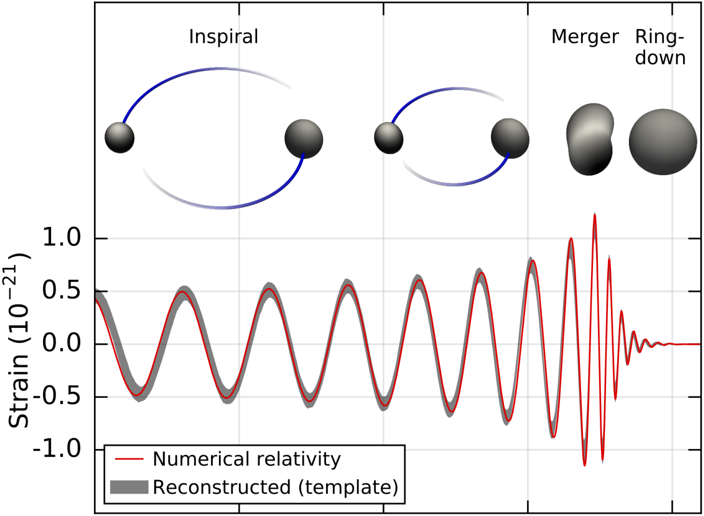
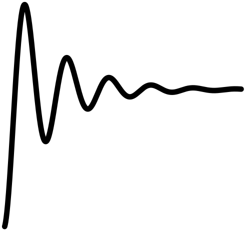


Figure: Theoretical signal and phases of a binary black hole merger [LIGO Collaboration]

Ringdown frequencies

- Perturbations of black hole decay over time
- GWs come from space around the black hole
- Fluctuations of a damped harmonic oscillator
- Boundary conditions set a dissipative system
- Resonance modes have complex frequencies



$$\sum A_k \exp(i\omega_k t)$$

Higher derivative Gravity

- Extend GR as an effective field theory of higher derivatives
- An approximation to study phenomena at one energy scale
- The complete theory at a higher energy scale is unknown

$$S = \int \mathrm{d}^4 x \sqrt{g} \left[R + \sum_{n=2}^{\infty} \ell^{2n-2} \mathcal{L}_{(n)} \right]$$

$$\mathcal{L}_{(3)} \ell^4 = \lambda_{\mathrm{ev}} R_{\mu\nu}{}^{\rho\sigma} R_{\rho\sigma}{}^{\delta\gamma} R_{\delta\gamma}{}^{\mu\nu}$$

Corrections from Cubic Curvature Term

- Corrections to GR are expected to be suppressed ($\lambda \ll 1$)
- GWs are perturbations of the background spacetime ($\varepsilon \ll 1$)
- Metric perturbations with odd and even parity and a range of l
- Compute the fundamental resonance frequencies for small λ
- Represent leading-order corrections of cubic curvature term

$$g_{\mu\nu}^{(\lambda)} = \bar{g}_{\mu\nu}^{(\lambda)} + \varepsilon h_{\mu\nu}^{(\lambda)} + \mathcal{O}\left(\varepsilon^2, \lambda^2\right)$$

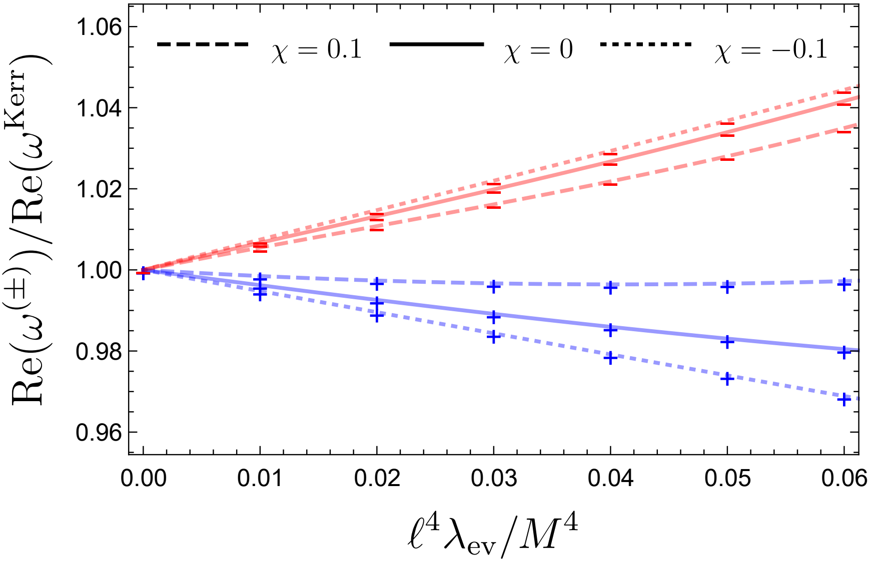
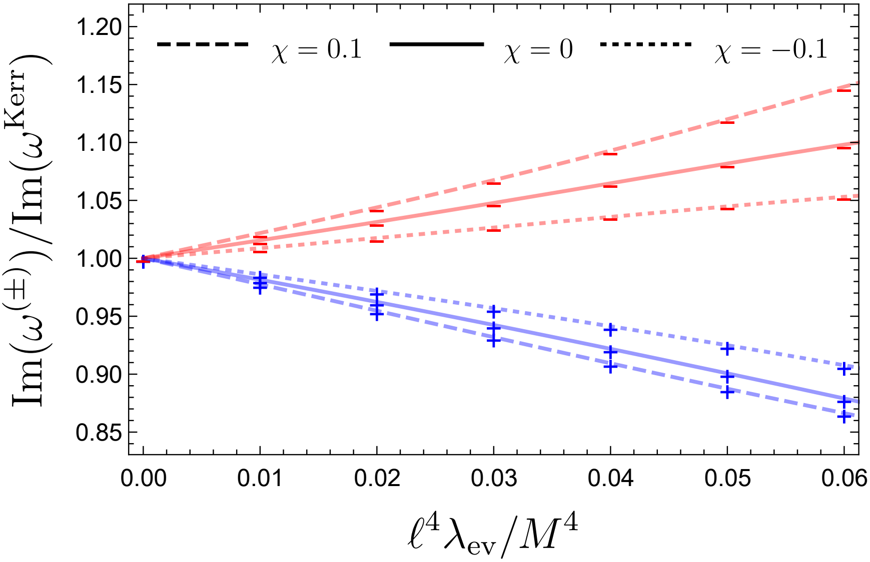


Figure: Fundamental QNM frequencies l = m = 2 relative to Kerr [arXiv:2110.11378]



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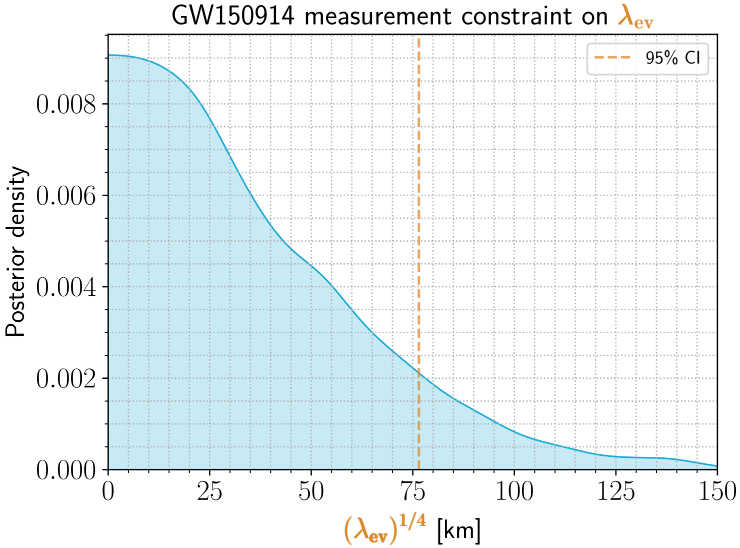
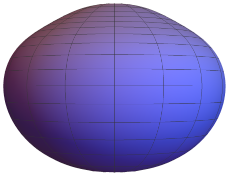


Figure: Calculated constraints on $\lambda_{\rm ev}$ from the ringdown analysis of GW150914

Future considerations

- Add parity-breaking higher-derivative terms
- Consider scalar field coupling (EdGB, dCS)
- Include possible inspiral and merger effects
- Frequency splitting as beyond GR signature
- Simulate sensitivity for future GW detectors



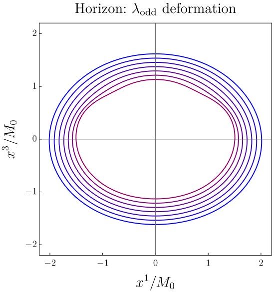


Figure: Example of the black hole horizon surface in a parity-breaking theory [Cano & Ruipérez 2019]

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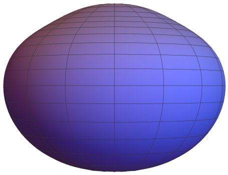

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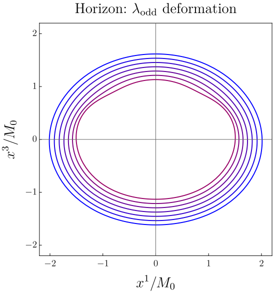

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Thank you for your attention!