

Black Holes in Dark Matter Environments: Ringdown and Tidal Response

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Astrophysical black holes are embedded in dark-matter environments, raising the question of how their surroundings affect gravitational-wave observables and whether these effects can be distinguished from genuine deviations from vacuum black-hole geometry. We study the ringdown and tidal response of a static, spherically symmetric black hole surrounded by an anisotropic dark-matter halo described by a generalized (α, β, γ) profile. We find that the halo shifts both the quasinormal-mode frequency and damping rate, with the inner slope γ playing the dominant role for centrally concentrated halos. In the eikonal limit, the shift is governed by a redshift integral determined by the matter distribution outside the light ring, linking the QNM spectrum to the light-ring frequency and Lyapunov exponent. Different halo configurations can produce nearly degenerate ringdown spectra, while the intermediate-time waveform retains information about the outer matter distribution. The tidal Love number probes the environment with a different radial weighting, offering a complementary observable. Together, ringdown and tidal response can help break environmental degeneracies and distinguish matter-induced effects from genuine modifications of black-hole gravity.

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