PRIMARY HAIRS MAY CREATE ECHOES

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Abstract

In most scenarios studied so far, the appearance of echoes in the ringdown signal requires modifications external to the black hole itself, such as the presence of matter in the near-horizon region, quantum field clouds, or exotic compact objects like wormholes that effectively introduce additional peaks in the effective potential. We show that echoes can naturally arise in a different setting: black holes endowed with primary Proca-Gauss-Bonnet hair. We demonstrate that the primary hair modifies the effective potential in such a way that a second peak is formed, giving rise to late-time echoes without invoking any external environment or exotic horizon-scale physics. Our results highlight a novel mechanism by which primary hairs alone can leave observable imprints on the ringdown signal of black holes in modified gravity.