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Black hole quasinormal mode spectroscopy

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The study of the evolution of small perturbations in black hole spacetimes, which is surprisingly related to the scattering problems in quantum mechanics, has played a fundamental role in gravitational-wave astronomy. Characteristic modes of vibrations are ubiquitous in nature, and it is expected that these characteristic frequencies are also associated with black holes. Similar to how the normal frequencies of various musical instruments carry information about the nature of the instrument, the characteristic frequencies associated with black holes also carry information about the nature of black holes, i.e., their charge, mass, and angular momentum. Due to the presence of an event horizon, these modes are complex frequencies, and the perturbed black hole system, just like any real-world physical system, becomes dissipative. To understand this phenomenon, I will talk about the equation governing the behavior of a massless scalar field in a Schwarzschild background and introduce the idea of quasinormal modes (QNMs). By using the Wentzel-Kramers-Brillouin (WKB) method, I will provide a detailed analysis of the QNM frequencies and discuss the intuitive relationship between characteristic modes of black holes and null circular orbits. I will show that for all spherically symmetric spacetime backgrounds, in the eikonal limit, damping time associated with QNMs can be indirectly obtained through the instability time scale of a null circular orbit given by the principal Lyapunov exponent. Further, by computing QNMs by Leaver's method, I will relate them to exciting developments in the detection of gravitational waves and the stability of black holes.

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