

Gravitational-Wave Signatures of Source Motion: Probing Dynamical Environments and Merger Recoils

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The motion of black-hole systems can leave distinctive imprints on gravitational-wave signals, offering a unique window into both their surrounding environments and merger dynamics. In this talk, I will discuss two representative effects associated with black-hole motion across different stages of binary evolution. First, I will consider stellar-mass binary black holes orbiting a supermassive black hole in galactic nuclei, where the long-term orbital motion produces characteristic modulations in the observed gravitational-wave signal. These modulations provide an opportunity to probe the mass, spin, and orientation of the central supermassive black hole, as well as the dynamical configuration of the system. I will then turn to the recoil of the merger remnant caused by asymmetric gravitational-wave emission. Such recoil signatures can be imprinted directly in the gravitational-wave signal and may be detectable with next-generation ground- and space-based observatories. Our forecasts indicate that these observations can substantially improve our ability to measure supermassive black-hole properties and characterize black-hole merger dynamics. Together, these studies highlight the broader role of source motion in gravitational-wave astronomy: rather than being a secondary correction, it can serve as a powerful probe of otherwise inaccessible astrophysical information and open new opportunities for studying black holes across multiple scales and frequency bands.

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