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Scattering and dynamical capture of two black holes: synergies between numerical and analytical methods

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Dense astrophysical environments, such as globular clusters, could host populations of black holes undergoing scatterings and dynamical captures. The gravitational wave event GW190521 may have originated from such a system, underscoring the need for accurate descriptions to fully leverage the scientific potential of current and future gravitational wave detectors.

We briefly introduce the topic by discussing the nonspinning test-mass limit, where we compute numerical waveforms by solving the Zerilli equation with the time-domain code RWZHyp for different dynamical capture scenarios. These results are then used to gain insights into the waveform properties and to test analytical prescriptions for effective-one-body (EOB) waveforms.

Next, we examine scatterings and dynamical captures for comparable mass spin-aligned systems. We present a dataset of numerical relativity simulations produced with the code GR-Athena++, which we use to study various phenomenological aspects, including waveforms and scattering angles. We also study in detail the transition from scattering to capture. Our numerical results validate the EOB model TEOBResumS-Dalí, showing remarkable agreement for initial energies E_0
$lesssim 1.02$, confirming the significant role that EOB models could play in describing these systems. Challenges and future steps, both on the numerical and analytical fronts, are also highlighted.

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