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Intertwining numerical relativity, perturbation theory and gravitational self-force

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We present a systematic comparison between gravitational waveforms emitted by quasi-circular non-spinning binary black holes in both comparable and large mass ratio regimes, generated with two different classes of waveform models: (i) second-order gravitational self-force (GSF) theory and (ii) numerical relativity (NR) informed point particle black hole perturbation theory (ppBHPT) waveforms as implemented in the BHPTNRSur1dq1e4 model, the cornerstone of BHPTNRSurrogate family of waveform models. The latter provides only adiabatically-driven waveforms whereas GSF includes first-order post-adiabatic corrections. However, BHPTNRSurrogate employs a simple linear scaling, known as the α-β scaling, to calibrate adiabatic-only ppBHPT waveforms to NR. We find that BHPTNRSur1dq1e4 waveforms closely match waveforms from second-order self-force theory everywhere in the mass ratio regime with the error dropping to ~ 10−3 for mass ratio q ≥ 10 - indicating the effectiveness of the α-β scaling. Our analysis then provides evidence for a simple scaling between the adiabatic-only and first-order post-adiabatic self-force waveform within GSF model and shows that the α-β scaling in BHPTNRSurrogate corrects for the missing higher-order self-force terms in adiabatic-only ppBHPT waveforms. This work helps to provide a physical interpretation to the α-β scaling in BHPTNRSurrogate and shows promise in guiding future higher-order self-force calculations.

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