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A phenomenological gravitational waveform model of binary black holes incorporating horizon fluxes

Being subject to the tidal field of its companion, each component of a coalescing binary suffers a slow change in its mass (tidal heating) and spin (tidal torquing) during the inspiral and merger. For black holes, these changes are associated with the energy and angular momentum fluxes down their horizons. This effect modifies the inspiral rate of the binary, and consequently, the phase and amplitude of its gravitational waveform. Numerical relativity waveforms contain these effects inherently, whereas analytical approximants for the early inspiral phase have to include them manually in the energy balance equation. In this work, we construct a frequency-domain gravitational waveform model which incorporates the effects of tidal heating of black holes, by recalibrating the inspiral phase of the waveform model IMRPhenomD to accommodate the phase corrections for tidal heating. We also include corrections to the amplitude, but add them directly to the inspiral amplitude model of IMRPhenomD. We show that the model is faithful, with better than 1% mismatches against a set of hybrid waveforms, except for one outlier that barely breaches this limit. The recalibrated model shows mismatches of up to $\sim 16\%$ with IMRPhenomD for high mass ratios and spins. Amplitude corrections become less significant for higher mass ratios, whereas phase corrections leave more impact - suggesting that the former is practically irrelevant for gravitational wave data analysis. Comparing with a set of numerical relativity waveforms, we find that the median of mismatches decreases by $\sim 4\%$ in Advanced LIGO, and by $\sim 2\%$ with a flat noise curve. This implies a modest but notable improvement in waveform systematics.

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