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Estimation of starting times of quasi-normal modes in ringdown gravitational waves with the Hilbert-Huang transform

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We propose a method of determining the starting time of the quasi-normal mode (QNM) and calculating the QNM frequency and amplitude of gravitational waves from binary black hole merger. Our method determines the starting time and calculates the parameters by regression analysis of time evolutions of the amplitude and frequency calculated by means of the Hilbert-Huang transform. We apply it to simulated merger waveforms by numerical relativity and the observed data of GW150914. As a result, we confirmed that the obtained QNM frequencies and time evolutions of amplitudes are consistent with the theoretical values within 1% accuracy for pure waveforms free from detector noise. In addition, it is revealed that there is a correlation between the starting time of the QNM and the spin of the remnant black hole. In the analysis of GW150914, the parameters of the remnant black hole determined through our method are consistent with those given by the LIGO-Virgo collaboration, and a reasonable starting time of the QNM is determined.

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