Pseudo-quasinormal modes used in SEOBNRv3 (LIGO DCC: LIGO-T1600554-v2)

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Similarly to what is done in the underlying nonprecessing EOBNR model [1], pseudo-quasinormal modes (QNMs) are introduced in the precessing EOBNR model to bridge the gap between the end-of-inspiral and the least-damped-QNM frequency, especially for large mass ratios and large spin magnitudes, and replace some of the highest physical overtones. The pseudo-QNMs are functions that depend of the GW frequency at $t = t_{\rm match}$ (the time where the ringdown is attached to the inspiral-plunge signal), the least-damped QNM frequency ω_{220} and decay time τ_{220}, and the symmetric mass ratio. Let M be the total mass of the binary, M_f be the mass of the remnant BH, ω_{22} be the instantaneous GW frequency. Let us define

$$\omega_{1,0} = \frac{1}{3}\left[2\,\omega_{22}(t_{\rm match})\frac{M}{M_f} + \omega_{220}\right]\,, \tag{1}$$

$$\tau_{1,0} = 0.257\,\tau_{220}\,, \tag{2}$$

$$\omega_{2,0} = \frac{1}{4}\left[3\,\omega_{22}(t_{\rm match})\frac{M}{M_f} + \omega_{220}\right]\,, \tag{3}$$

$$\tau_{2,0} = 0.286\,\tau_{220}\,. \tag{4}$$

Let us introduce the spin combination

$$\chi \equiv \frac{1}{1-2\nu}\frac{(\boldsymbol{S}_1+\boldsymbol{S}_2)\cdot\hat{\boldsymbol{L}}_{\rm match}}{M^2}\,, \tag{5}$$

where $\boldsymbol{S}_{1,2}$ are the component BH spins, ν is the symmetric mass ratio, $\hat{\boldsymbol{L}}_{\rm match}$ is the direction of the orbital angular momentum at $t = t_{\rm match}$, and the following functions:

$$f_\omega = 0.7 + 0.3\,e^{100(\nu-1/4)}\,, \tag{6}$$

$$f_{\tau_1} = [0.5\,(1+267\,\nu^2)^{1/2} - 0.125]e^{-(\nu-0.005)/0.03}\,, \tag{7}$$

$$f_{\tau_2} = [0.5\,(1+22.2\,\nu^{3/2})^{2/3} - 0.2]e^{-(\nu-0.005)/0.03}\,. \tag{8}$$

By default, when building the QNM spectrum for the $(2,2)$ mode, we introduce two pseudo-QNMs whose frequencies and decay times are $\omega_i^{\rm pQNM} = \omega_{i,0}$ and $\tau_i^{\rm pQNM} = \tau_{i,0}$ ($i = 1,2$), respectively. We have a special treatment for other parts of parameter space. When $q < 10$ and $\chi \geq 0.8$, we prescribe that $\omega_i^{\rm pQNM} = f_\omega\,\omega_{i,0}$ and $\tau_1^{\rm pQNM} = f_{\tau_1}\,\tau_{1,0}$, and $\tau_2^{\rm pQNM} = 0.95 f_{\tau_2}\,\tau_{2,0}$. When $10 \leq q < 30$ and $\chi \geq 0.8$ or when $q \geq 30$ and $0.8 \leq \chi < 0.9$, we prescribe that $\omega_i^{\rm pQNM} = f_\omega\,\omega_{i,0}$ and $\tau_i^{\rm pQNM} = f_{\tau_i}\,\tau_{i,0}$ ($i = 1,2$), and we also introduce two additional pseudo-QNMs whose frequencies and decay times read $\omega_{i+2}^{\rm pQNM} = 0.4\,(1+f_\omega)\,\omega_{i,0}$ ($i = 1,2$), $\tau_3^{\rm pQNM} = 1.5 f_{\tau_1}\tau_1^{\rm pQNM}$, and $\tau_4^{\rm pQNM} = 2.5 f_{\tau_2}\tau_2^{\rm pQNM}$, respectively. Finally, when $q \geq 30$ and $\chi \geq 0.9$, we slightly modify the third and fourth pseudo-QNMs just discussed, namely we put $\omega_3^{\rm pQNM} = 0.4\,(1+f_\omega)\,\omega_{1,0}$, $\omega_4^{\rm pQNM} = 0.44\,(1+f_\omega)\,\omega_{2,0}$, $\tau_3^{\rm pQNM} = 1.575 f_{\tau_1}\tau_1^{\rm pQNM}$, and $\tau_4^{\rm pQNM} = 2.625 f_{\tau_2}\tau_2^{\rm pQNM}$. When building the QNM spectrum for the $(2,1)$ mode, we introduce one pseudo-QNM whose frequency and decay time read $\omega_1^{\rm pQNM} = \omega_{22}(t_{\rm match})$ and $\tau_1^{\rm pQNM} = 0.5\,\tau_{220}$, respectively.

[1] A. Taracchini et al., Phys. Rev. **D89**, 061502 (2014), 1311.2544.