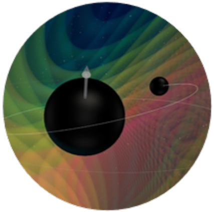
Can we predict Self-Force from Numerical Relativity?



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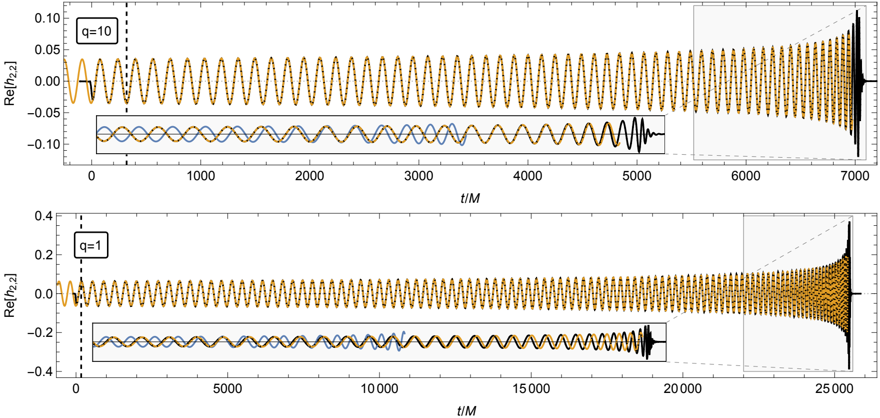
Motivation

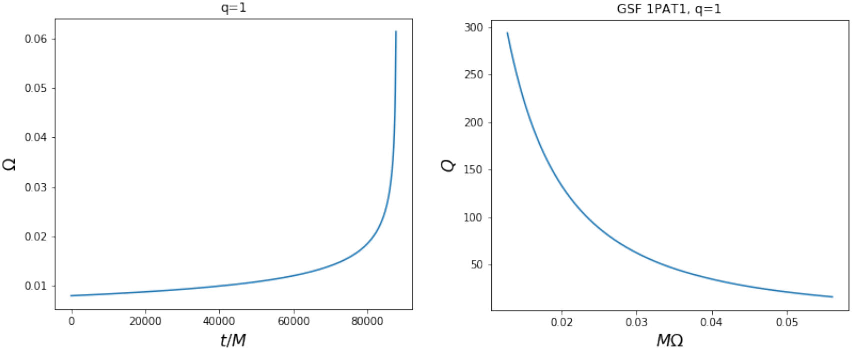
How well does BHPT describe IMRIs or comparable mass systems?
Can we predict higher order self-force terms from numerical relativity simulations?



Wardell *et al.* 2021 PRL **130**, 241402

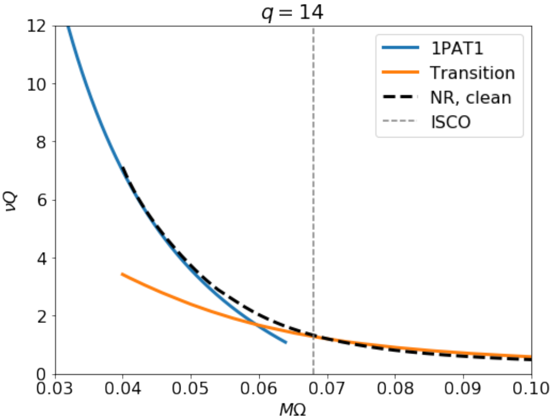
Adiabaticity Parameter

$Q = \frac{\Omega^2}{\dot{\Omega}}$ Adiabatic inspiral regime: $1/Q \ll 1$ ISCO: $M\Omega = 0.068$



Expect frequency to be increasingly monotonically for quasicircular orbits, $\Omega = \Omega_\phi \propto \omega_{\rm GW}$

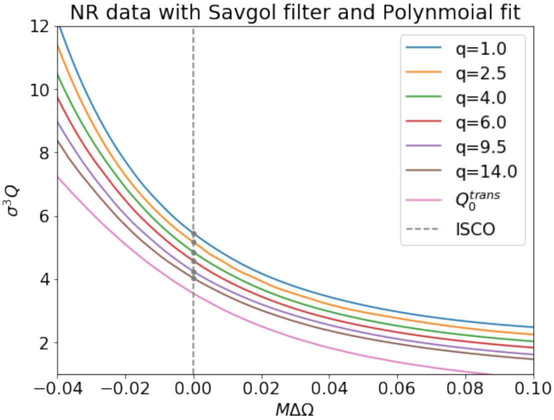
Transition to plunge



$$\nu Q_{\rm SF}^{\rm insp} = Q_0^{\rm insp} + \nu Q_1^{\rm insp} + \mathcal{O}(\nu^2) \quad \rightarrow \quad \sigma^3 Q_{\rm SF}^{\rm trans} = Q_0^{\rm trans} + \sigma^2 Q_2^{\rm trans} + \mathcal{O}(\sigma^3)$$

$$\varepsilon t \rightarrow t\lambda, \quad \lambda = \varepsilon^{1/5}, \quad \sigma = \nu^{1/5}$$

Cleaning NR data during the transition to plunge

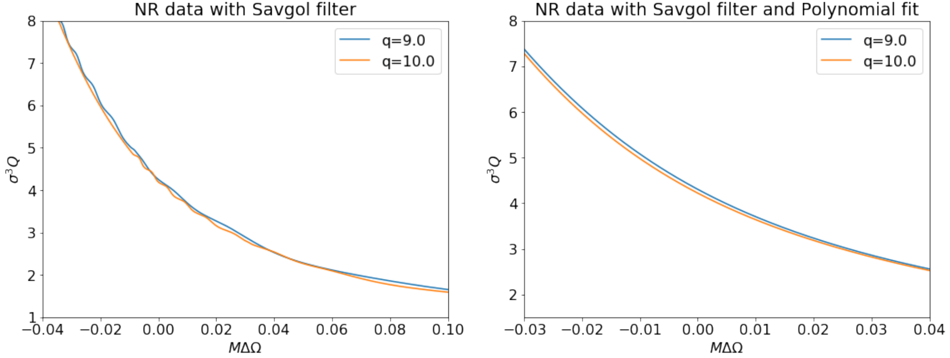


$$\sigma^3 Q_{\rm SF}^{\rm trans} = Q_0^{\rm trans} + \sigma^2 Q_2^{\rm trans} + \mathcal{O}(\sigma^3)$$

Cleaning NR data during the transition to plunge

$\Phi \to Q = \frac{\Omega^2}{\dot{\Omega}}$

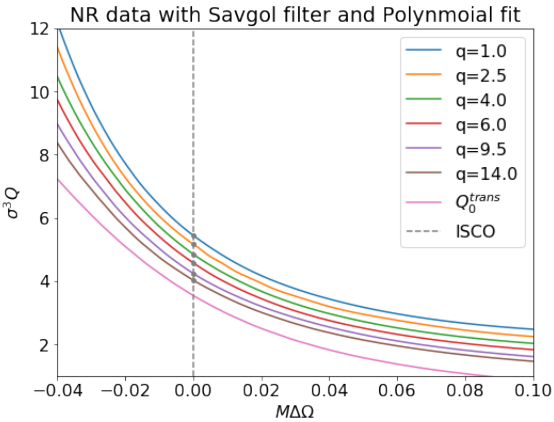
Filter residual eccentricity $(< 10^{-4})$ and spin $(< 10^{-7})$



Savitzky-Golay ('Savgol') filter

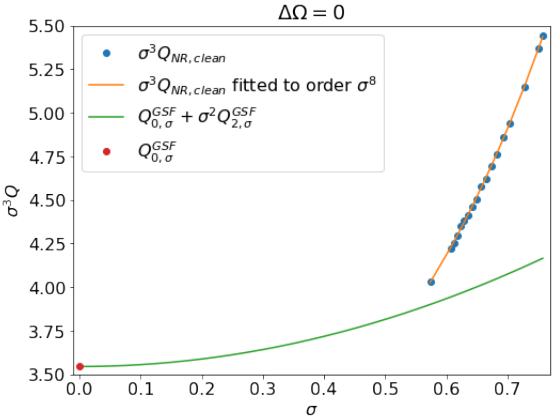
Some simulations also require fitting to a polynomial in powers of $\Delta\Omega$.

Cleaning NR data during the transition to plunge



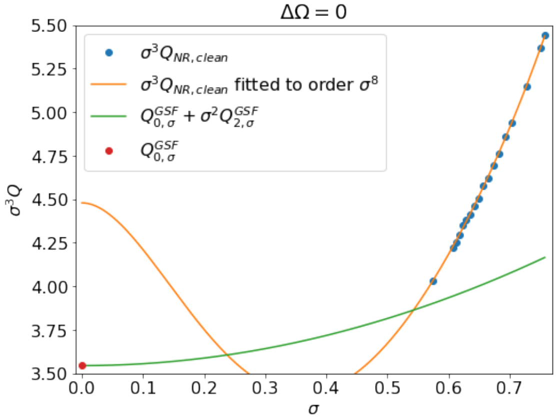
$$\sigma^3 Q^{\rm trans}_{\rm SF} = Q^{\rm trans}_0 + \sigma^2 Q^{\rm trans}_2 + \mathcal{O}(\sigma^3)$$

Fitting NR data during the transition to plunge



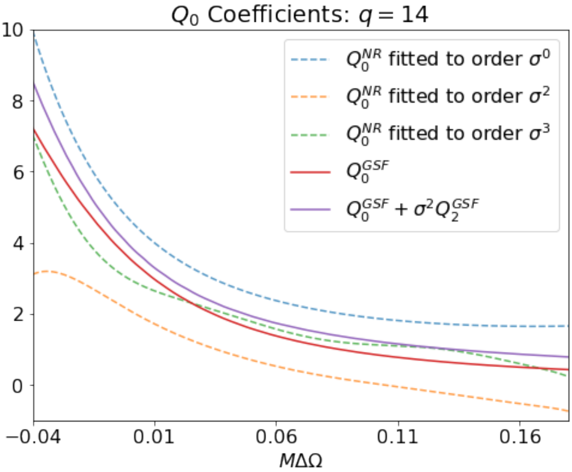
$$\sigma^3 Q^{\text{trans}} = Q_0^{\text{trans}} + \sigma^2 Q_2^{\text{trans}} + \sigma^3 Q_3^{\text{trans}} + \mathcal{O}(\sigma^4),$$

Fitting NR data during the transition to plunge...??



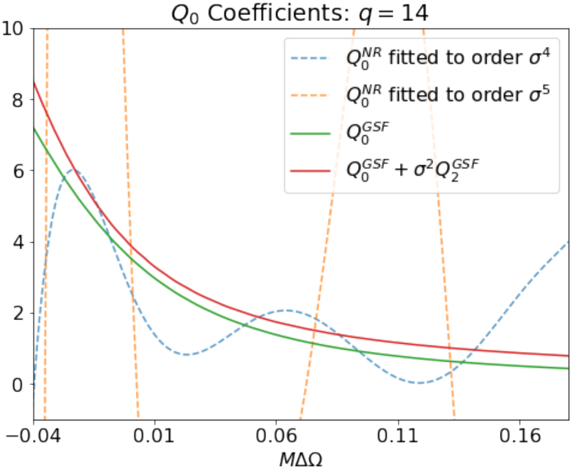
$$\sigma^3 Q^{\text{trans}} = Q_0^{\text{trans}} + \sigma^2 Q_2^{\text{trans}} + \sigma^3 Q_3^{\text{trans}} + \mathcal{O}(\sigma^4),$$

Extracting SF information from NR during the transition to plunge



Extracting SF information from NR during the transition to plunge

(...or not??)



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Conclusions:

- In the inspiral: yes!
- During the transition: No?
- Degeneracy of powers of $\nu^{1/5}$ for comparable mass ratios.
- Is this evidence that BHPT cannot describe comparable mass systems during the transition to plunge?

ToDo:

- Stabilise fit: *Can this be done?*
- Use Φ instead of Q to reduce numerical noise.

Bonus Slide

Frequency evolution during inspiral via the SF approach

$$Q = \frac{\Omega^2}{\dot{\Omega}}, \qquad \frac{d\Omega}{dt} = \nu F_0^{\Omega} + \nu^2 F_1^{\Omega} + \mathcal{O}(\nu^3), \qquad \nu = \frac{\varepsilon}{(1+\varepsilon)^2},$$

$$\begin{aligned}
F_0^{\Omega} &= -\left(\partial_\Omega E_0^{\text{bind}}\right)^{-1} \mathcal{F}_\nu^1, \\
F_1^{\Omega} &= -\left(\partial_\Omega E_0^{\text{bind}}\right)^{-1} \mathcal{F}_\nu^2 + \left(\partial_\Omega E_0^{\text{bind}}\right)^{-2} \mathcal{F}_\nu^1 \partial_\Omega E_1^{\text{bind}},
\end{aligned}$$

$$\begin{aligned}
E_0^{\text{bind}} &= E_0^{\text{geo}}, \\
E_1^{\text{bind}} &= E_1^{\text{SF}}.
\end{aligned}$$