Intertwining numerical relativity and perturbation theory

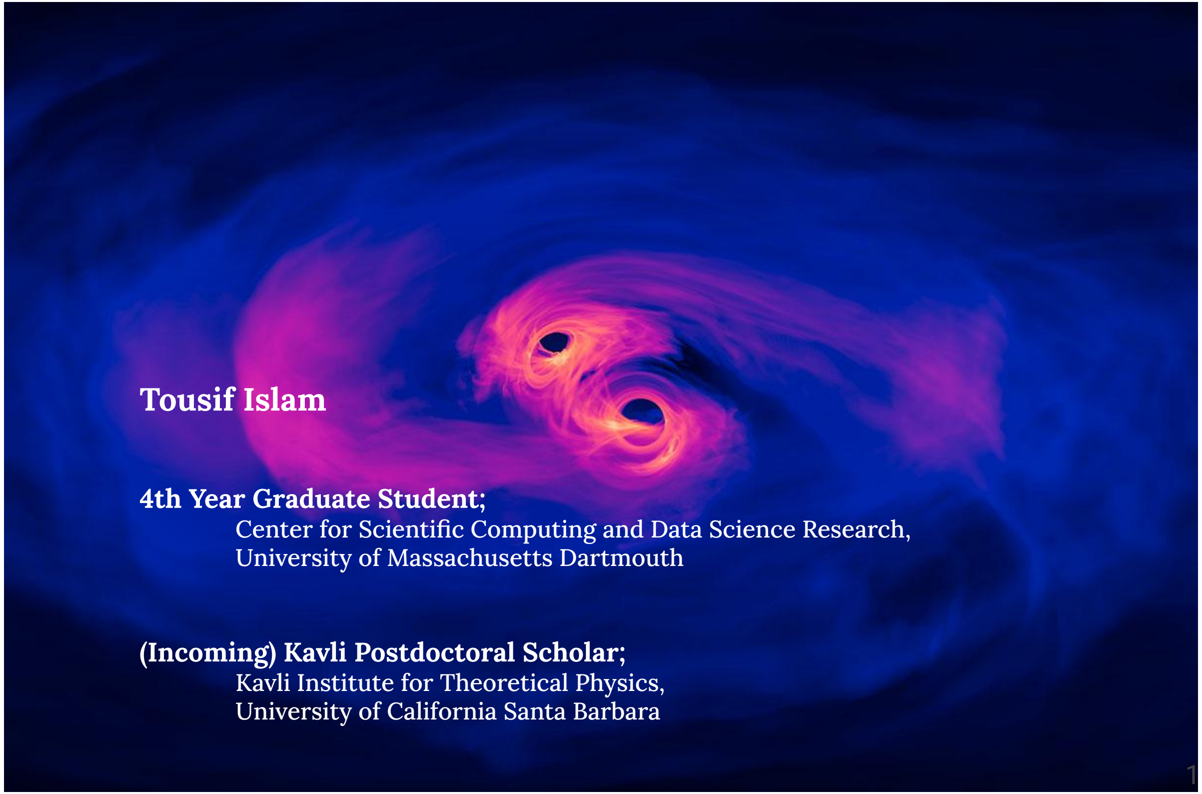
TauSigmaIota

www.tousifislam.com

tislam@umassd.edu

U²GRC

UMass Dartmouth

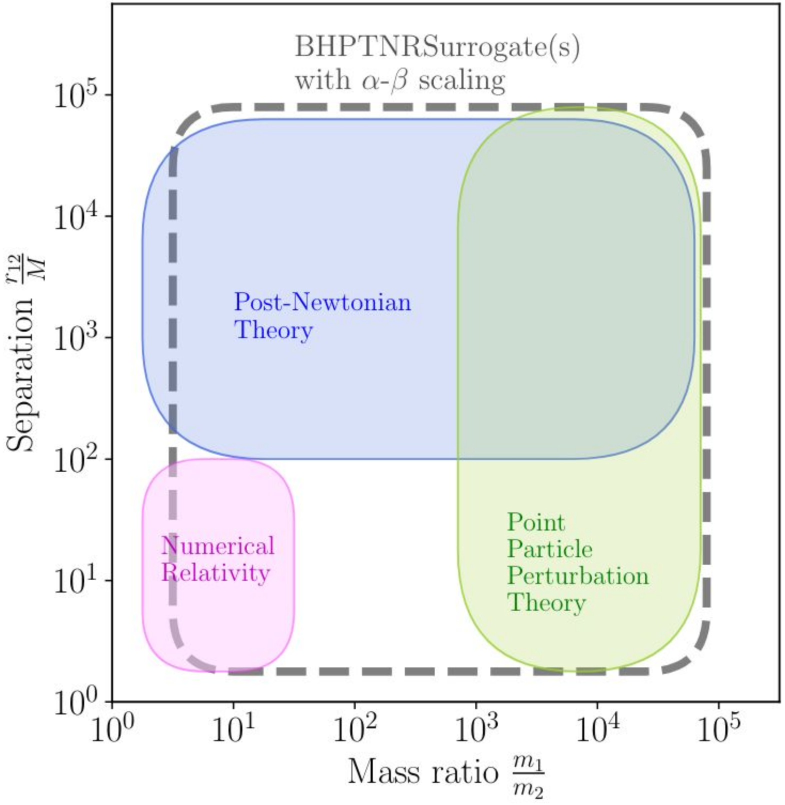


Tousif Islam

4th Year Graduate Student;
Center for Scientific Computing and Data Science Research,
University of Massachusetts Dartmouth

(Incoming) Kavli Postdoctoral Scholar;
Kavli Institute for Theoretical Physics,
University of California Santa Barbara

1. Gravitational waveform models
Different techniques and their regime of validity



α-β scaling : approximate non-trivial relation between perturbation and NR

BHPTNRSurrogate : perturbation based NR tuned model for waveform

BHPTNRSurRemnant : perturbation based NR tuned model for the remnant black hole

Islam, Field, Hughes, Khanna, Varma, Geisler, Scheel, Kidder & Pfeiffer 2022,
Islam, Field & Khanna 2023,
Islam 2023,
Islam & Khanna 2023a,
Islam & Khanna 2023b

Waveform Models

Surrogate model for gravitational wave signals from non-spinning, comparable- to large-mass-ratio black hole binaries built on black hole perturbation theory waveforms calibrated to numerical relativity

arXiv:2204.01972

Tousif Islam,[1,2,3,4,*] Scott E. Field,[2,3] Scott A. Hughes,[5] Gaurav Khanna,[6,1,3] Vijay Varma,[7,†] Matthew Giesler,[8] Mark A. Scheel,[9] Lawrence E. Kidder,[8] and Harald P. Pfeiffer[7]

Remnant black hole properties from numerical-relativity-informed perturbation theory and implications for waveform modelling

arXiv:2301.07215

Tousif Islam,[1,2,3,*] Scott E. Field,[2,3] and Gaurav Khanna[4,1,3]

Understanding interconnections

Interplay between numerical relativity and perturbation theory : finite size effects

Tousif Islam[1,2,3,*] and Gaurav Khanna[4,1,3]

arXiv:2306.08767

Interplay between numerical-relativity and black hole perturbation theory in the intermediate-mass-ratio regime

arXiv:2306.08771

Tousif Islam[1,2,3,*]

On the approximate relation between black-hole perturbation theory and numerical relativity

In Preparation

Tousif Islam.[1,2,3,*] Gaurav Khanna.[4,1,3]

Intertwining numerical relativity, perturbation theory and gravitational self-force

Tousif Islam,[1,2,3,*] Scott E. Field,[2,3] Gaurav Khanna,[4,1,3] Adam Pound,[5] Niels Warburton,[6] and Barry Wardell[6]

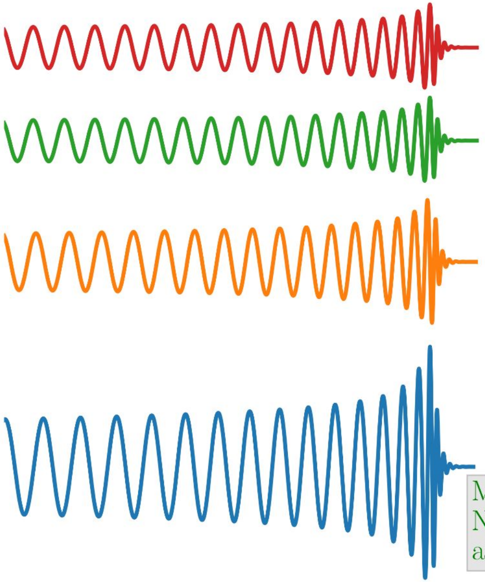
In Preparation

2a. BHPTNRSurrogate(s)

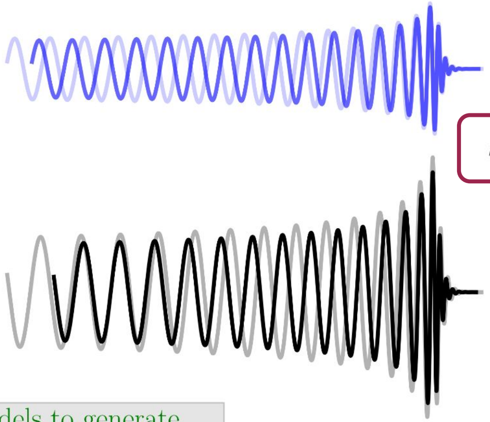
Building the model

```
git clone https://github.com/BlackHolePerturbationToolkit/BHPTNRSurrogate.git
```

Build a surrogate model using ppBHPT waveforms for $2.5 \leq q \leq 10^4$



Build an analytical model for NR calibration parameters from $2.5 \leq q \leq 10$



$$h_{\mathtt{NR}}^{\ell,m}(t;q) \sim \alpha_\ell h_{\mathtt{ppBHPT}}^{\ell,m}(t\beta;q)$$

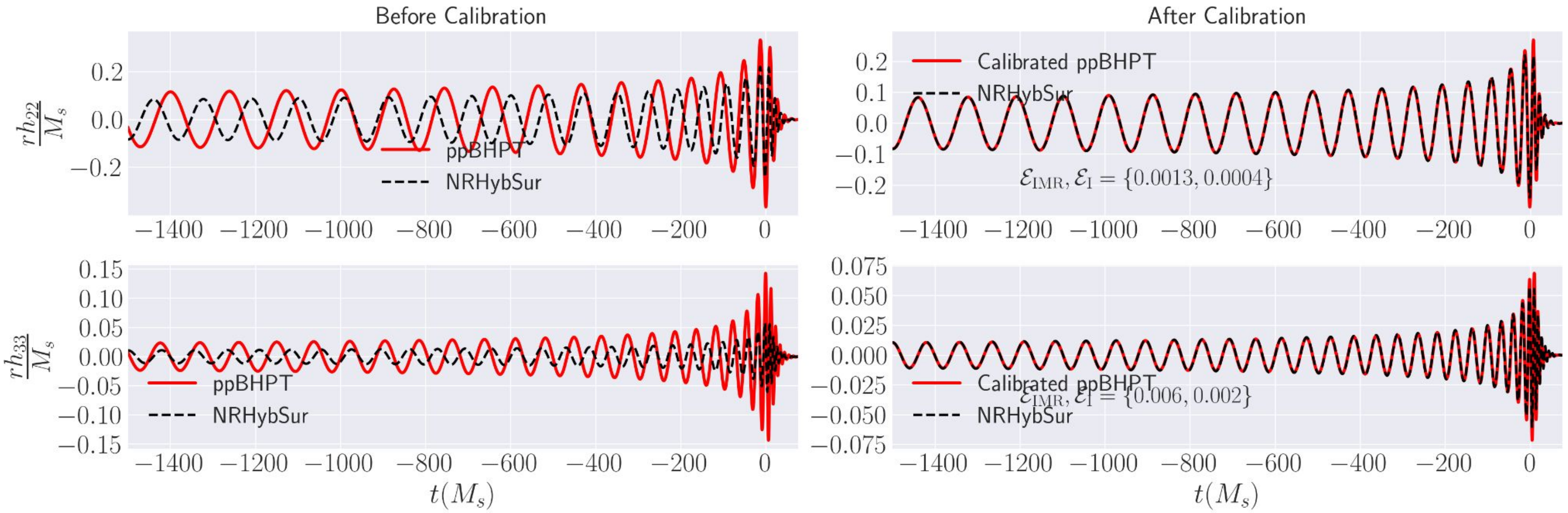
Merge the models to generate NR-tuned ppBHPT waveforms anywhere in the parameter space

Islam, Field, Hughes, Khanna, Varma, Geisler, Scheel, Kidder & Pfeiffer | arXiv:2204.01972

2b. BHPTNRSurrogate(s)

αβ-Scaling between ppBHPT and NR

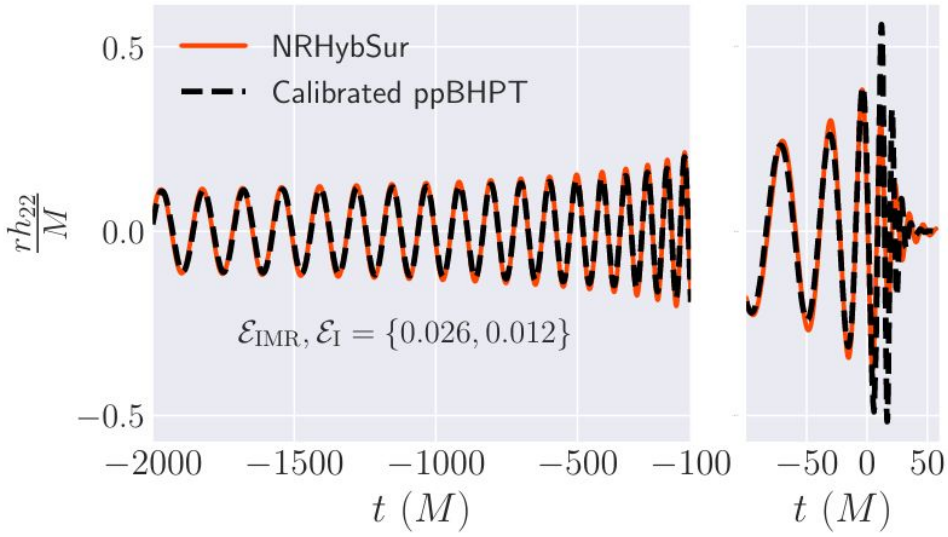
$$h_{\rm NR}^{\ell,m}(t;q) \sim \alpha_\ell h_{\rm ppBHPT}^{\ell,m}(t\beta;q)$$



Islam, Field, Hughes, Khanna, Varma, Geisler, Scheel, Kidder & Pfeiffer | arXiv:2204.01972

3a. BHPTNRSurrogate(s)

Model validation : almost equal mass binary?

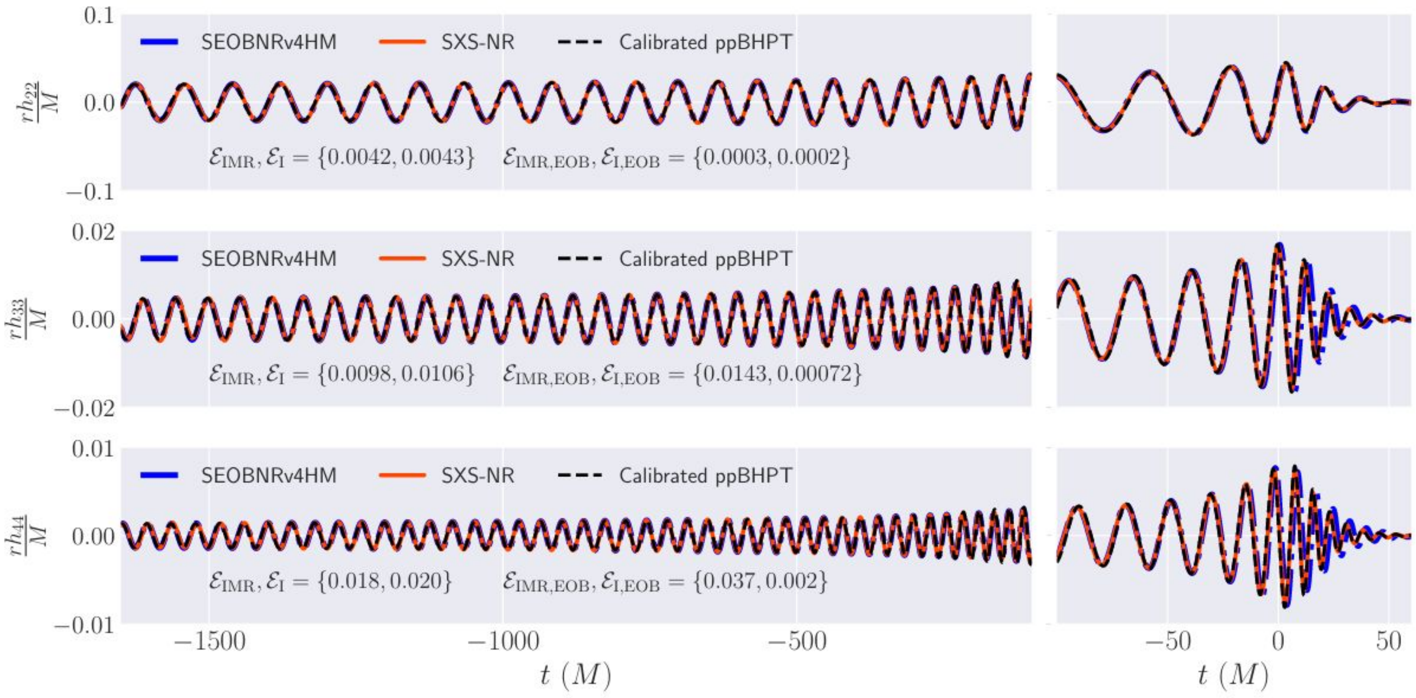


We have been able to obtain reasonable scaling until q=1.2

Islam, Field, Hughes, Khanna, Varma, Geisler, Scheel, Kidder & Pfeiffer | arXiv:2204.01972

3b. BHPTNRSurrogate(s)

Model validation : Intermediate mass ratio regime

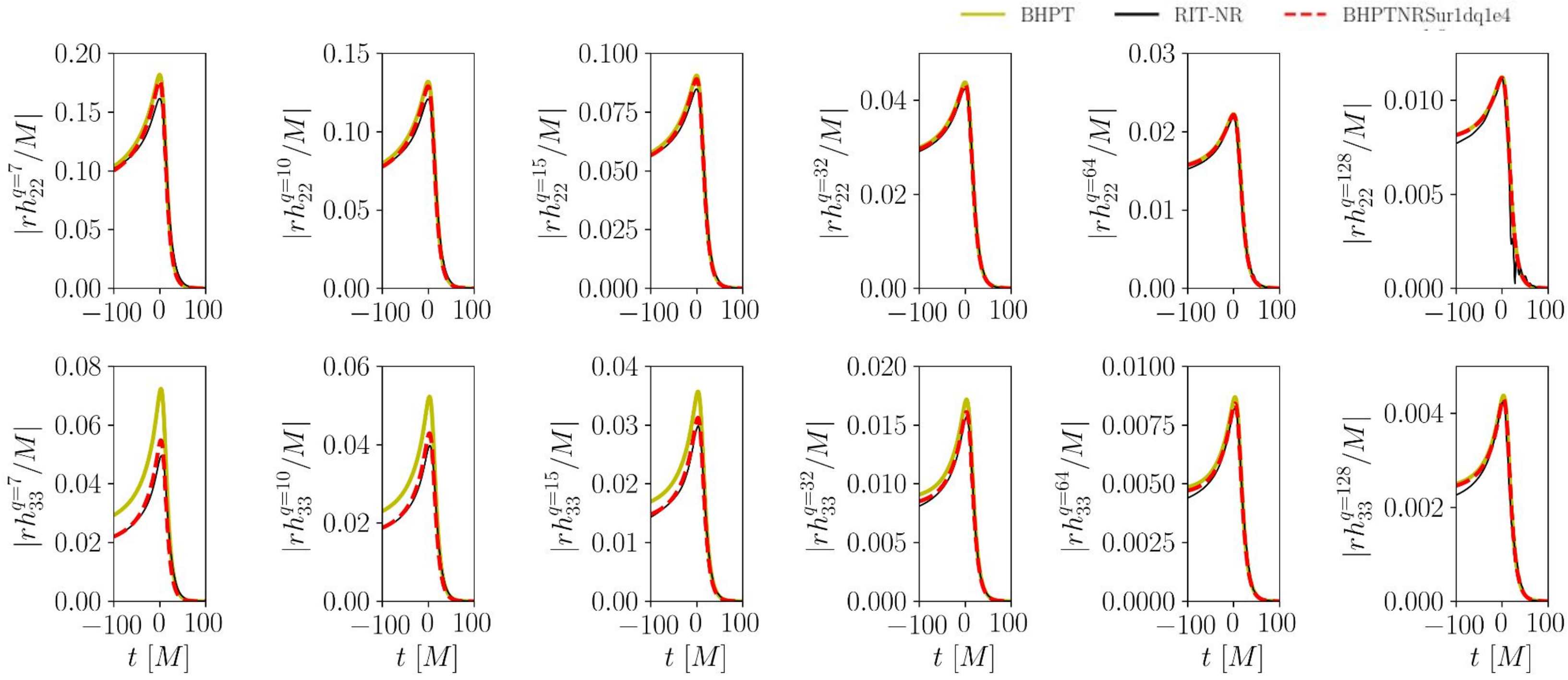


SXS-NR Simulation
@ q=30

Islam, Field, Hughes, Khanna, Varma, Geisler, Scheel, Kidder & Pfeiffer | arXiv:2204.01972

3c. BHPTNRSurrogate(s)

Model validation : Intermediate mass ratio regime

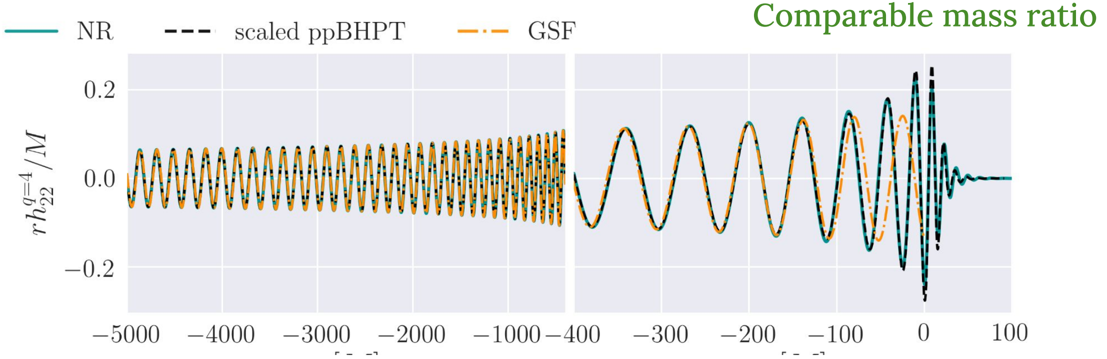


Islam | arXiv:2306.08771

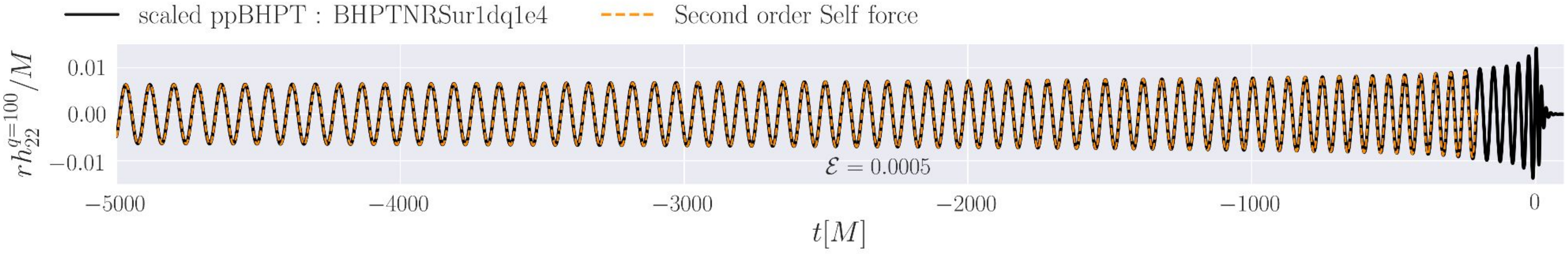
3d. BHPTNRSurrogate vs GSF

Waveform comparison

Comparable mass ratio



Intermediate mass ratio

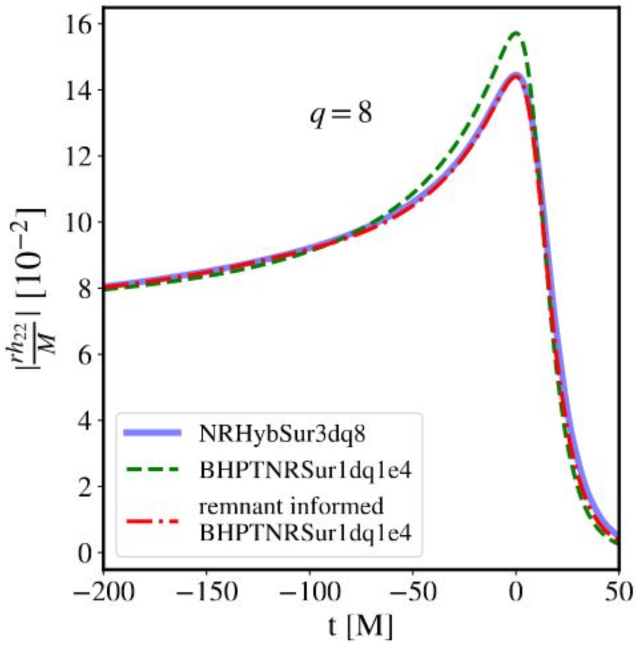


Islam, Field, Khanna, Pound, Warburton & Wardell 2023 | In Preparation

3e. BHPTNR_Remnant
Incorporating remnant information into waveform modelling

Surrogate Fits for

- final mass
- final spin
- peak luminosity
- kick velocity



Islam, Field & Khanna | arXiv:2301.07215

`git clone https://github.com/tousifislam/BHPTNR_Remnant`

4a. NR vs Perturbation theory

α-β scaling & finite size effect

Finite size BHPT : Barausse, Berti, Cardoso, Hughes & Khanna, arXiv:2106.09721

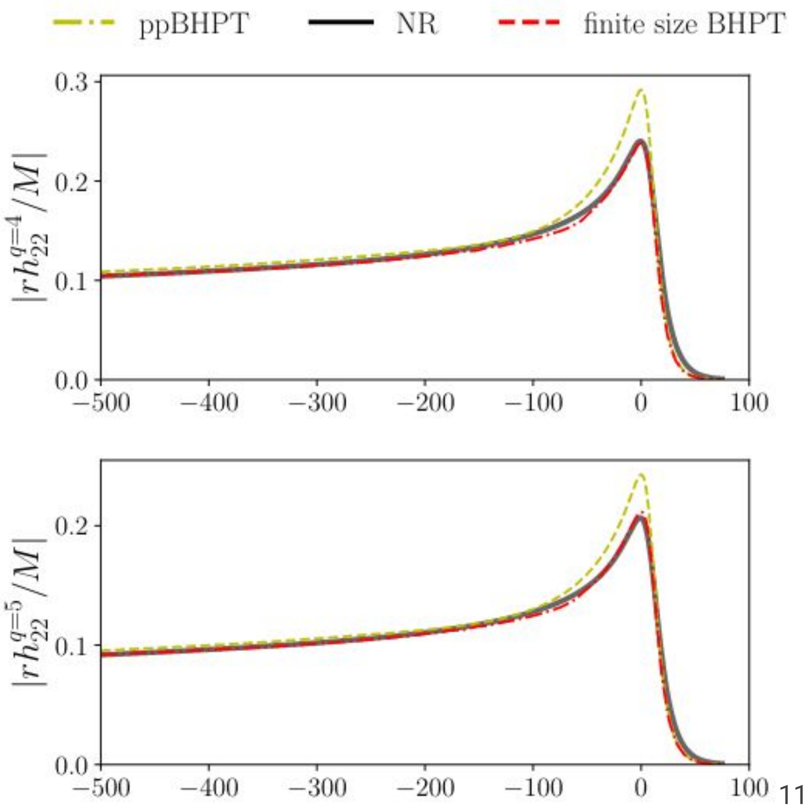
Scaling between ppBHPT and NR

$$h_{\mathrm{NR}}^{\ell,m}(t;q) \sim \alpha_\ell h_{\mathrm{ppBHPT}}^{\ell,m}(t\beta;q)$$

Breaking down the calibration parameters into pieces

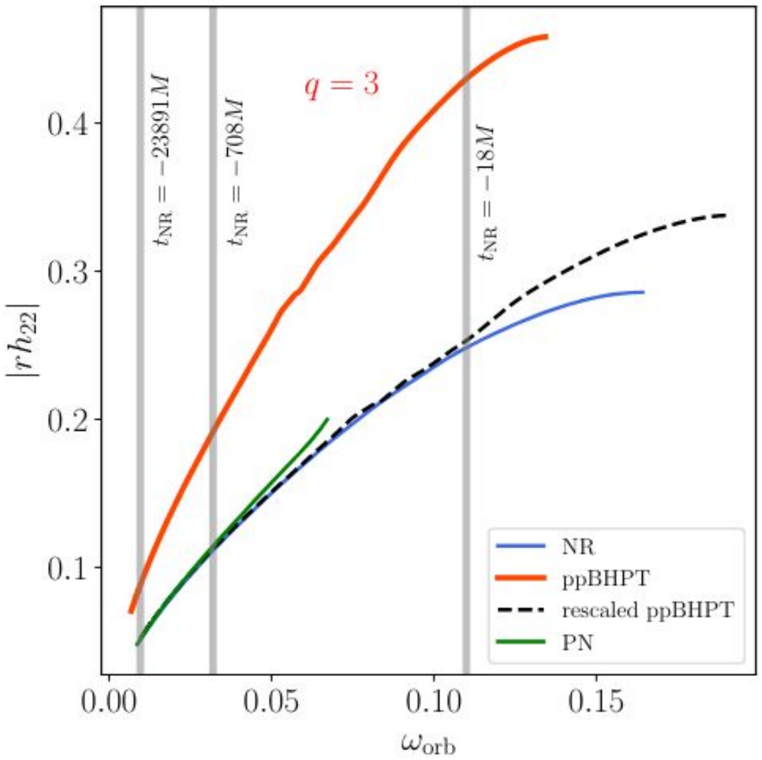
$$\alpha_{\ell=2} = \frac{1}{1+1/q} \times \alpha_{\ell,\mathrm{size}}$$

Islam & Khanna | arXiv:2306.08767



4b. NR vs Perturbation theory

α-β scaling : regime of validity

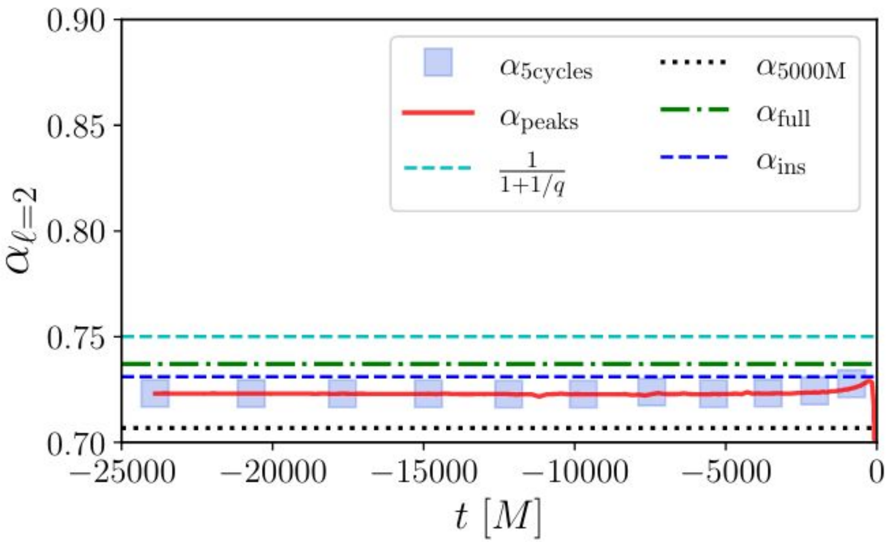


Constant **α-β** scaling introduces frequency dependent corrections

Islam & Khanna | In Preparation

4c. NR vs Perturbation theory

α-β scaling : regime of validity



Constant **α-β** scaling is valid upto very close to the merger;

The differences at the merger-ringdown part is because of a different mass/spin value

Islam & Khanna | In Preparation

5. Summary

αβ scaling : non-trivial scaling between linear perturbation and NR

BHPTNRSurrogate(s) : a single model to provide accurate waveform from comparable to extreme mass ratio binary black hole mergers

BHPTNR_Remnants : a single model to provide accurate estimate of the final black hole properties for comparable to extreme mass ratio binary mergers

We provide some theoretical foundation of the interconnections between NR, perturbation theory and second order self-force

TauSigmaIota www.tousifislam.com tislam@umassd.edu