Adding eccentricity to quasicircular binary-black-hole waveform models

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Phys. Rev. D 103.124011 (2021)

9th Belgian-Dutch GW Meeting, June 2021

Utrecht University

INTRO

The detection of gravitational-wave signals from coalescing eccentric binary black holes would yield unprecedented information about the formation and evolution of compact binaries in specific scenarios, such as dynamical formation in dense stellar clusters and three-body interactions. The gravitational-wave searches by the ground-based interferometers, LIGO and Virgo, rely on analytical waveform models for binaries on quasicircular orbits.

Eccentric merger waveform models are less developed, and only few numerical simulations of eccentric mergers are publicly available, but several eccentric inspiral models have been developed from the post-Newtonian expansion. Here we present a novel method to convert the dominant quadrupolar mode of any circular analytical binary-black-hole model into an eccentric model. A Python package pyrex [1] easily carries out the computation of this method.

AIMS

- **T**ransform any quasicircular (semi)-analytical binary-black-hole waveform models into the eccentric ones.
- **P**rovide a ready-to-use algorithm in the late merger-ringdown area.

METHOD

- ✓ Use 20 (12 training and 8 test dataset) publicly available numerical simulations from the nonspinning SXS catalog [2] ($q \leq 3, e \leq 0.2$).
- ✓ Decompose amplitude and phase of the $h_{2\pm2}$ mode.
- ✓ Calculate the residual oscillation for each NR for late merger by subtracting amp/phase (X_{NR}) from its quasicircular amp/phase (X_c) with the same mass ratio,

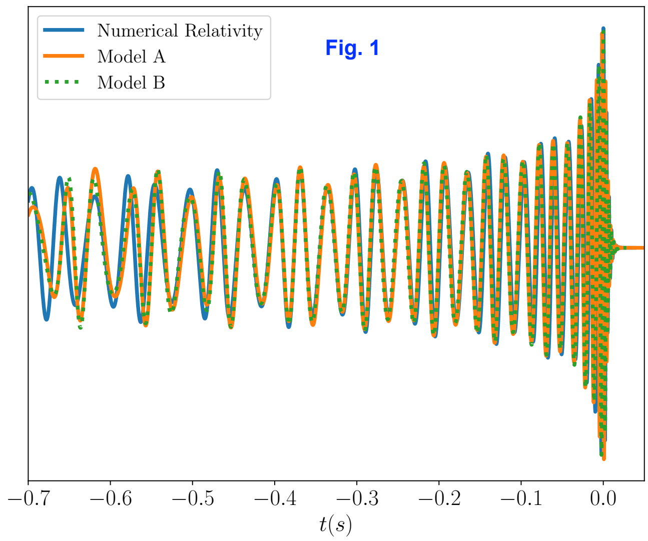
$$e_X(t) = \frac{X_{NR}(t) - X_c(t)}{2X_c(t)}.$$

- ✓ The eccentricity estimator e_X can be modeled with four parameters. (A, B, f, φ)
- ✓ Fit e_X for different mass ratios and eccentricities.
- ✓ Apply the model to semi-analytical waveform, such as IMRPhenom* or SEOB* models.

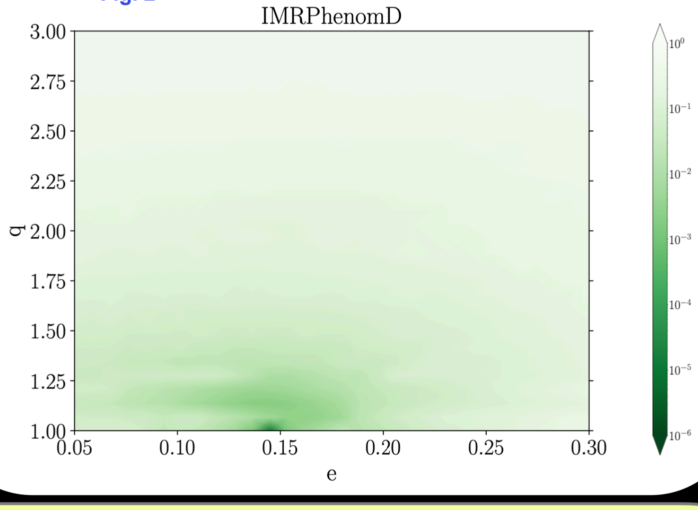
CONCLUSION & FUTURE STUDIES

- ✻ Algorithm is publicly available in a python package [1].
- ✻ IMR model: hybridize with 4PN inspiral [3].
- ✻ Expand with higher eccentricity, $e \geq 0.2$ and mass ratio $q \geq 3$

RESULTS



- Waveform A: IMRPhenomD and waveform B: SEOBNRv4 with the 'twisted' eccentricity.
- Compute the overlap maximised over phase shift and the phase parameter, φ.
- Minimum mismatch around 0.98 with aLIGO A+ design sensitivity curve.
- Mismatch results are relatively similar with other 3G detectors: Cosmic Explorer and Einstein Telescope.
- Fig. 2: 'Injection' results for $q = 1, e = 0.144$ and recovered by waveforms with $0 \leq q \leq 3$ and $0 \leq e \leq 0.3$.



REFERENCES

[1] https://bit.ly/3wvV8H7
[2] https://data.black-holes.org/waveforms/catalog.html
[3] Cho, Tanay, Gopakumar, Lee (in prep.)

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KEYWORDS

Waveform, binary-black-hole, eccentricity