Gravitational Waveform Model for eccentric Binary Compact Object coalescence

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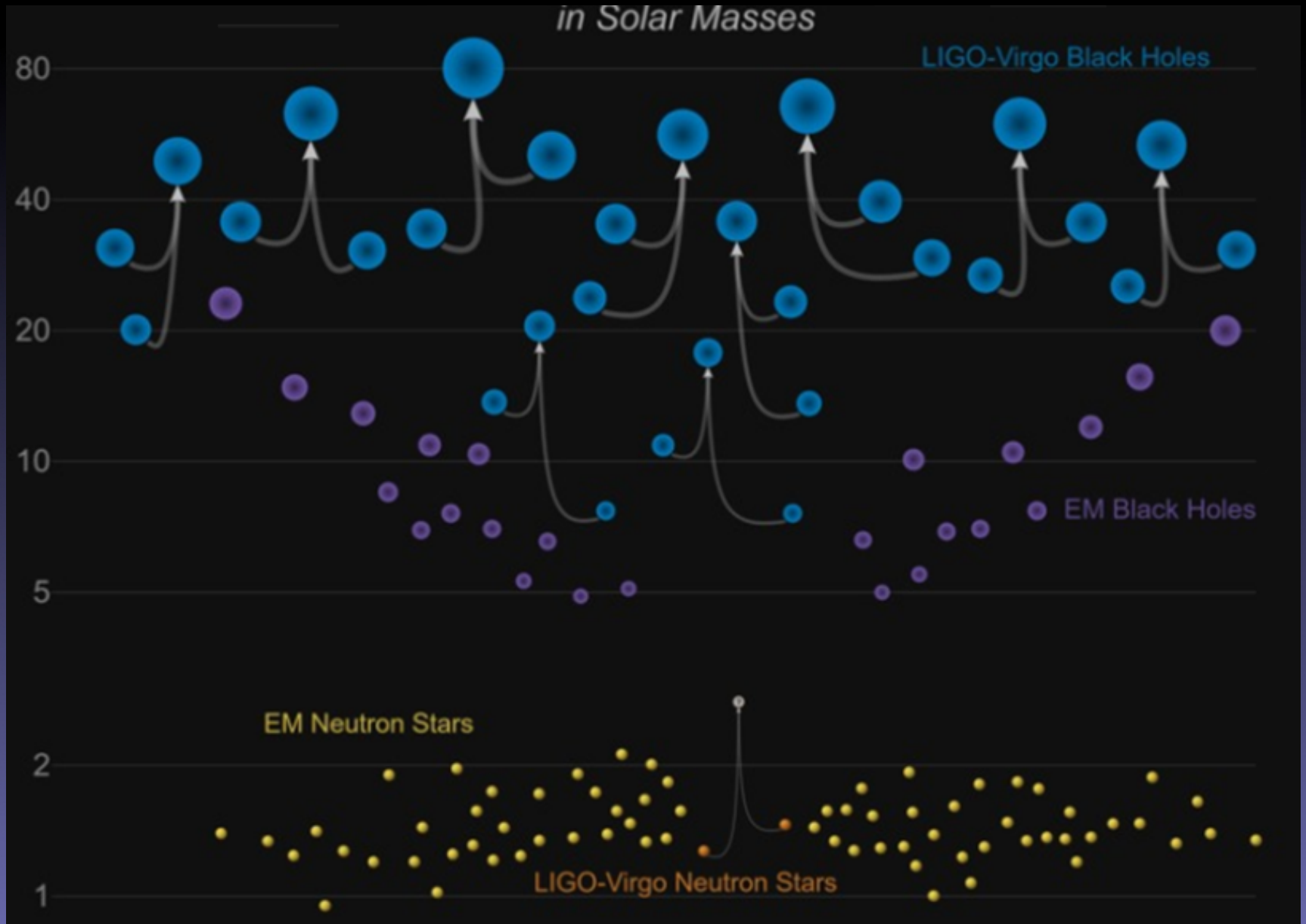
The 8th Huada QCD School

LIGO O1 and O2



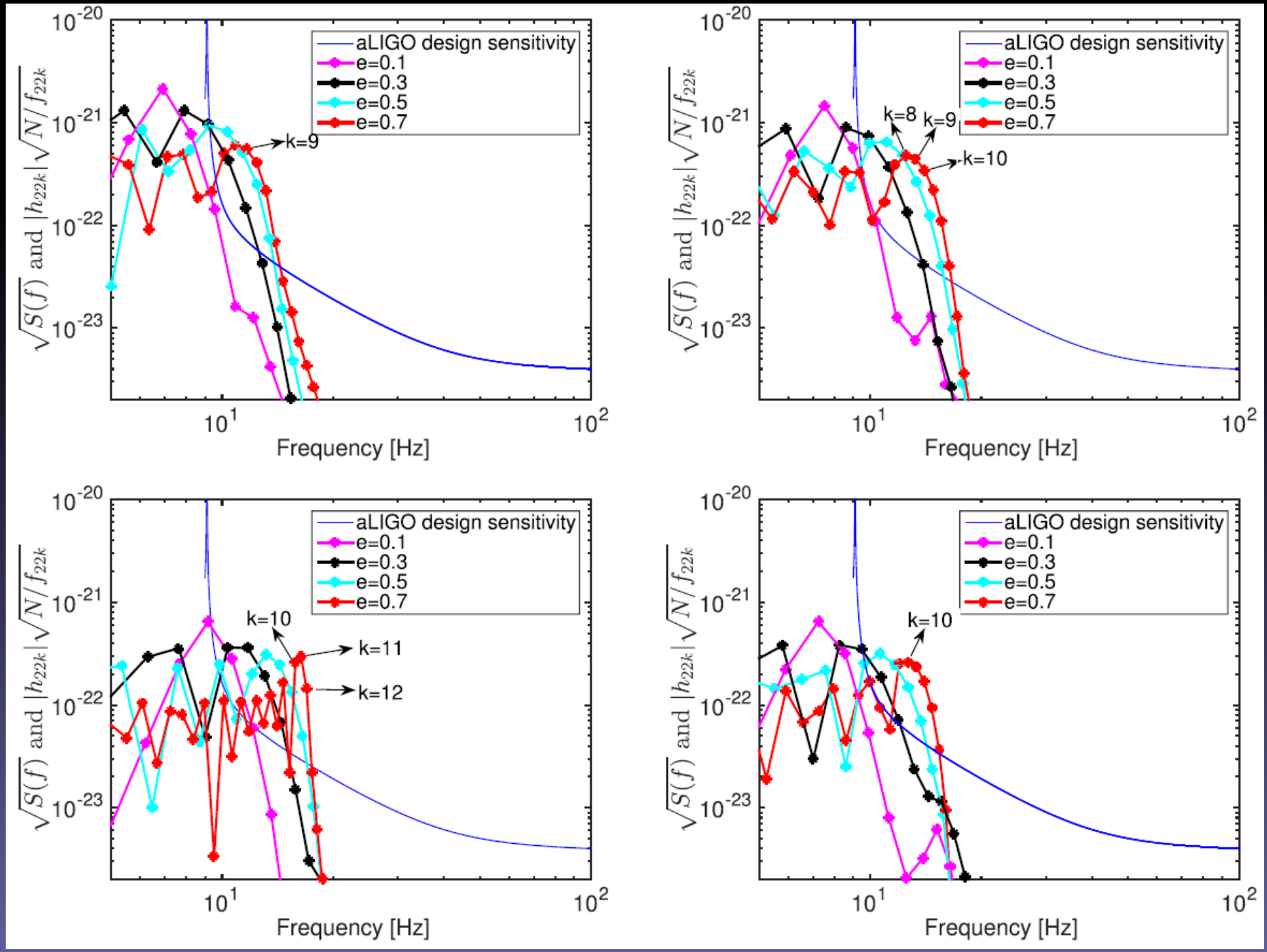
LIGO O3

Binary Black Hole

Binary Neutron star

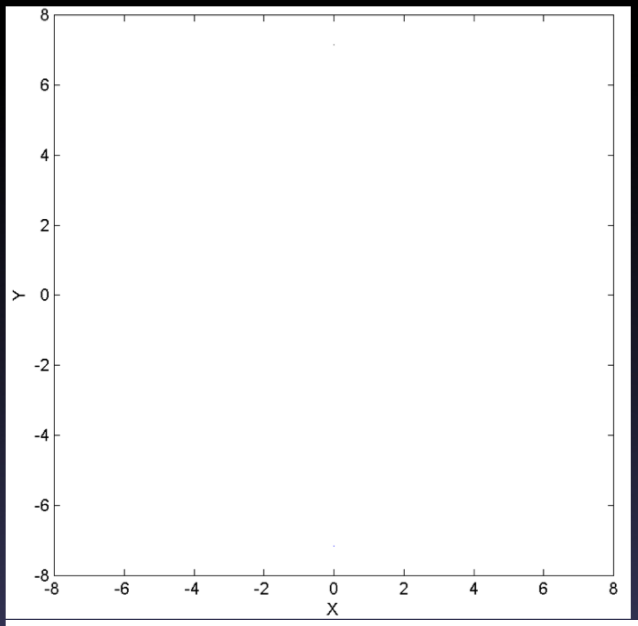
Black Hole-neutron star binary

Intermediate massive black hole binary ~ 1000 solar mass?



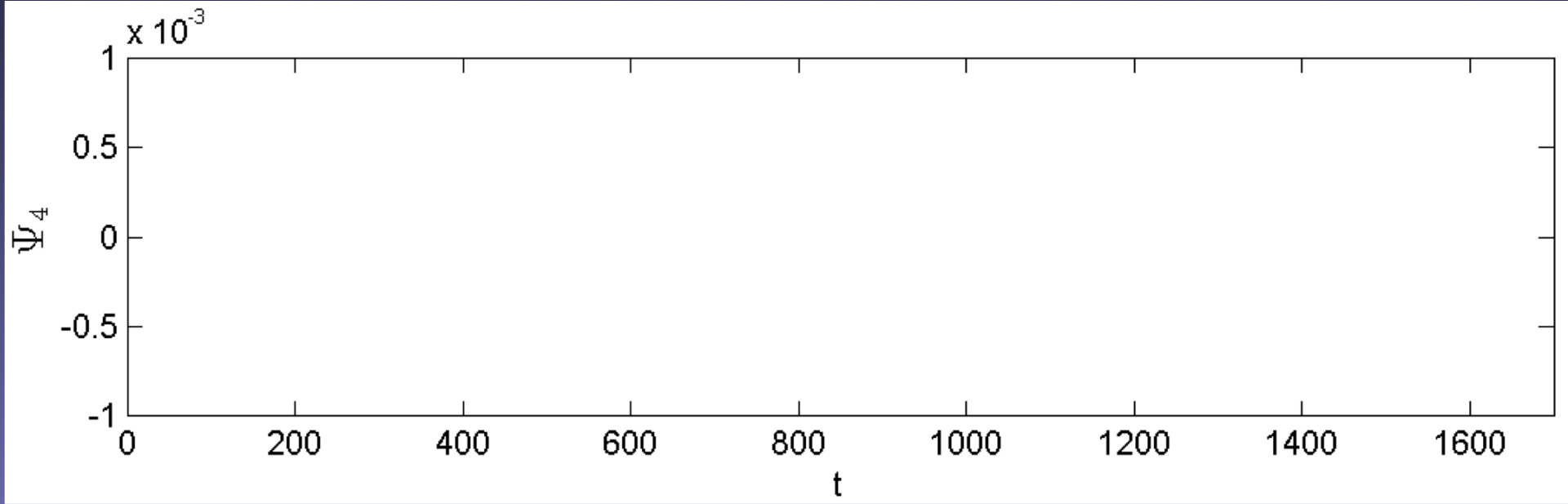
Wen-Biao Han, Cao, Yi-Ming Hu, CQG, 2017

Binary Black Hole with eccentric orbit



Plausible source for LIGO

Many sources for LISA



Properties of the Binary Black Hole Merger GW150914

EOBNR models are called SEOBNRv2, SEOBNRv3 and SEOBNRv2_ROM_DoubleSpin, respectively). Bayesian analyses that use the double precessing spin model [55] are more time consuming and are not yet finalized. The results will be fully reported in a future publication.

An alternative inspiral-merger-ringdown phenomenological formalism [79–81] is based on extending frequency-domain PN expressions and hybridizing PN and EOB with NR waveforms. Henceforth, we use "IMRPhenom" to indicate waveforms within this formalism. Several waveform models that include aligned-spin effects have been

State of art for EOBNR

- Total mass: $0<M<\infty$
- Mass ratio: $1<q<20$

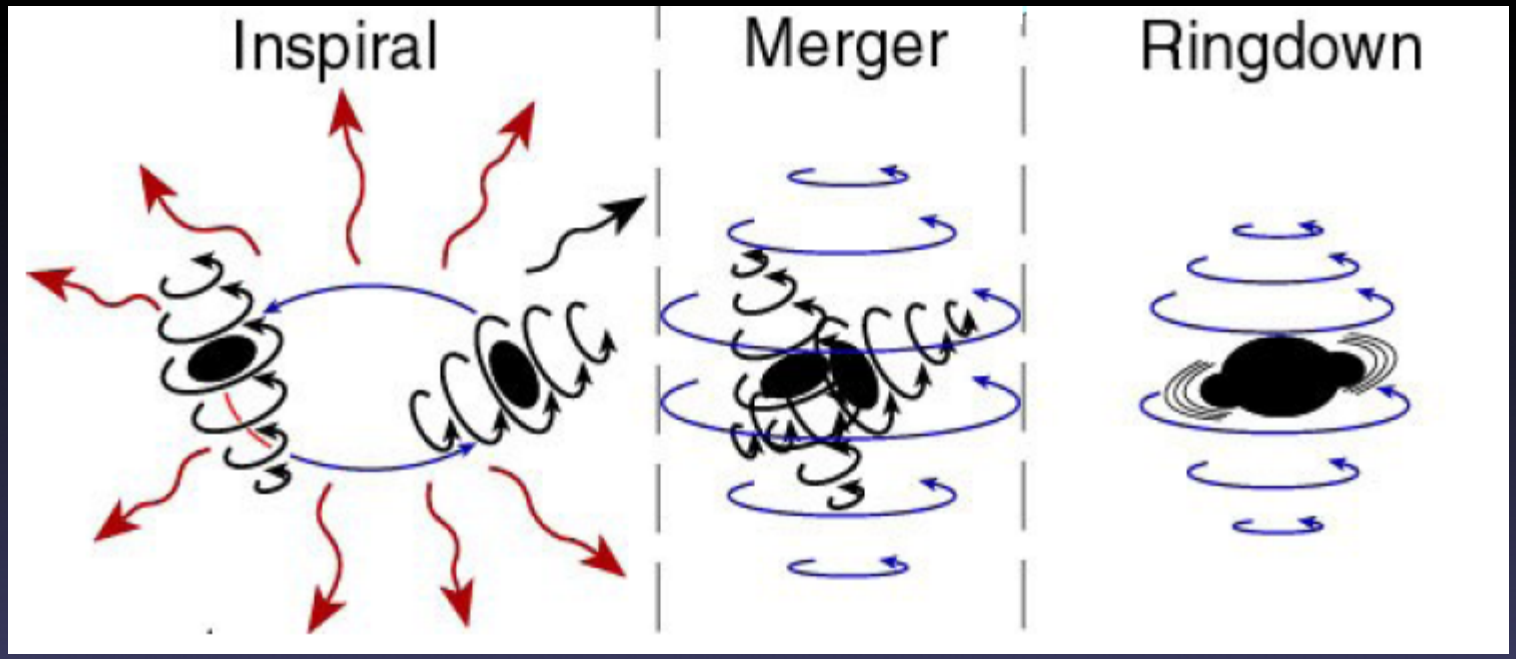
  GW150914 (1.24), LVT151012 (1.77), GW151226 (1.89), GW170104 (1.61), GW170608 (1.71), GW170814 (1.21)
- Spin: $-1<s<0.9$

  GW150914 (<0.24), LVT151012 (<0.3), GW151226 (<0.35), GW170104 (<0.42), GW170608 (<0.3), GW170814 (<0.18)
- Precession simplified (BCV)

  GW150914, LVT151012 & GW151226 assume no precession, GW170104, GW170608 & GW170814 gain little constrain on precession
- e = 0

  All announced CBC GW events assumed

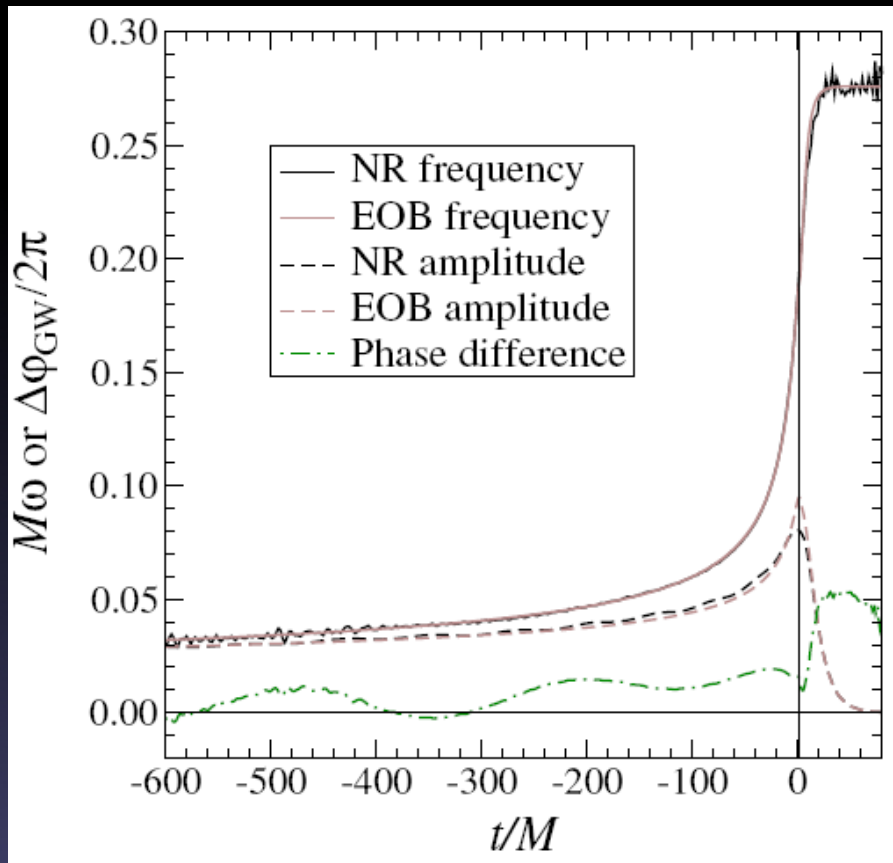
Effective One Body Numerical Relativity model

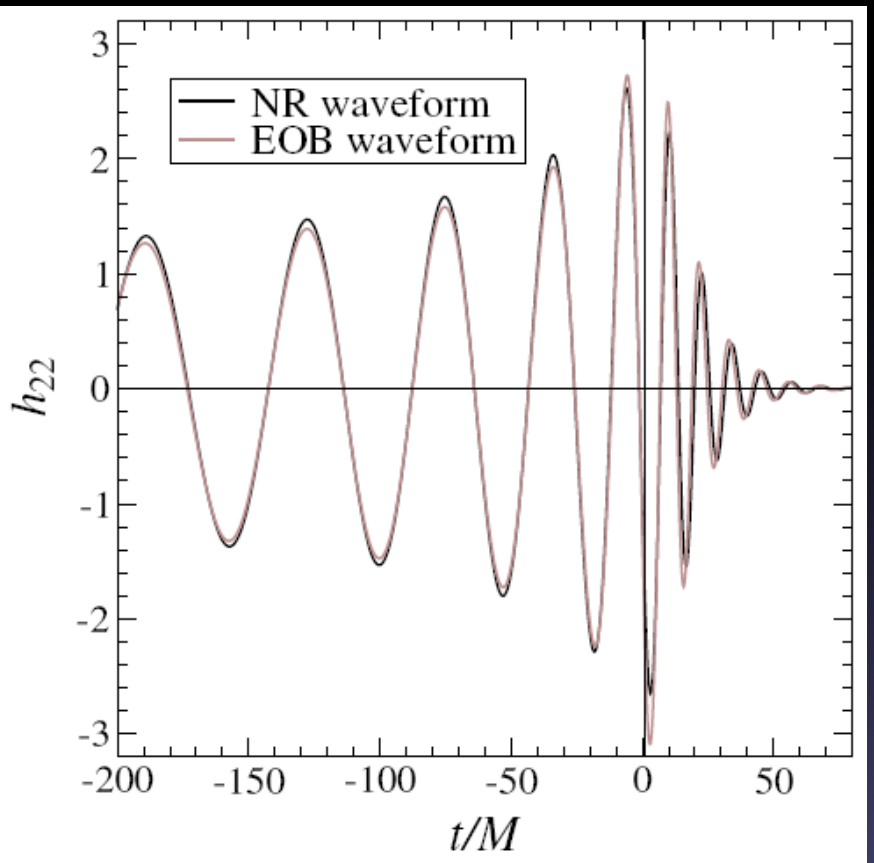


EOB formalism: improved PN [Buonanno and Damour, PRD 1999]

EOBNR: set more parameters and fit NR [Buonanno, Pan， et al, PRD 2007]

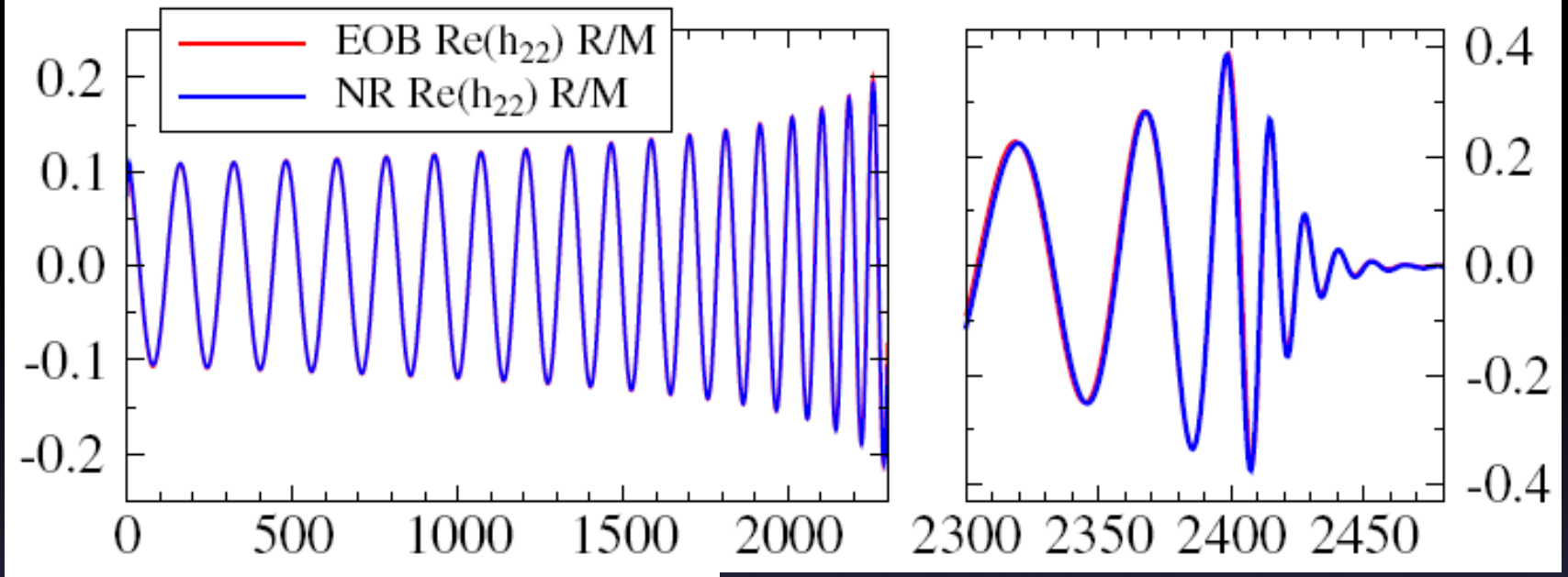
calibrate to NR results [Buonanno, Pan, et al, PRD 2009 (nonspinning, equal mass black holes), 2010 (nonprecessing, spinning, equal-mass black holes), 2014 (generic mass ratios and aligned spins), 2014 (spinning, precessing)]

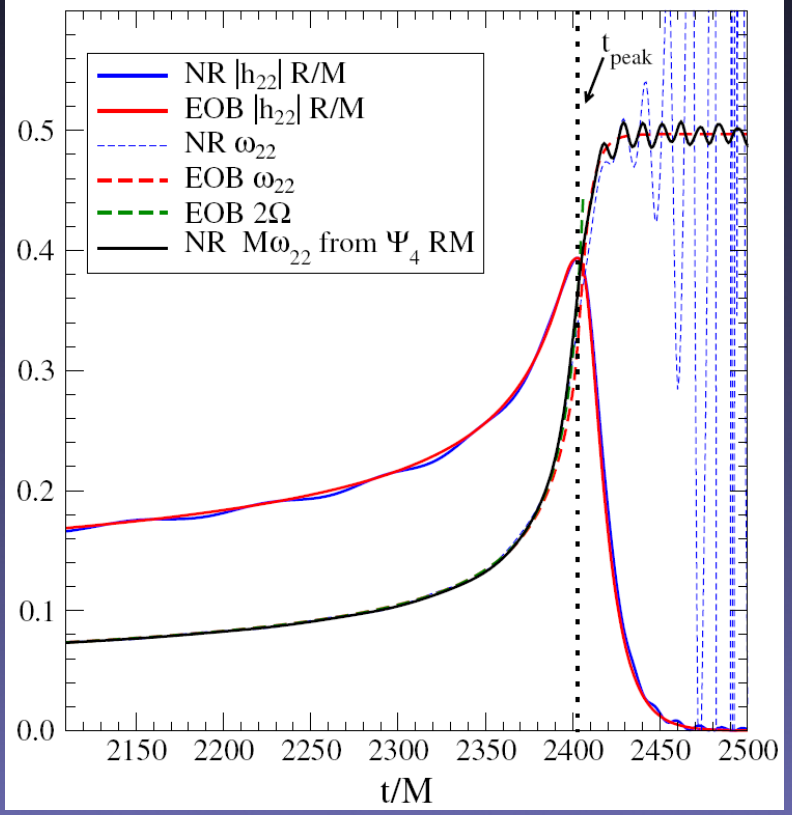




set more parameters and fit NR [Buonanno, Pan，et al, PRD 2007]

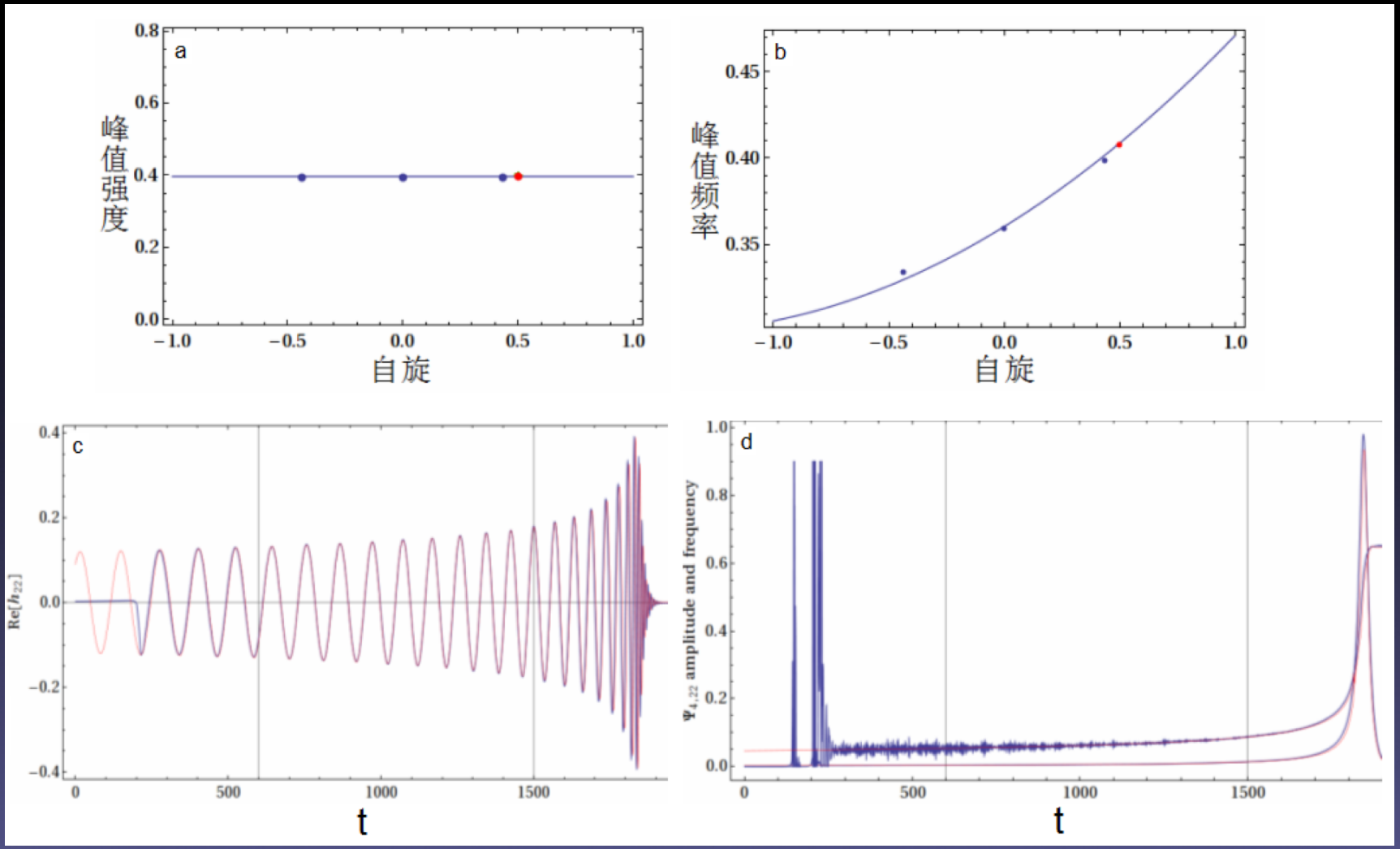
NR results of NASA group





calibrate to NR results [Buonanno, Pan，et al, PRD 2010 (nonprecessing, spinning, equal-mass black holes)

NR results of Caltech/Cornell group



AMSS-NCKU result, Cao, Pan, Yo, et al, 2012

SEOBNRE model

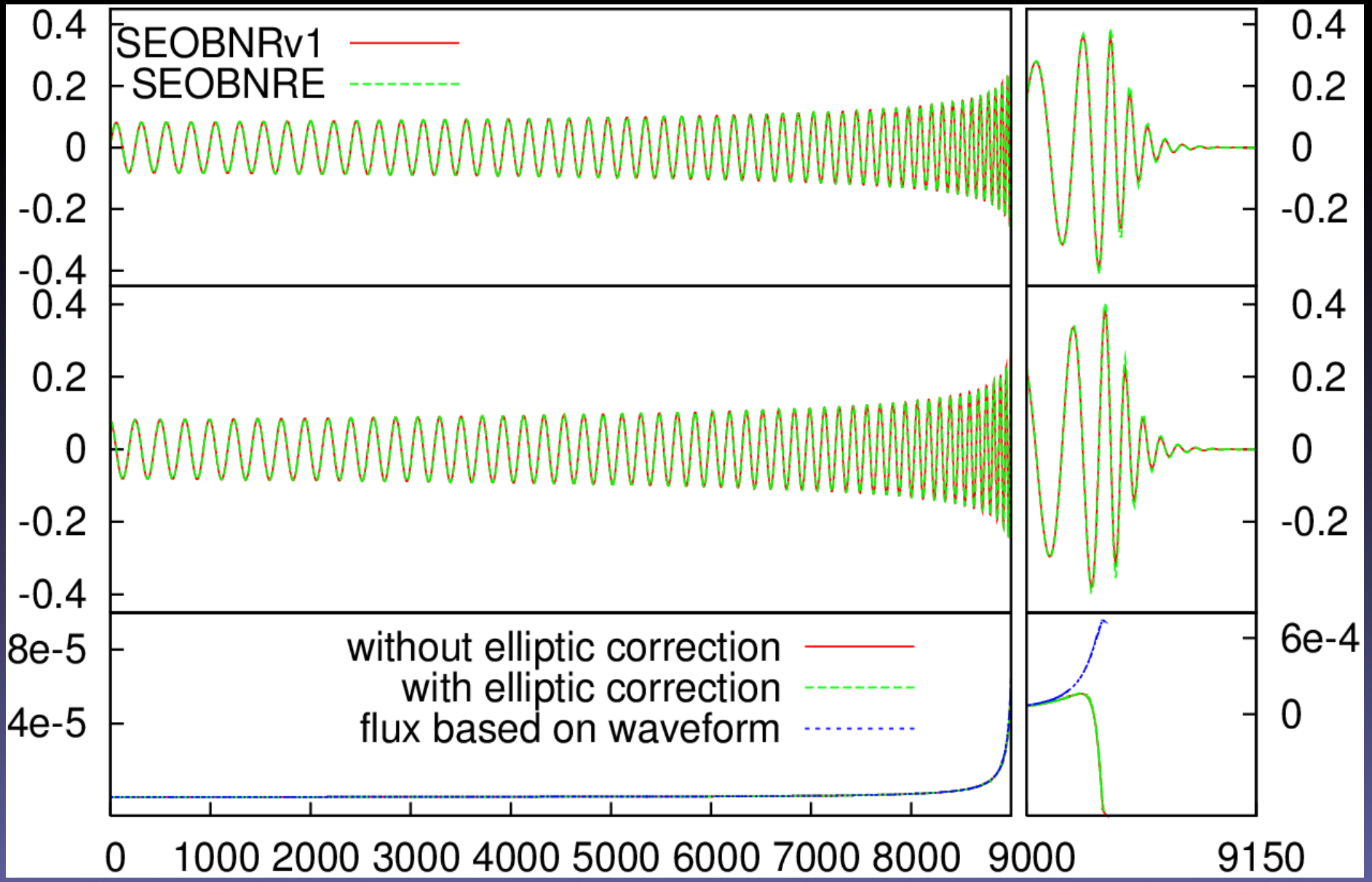
$$h_{22}^{insp-plun} = h_{22}^{(C)} + h_{22}^{(PNE)}$$

$$\frac{dE}{dt} = \frac{dE}{dt}|_{(C)} + \frac{dE}{dt}|_{Elip}$$

Assume small eccentricity expansion

(c) part effectivly more than 4 PN

Elip part about 2PN


SEOBNRv1
SEOBNRE
0.4
0.2
0
-0.2
-0.4
without elliptic correction
with elliptic correction
flux based on waveform
8e-5
4e-5
6e-4
0
0 1000 2000 3000 4000 5000 6000 7000 8000 9000 9150

ax-model for eccentric BBH

PHYSICAL REVIEW D **95,** 024038 (2017)

Complete waveform model for compact binaries on eccentric orbits

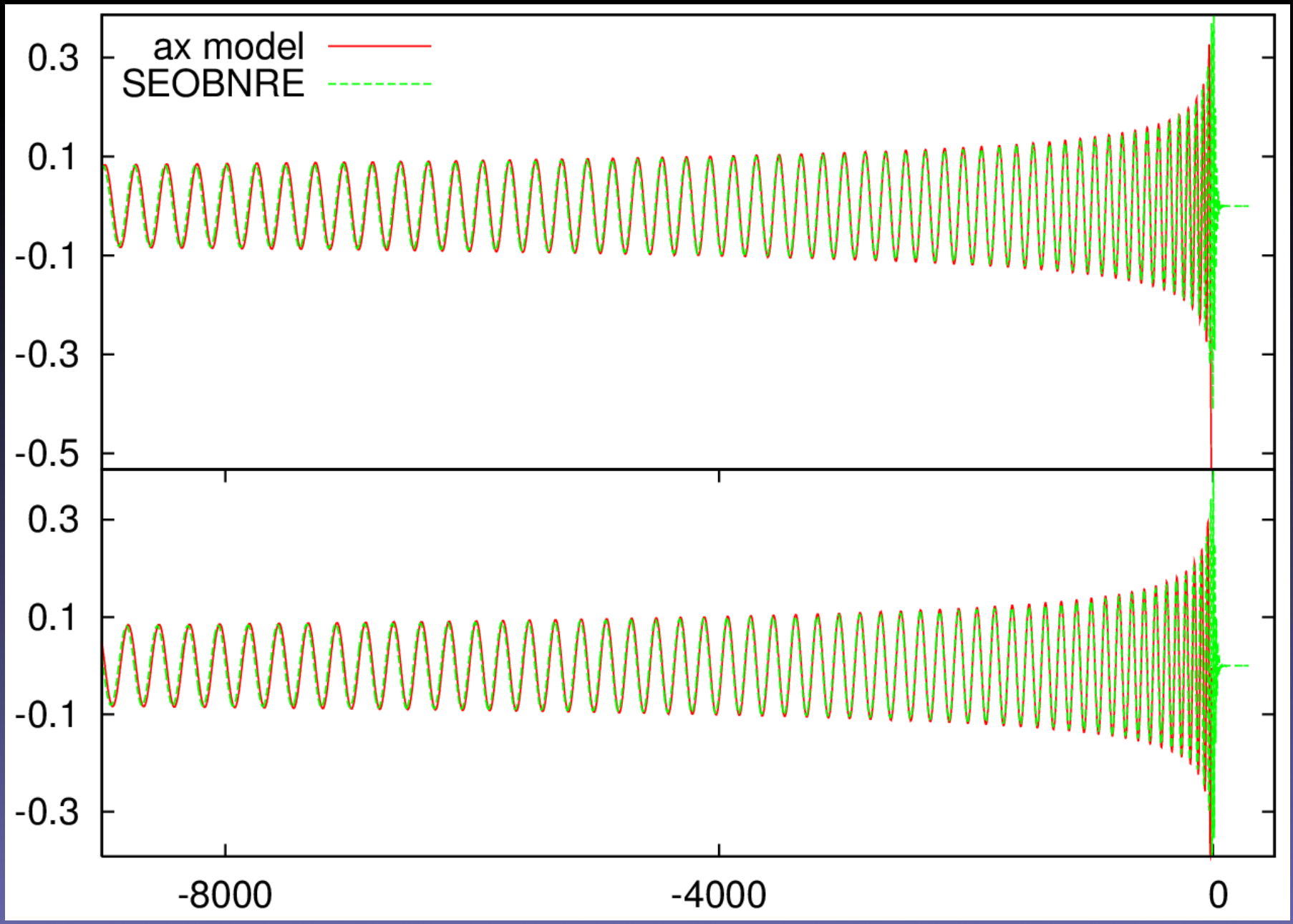
E. A. Huerta,[1,*] Prayush Kumar,[2] Bhanu Agarwal,[3,4] Daniel George,[5] Hsi-Yu Schive,[1] Harald P. Pfeiffer,[2,6,7] Roland Haas,[1] Wei Ren,[8,4] Tony Chu,[9] Michael Boyle,[10] Daniel A. Hemberger,[11] Lawrence E. Kidder,[10] Mark A. Scheel,[11] and Bela Szilagyi[11,12]

$$M\dot{x} = \dot{x}_{0\mathrm{PN}}x^5 + \dot{x}_{1\mathrm{PN}}x^6 + \dot{x}_{2\mathrm{PN}}x^7 + \dot{x}_{3\mathrm{PN}}x^8 + \dot{x}_{\mathrm{HT}},$$

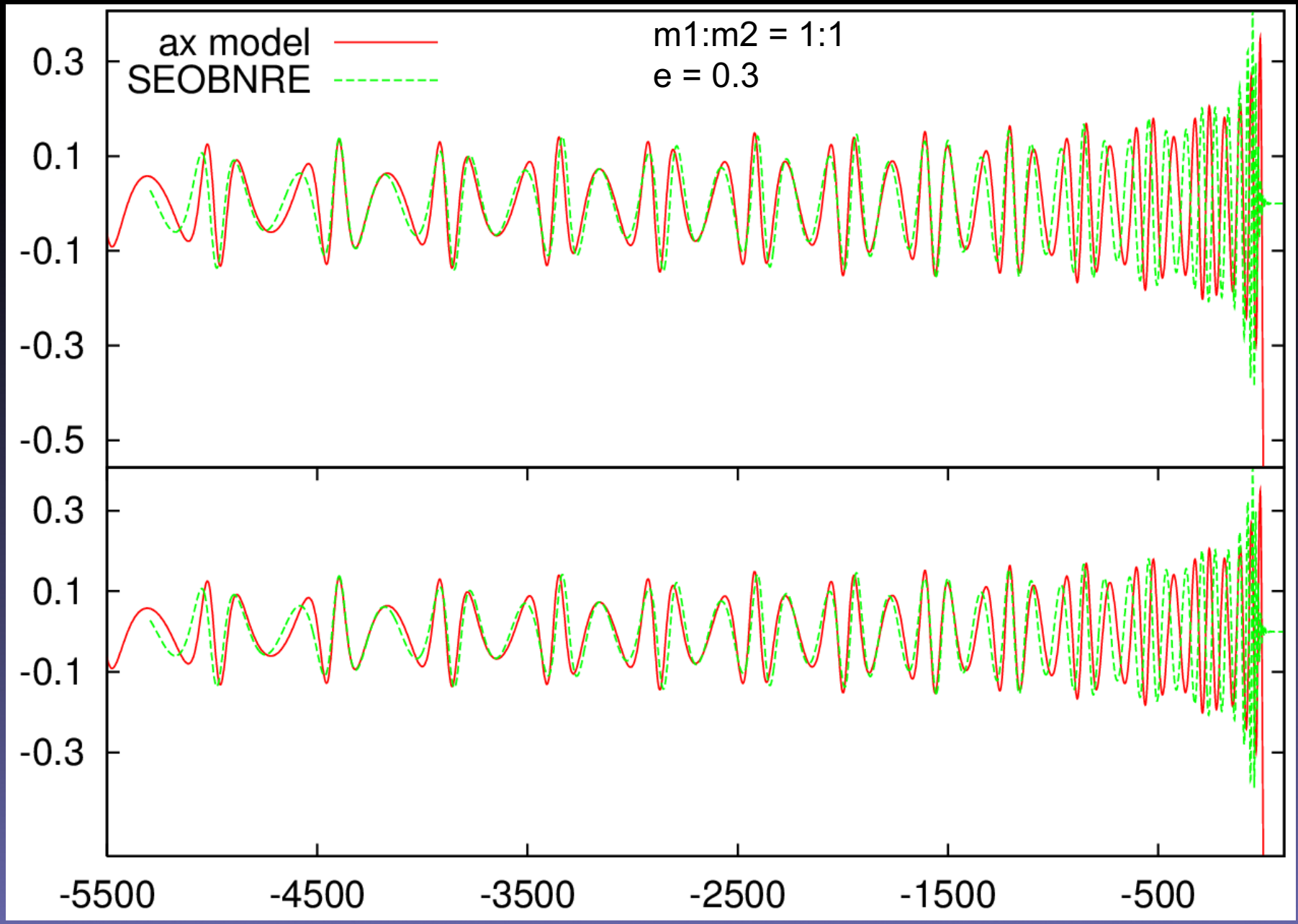
$$M\dot{e} = \dot{e}_{0\mathrm{PN}}x^4 + \dot{e}_{1\mathrm{PN}}x^5 + \dot{e}_{2\mathrm{PN}}x^6 + \dot{e}_{3\mathrm{PN}}x^7 + \dot{e}_{\mathrm{HT}}.$$

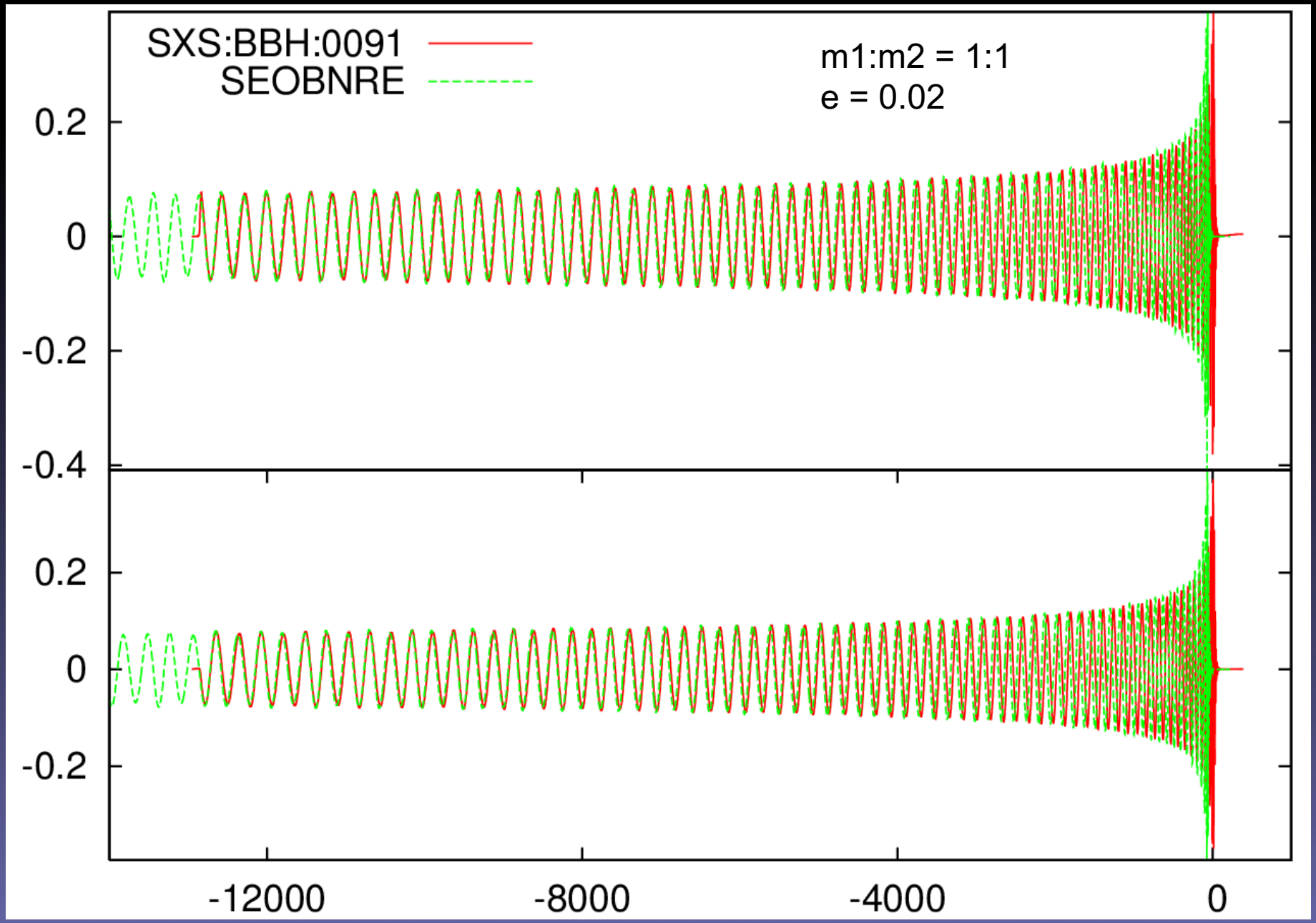
adiabatic approximation model

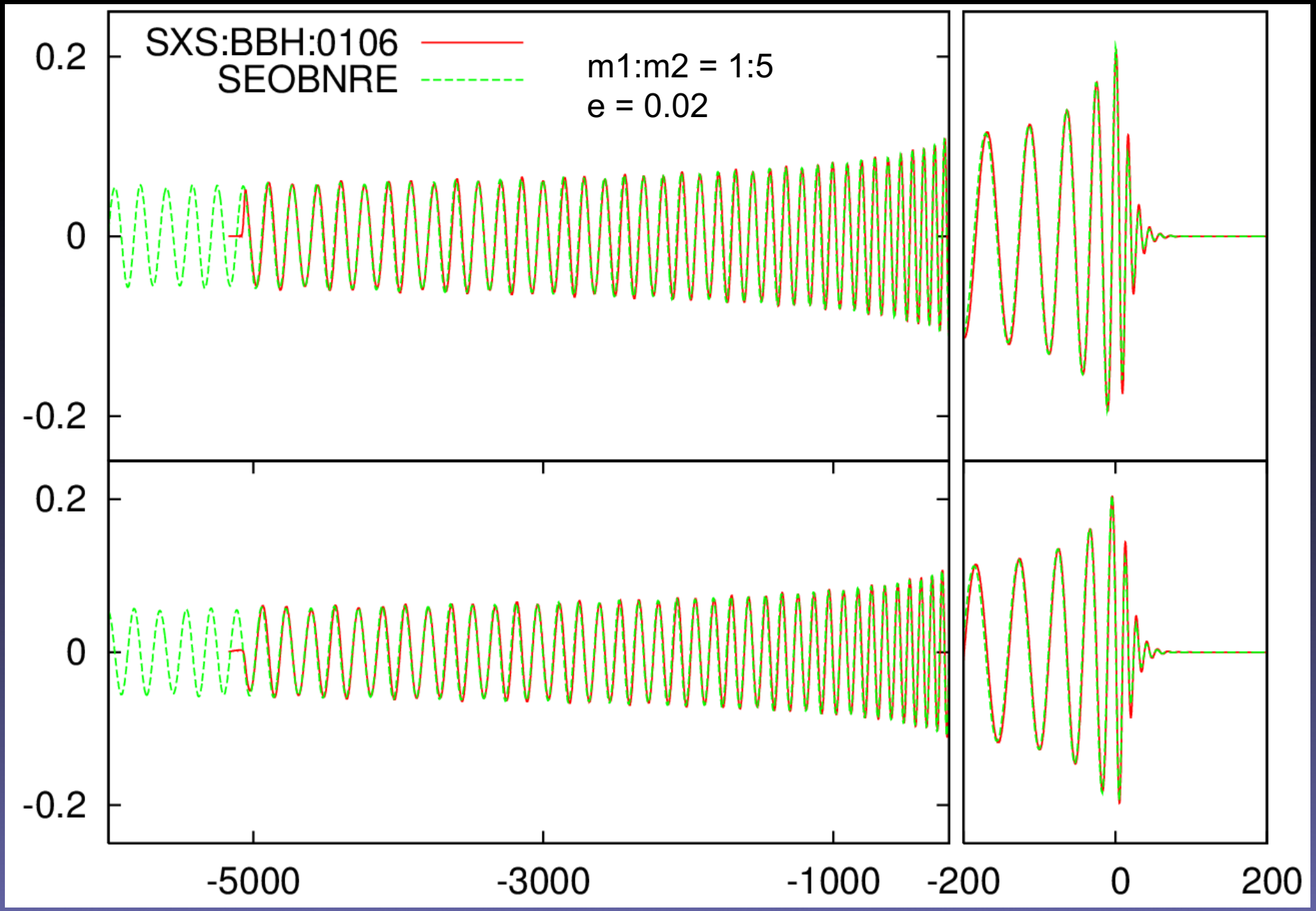
SEOBNRE model is more accurate than ax model for e=0 case

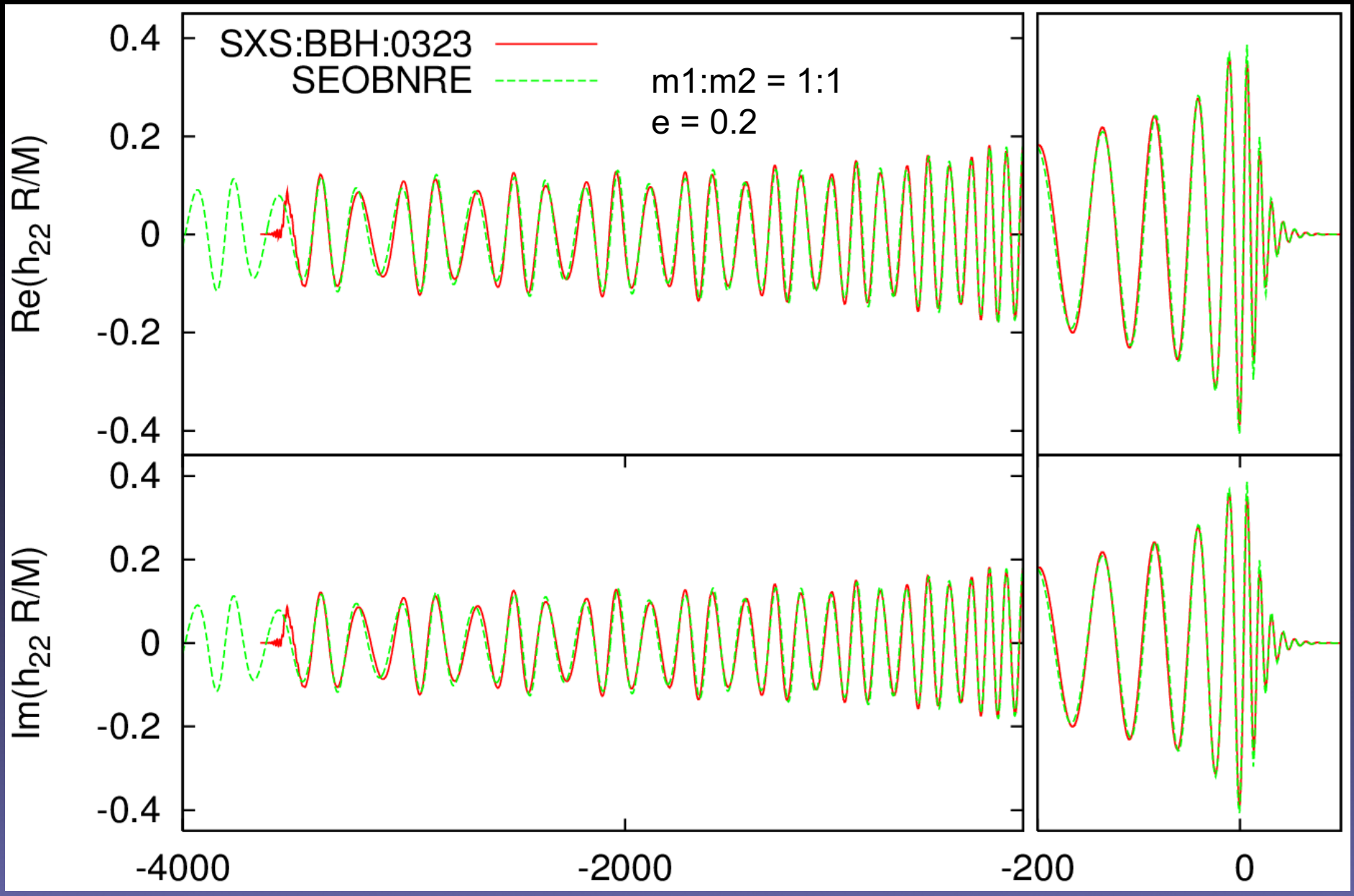


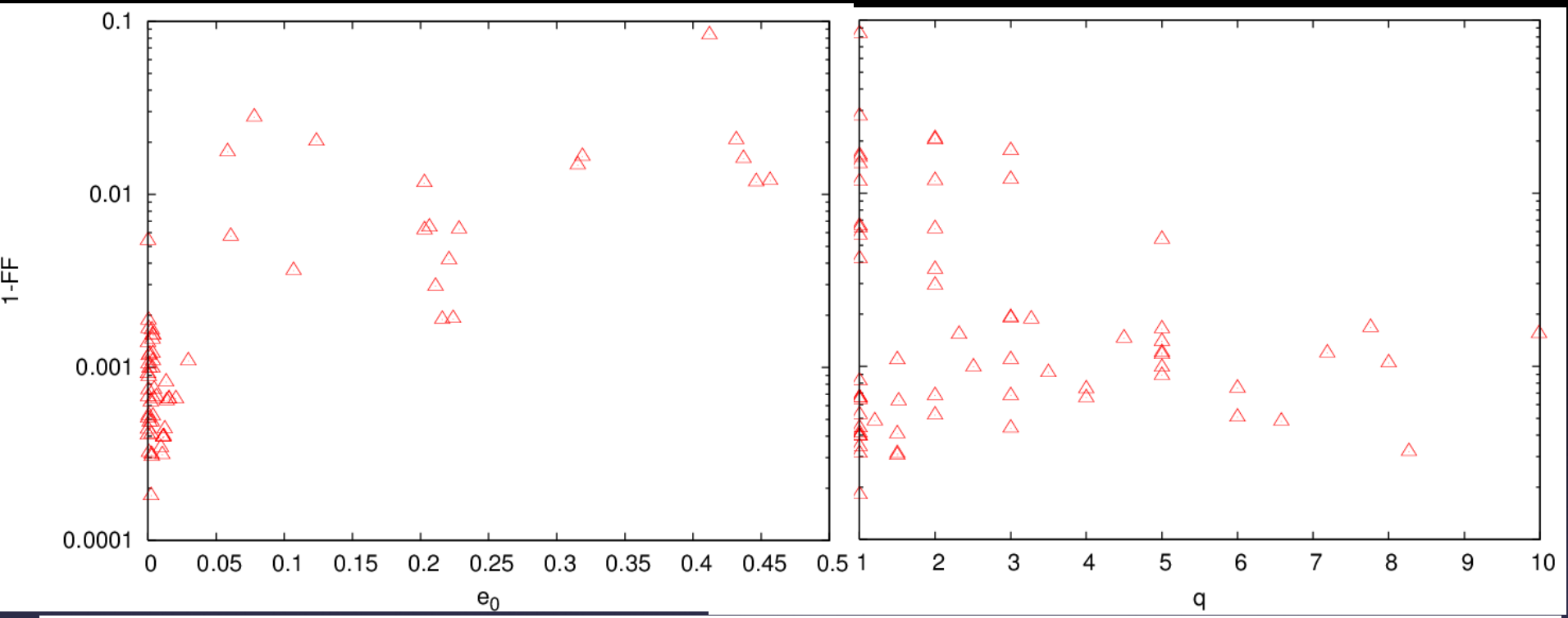
Phase error accumulated

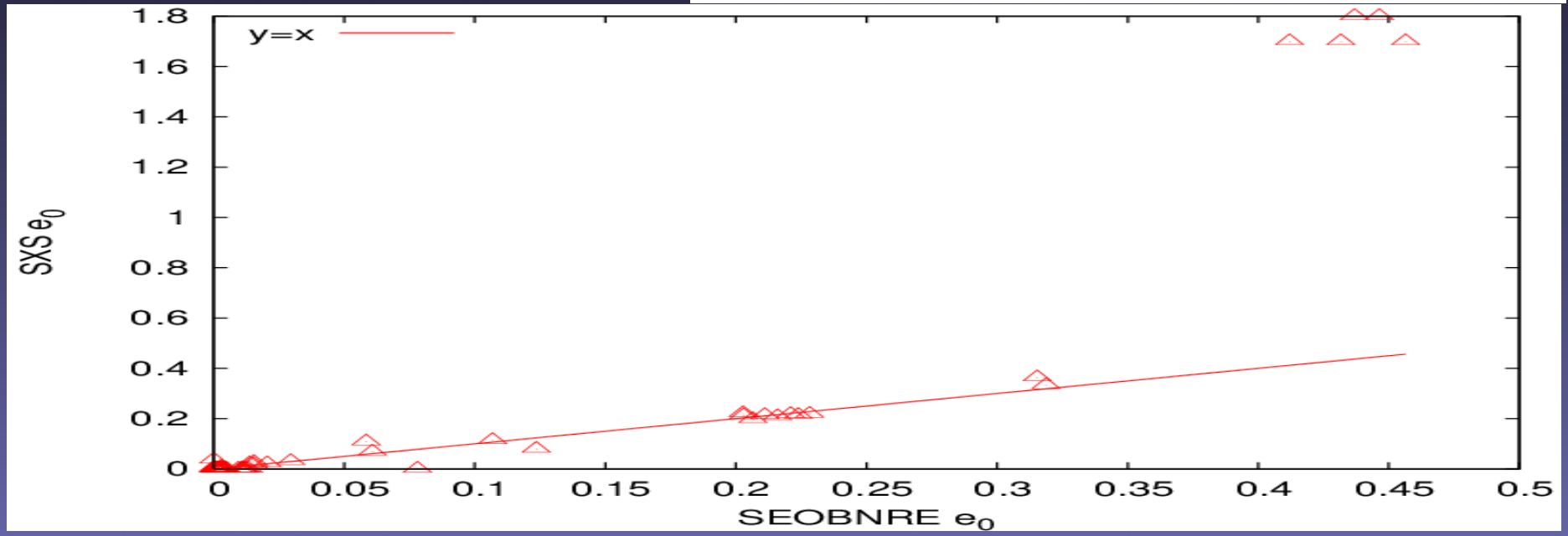



SXS:BBH:0091
SEOBNRE
m1:m2 = 1:1
e = 0.02
0.2
0
-0.2
-0.4
0.2
0
-0.2
-12000
-8000
-4000
0

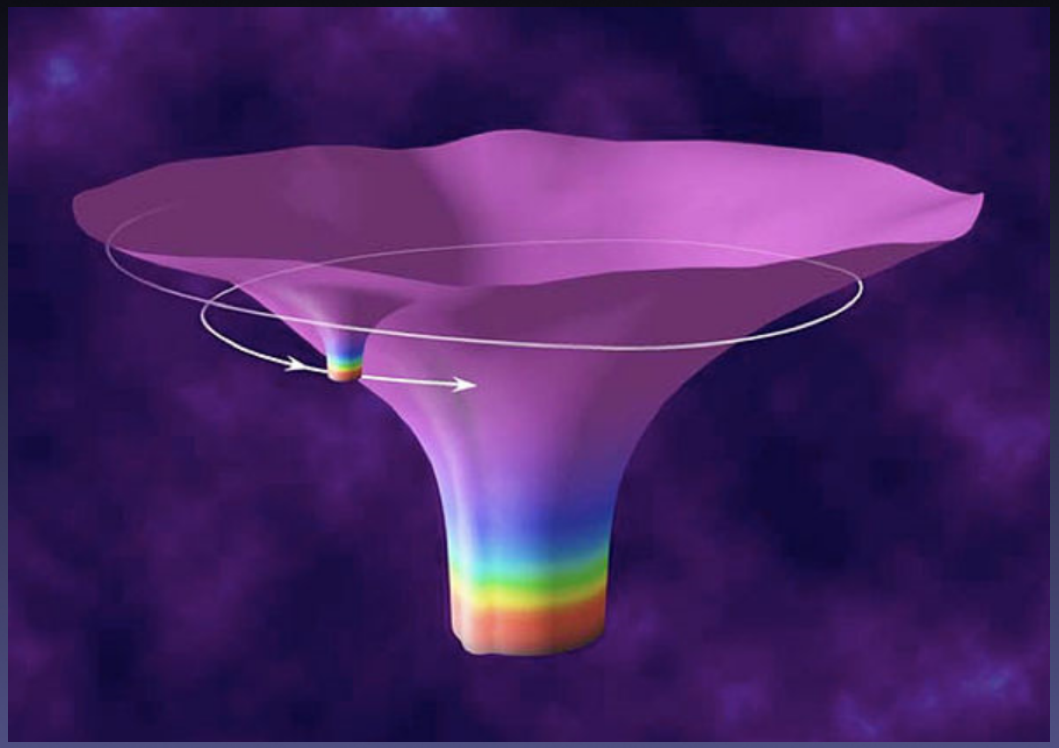

SXS:BBH:0106
SEOBNRE
m1:m2 = 1:5
e = 0.02
0.2
0
-0.2
0.2
0
-0.2
-5000
-3000
-1000
-200
0
200


SXS:BBH:0323
SEOBNRE
m1:m2 = 1:1
e = 0.2
Re(h22 R/M)
Im(h22 R/M)
0.4
0.2
0
-0.2
-0.4
-4000
-2000
-200
0


1-FF
0.1
0.01
0.001
0.0001
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
e_0
1
2
3
4
5
6
7
8
9
10
q

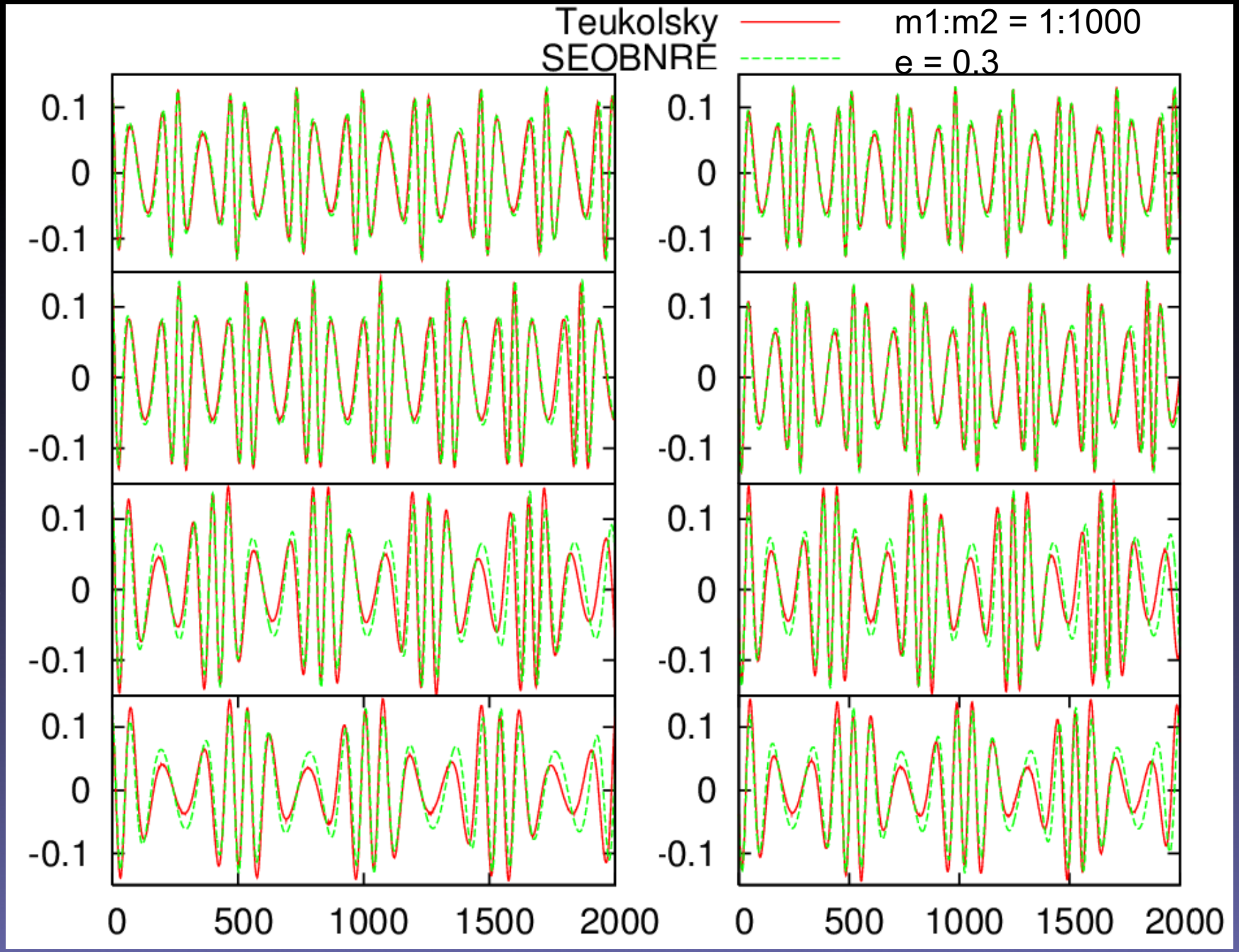

y=x
SXS e_0
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
SEOBNRE e_0

Perturbation model for extreme mass ratio BBH



Teukolsky equation based model:

1. Trajectory of small BH
2. Perturbation to big BH


Teukolsky
SEOBNRE
m1:m2 = 1:1000
e = 0.3
a = 0.9
a = 0.5
a =-0.5
a =-0.9
0.1
0
-0.1
0
500
1000
1500
2000

Summary

- EOBNR is promising to convert NR to reliable GW theoretical model
- SEOBNRE the EOBNR model including eccentricity
- Eccentric BNS, what astrophysics?