NR-EOB comparison

EOB@Work 2023: Fall Meeting

Torino, October 16, 2023

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Comparison EOB - ICC/RIT/MAYA/SXS

- example plots of very different waveform
- plot of initial data in (E0,J0) plane, superpose NR pts on EOB prediction plots
- encounter histogram plot (see Nagar+ 2021)
- example plot with EOB potential and different orbits
- mismatch summary plots for all data (eccentric, dynamical encounter, scattering from BCN, RIT, SXS etc)
- table of scattering angles (Nagar-Hopper references)

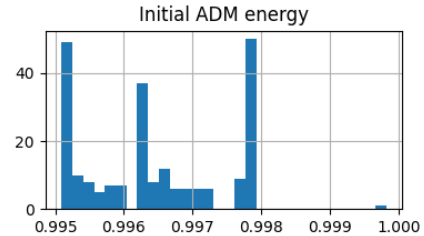
ICC catalogue

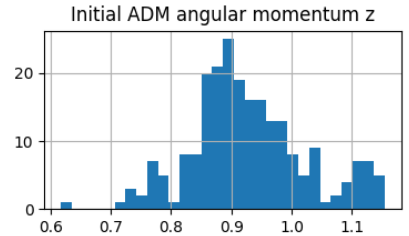
223 simulations

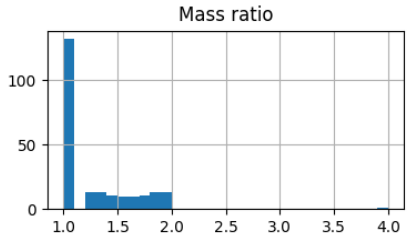
- **E0_ADM range: 0.9951 – 0.9998**
- **J0_ADM: 0.6169 – 1.1548**
- **Mass ratio: 1 – 1.95**
- **Chi: -0.5 – 0.5**
- **Initial separation: 40M**

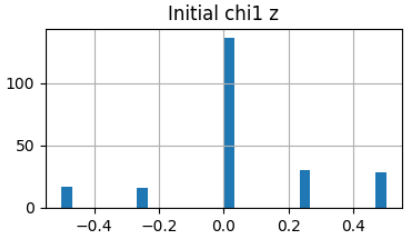
- **Three general sets**

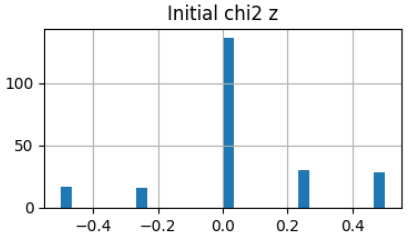
q	χ	# sims
1	0	37
1	-0.5 – 0.5	91
1.25 – 1.95	0	95

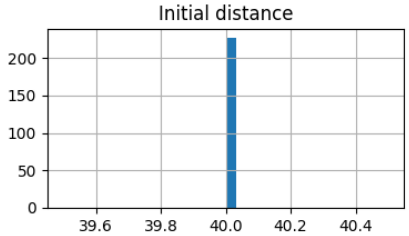


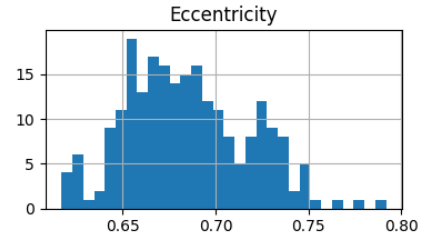










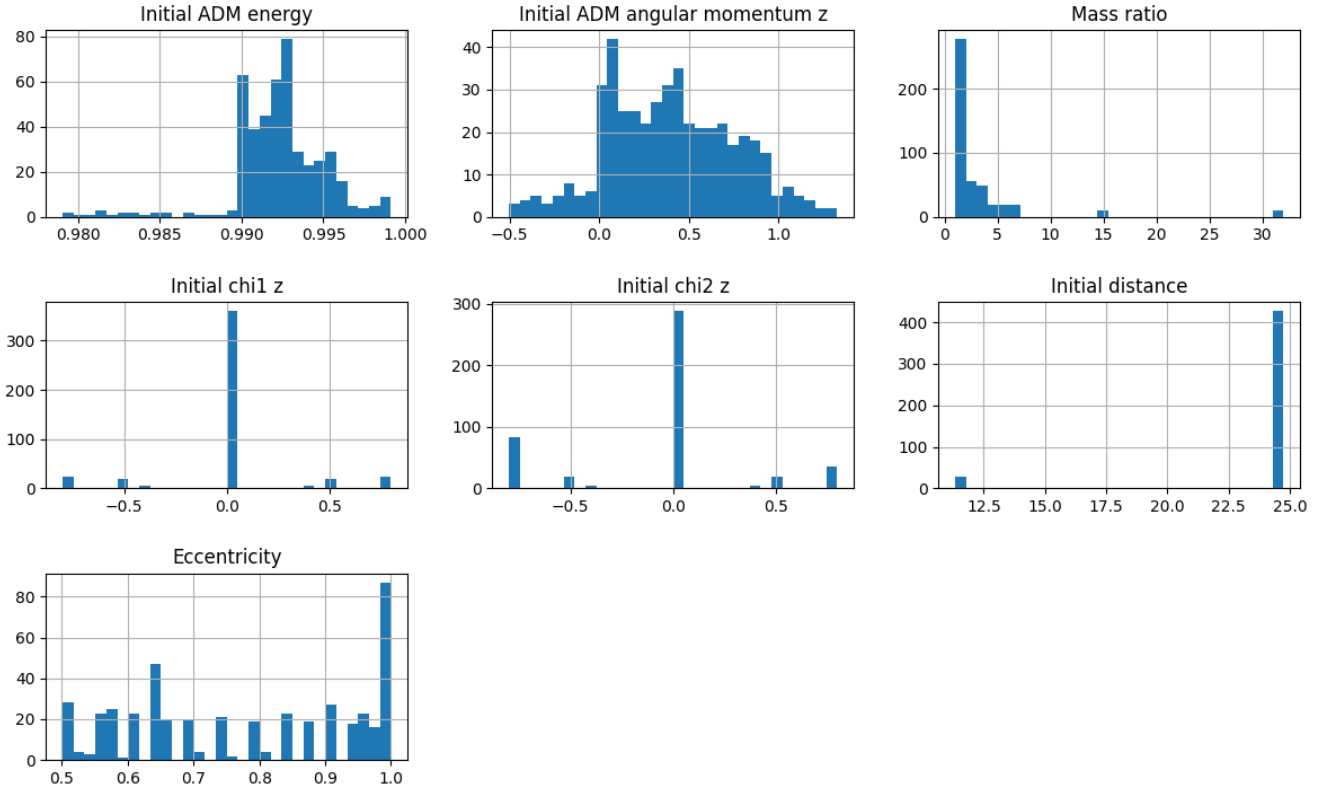


RIT catalogue

457 selected simulations

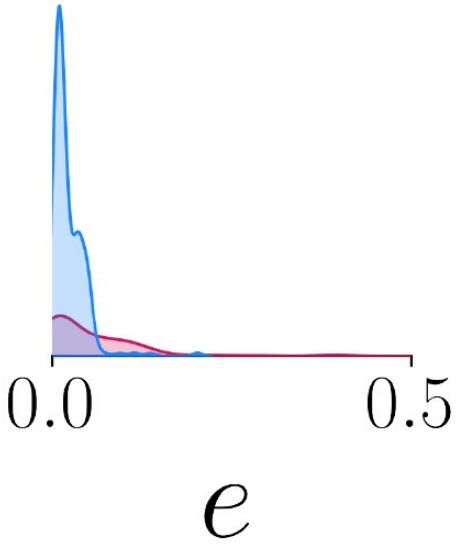
- E0_ADM range: 0.9790 – 0.9991
- J0_ADM: -0.5032 – 1.3259
- Mass ratio: 1 – 32
- Chi: -0.8 – 0.8
- Initial separation:

  11.33M – 24.75M



2nd Maya Catalogue

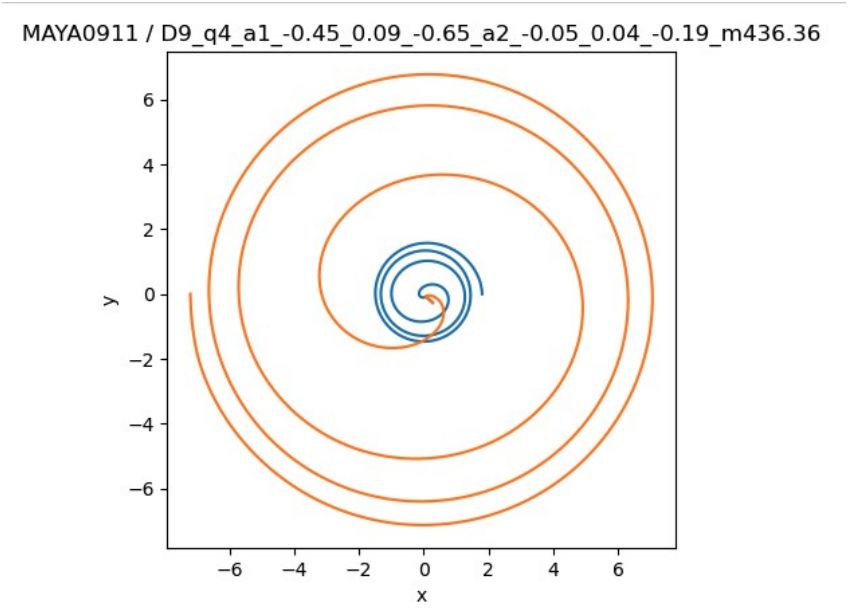
- Sep 2023 → Second Maya Catalogue
  - Total: 181 waveforms
    - 55 with high mass ratio q>=4
    - 48 precessing
    - 92 eccentric (e>0.01)

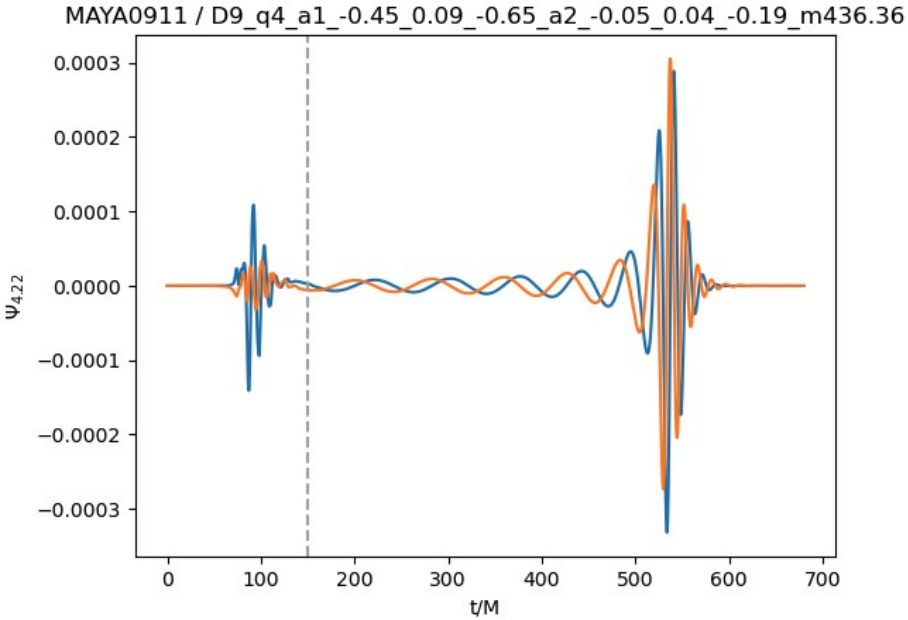


92 eccentric

- 80 waveforms
  - Mass ratio 1 <= q <= 4 (by steps of 1)
  - Spins a1 = a2 = {0,0.4} aligned with J
  - 0.01 < e < 0.1
- 5 waveforms
  - Mass ratio q = 1
  - Eccentricity up to e = 0.6
- 7 waveforms
  - Eccentricity and precession

e = 0.004

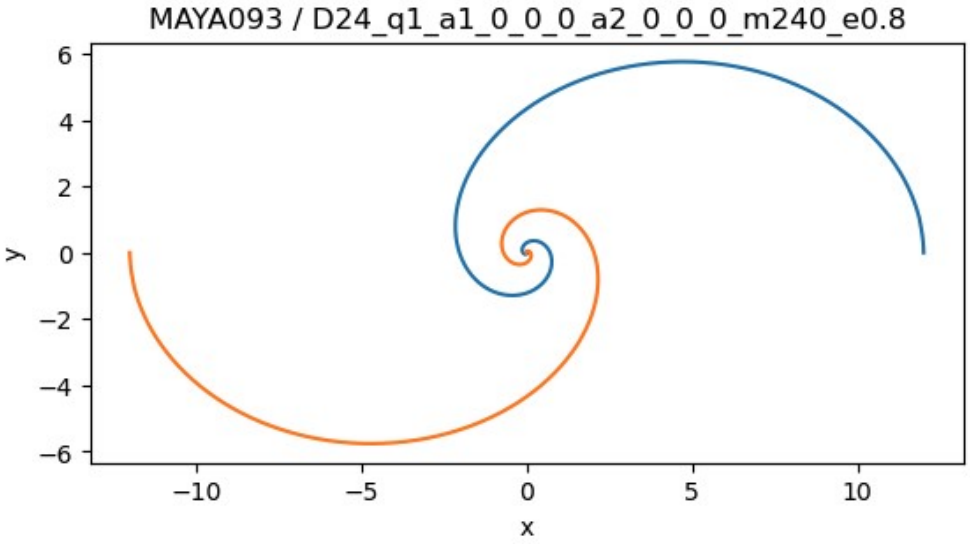

MAYA0911 / D9_q4_a1_-0.45_0.09_-0.65_a2_-0.05_0.04_-0.19_m436.36
6
4
2
0
−2
−4
−6
y
−6
−4
−2
0
2
4
6
x

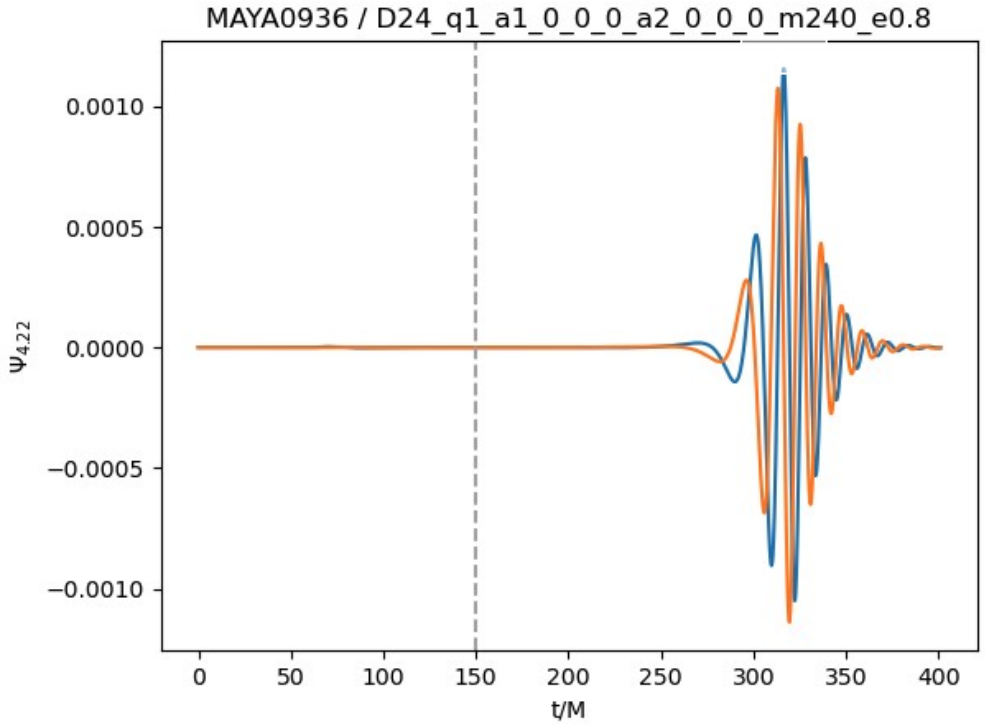

MAYA0911 / D9_q4_a1_-0.45_0.09_-0.65_a2_-0.05_0.04_-0.19_m436.36
0.0003
0.0002
0.0001
0.0000
−0.0001
−0.0002
−0.0003
Ψ422
0
100
200
300
400
500
600
700
t/M

92 eccentric (e>0.01)

- 80 waveforms
  - Mass ratio 1 <= q <= 4 (by steps of 1)
  - Spins a1 = a2 = {0,0.4} aligned with J
  - 0.01 < e < 0.1
- 5 waveforms
  - Mass ratio q = 1
  - Eccentricity (4 with e <0.3 and 1 with e=0.6)
- 7 waveforms
  - Eccentricity and precession e<0.2

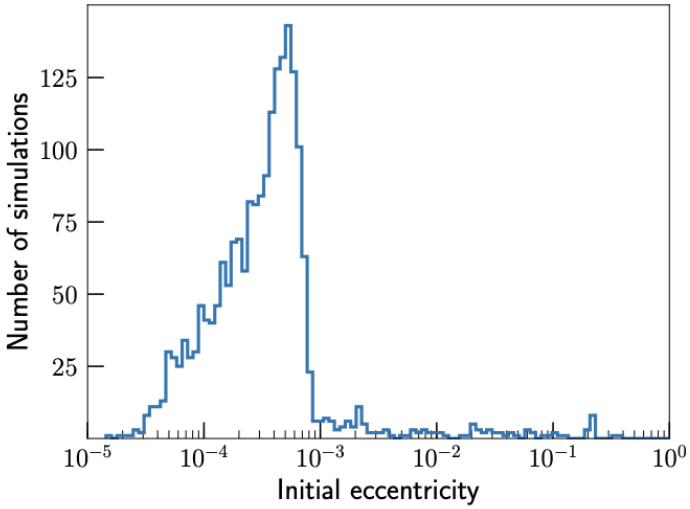
e = 0.6

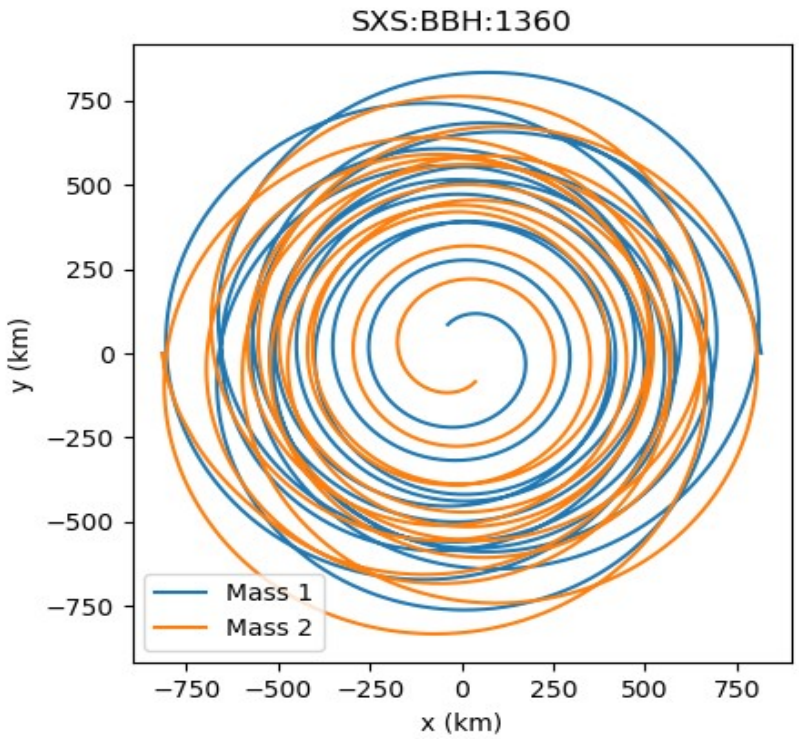

MAYA093 / D24_q1_a1_0_0_0_a2_0_0_0_m240_e0.8
6
4
2
0
−2
−4
−6
y
−10
−5
0
5
10
x


MAYA0936 / D24_q1_a1_0_0_0_a2_0_0_0_m240_e0.8
0.0010
0.0005
0.0000
−0.0005
−0.0010
Ψ422
0
50
100
150
200
250
300
350
400
t/M

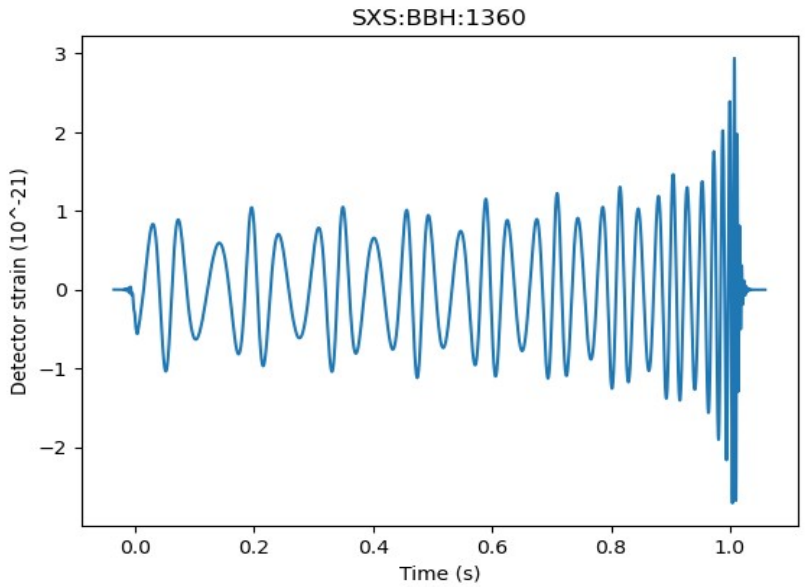
SXS Catalogue

- Sep 2019 → SXS Catalogue (arXiv:1904.04831v2)
  - Total: 2018 waveforms
    - e_{max} = 0.14



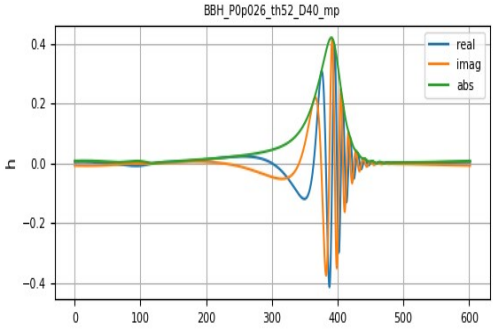

SXS:BBH:1360
750
500
250
0
−250
−500
−750
y (km)
−750
−500
−250
0
250
500
750
x (km)
Mass 1
Mass 2

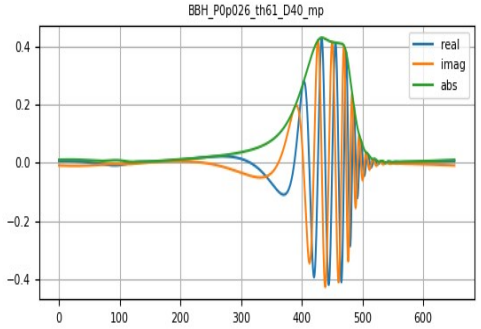
$e_{max} = 0.14$

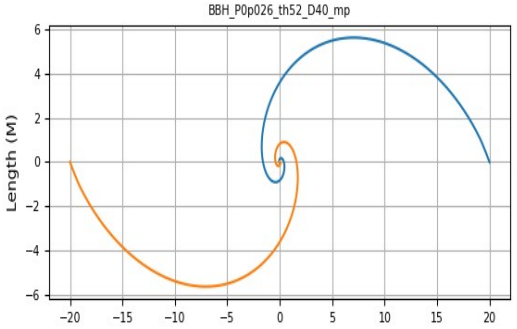

SXS:BBH:1360
3
2
1
0
−1
−2
Detector strain (10^-21)
0.0
0.2
0.4
0.6
0.8
1.0
Time (s)

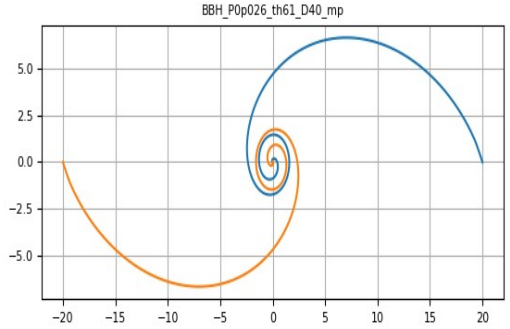
ICC Catalogue

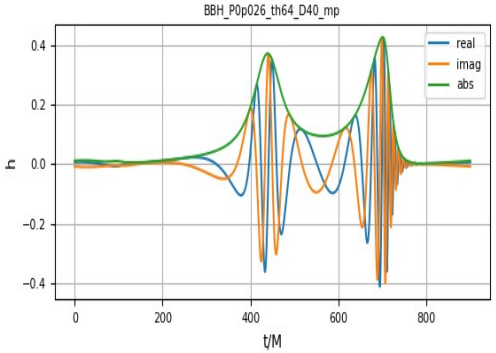
Exemples of differents waveforms ICC: q=1; spin=0

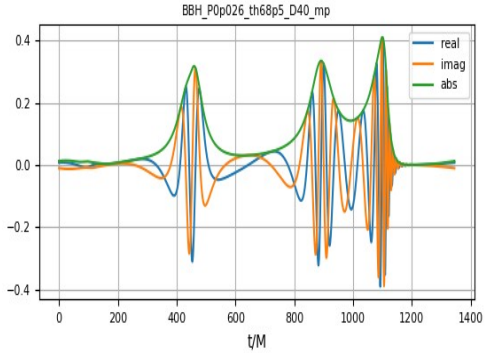


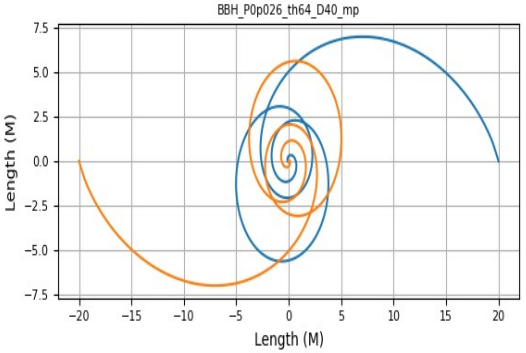


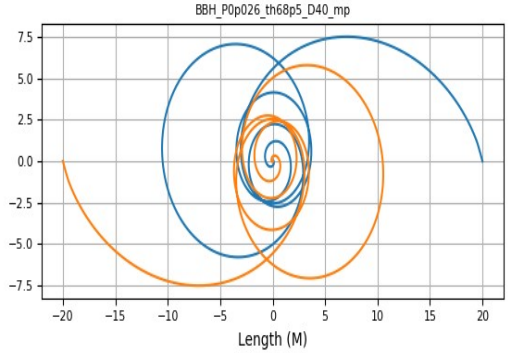




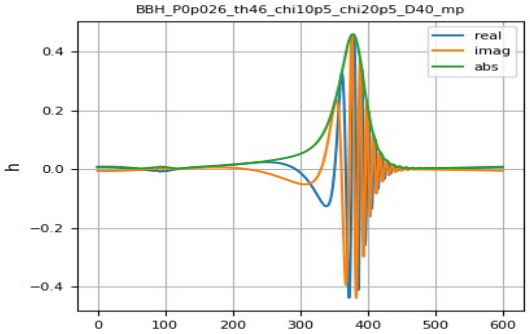


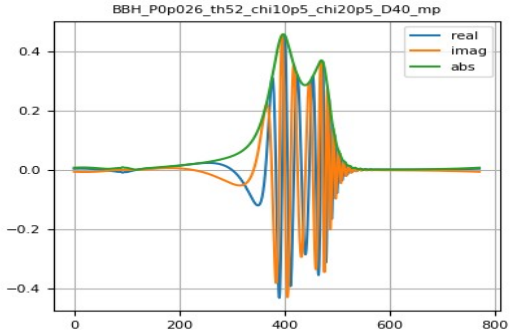


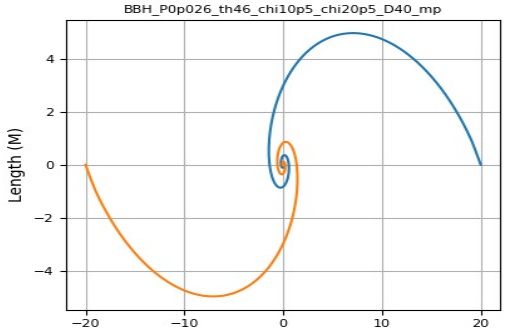


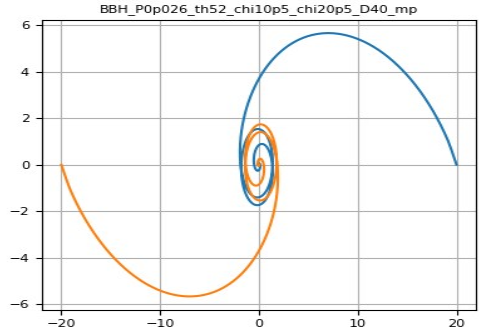


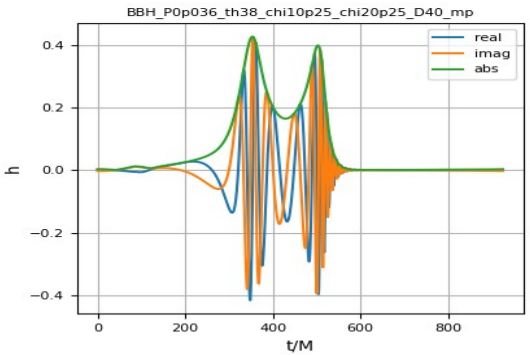
Exemples of differents waveforms ICC: q=1; spin≠0

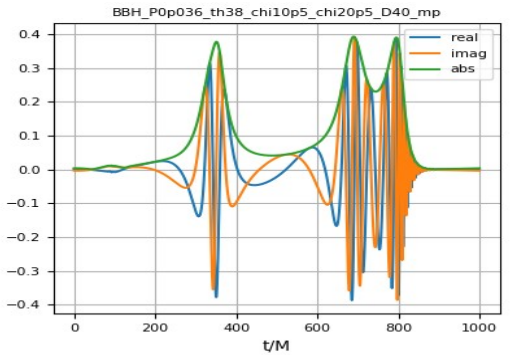


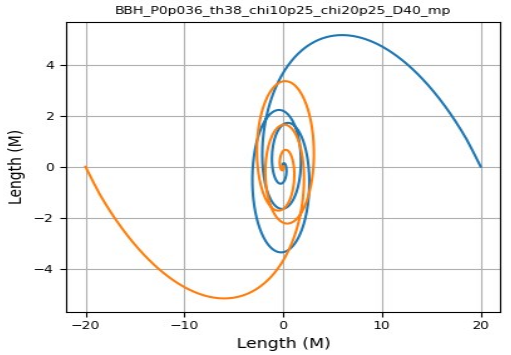


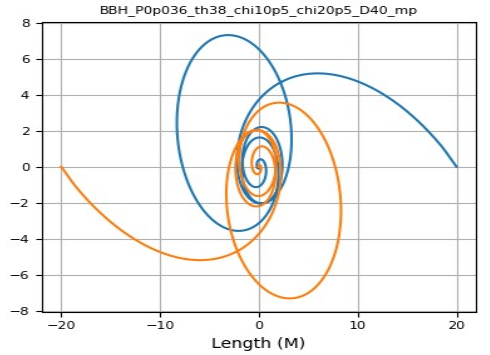




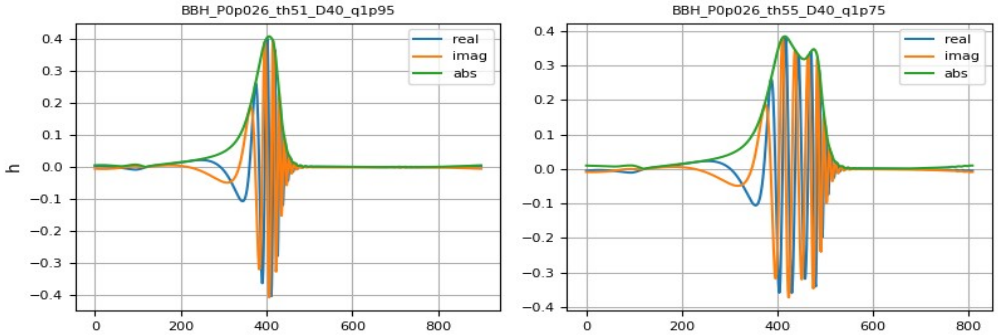


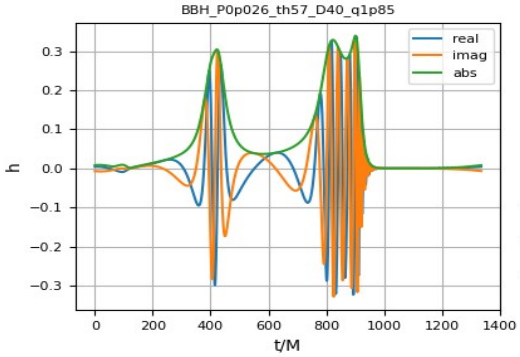


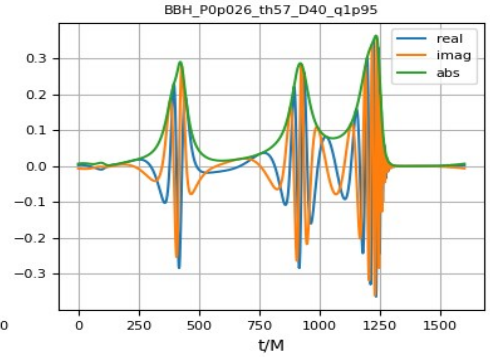


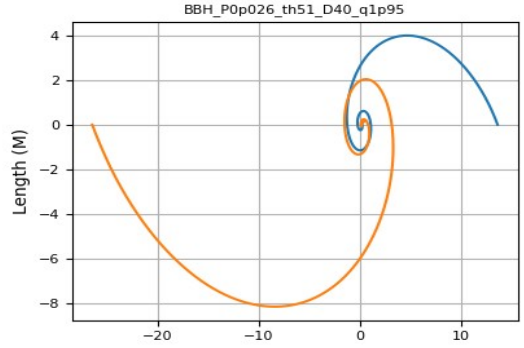


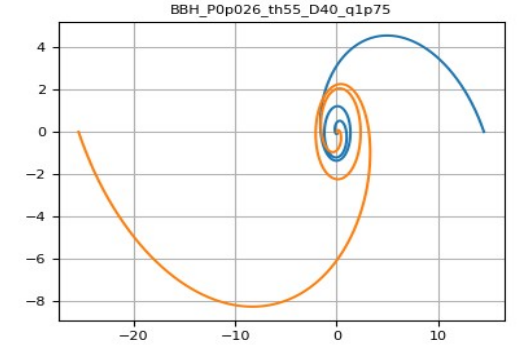
Exemples of differents waveforms ICC: q≠1; spin=0

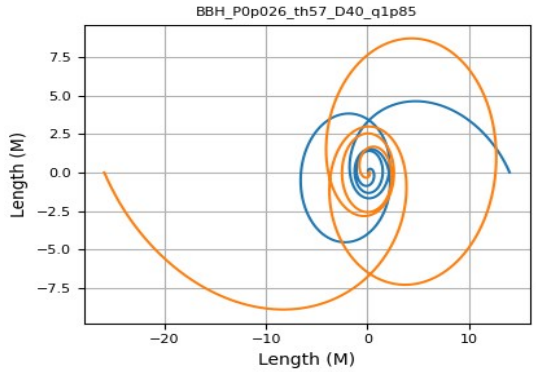


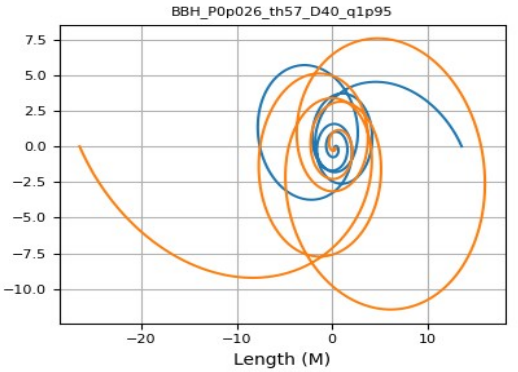








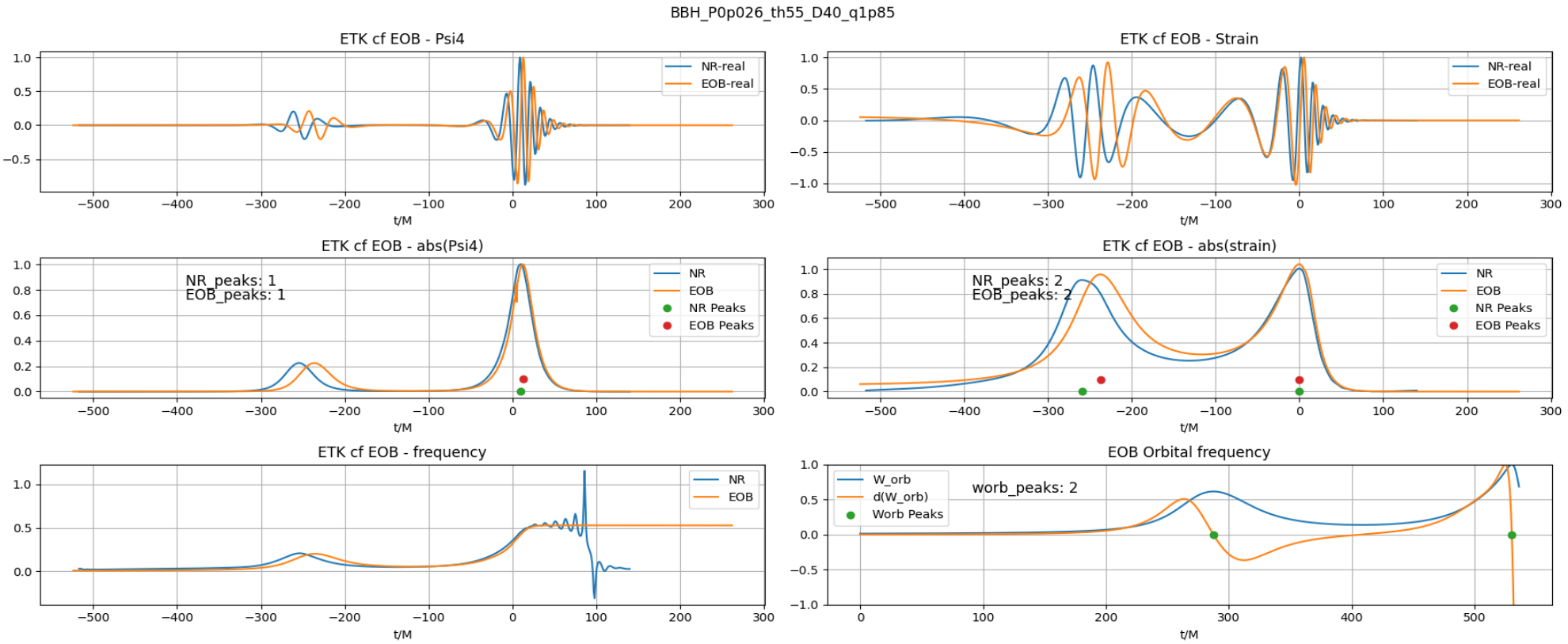




Encounters ICC-EOB. Algorithm.

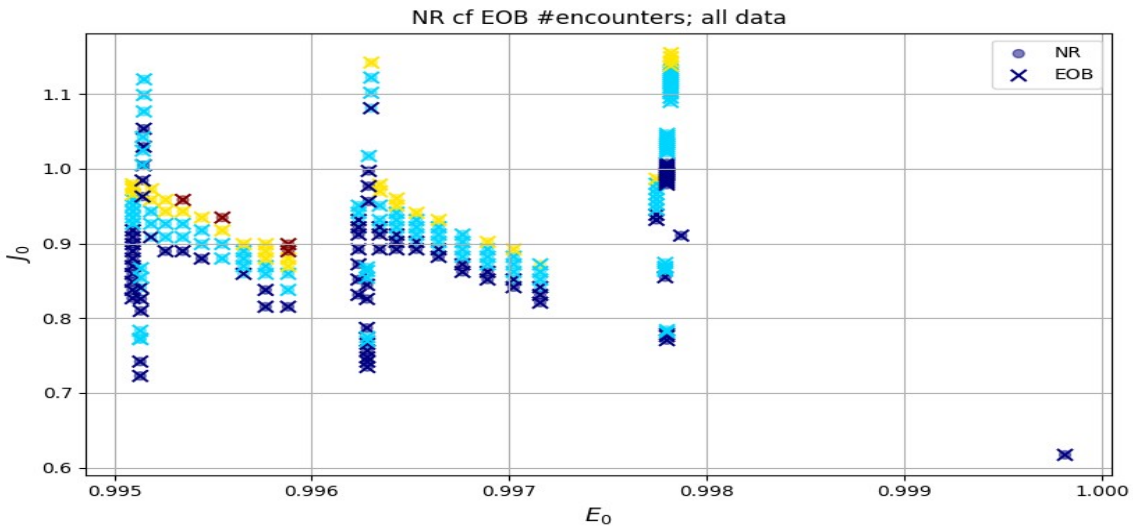
- **Three different analysis**
  1. Counting encounters using abs(psi4) in NR and abs(strain) in EOB
     - Scipy find_peaks with min. distance between peaks: 40M
  2. Counting encounters using abs(strain) in NR and abs(strain) in EOB
     - Integration in NR using FFI with constant f0=0.0023
     - Scipy find_peaks with min. height=0.1 and min. distance between peaks: 40M and prominence=0.03
  3. Countins encounters using abs(strain) in NR and worb in EOB
     - Integration in NR using FFI with constant f0=0.0023
     - For NR: Scipy find_peaks with min. height=0.1 and min. distance between peaks: 40M and prominence=0.03
     - For EOB: find_peaks through derivation of worb

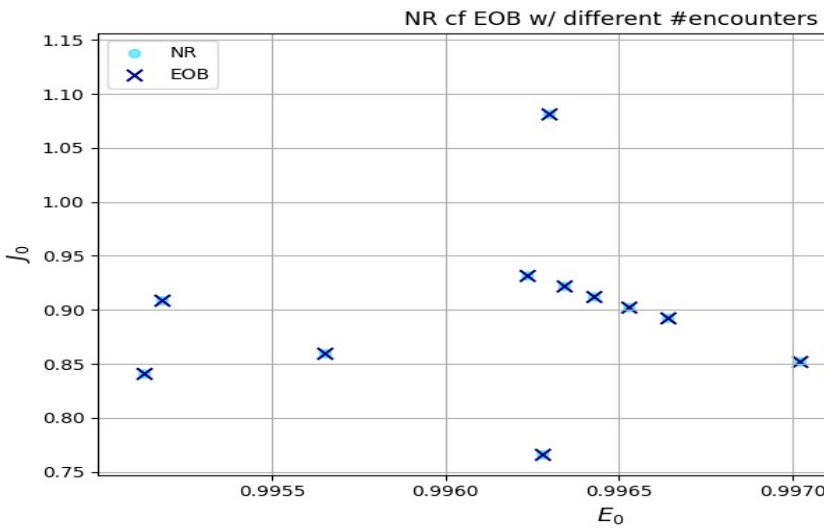
Encounters ICC-EOB. Example of analysis

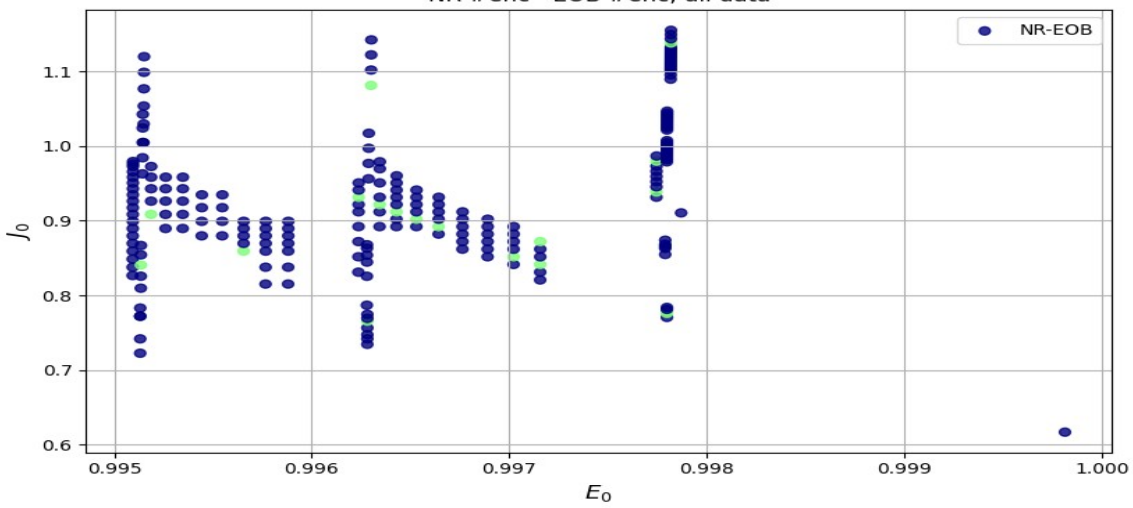


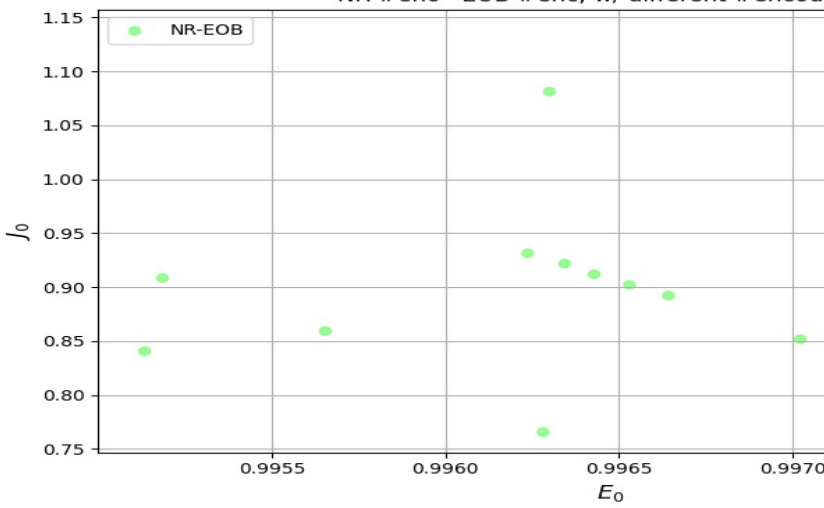
Encounters ICC-EOB. Totals

Algorithm	Set	Coincidence per set (%)	Total Coincidence (%)
NR(Psi4) - EOB(h)	q=1 χ=0	94,44%	92,31%
	q=1 χ≠0	94,51%	
	q≠1 χ=0	89,36%	
NR(Psi4) - EOB(worb)	q=1 χ=0	94,59%	93,72%
	q=1 χ≠0	95,60%	
	q≠1 χ=0	91,58%	
NR(h) - EOB(h)	q=1 χ=0	91,89%	87,89%
	q=1 χ≠0	90,11%	
	q≠1 χ=0	84,21%	
NR(h) - EOB(worb)	q=1 χ=0	91,89%	91,48%
	q=1 χ≠0	92,31%	
	q≠1 χ=0	90,53%	

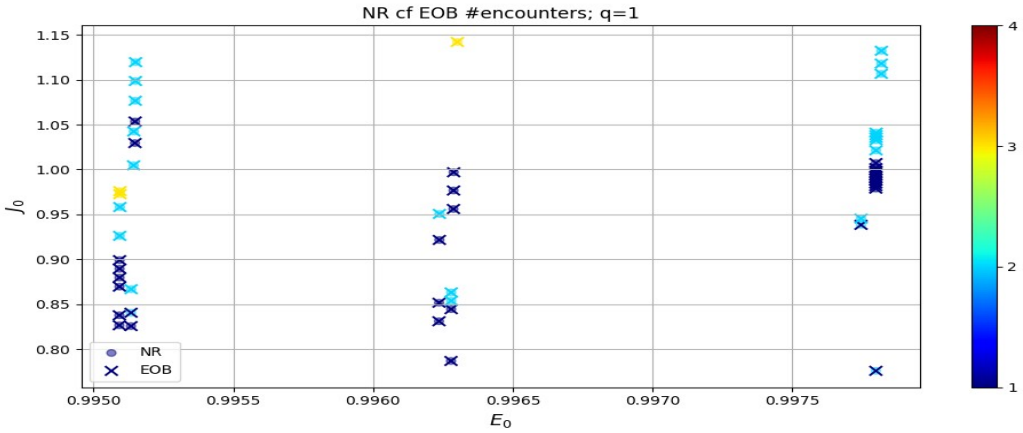

NR cf EOB #encounters; all data
NR
EOB
J_0
E_0

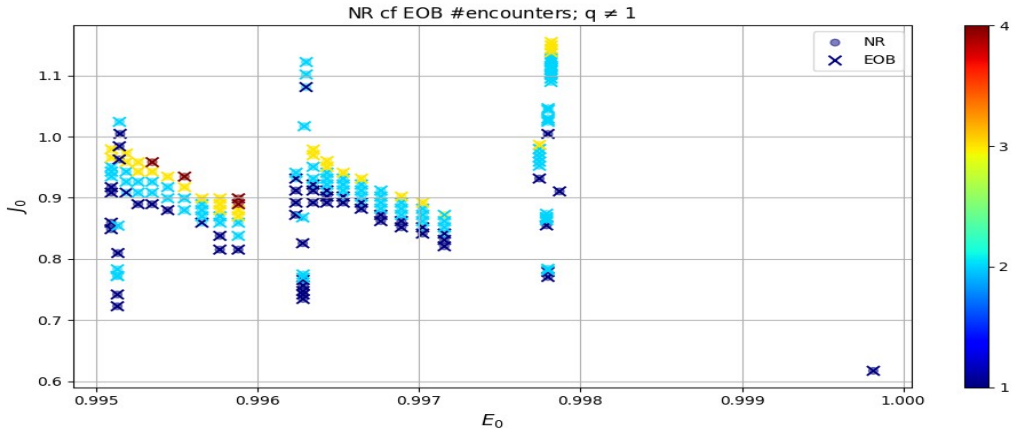

NR cf EOB w/ different #encounters
NR
EOB
J_0
E_0

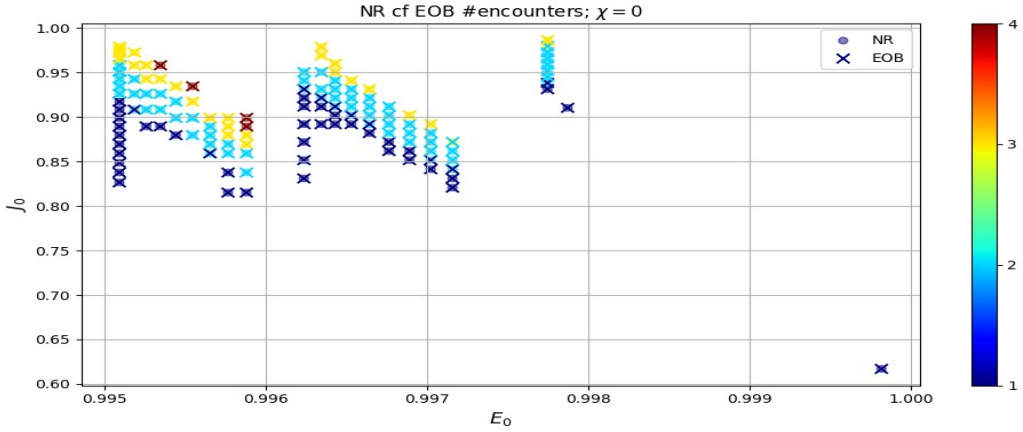

NR #enc - EOB #enc; all data
NR-EOB
J_0
E_0

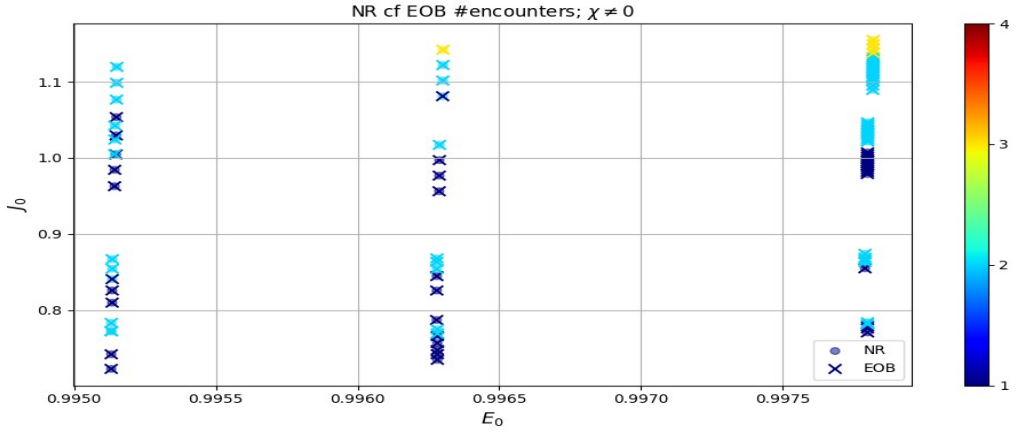

NR #enc - EOB #enc; w/ different #encou
NR-EOB
J_0
E_0

Encounters (E0, J0) computed with abs(strain) for NR and EOB

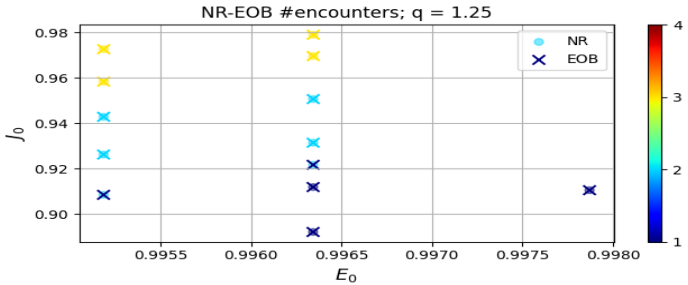


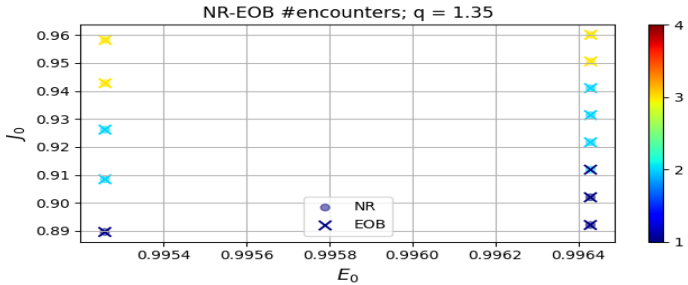


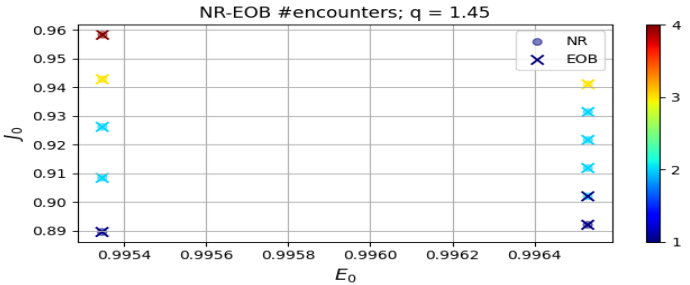


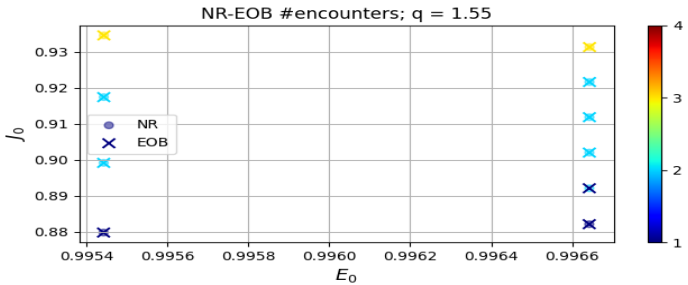


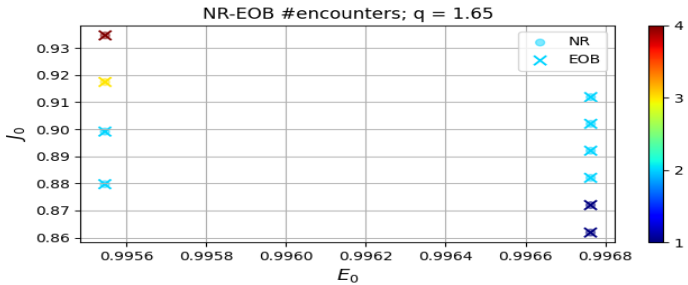
Encounters (E0, J0) computed with abs(strain) for NR and EOB

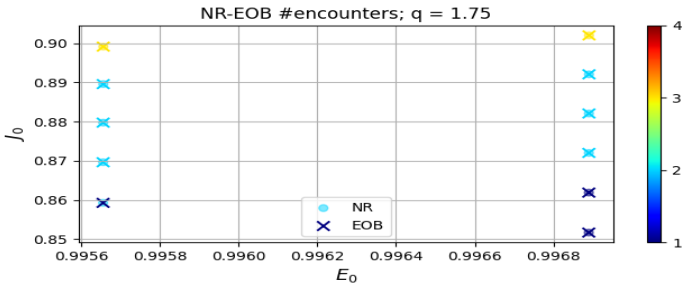


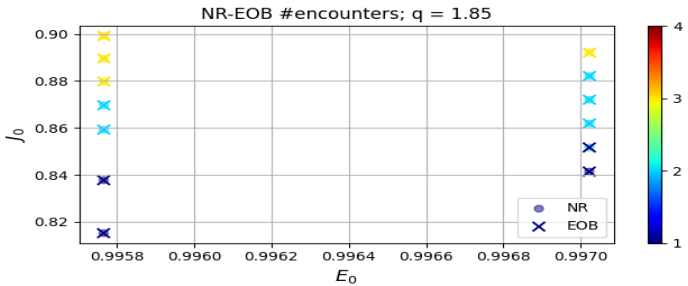


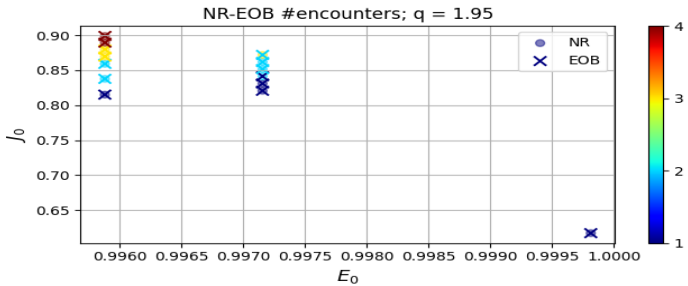




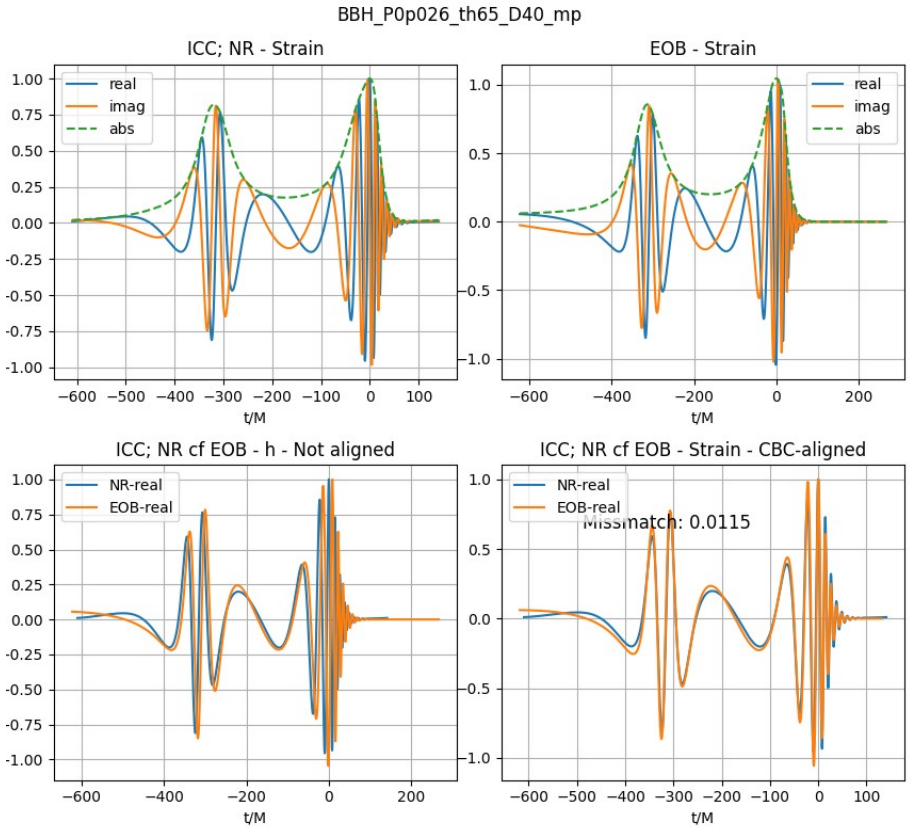


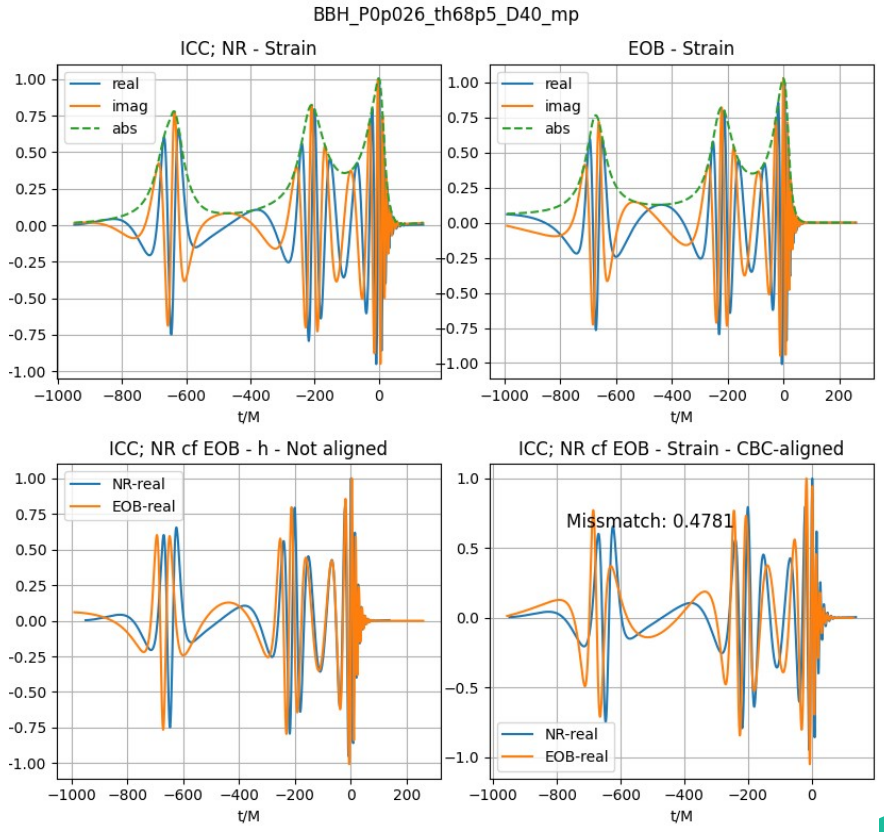




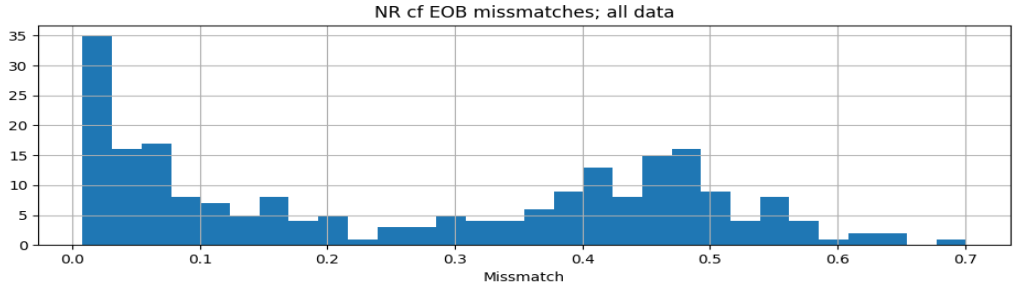


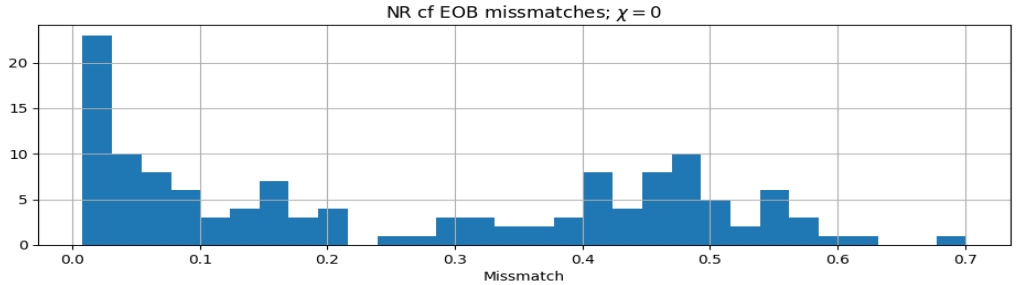
Mismatches.

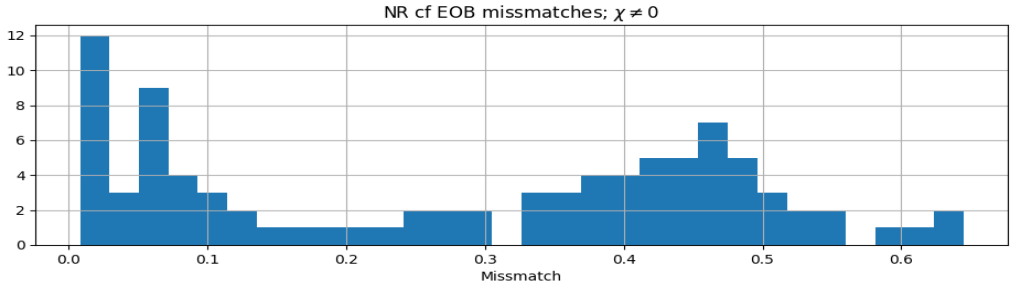

BBH_P0p026_th65_D40_mp
ICC; NR - Strain
EOB - Strain
real
imag
abs
t/M
ICC; NR cf EOB - h - Not aligned
ICC; NR cf EOB - Strain - CBC-aligned
NR-real
EOB-real
Missmatch: 0.0115

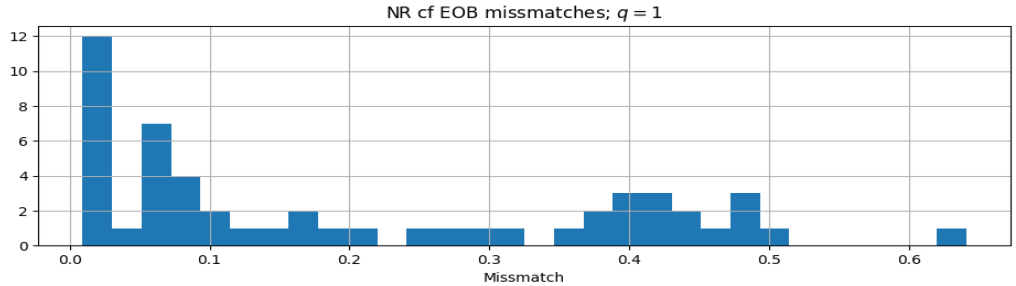

BBH_P0p026_th68p5_D40_mp
ICC; NR - Strain
EOB - Strain
real
imag
abs
t/M
ICC; NR cf EOB - h - Not aligned
ICC; NR cf EOB - Strain - CBC-aligned
NR-real
EOB-real
Missmatch: 0.4781

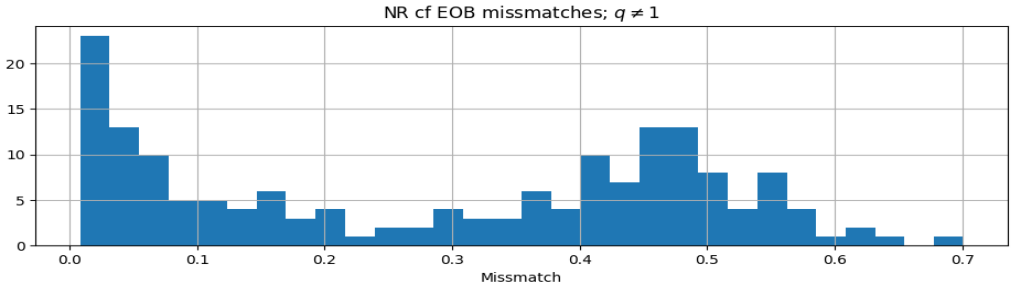
Mismatches


NR cf EOB missmatches; all data
Missmatch

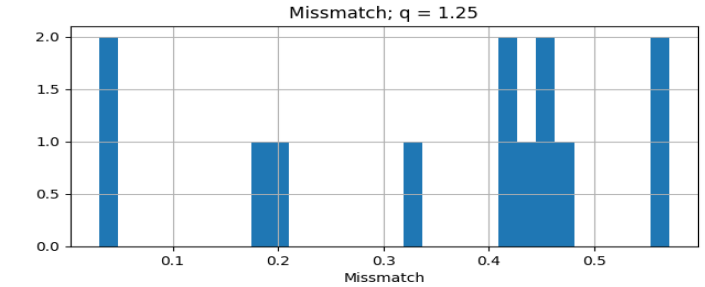

NR cf EOB missmatches; $\chi = 0$
Missmatch

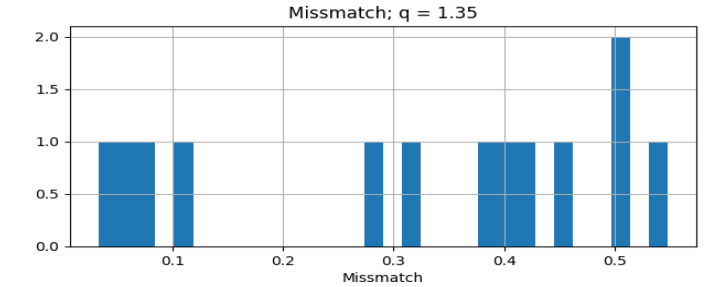

NR cf EOB missmatches; $\chi \neq 0$
Missmatch

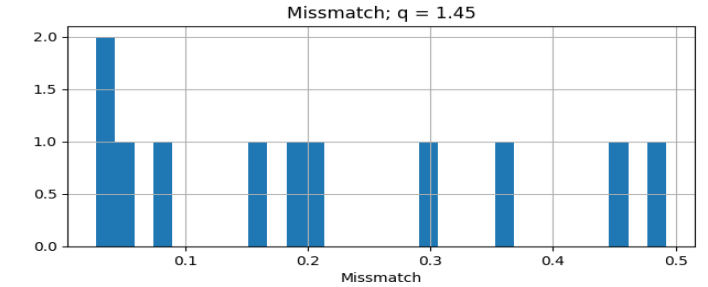

NR cf EOB missmatches; $q = 1$
Missmatch

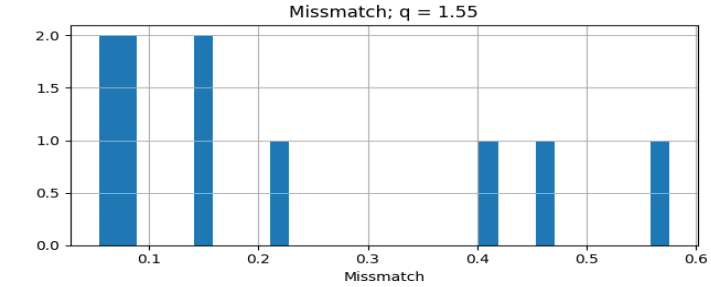

NR cf EOB missmatches; $q \neq 1$
Missmatch

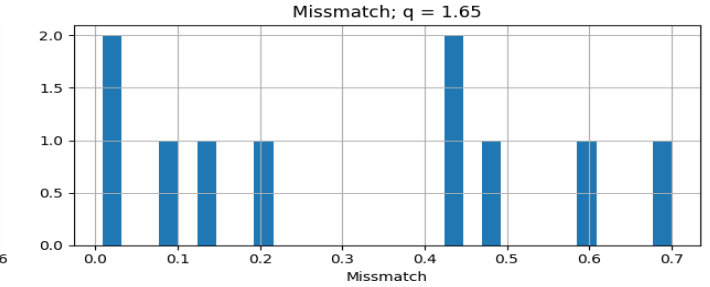
Mismatches. Cuts in q and chi

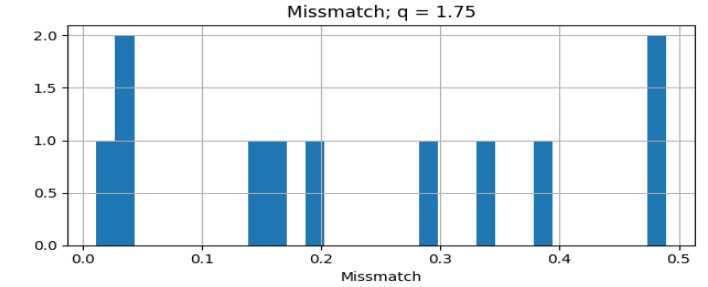


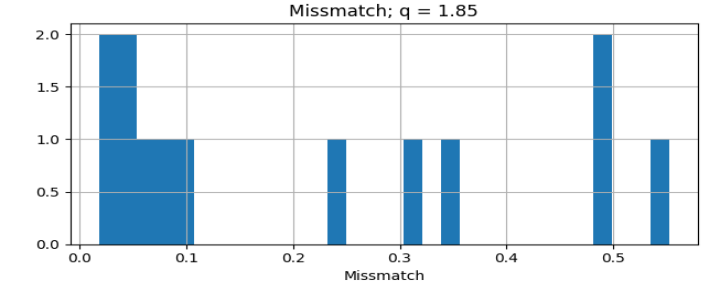


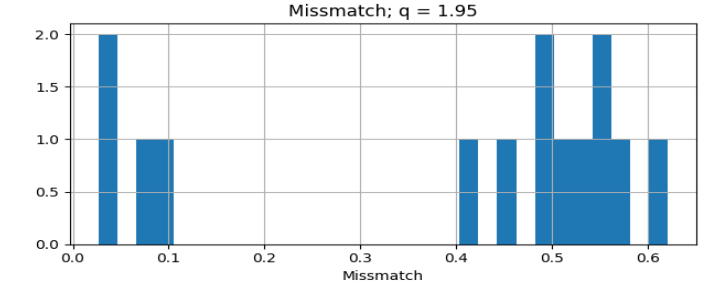




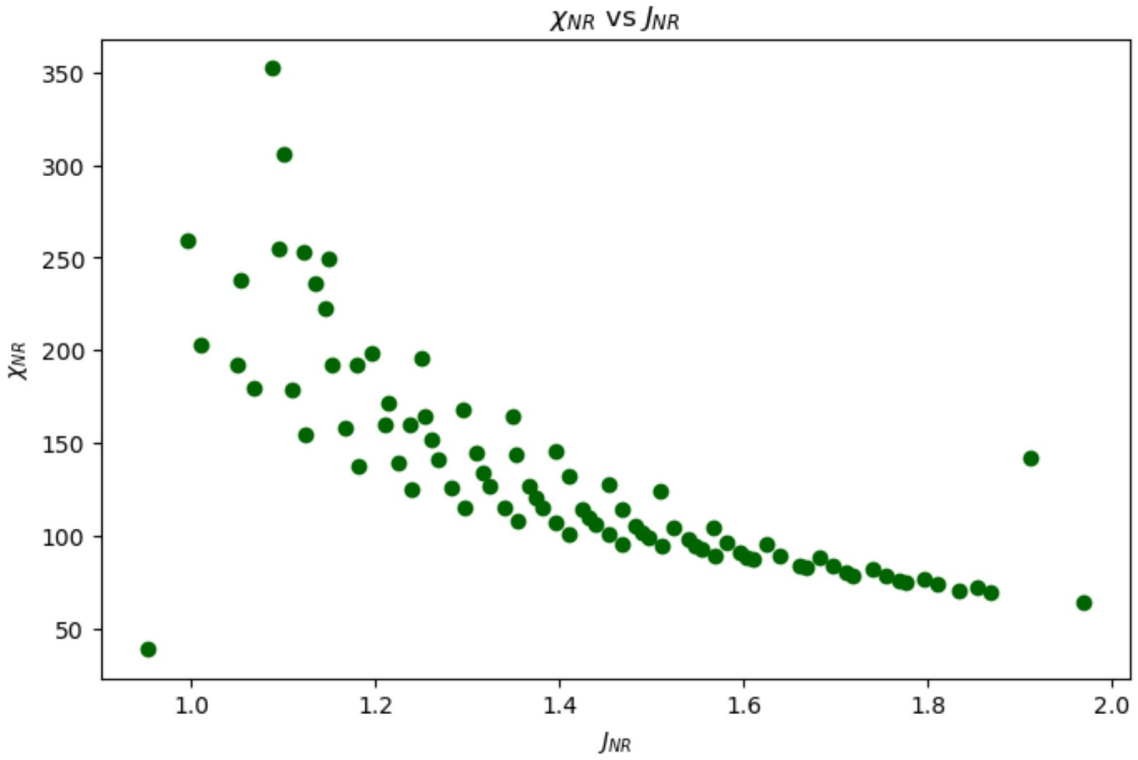








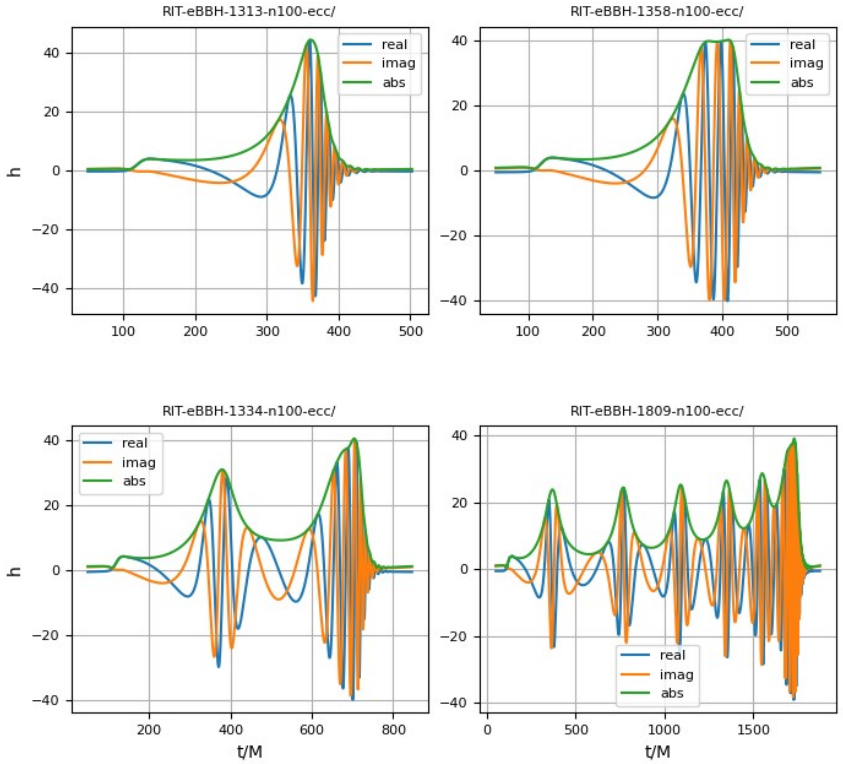
Scattering angles



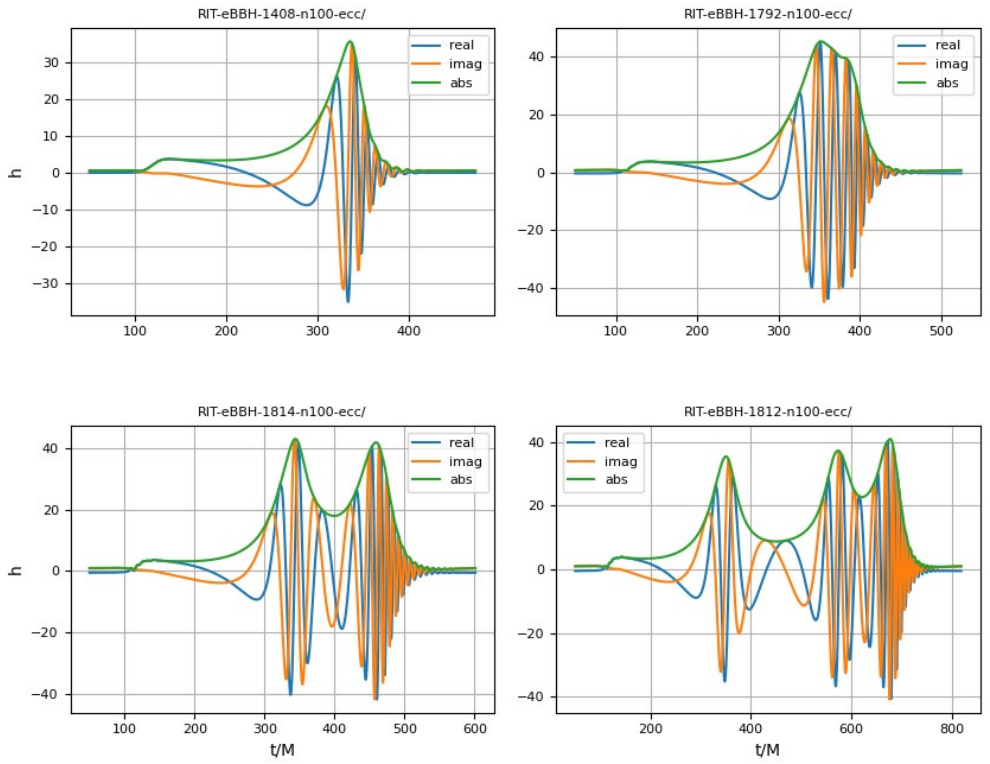
RIT Catalogue

Exemples of differents waveforms RIT:

Ecc: 0.5 → 0.6

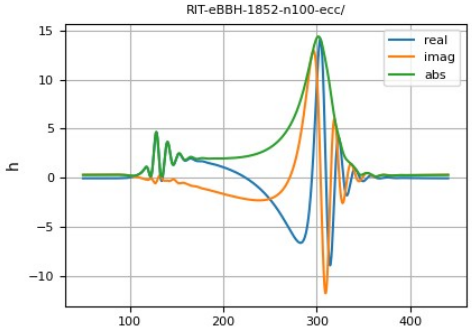


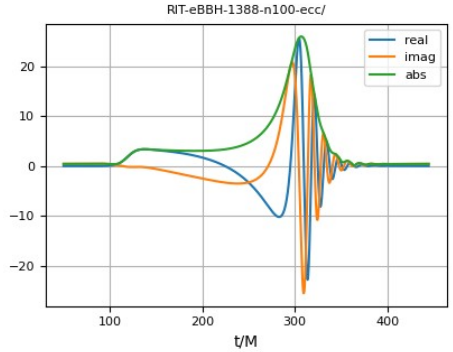
Ecc: 0.6 → 0.7

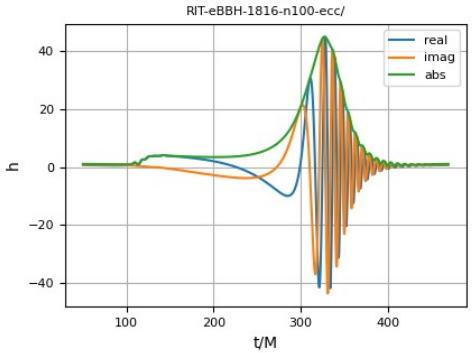


Exemples of differents waveforms RIT:

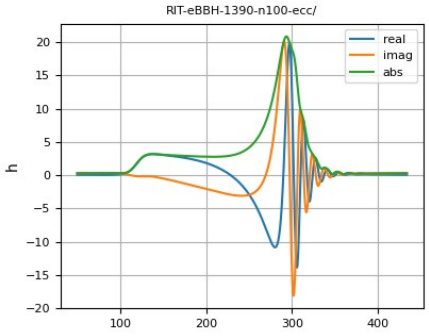
Ecc: 0.7 → 0.8

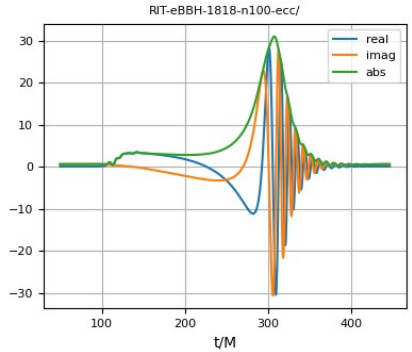


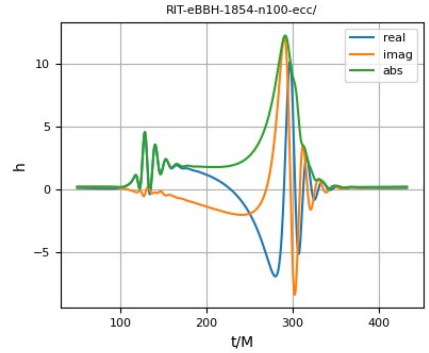




Ecc: 0.8 → 0.9

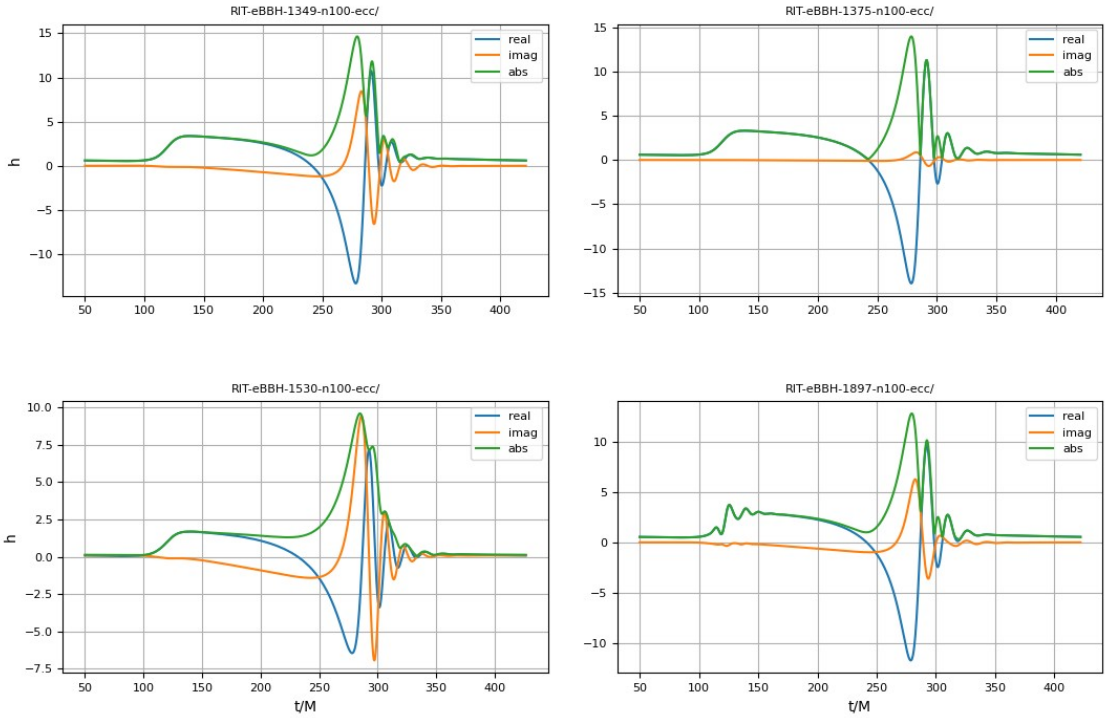






Exemples of differents waveforms RIT:

Ecc: 0.9 → 0.99



Encounters RIT-EOB. Algorithm.

- **Two different analysis**

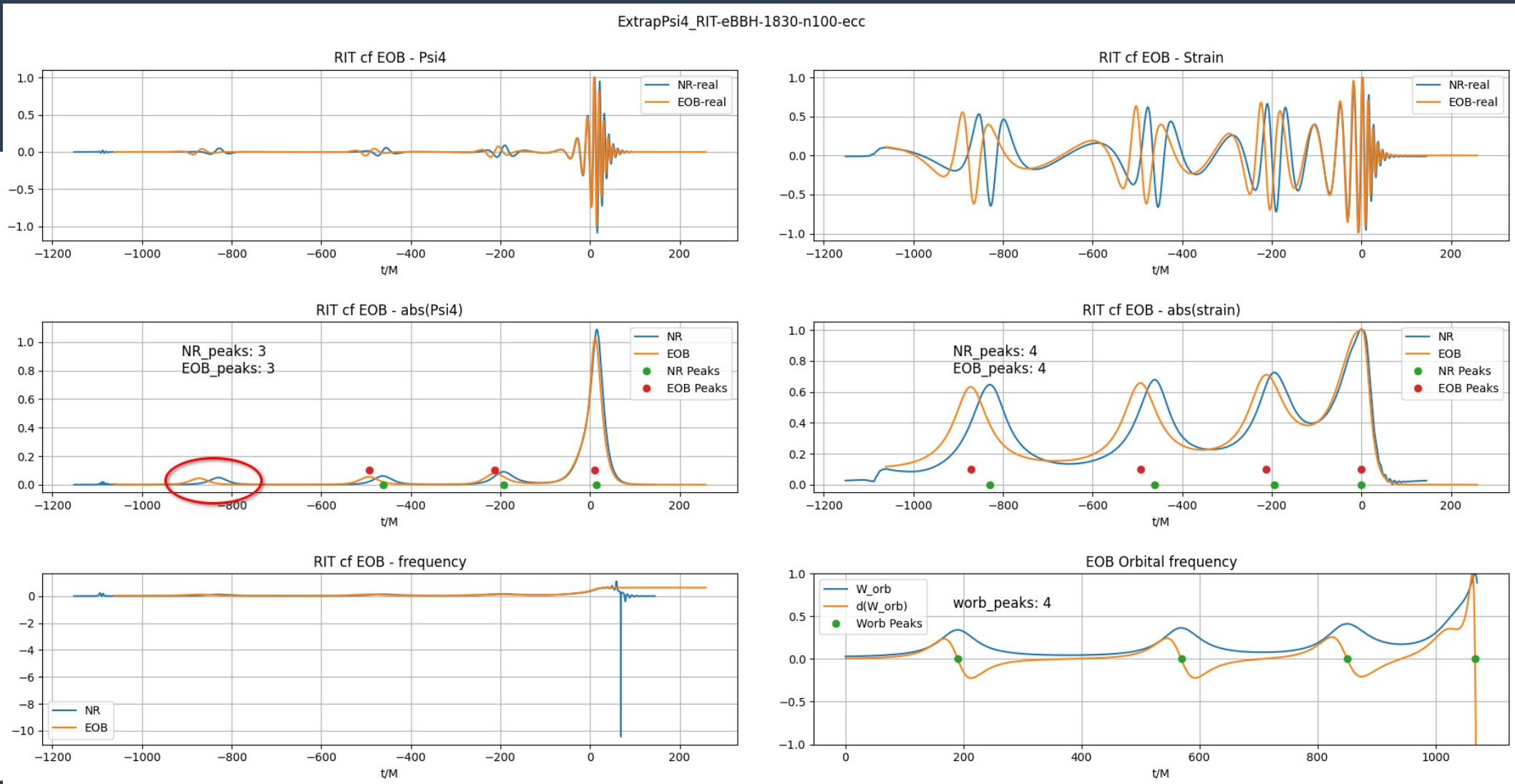
  Only considering signals with D=24.75M

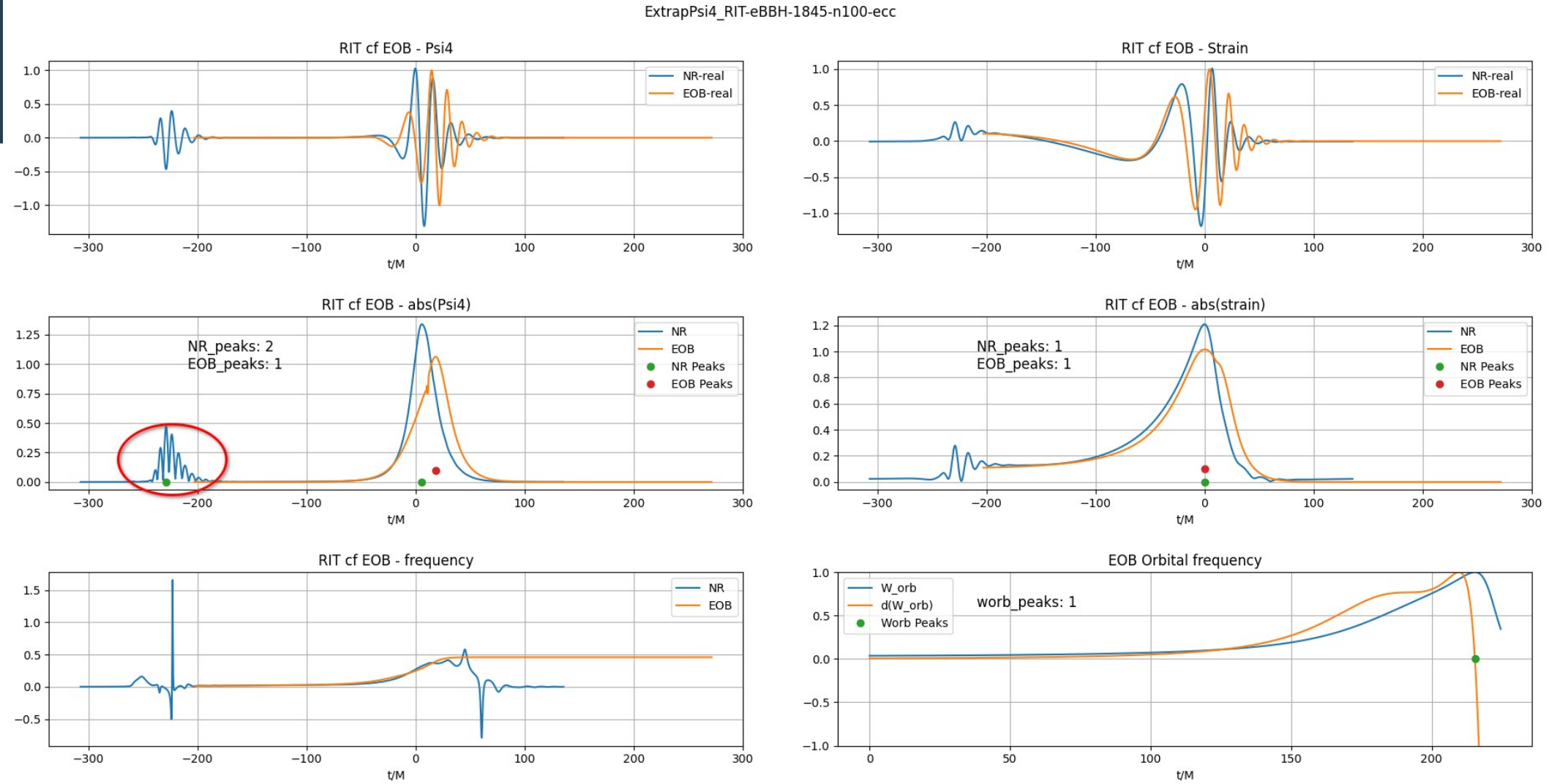
  1. Counting encounters using abs(strain) in NR and abs(strain) in EOB
     - Integration in NR using FFI with constant f0=0.0023
     - Scipy find_peaks with min. height=0.3 and min. distance between peaks: 40M
  2. Countins encounters using abs(strain) in NR and worb in EOB
     - Integration in NR using FFI with constant f0=0.0023
     - For NR: Scipy find_peaks with min. height=0.3 and min. distance between peaks: 40M
     - For EOB: find_peaks through derivation of worb

Encounters RIT-EOB. Totals

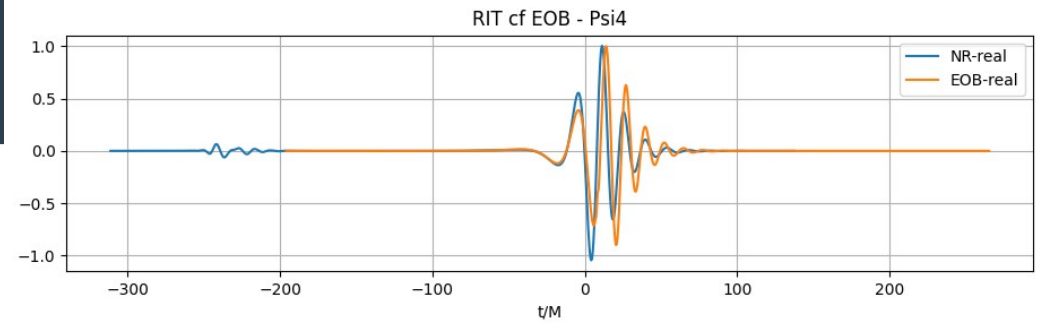
Algorithm	Set	# sims	Coincidence per set (%)	Total Coincidence (%) (2)
NR(Psi4) - EOB(worb)	0.5 ≤ ecc < 0.6	76	82,89%	76,60%
	0.6 ≤ ecc < 0.7	105	72,38%	
	0.7 ≤ ecc < 0.8	42	78,57%	
	0.8 ≤ ecc < 0.9	42	73,81%	
	0.9 ≤ ecc < 1.0	163	52,76%	
NR(h) - EOB(worb)	0.5 ≤ ecc < 0.6	76	93,42% (1)	93,96%
	0.6 ≤ ecc < 0.7	105	95,24%	
	0.7 ≤ ecc < 0.8	42	95,24%	
	0.8 ≤ ecc < 0.9	42	90,48%	
	0.9 ≤ ecc < 1.0	163	80,37%	
NR(h) - EOB(worb)	0.5 ≤ ecc < 0.6	76	89,47%	89,81%
	0.6 ≤ ecc < 0.7	105	91,43%	
	0.7 ≤ ecc < 0.8	42	90,48%	
	0.8 ≤ ecc < 0.9	42	85,71%	
	0.9 ≤ ecc < 1.0	163	69,33%	

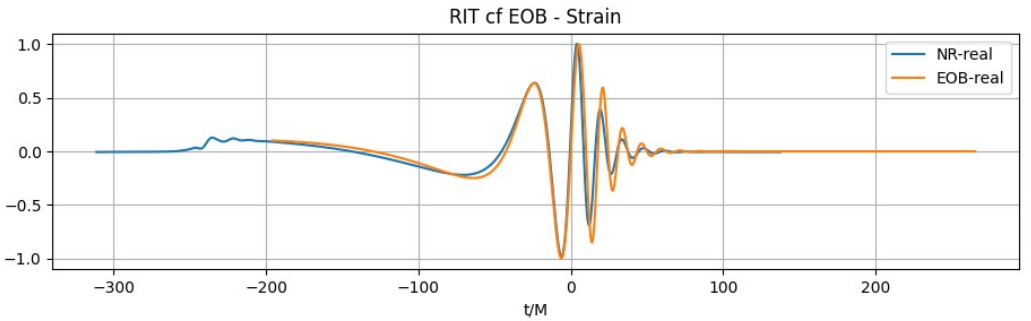
(1) See examples in next slides
(2) For 0.5 ≤ ecc < 0.9, D=25M

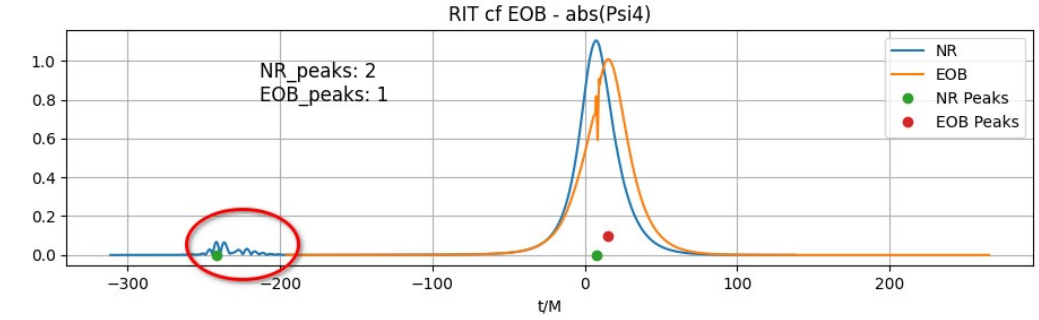

ExtrapPsi4_RIT-eBBH-1830-n100-ecc
RIT cf EOB - Psi4
NR-real
EOB-real
t/M
RIT cf EOB - Strain
NR-real
EOB-real
t/M
RIT cf EOB - abs(Psi4)
NR_peaks: 3
EOB_peaks: 3
NR
EOB
NR Peaks
EOB Peaks
t/M
RIT cf EOB - abs(strain)
NR_peaks: 4
EOB_peaks: 4
NR
EOB
NR Peaks
EOB Peaks
t/M
RIT cf EOB - frequency
NR
EOB
t/M
EOB Orbital frequency
W_orb
d(W_orb)
Worb Peaks
worb_peaks: 4
t/M

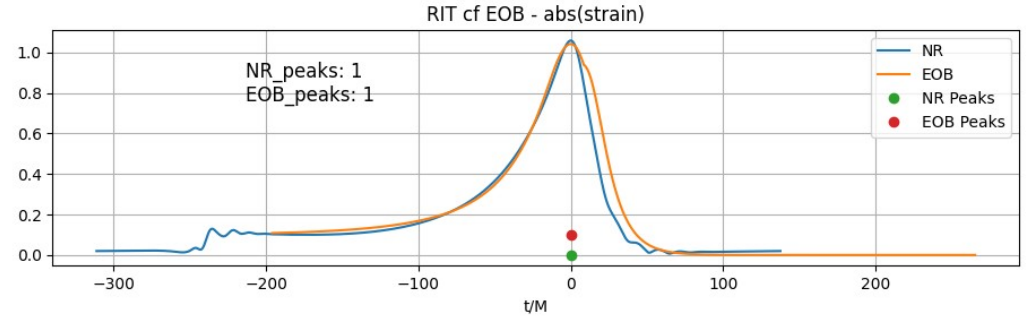

ExtrapPsi4_RIT-eBBH-1845-n100-ecc
RIT cf EOB - Psi4
NR-real
EOB-real
t/M
RIT cf EOB - Strain
NR-real
EOB-real
t/M
RIT cf EOB - abs(Psi4)
NR_peaks: 2
EOB_peaks: 1
NR
EOB
NR Peaks
EOB Peaks
t/M
RIT cf EOB - abs(strain)
NR_peaks: 1
EOB_peaks: 1
NR
EOB
NR Peaks
EOB Peaks
t/M
RIT cf EOB - frequency
NR
EOB
t/M
EOB Orbital frequency
W_orb
d(W_orb)
Worb Peaks
worb_peaks: 1
t/M

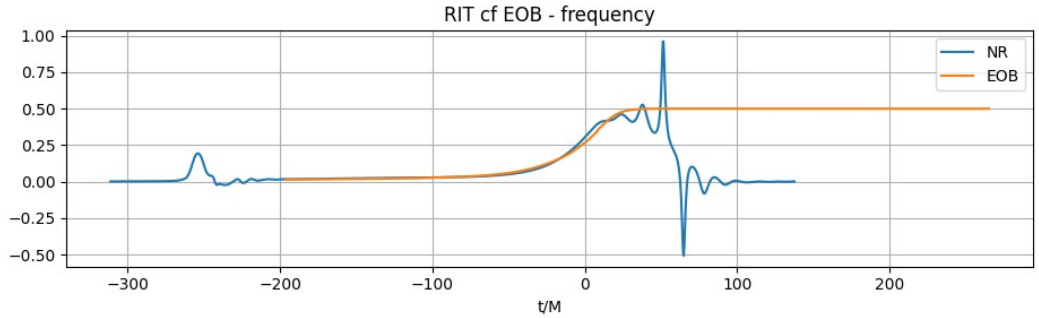
ExtrapPsi4_RIT-eBBH-1887-n100-ecc

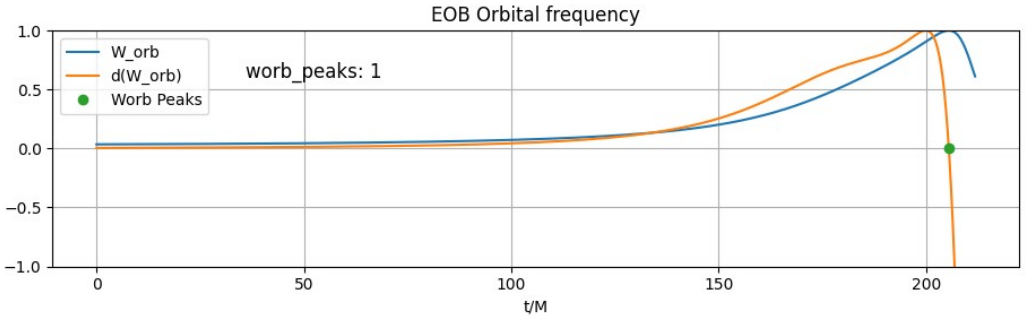


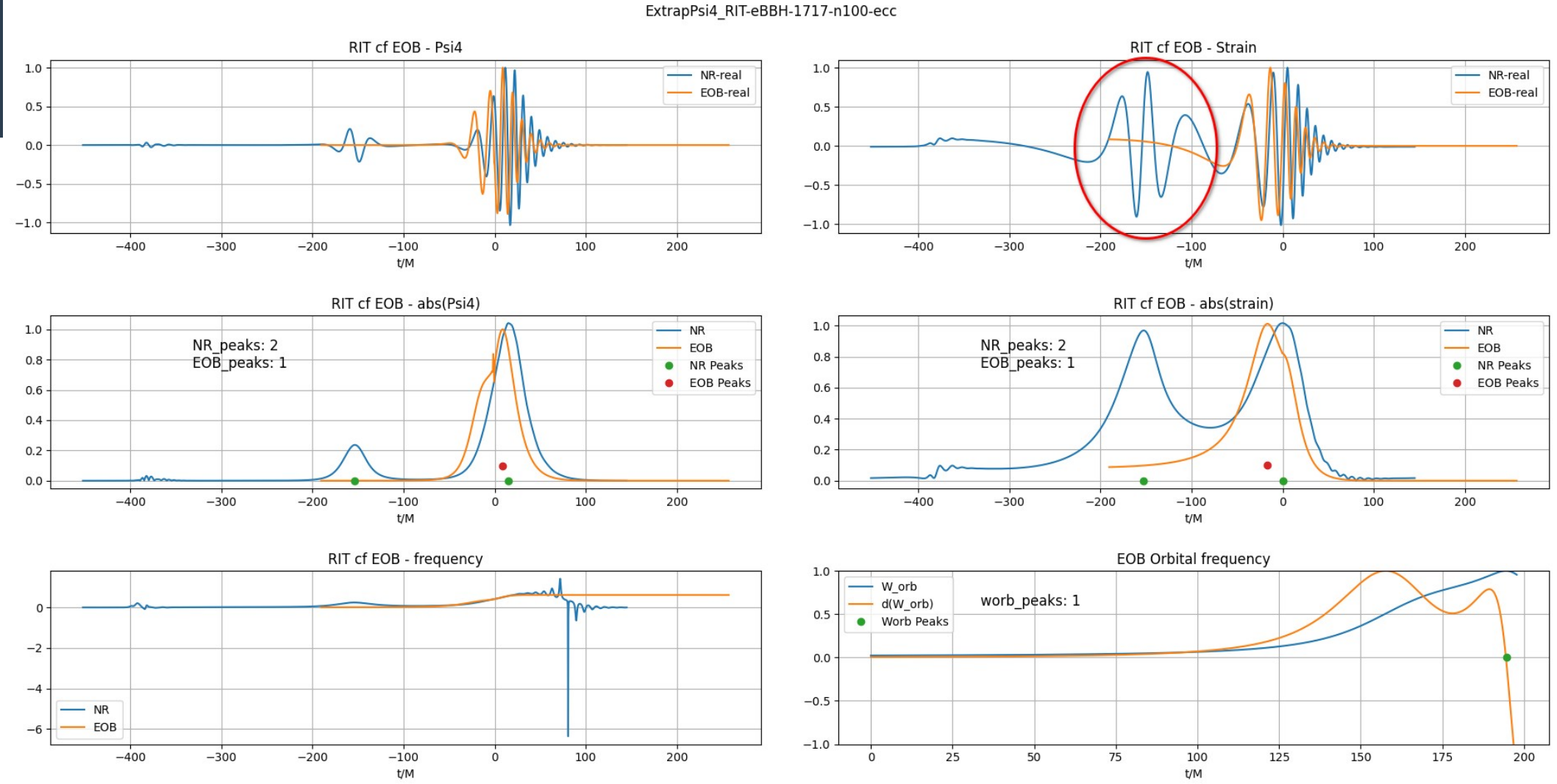




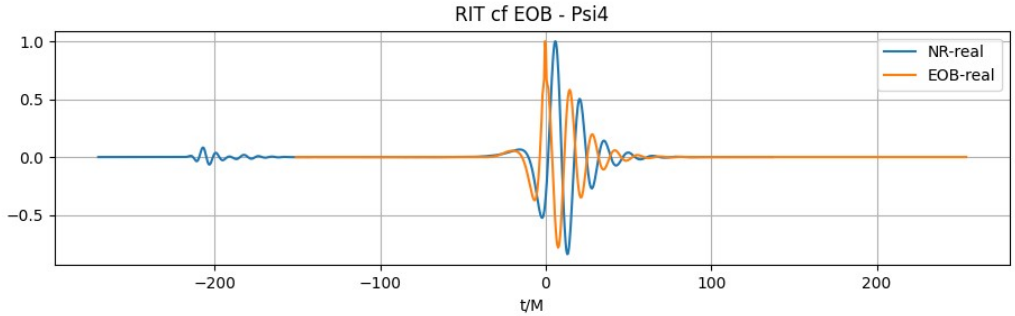


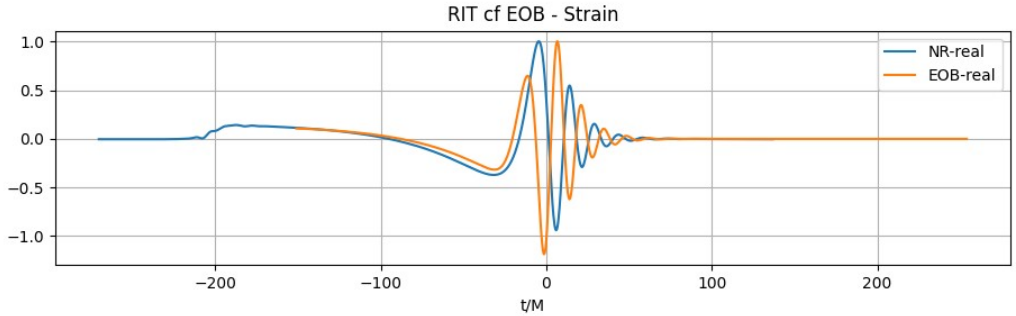


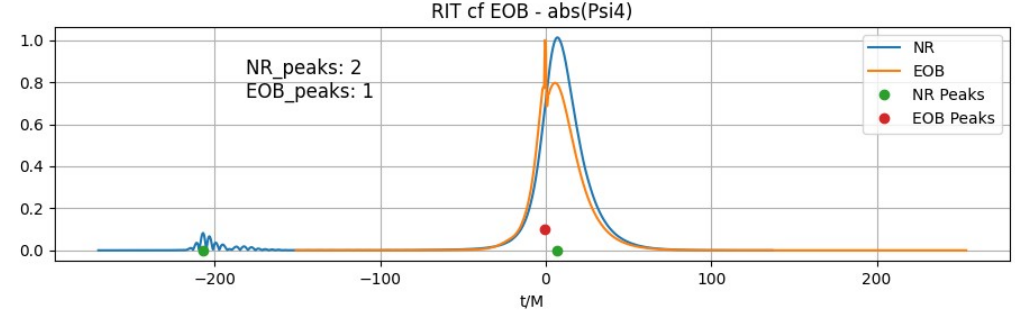


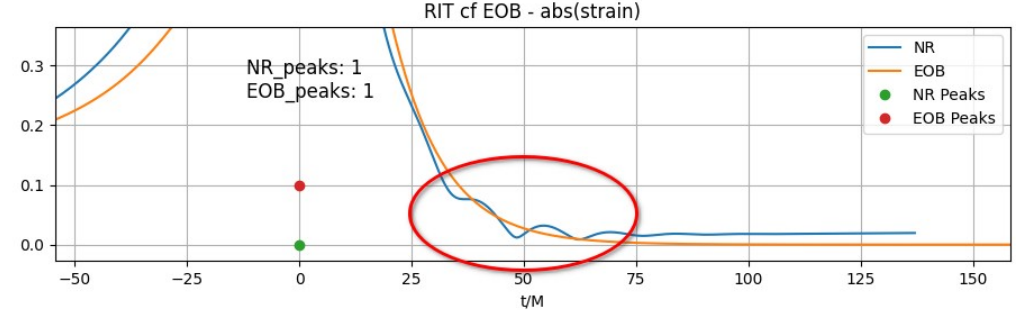

ExtrapPsi4_RIT-eBBH-1717-n100-ecc
RIT cf EOB - Psi4
NR-real
EOB-real
t/M
RIT cf EOB - Strain
NR-real
EOB-real
t/M
RIT cf EOB - abs(Psi4)
NR_peaks: 2
EOB_peaks: 1
NR
EOB
NR Peaks
EOB Peaks
t/M
RIT cf EOB - abs(strain)
NR_peaks: 2
EOB_peaks: 1
NR
EOB
NR Peaks
EOB Peaks
t/M
RIT cf EOB - frequency
NR
EOB
t/M
EOB Orbital frequency
W_orb
d(W_orb)
Worb Peaks
worb_peaks: 1
t/M

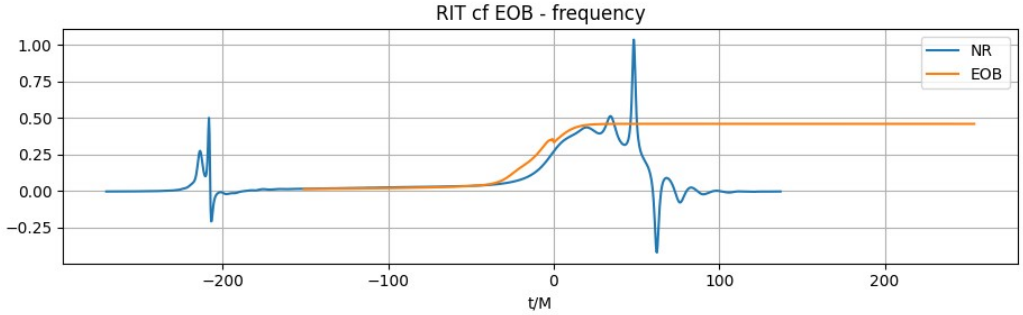
ExtrapPsi4_RIT-eBBH-1773-n100-ecc

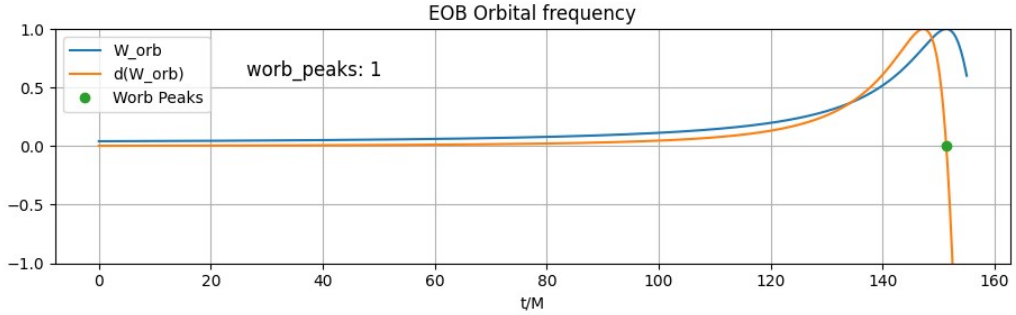




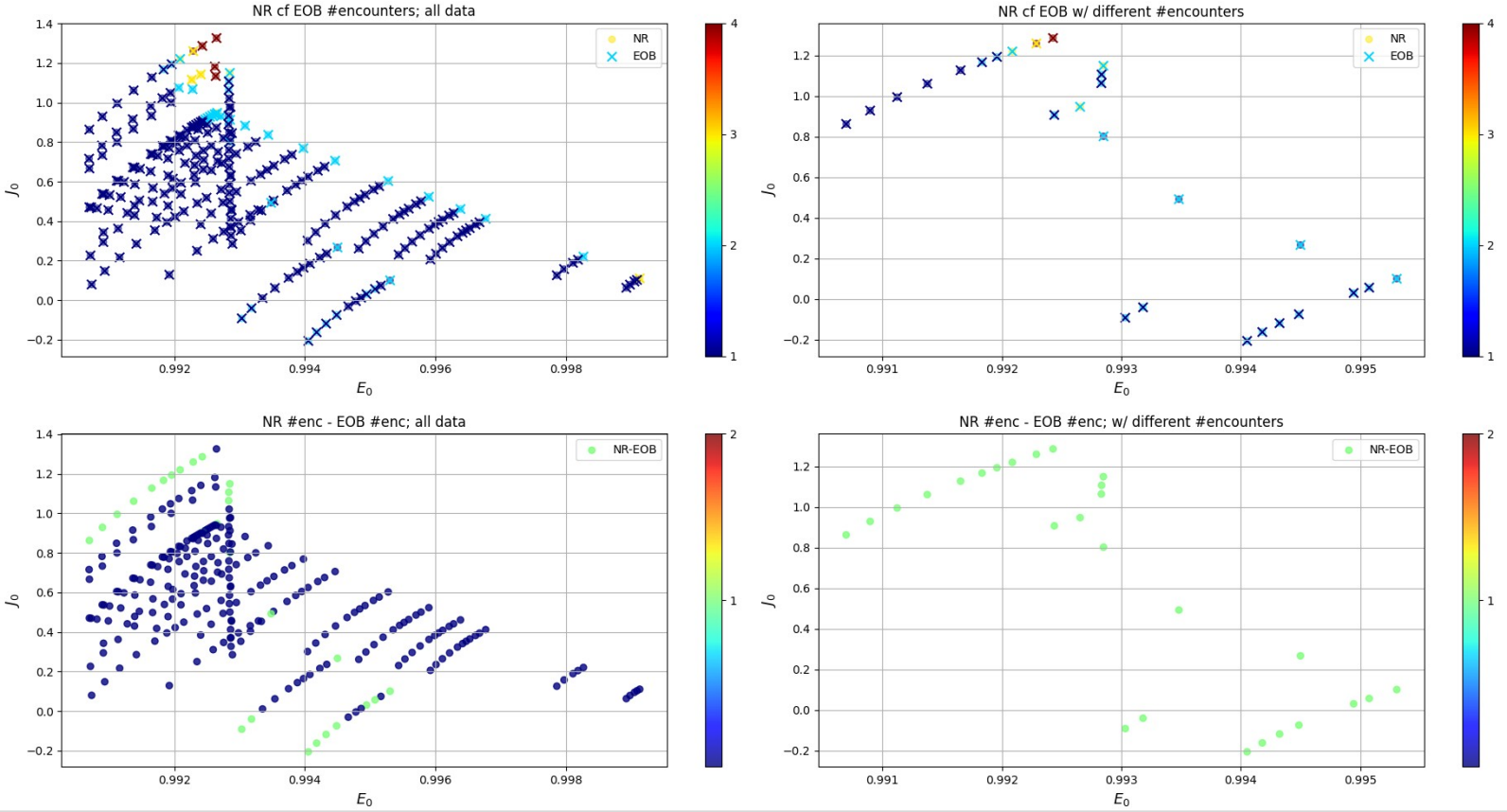




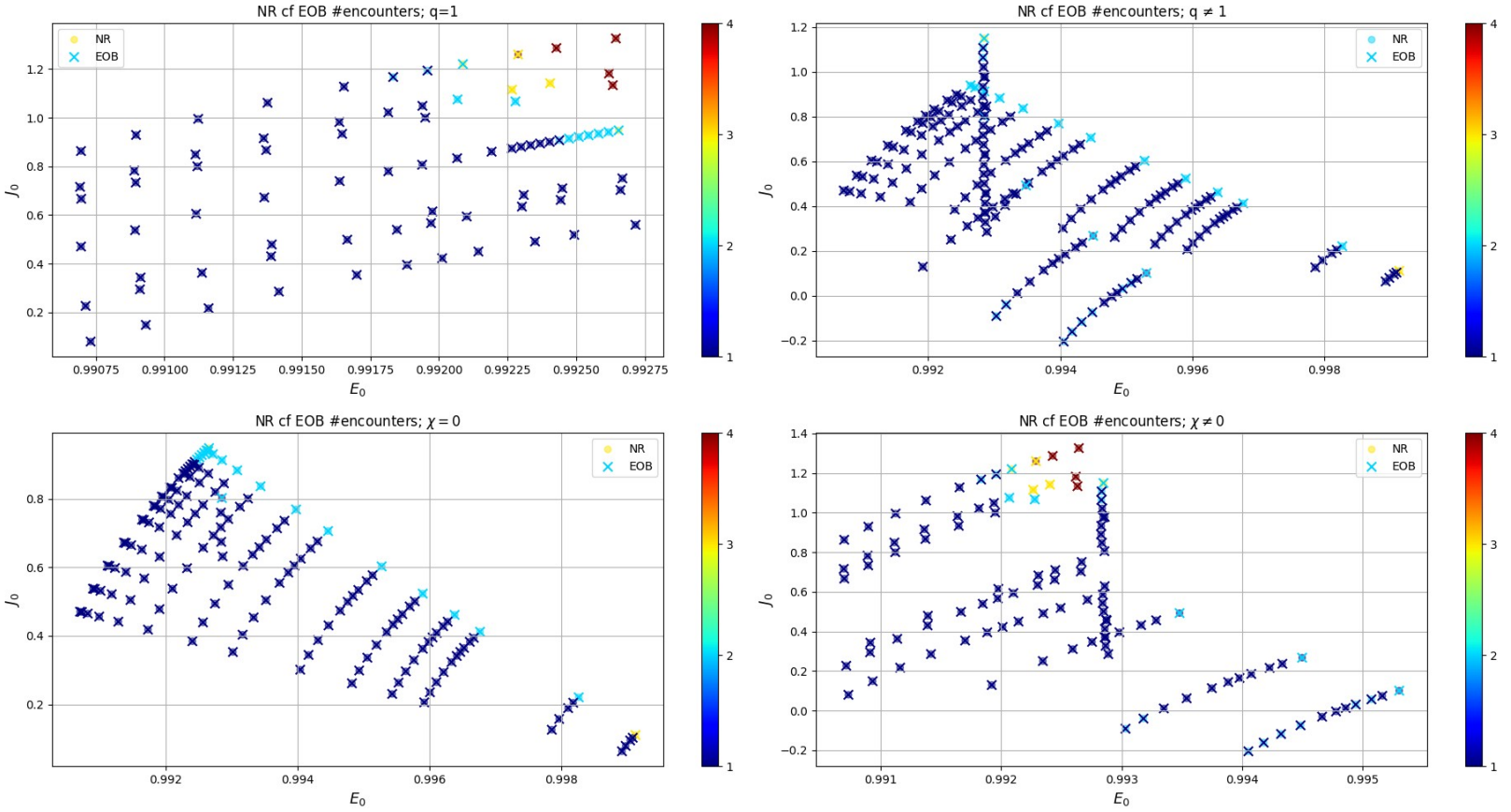




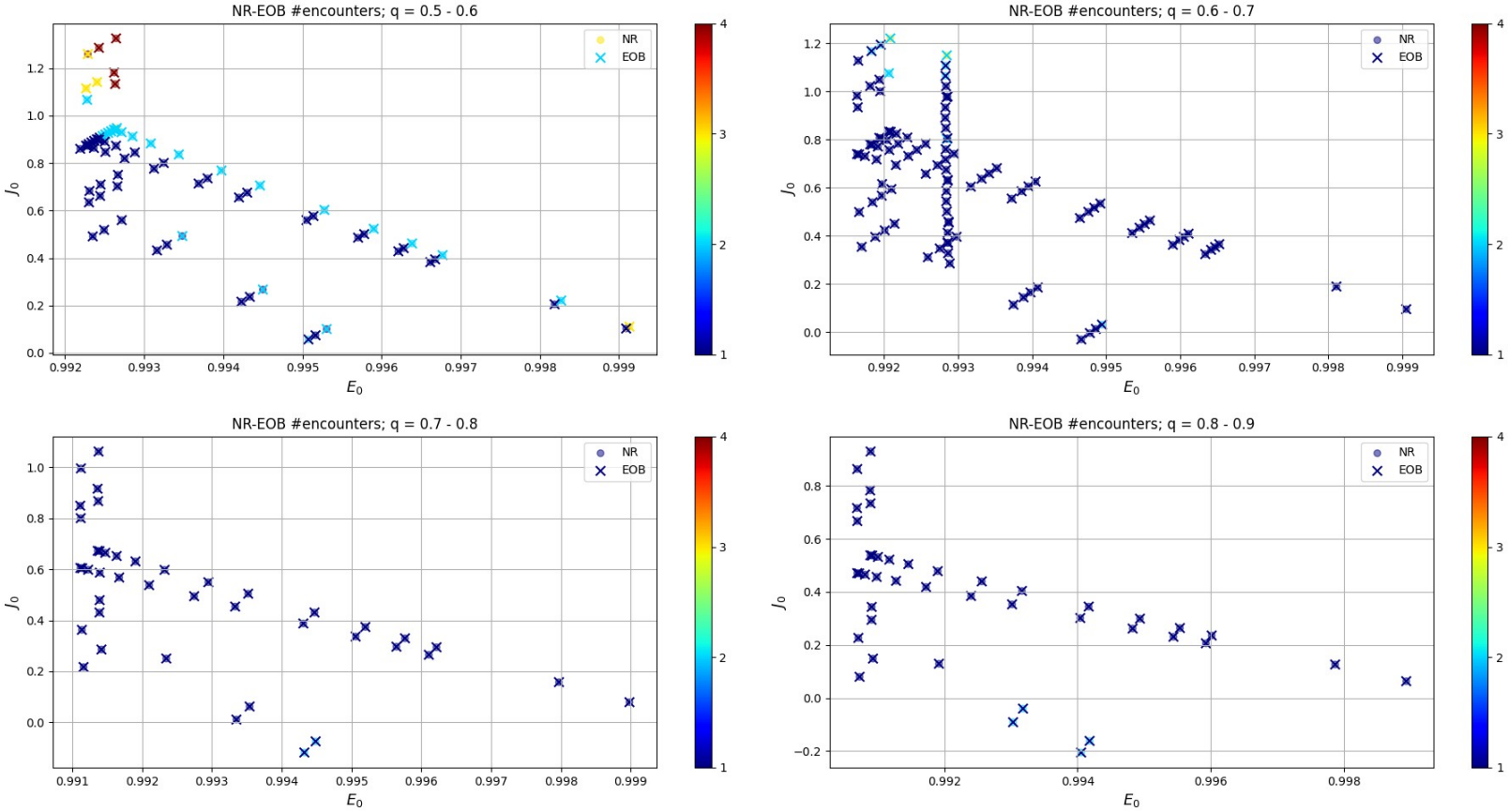
Encounters (E0, J0) RIT, computed with abs(strain) for NR and d(worb) for EOB. Data: 0.5>ecc>0.9



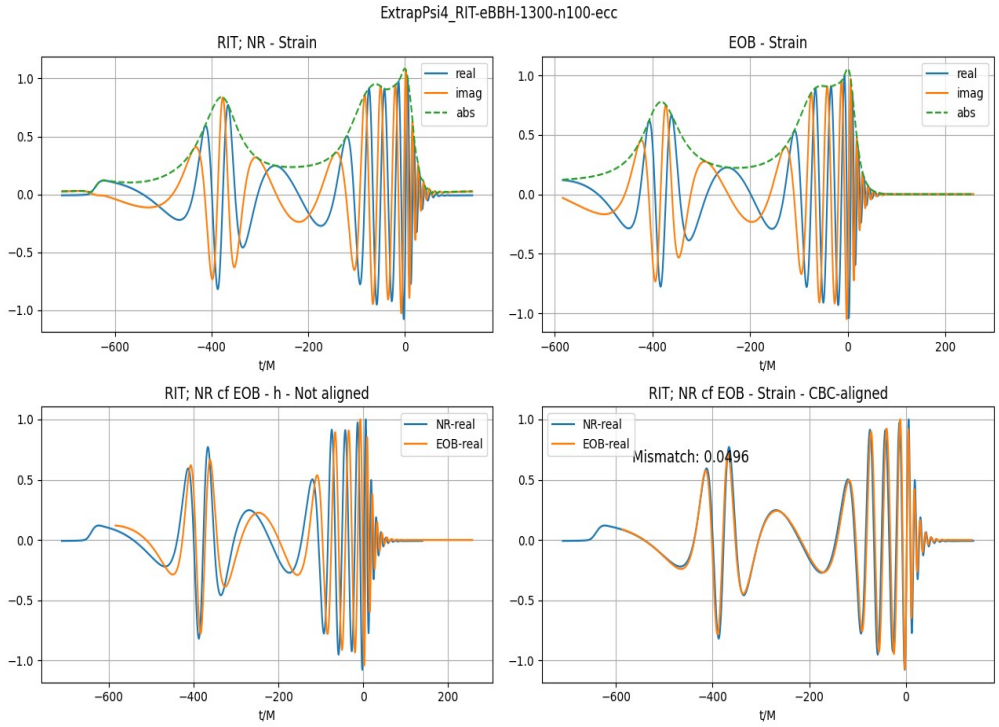
Encounters (E0, J0) RIT, computed with abs(strain) for NR and d(worb) for EOB. Data: 0.5>ecc>0.9

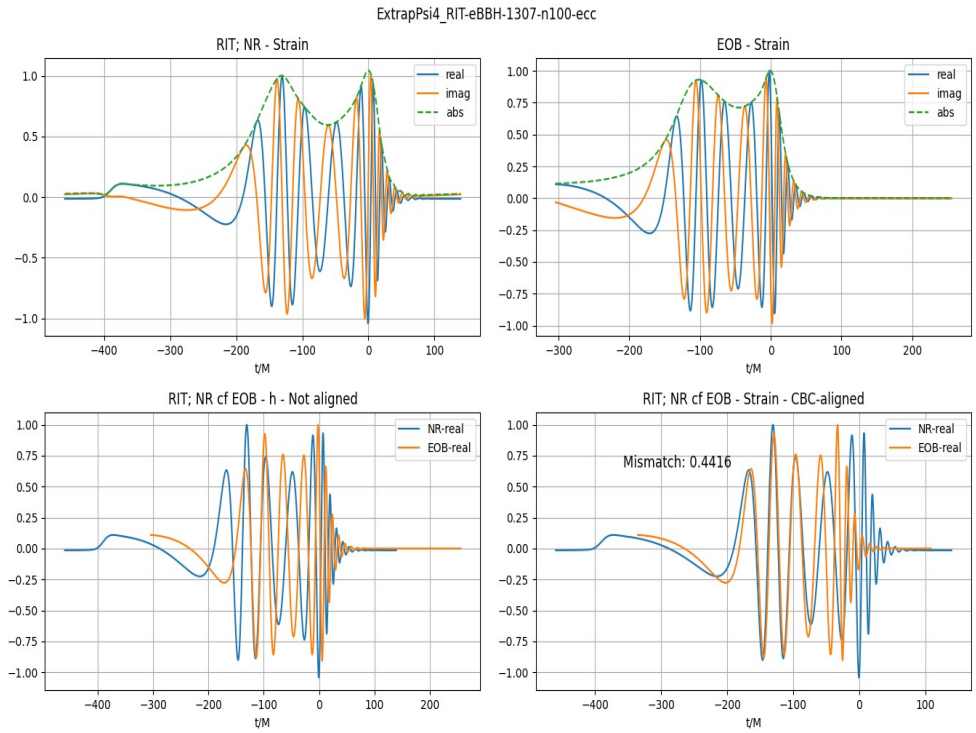


Encounters (E0, J0) computed with abs(strain) for NR and and d(worb) for EOB.

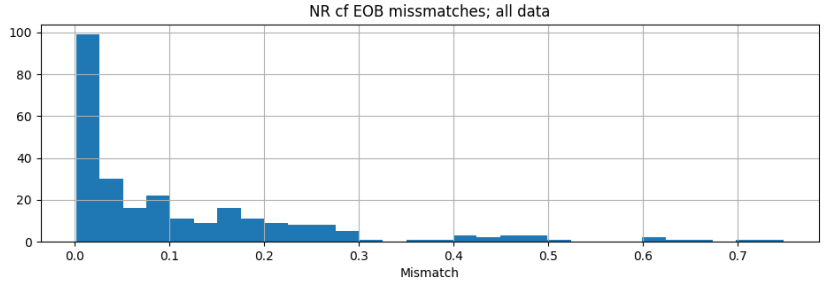


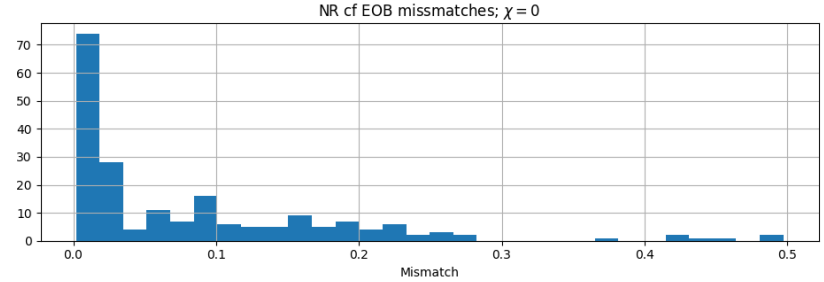
Mismatches.

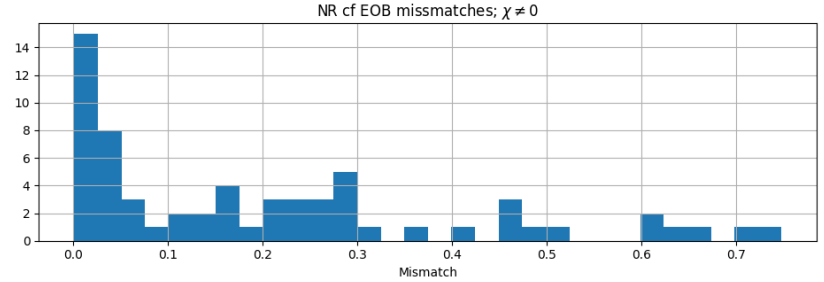

ExtrapPsi4_RIT-eBBH-1300-n100-ecc
RIT; NR - Strain
EOB - Strain
real
imag
abs
t/M
RIT; NR cf EOB - h - Not aligned
RIT; NR cf EOB - Strain - CBC-aligned
NR-real
EOB-real
Mismatch: 0.0496

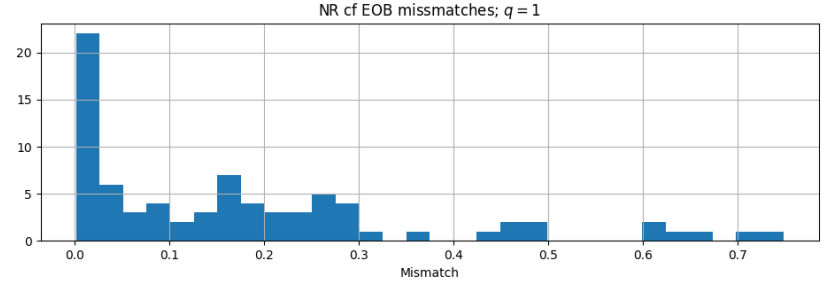

ExtrapPsi4_RIT-eBBH-1307-n100-ecc
RIT; NR - Strain
EOB - Strain
real
imag
abs
t/M
RIT; NR cf EOB - h - Not aligned
RIT; NR cf EOB - Strain - CBC-aligned
NR-real
EOB-real
Mismatch: 0.4416

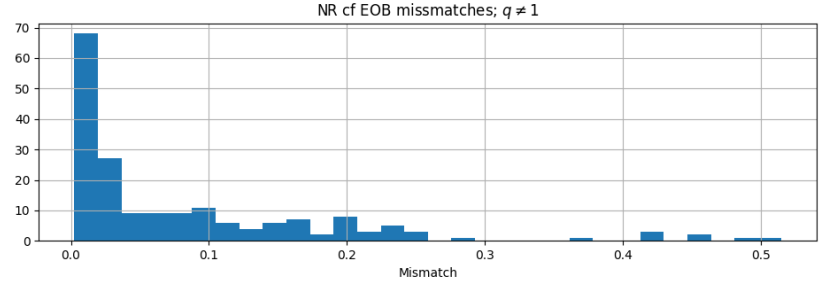
Mismatches


NR cf EOB missmatches; all data
Mismatch

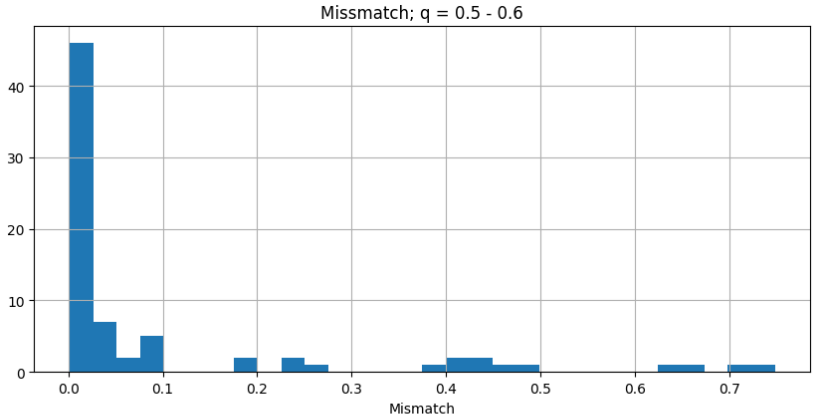

NR cf EOB missmatches; $\chi = 0$
Mismatch

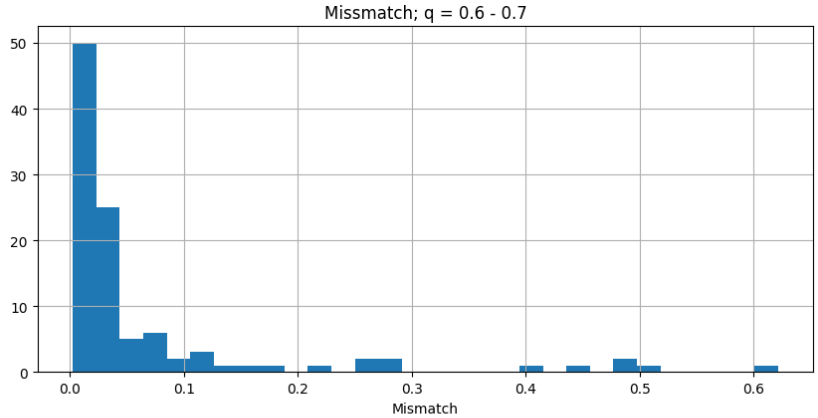

NR cf EOB missmatches; $\chi \neq 0$
Mismatch

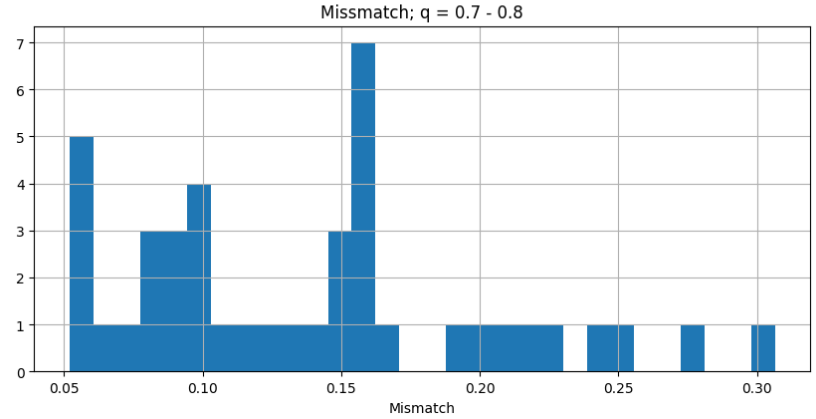

NR cf EOB missmatches; $q = 1$
Mismatch

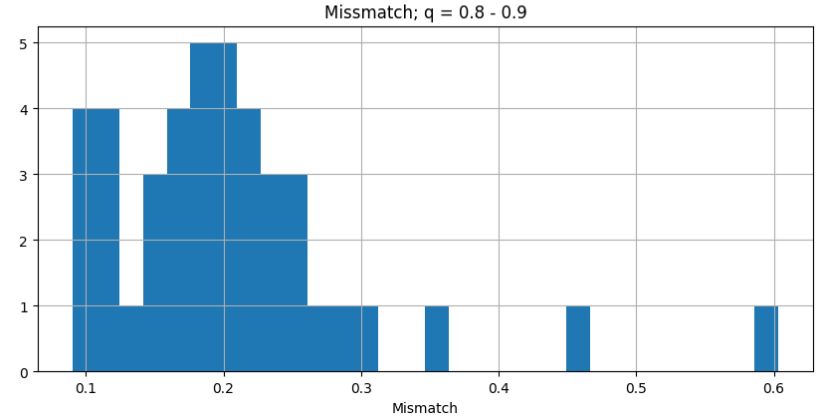

NR cf EOB missmatches; $q \neq 1$
Mismatch

Mismatches. Cuts in q, chi and ecc



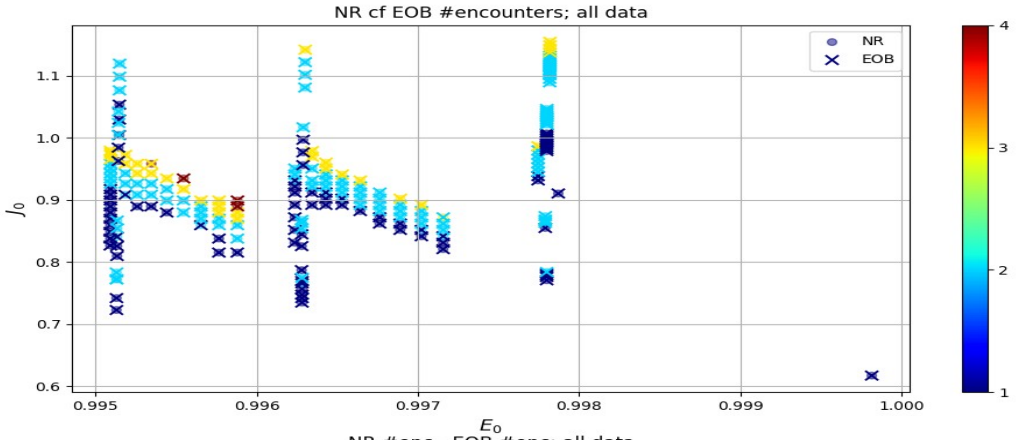


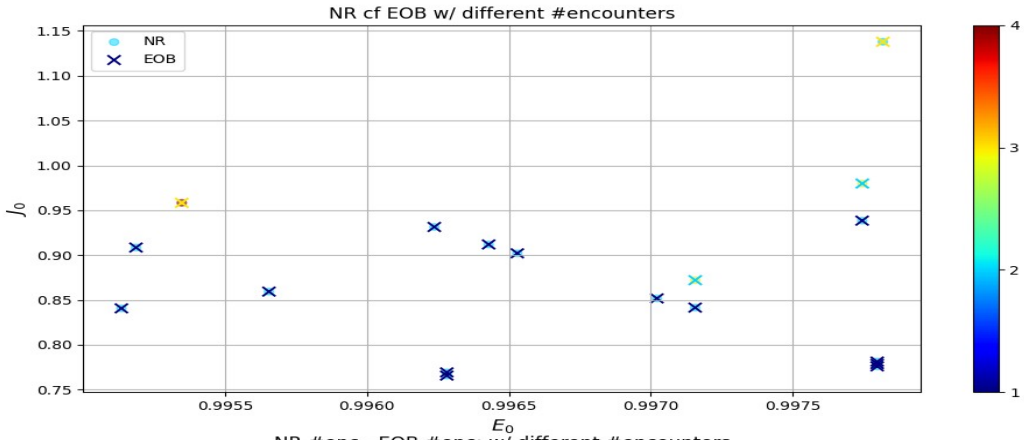


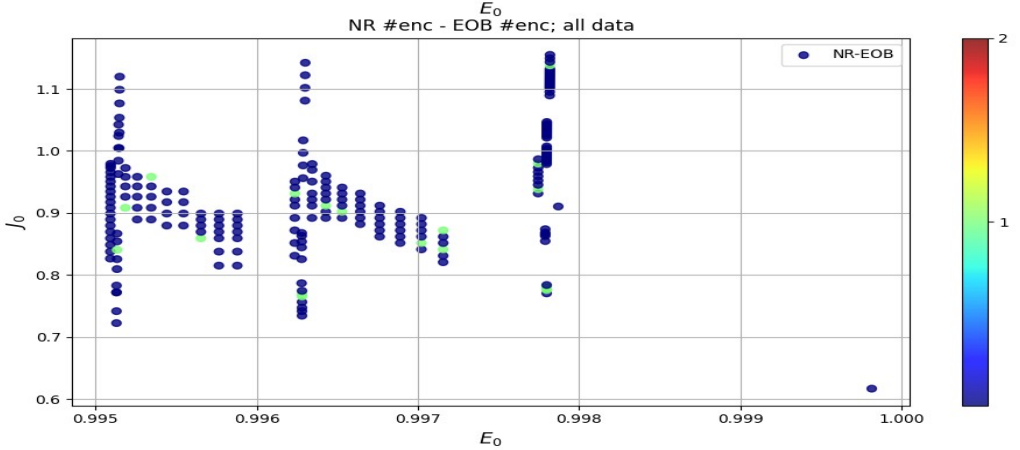


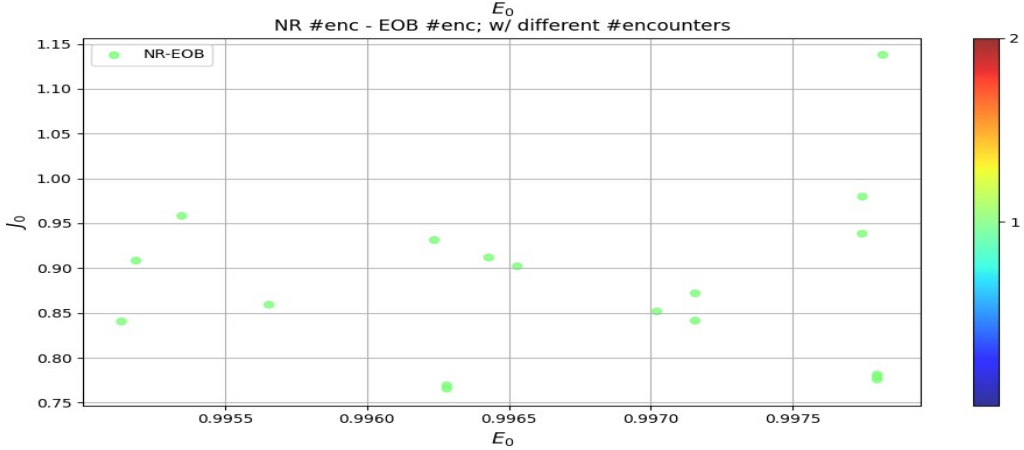
BACK-UP SLIDES

Encounters (E0, J0) ICC, computed with abs(strain) for NR and d(worb) for EOB

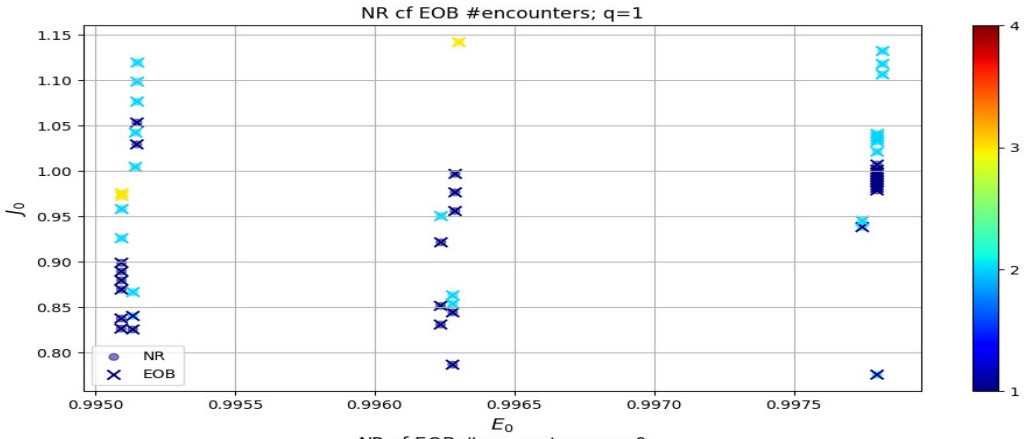


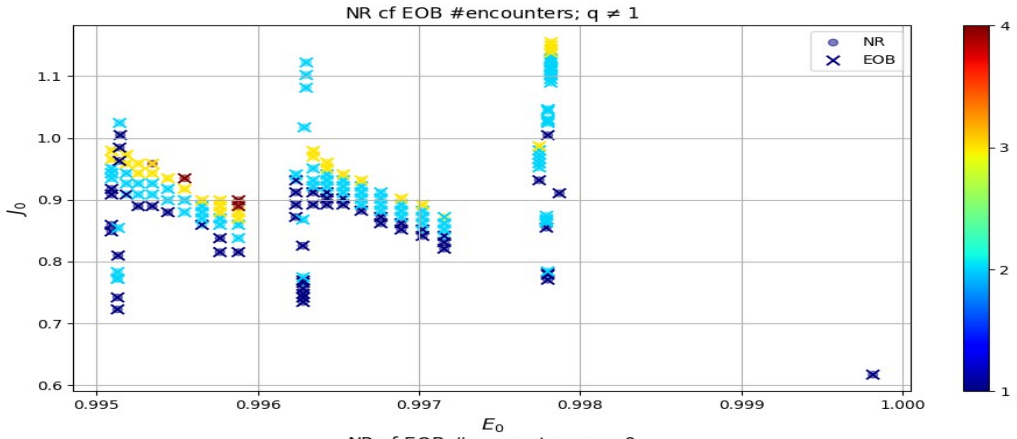


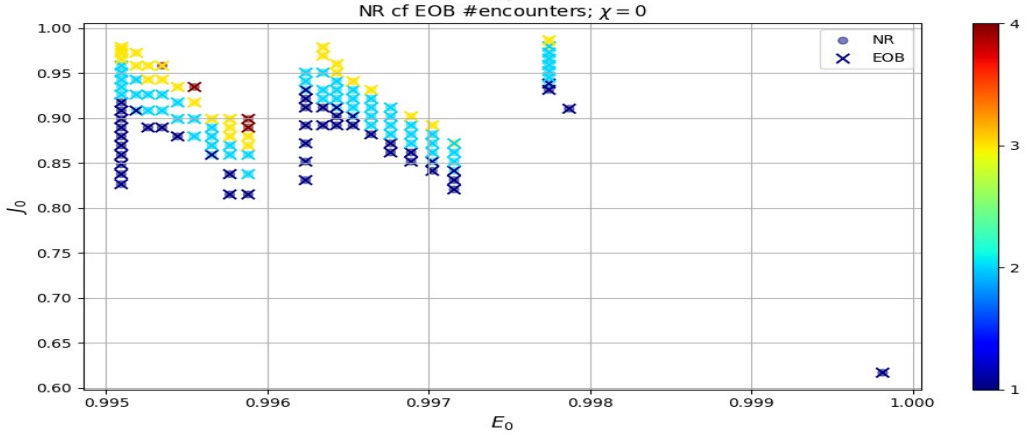


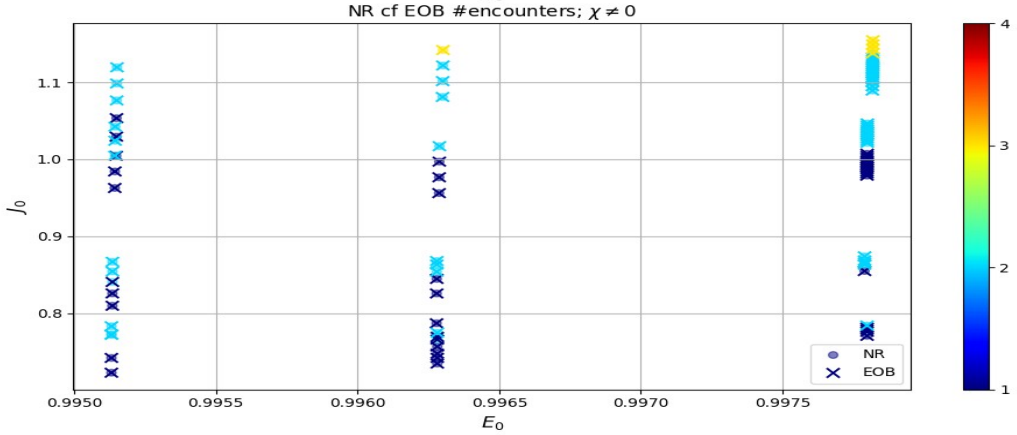


Encounters (E0, J0) ICC, computed with abs(strain) for NR and d(worb) for EOB

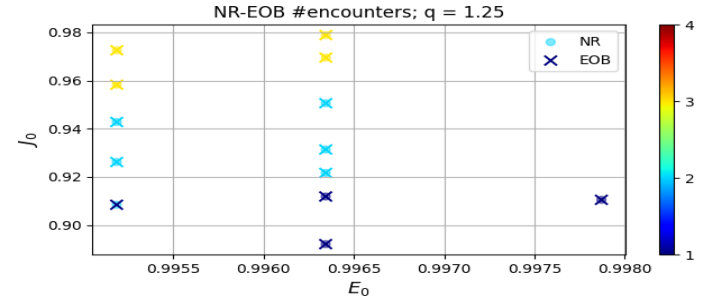


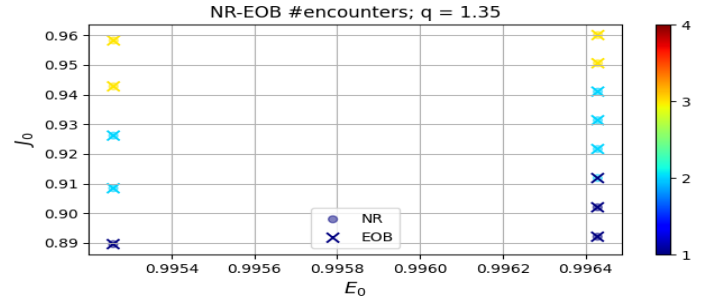


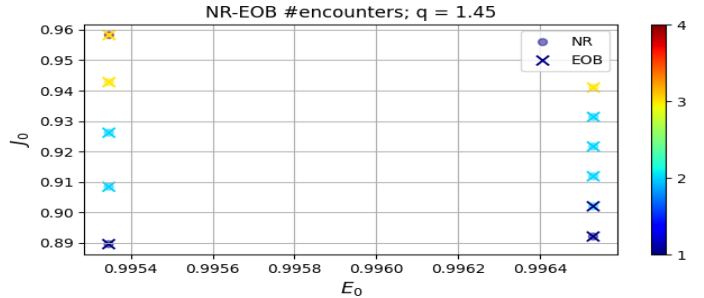


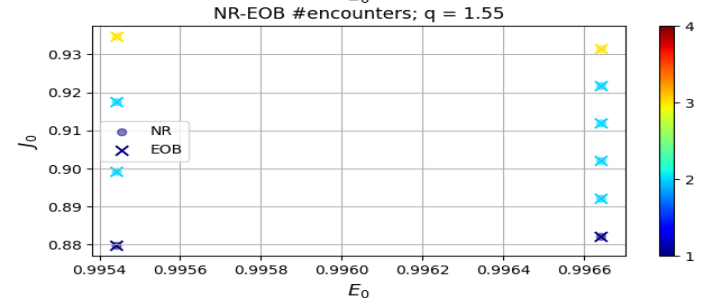


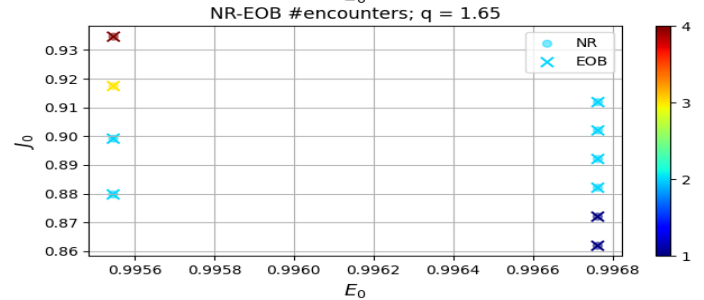
Encounters (E0, J0) ICC, computed with abs(strain) for NR and d(worb) for EOB

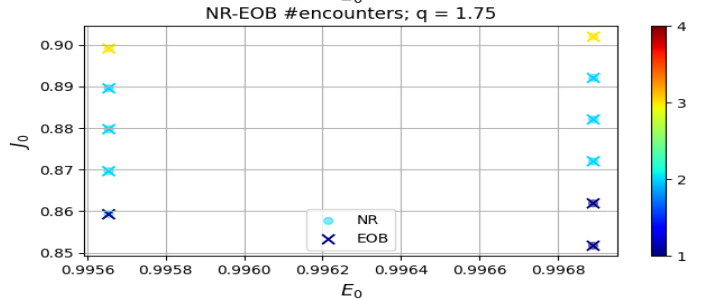


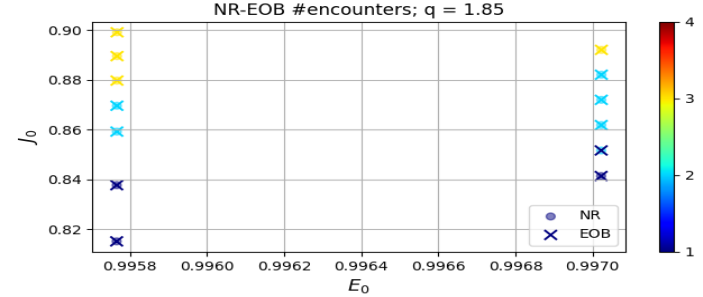


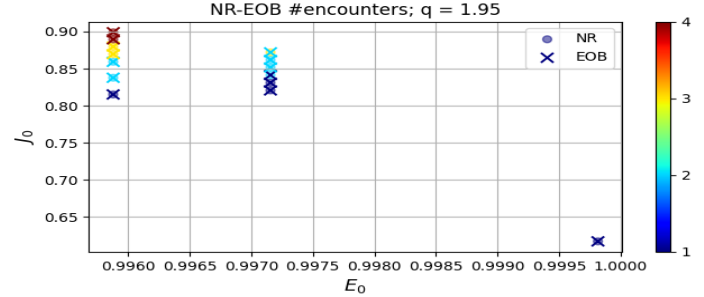




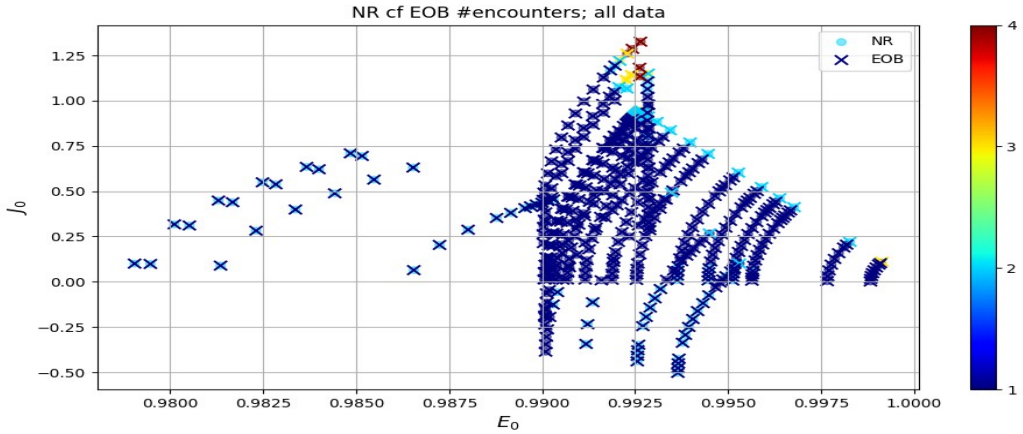


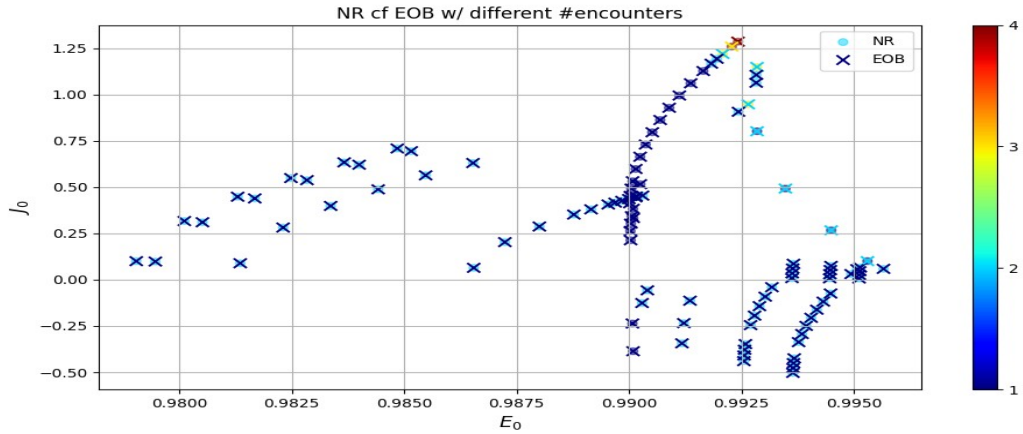


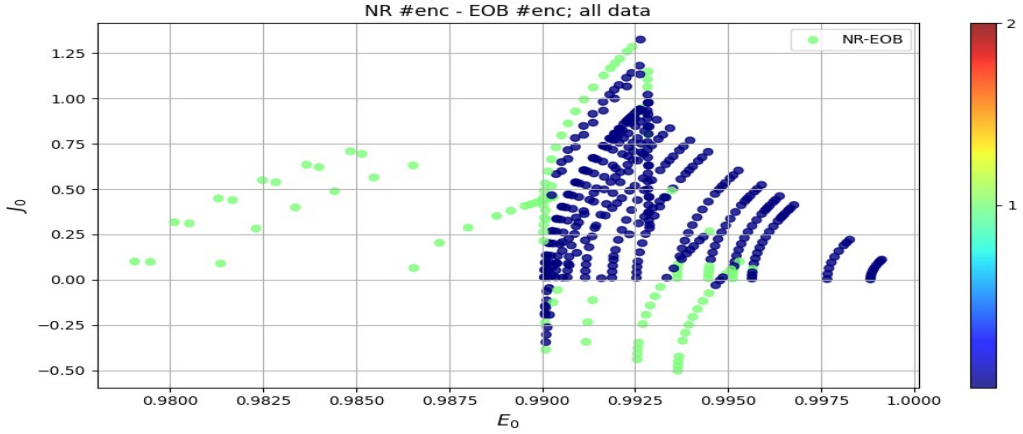


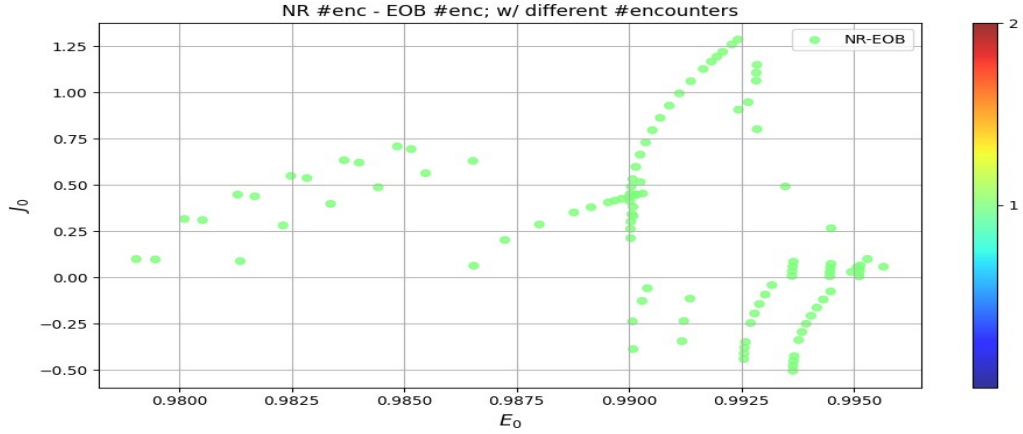
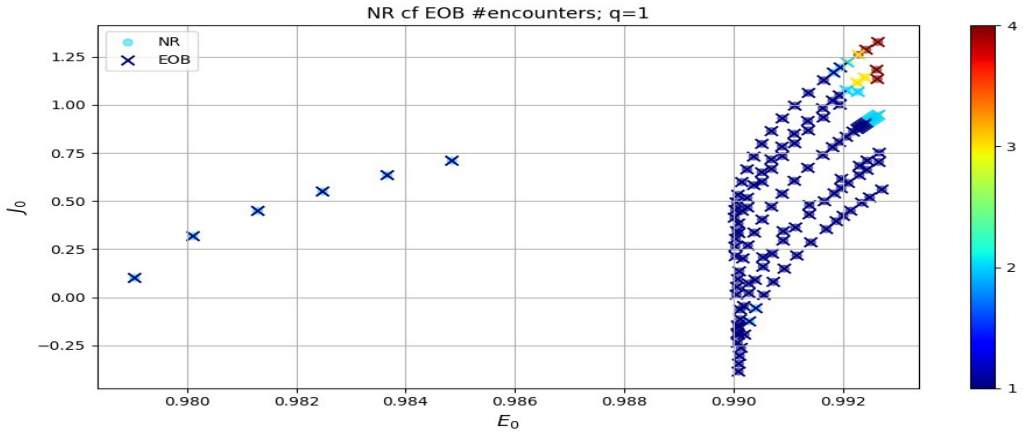
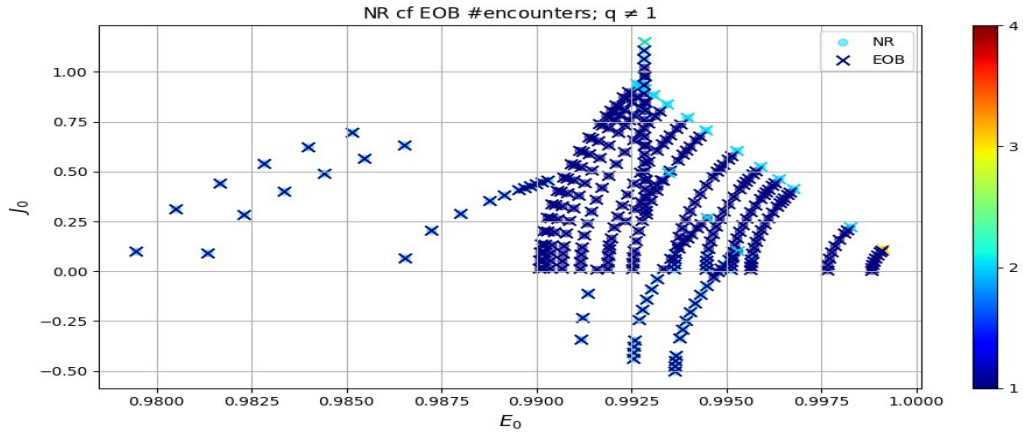
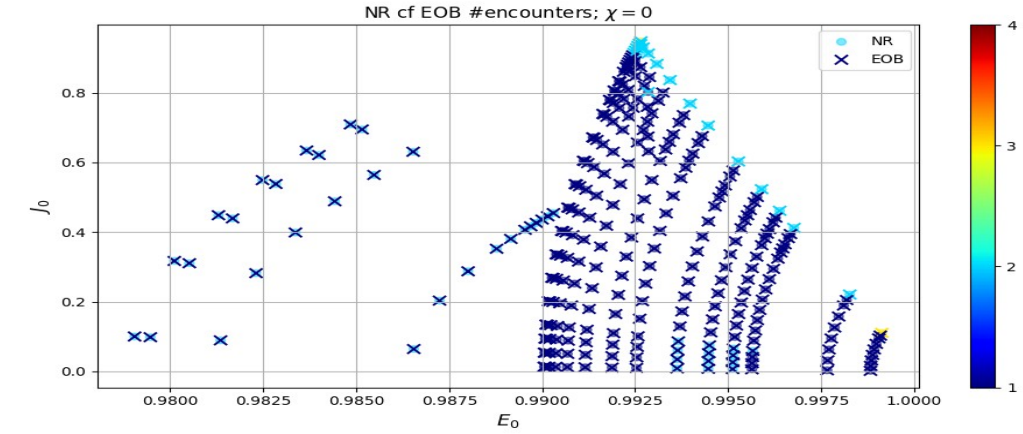
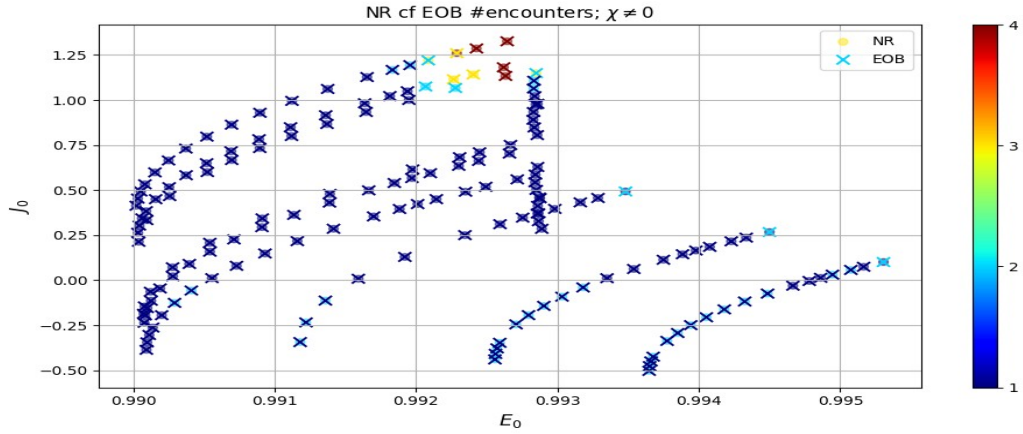


Encounters (E0, J0) RIT, computed with abs(strain) for NR and d(worb) for EOB









Encounters (E0, J0) RIT, computed with abs(strain) for NR and d(worb) for EOB