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Final Presentation

P230825

**Taking It to the Next Level:
Searching for Gravitational Waves with
Eccentricity from Compact Binary
Coalescences**

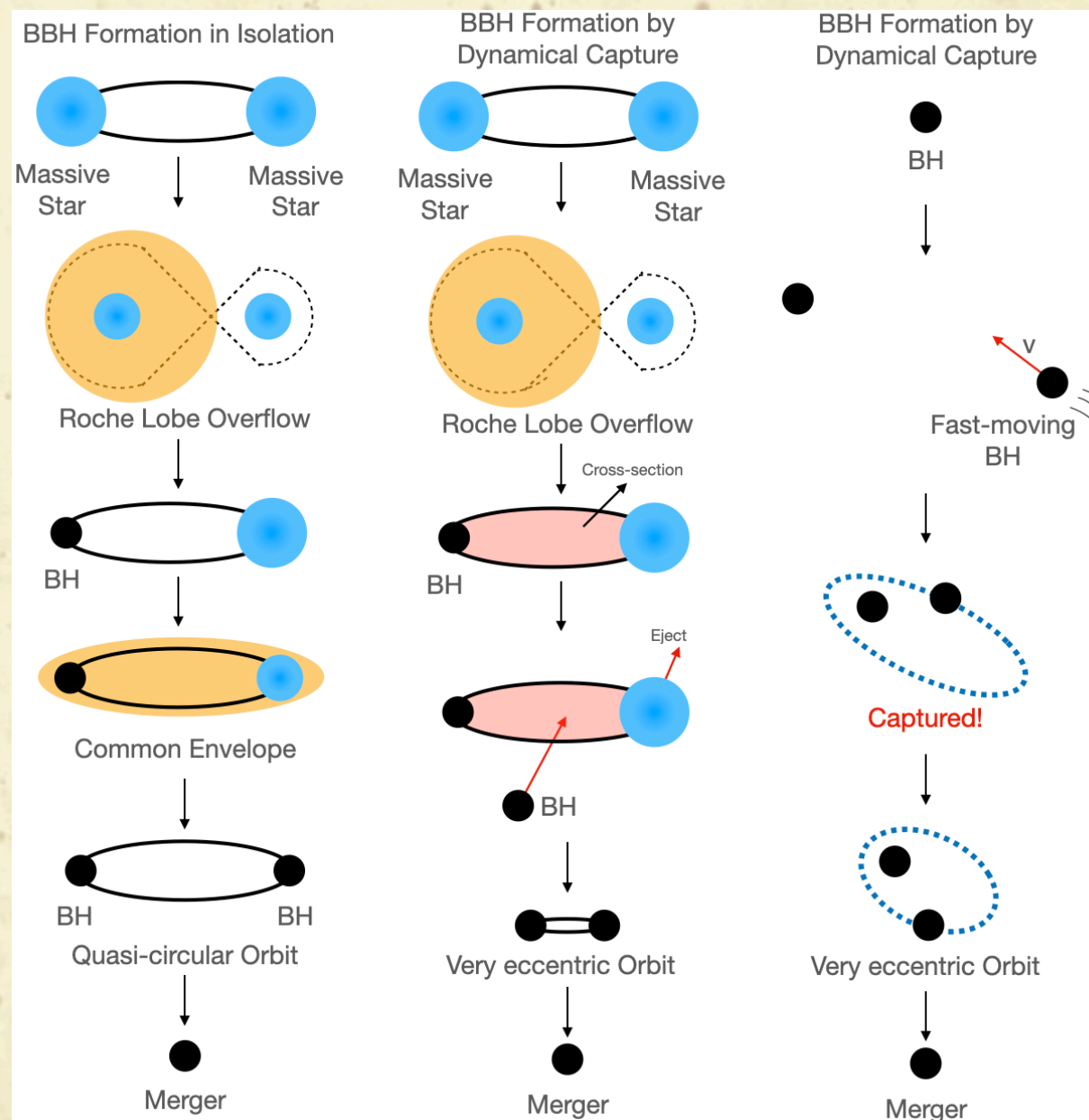
Date : 25 August 2023

Elwin K. Y. Li

Mentor: Alan J. Weinstein

Project Goals

- Review the new waveform model – TEOBResumS
- Find out the **population of dynamical capture** (Ultimate Goal!)





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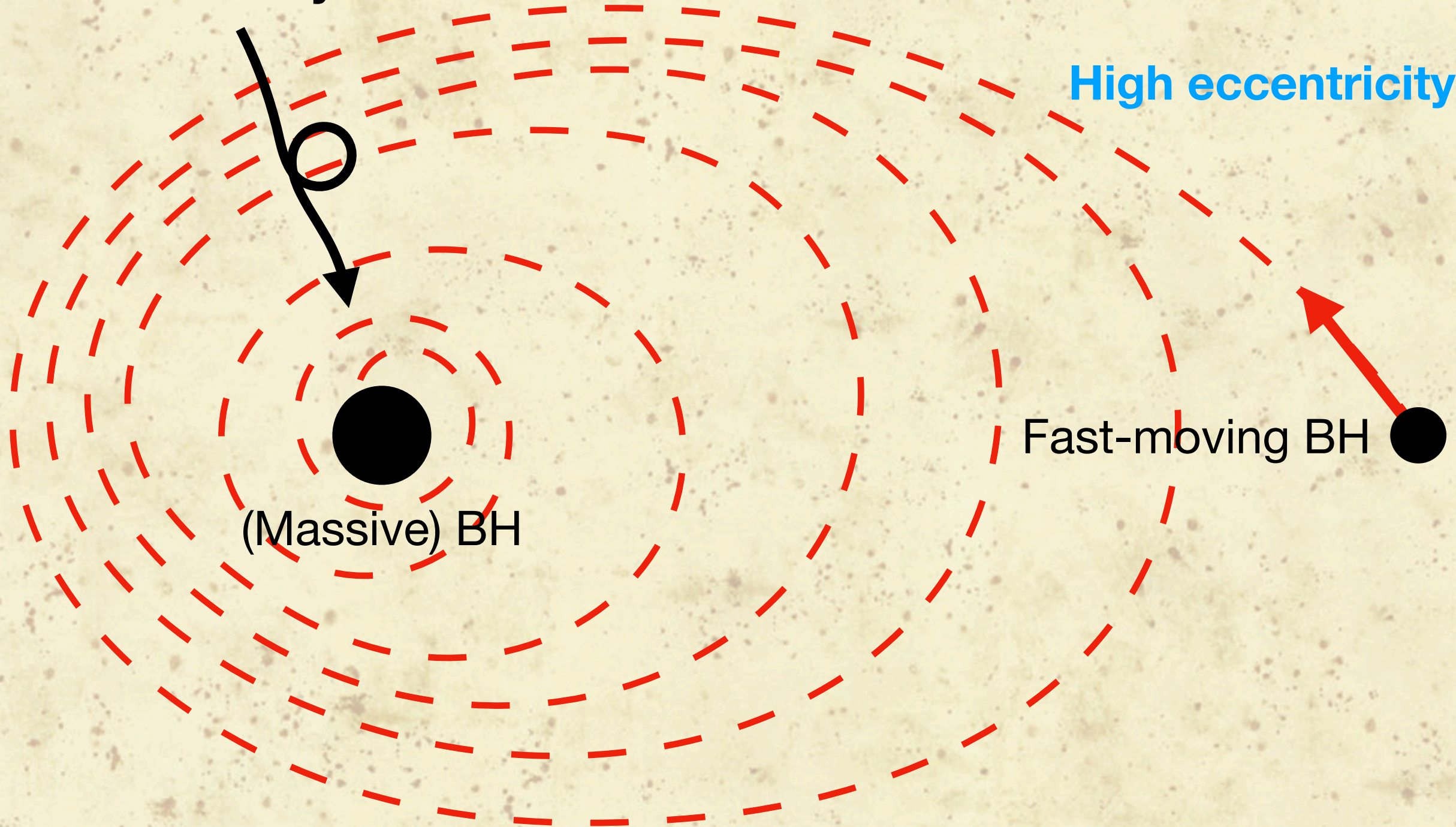
Approaches

Approaches

- **Eccentricity evolution investigation**
- **Comparisons between waveforms**
- **Test for the detectability of eccentric waveforms**
- **Parameter estimation with Bilby implementation**
- **PE on real data using Bilby**

Low eccentricity

High eccentricity



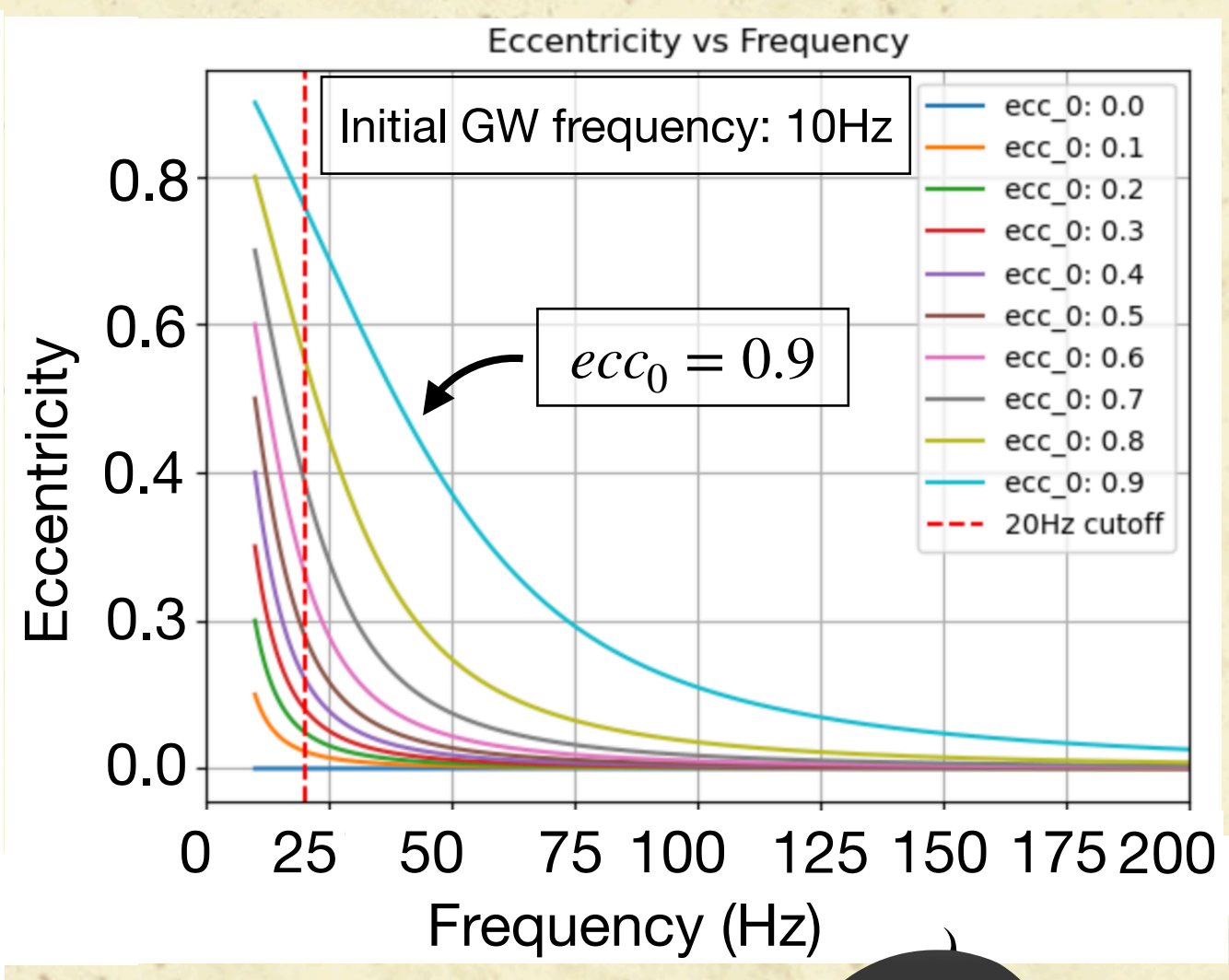
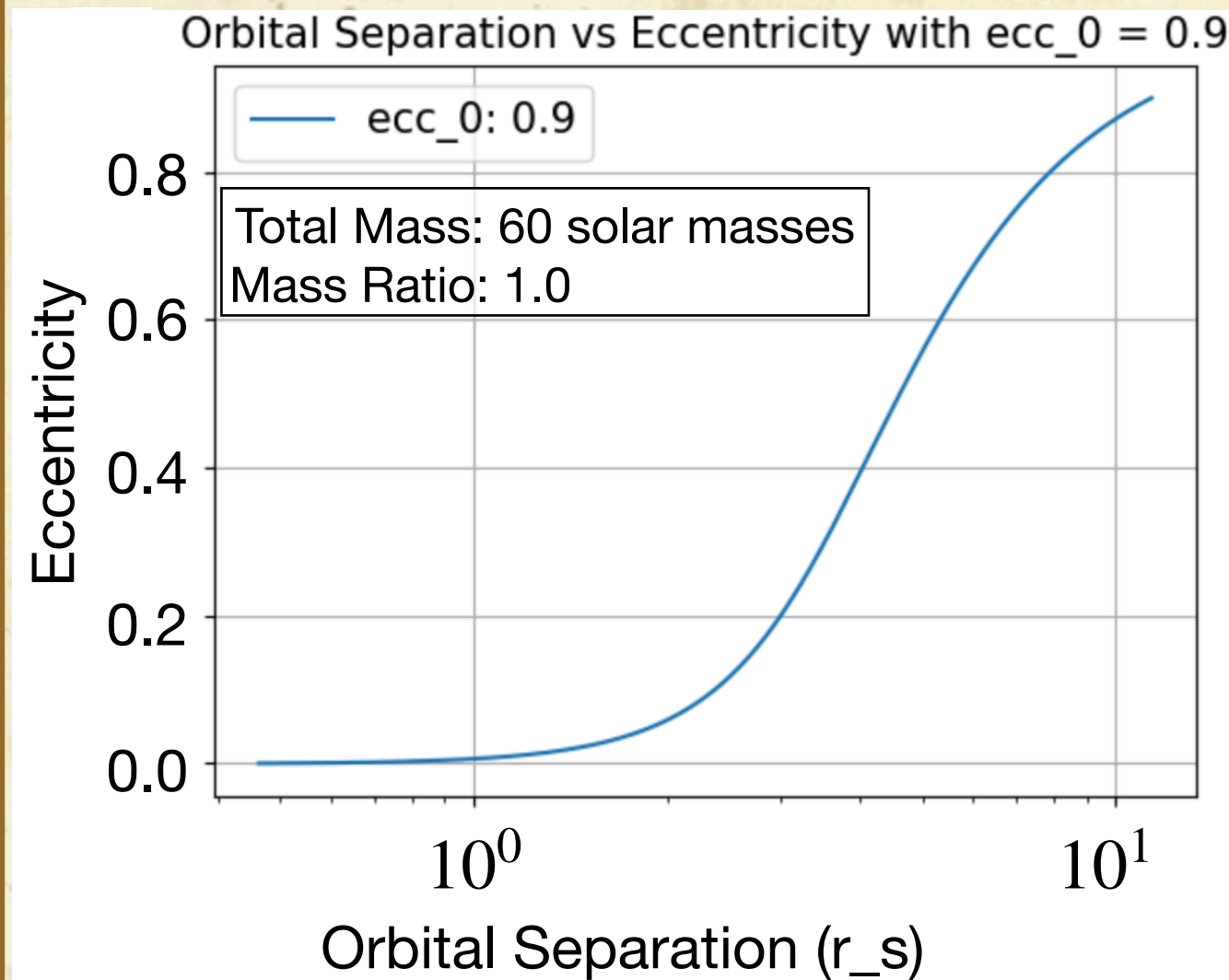


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Eccentricity Evolution Investigation

Eccentricity Evolution Investigation (According to Equation 5.7 in Peters paper, 1964)



The results show the feasibility of achieving the Ultimate Goal!

(Keynote drawing skills inherited from my brother)





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Review the TEOBResumS
waveform model

Review the NEW TEOBResumS waveform model

- Sanity check (by eyeballs)
- Waveforms overlap and match

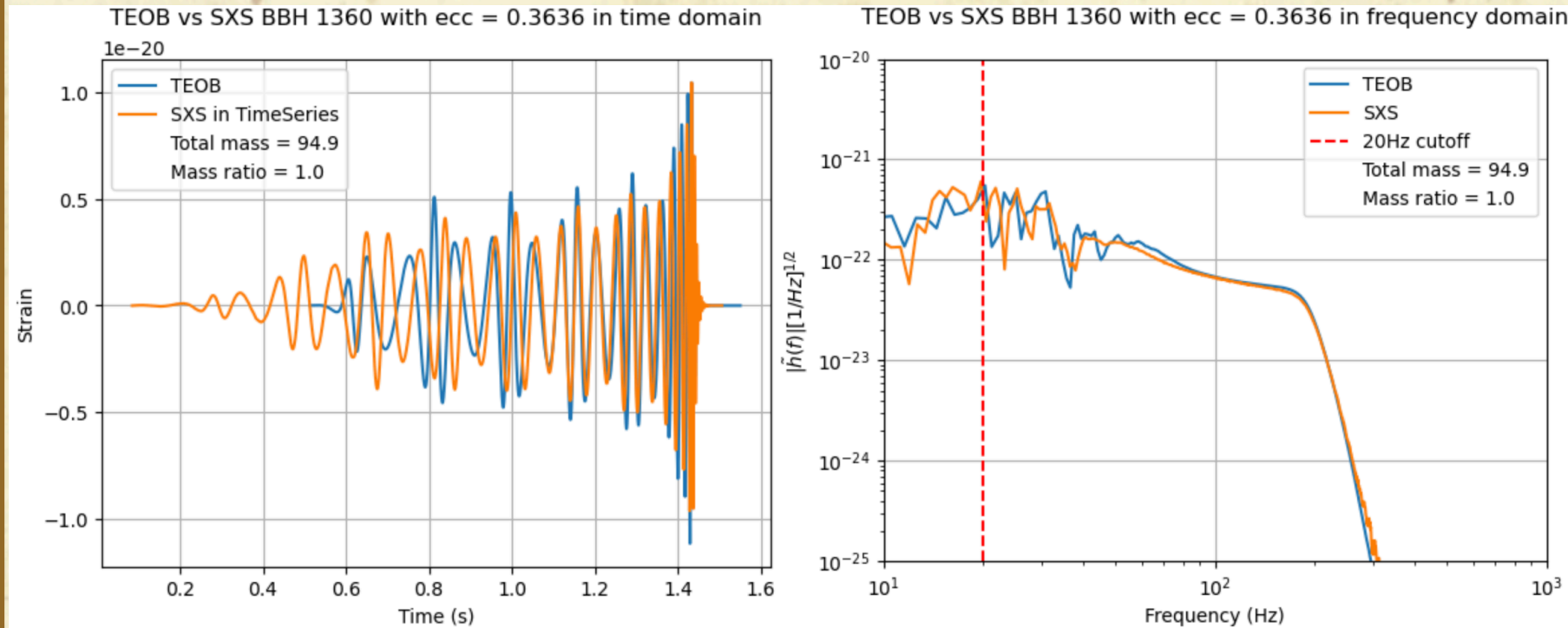
Top 4 important comparisons:

1. TEOB-ecc vs SXS-ecc
2. TEOB-ecc vs EccentricFD/TaylorF2Ecc
3. TEOB-spin vs IMRPhenomXPHM-spin
4. TEOB-ecc vs IMRPhenomXPHM-prec

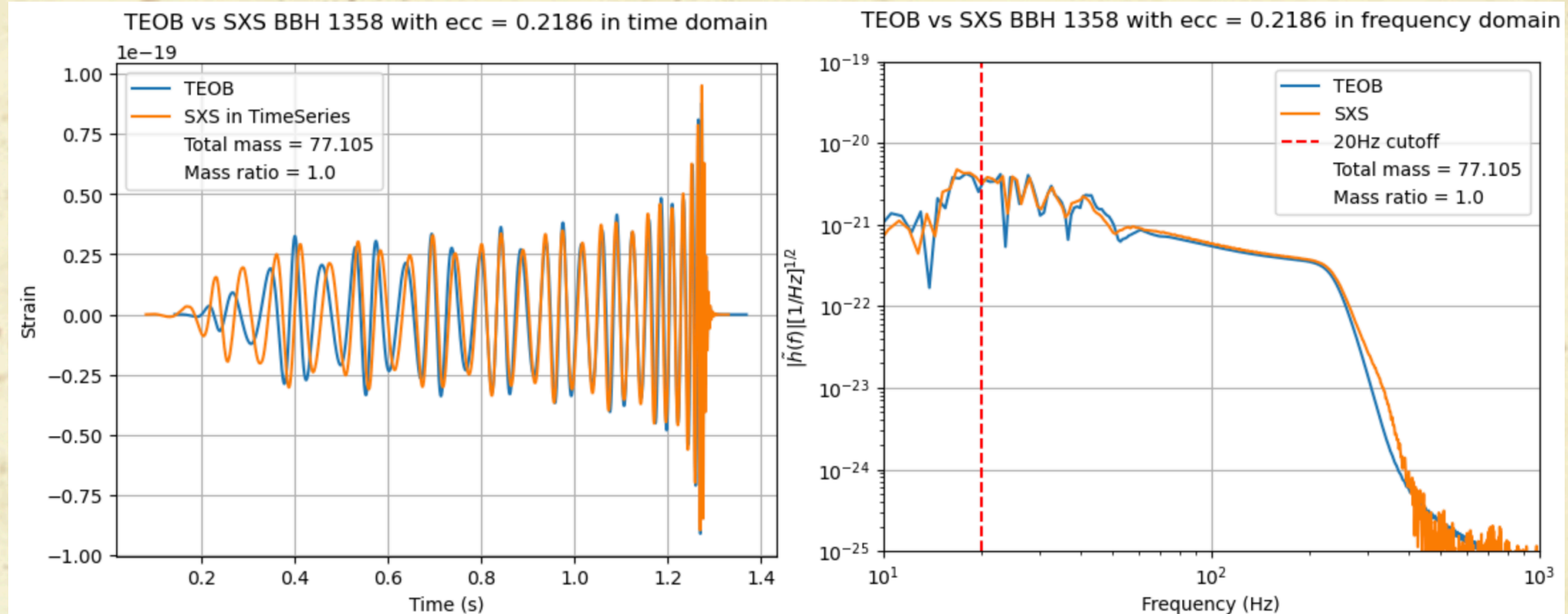
Are they similar?



TEOB vs SXS



Match $\geq 85\%$ in both TD and FD!





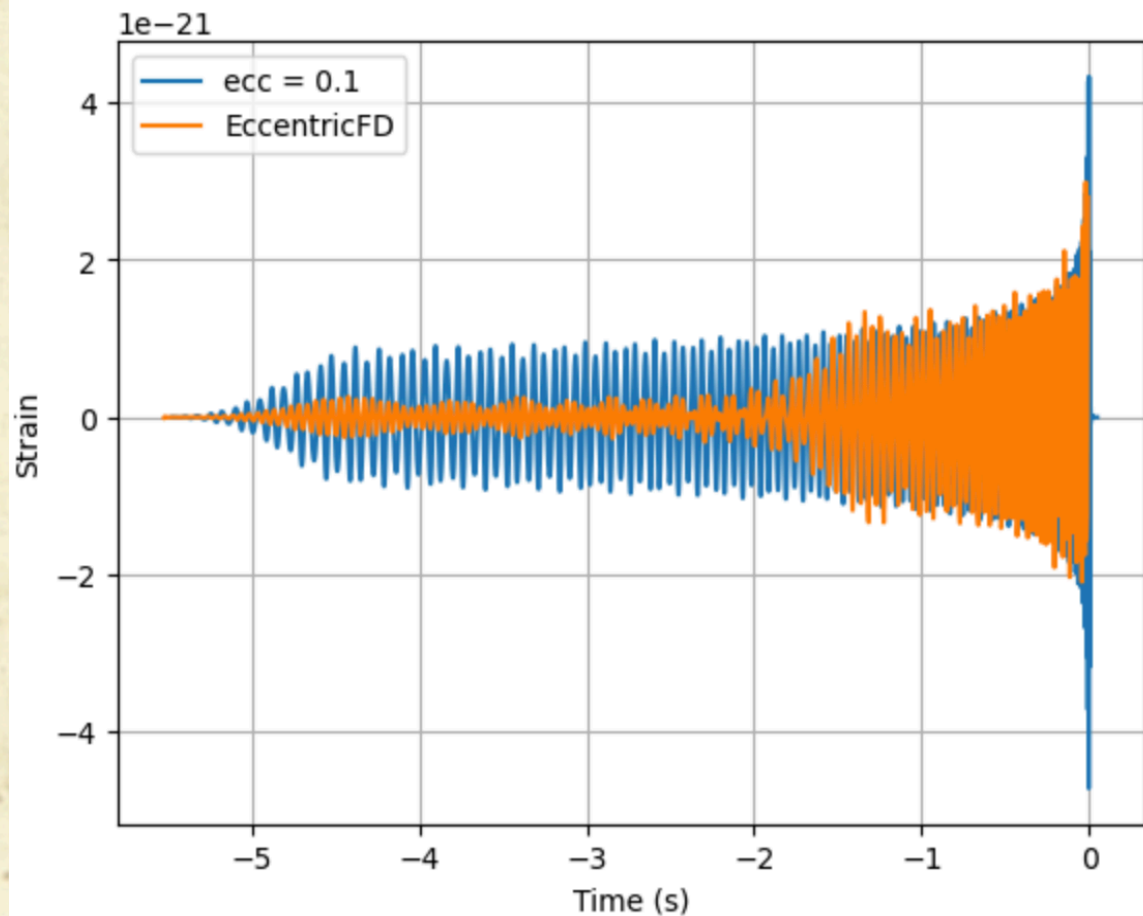
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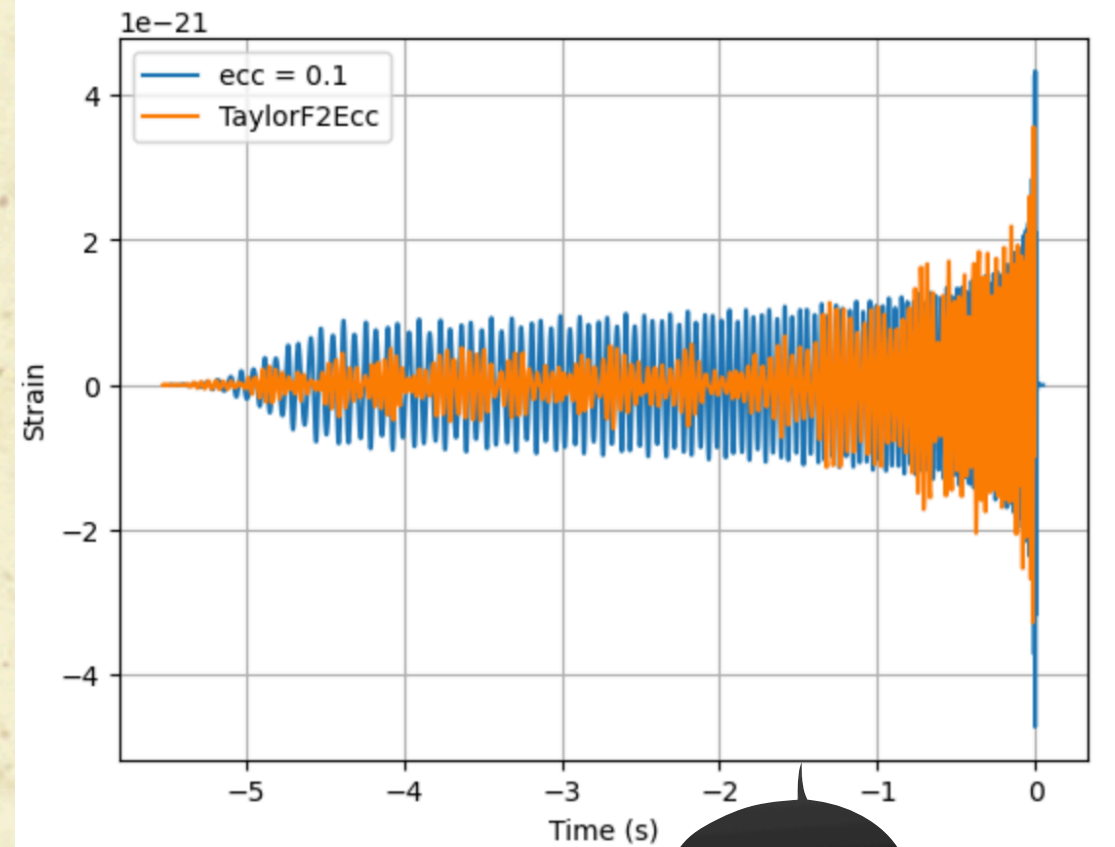
TEOB vs
EccentricFD/TaylorF2Ecc

TEOB vs EccentricFD/TaylorF2Ecc

Eccentric TEOB waveforms VS EccentricFD with ecc 0.1 in time domain



Eccentric TEOB waveforms VS TaylorF2Ecc with ecc 0.1 in time domain

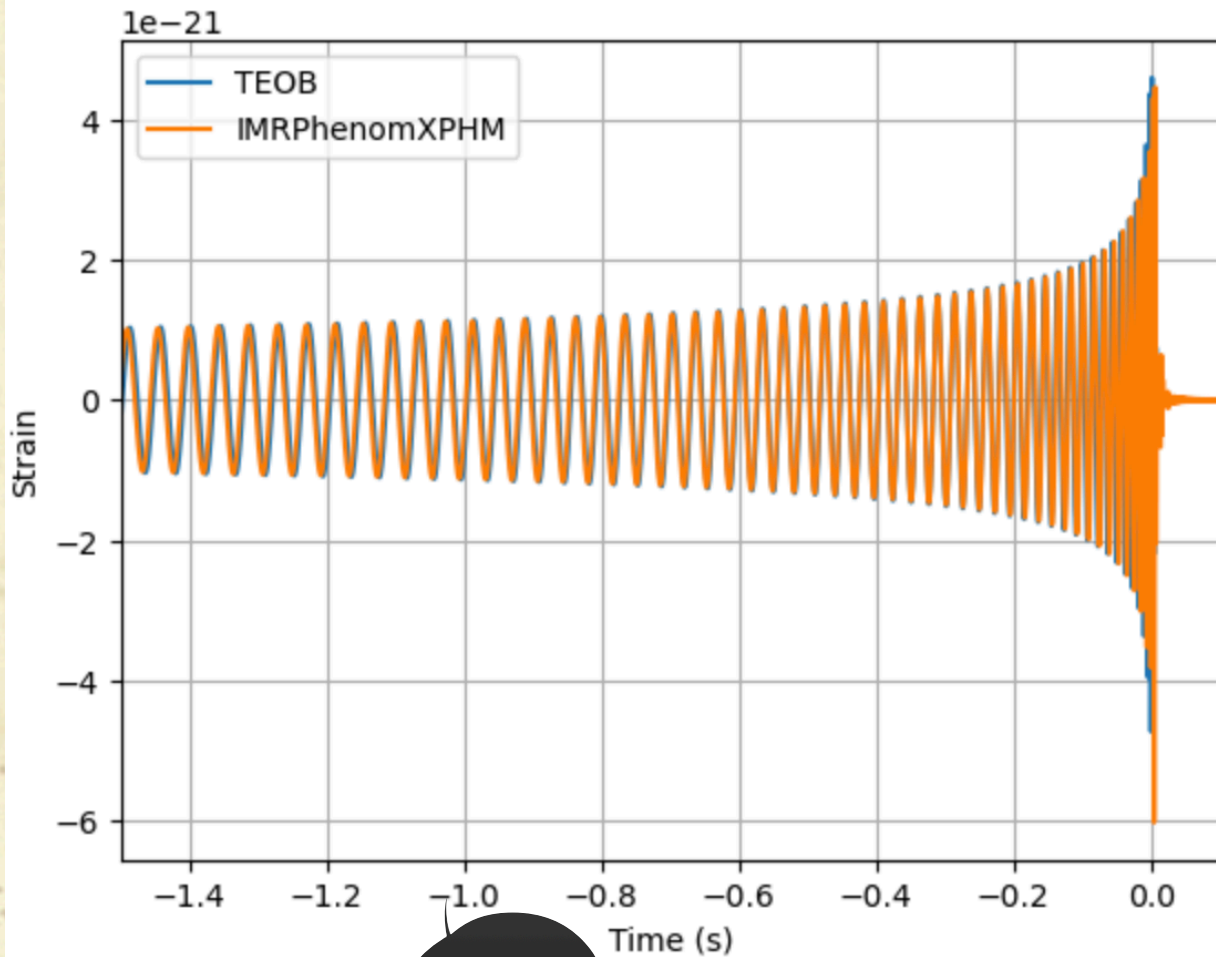


A better eccentric waveform model is needed!

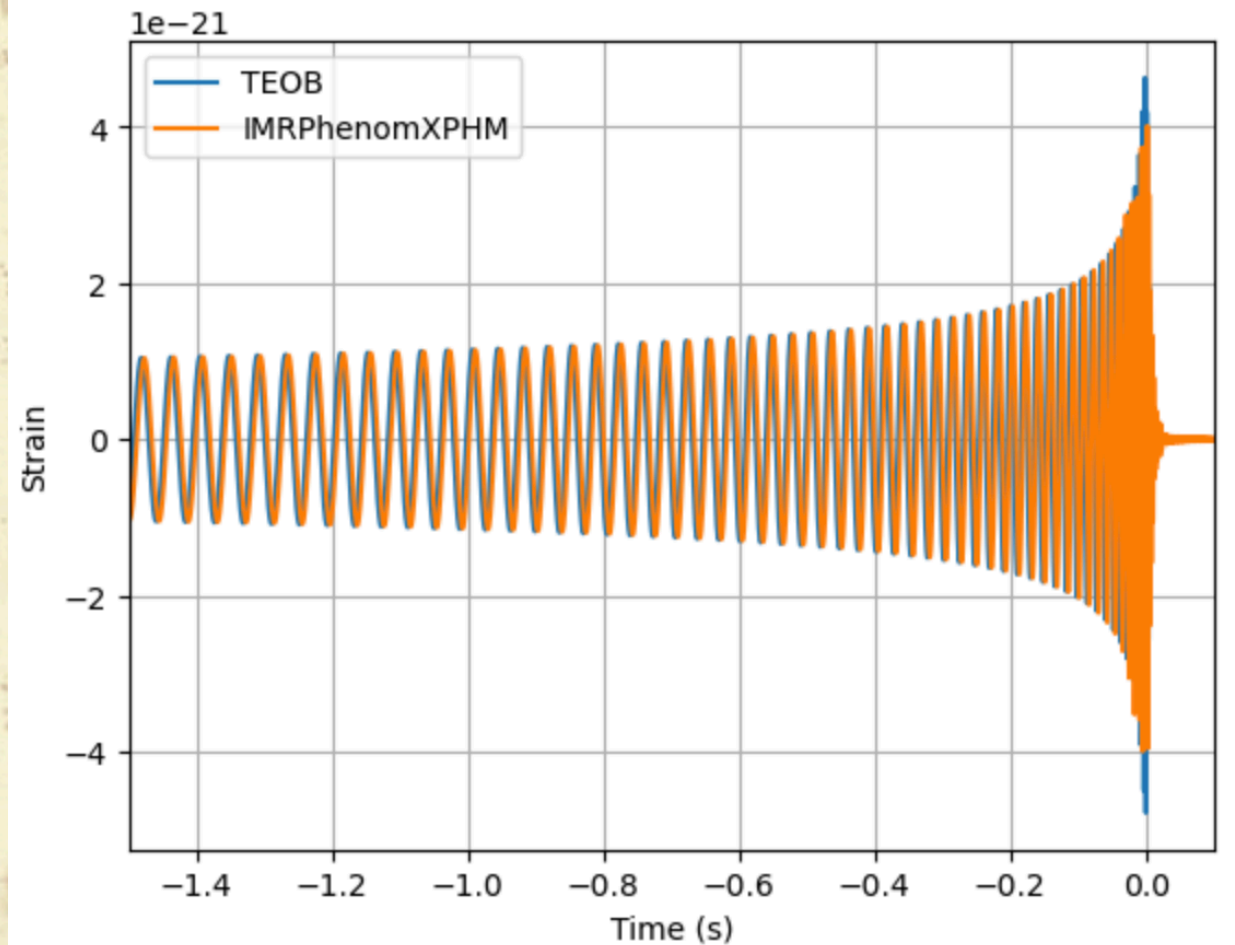


TEOB vs IMRPhenomXPHM (Aligned Spin)

IMRPhenomXPHM Spin1 = 0.4, Spin2 = 0.7 Vs TEOB in time domain



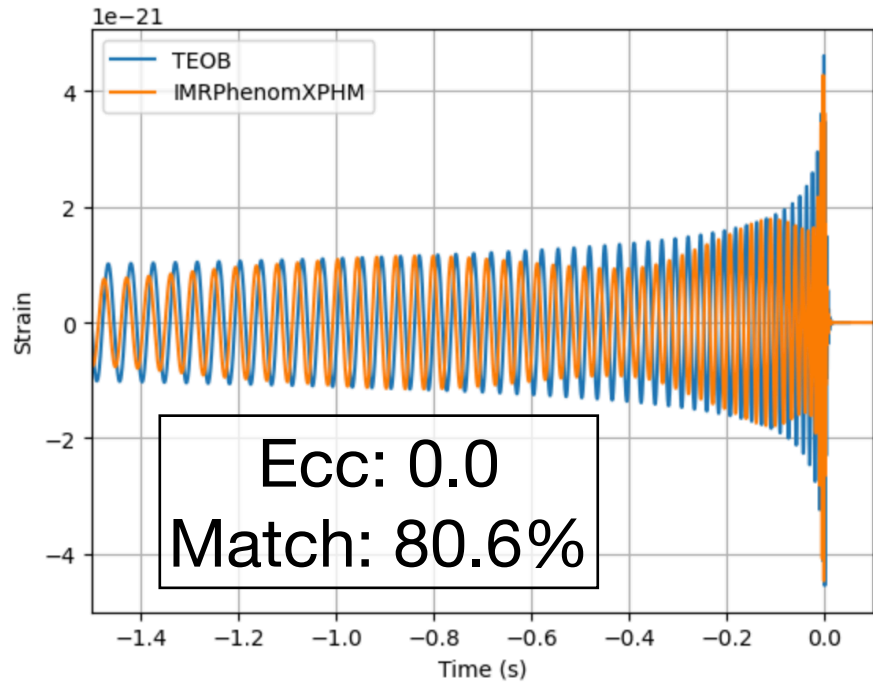
IMRPhenomXPHM Spin1 = 0.9, Spin2 = 0.9 Vs TEOB in time domain



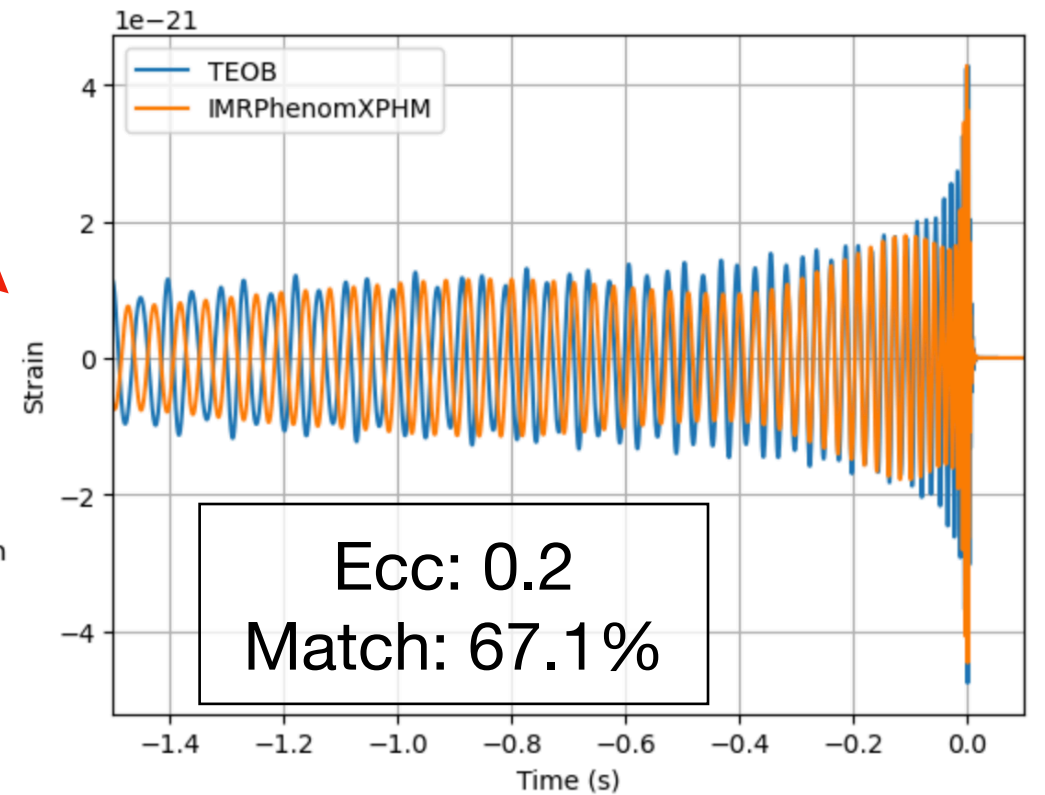
MA70#
95%

TEOB-ecc vs Precessing IMRPhenomXPHM

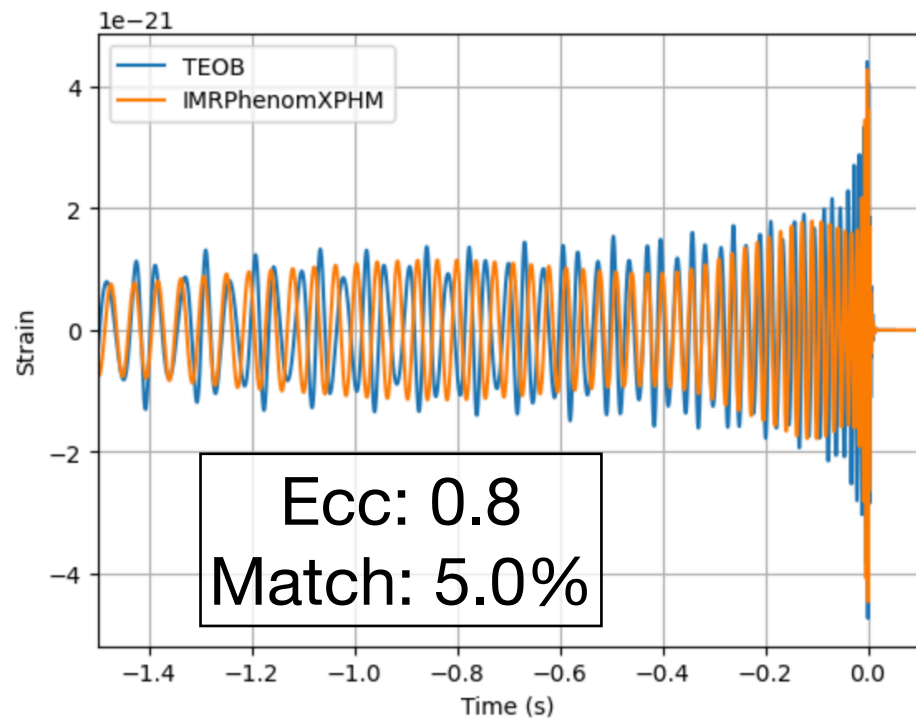
IMRPhenomXPHM Spin $x_{1,2} = 0.7$ Spin $y_{1,2} = 0.7$ Vs TEOB Ecc = 0.0 in time domain



IMRPhenomXPHM Spin $x_{1,2} = 0.7$ Spin $y_{1,2} = 0.7$ Vs TEOB Ecc = 0.2 in time domain



IMRPhenomXPHM Spin $x_{1,2} = 0.7$ Spin $y_{1,2} = 0.7$ Vs TEOB Ecc = 0.8 in time domain





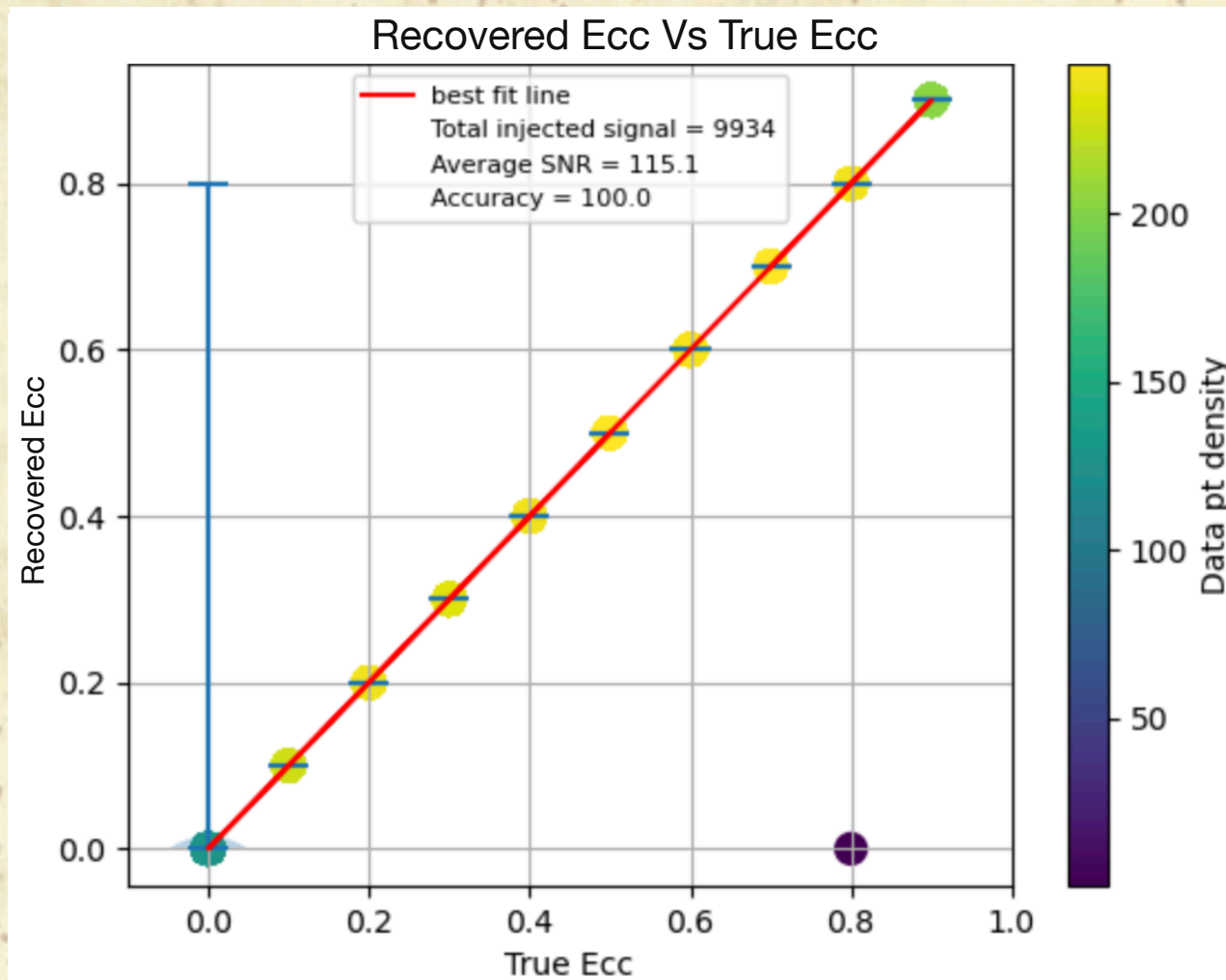
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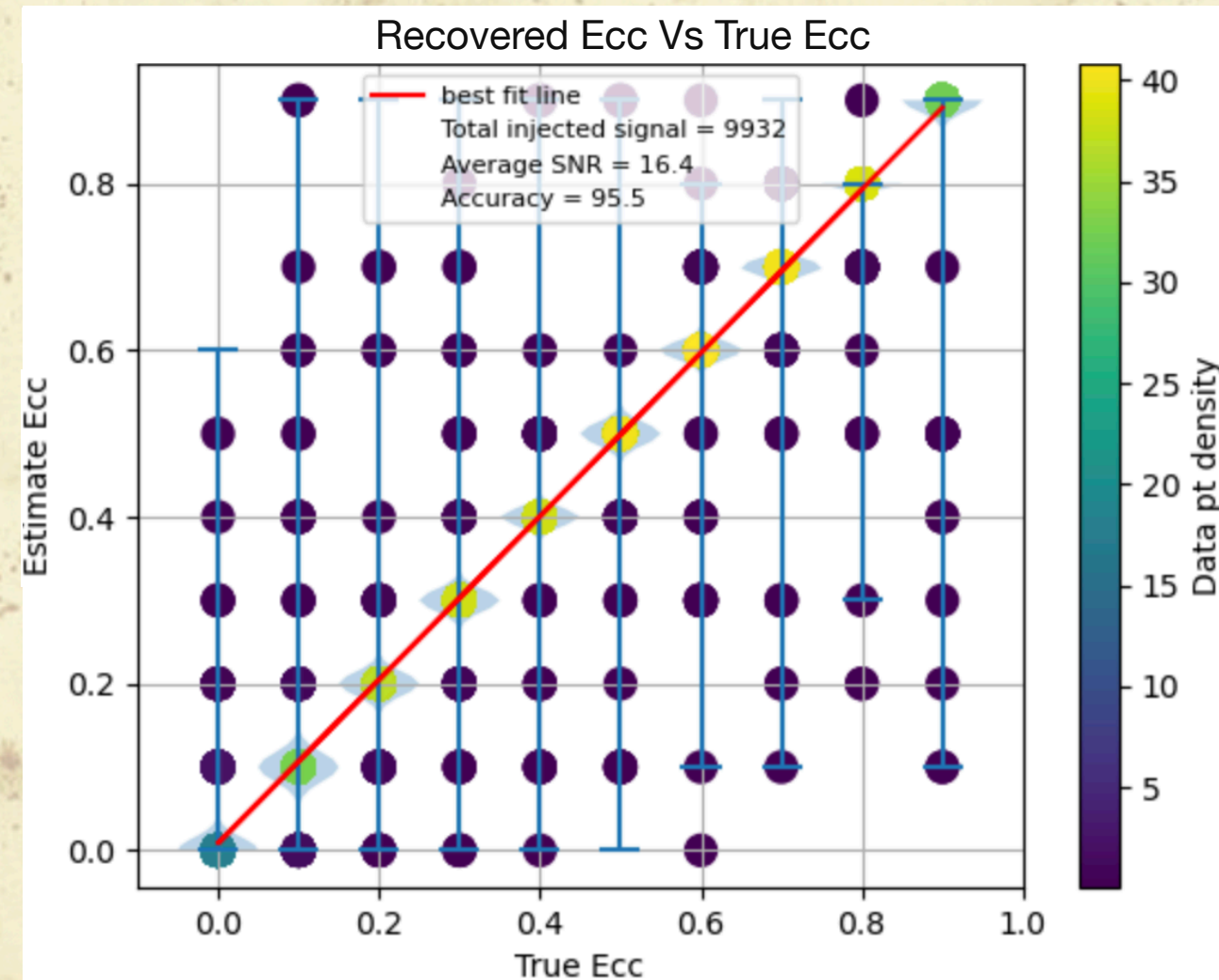
Test for the detectability of eccentric waveforms

eccENTric seaRch mOdel (ENTRO) (~~ECHO~~):

- Test for the **detectability** of eccentric waveforms



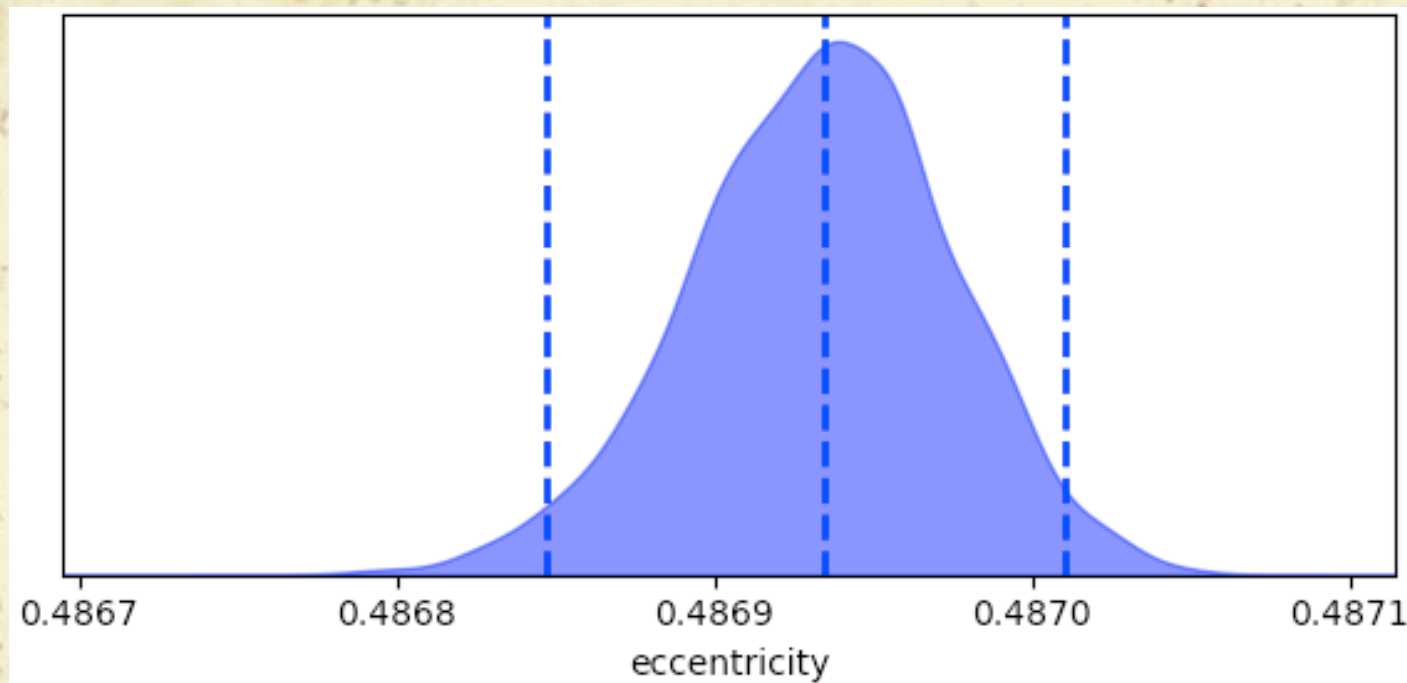
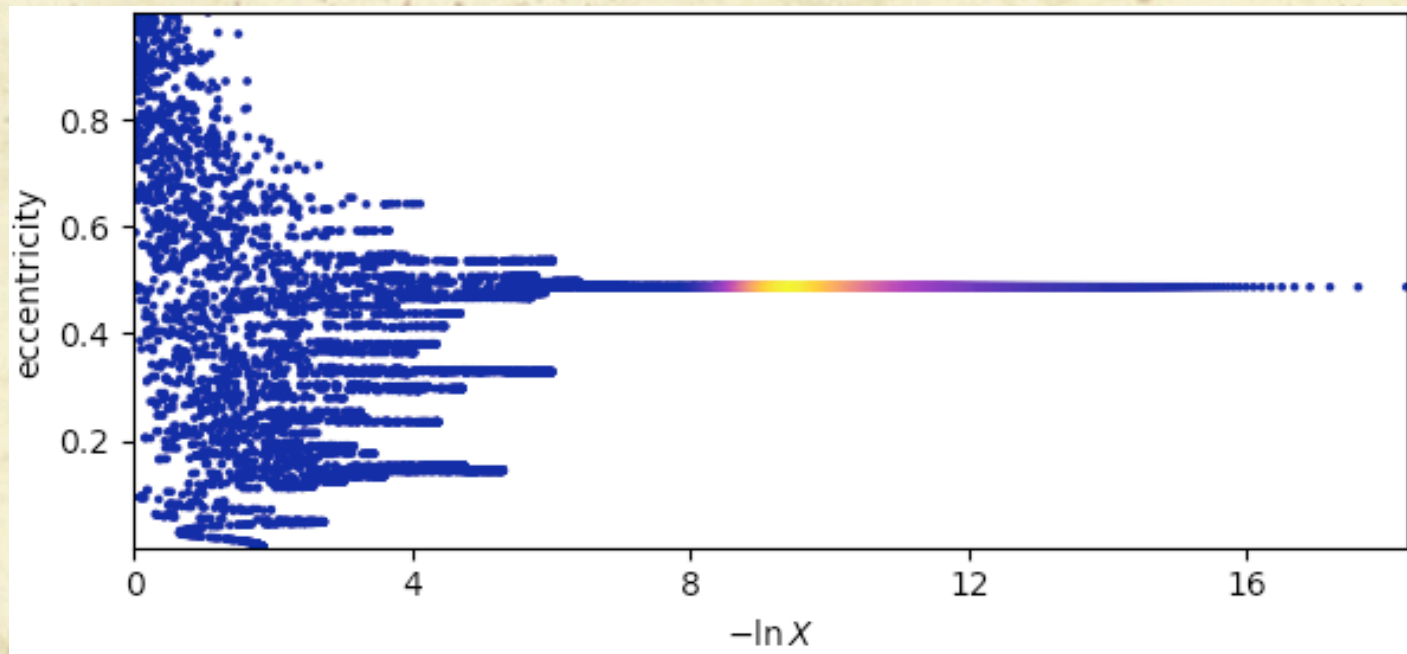
High average SNR



Low average SNR

Enhanced eccENTric seaRch mOdel (eENTRO)

- **Bilby** implementation



Total Mass: 40 solar masses
Mass Ratio: 1
Luminosity Distance: 1000 Mpc

3rd Trial Run:

Recovered ecc 0.48695

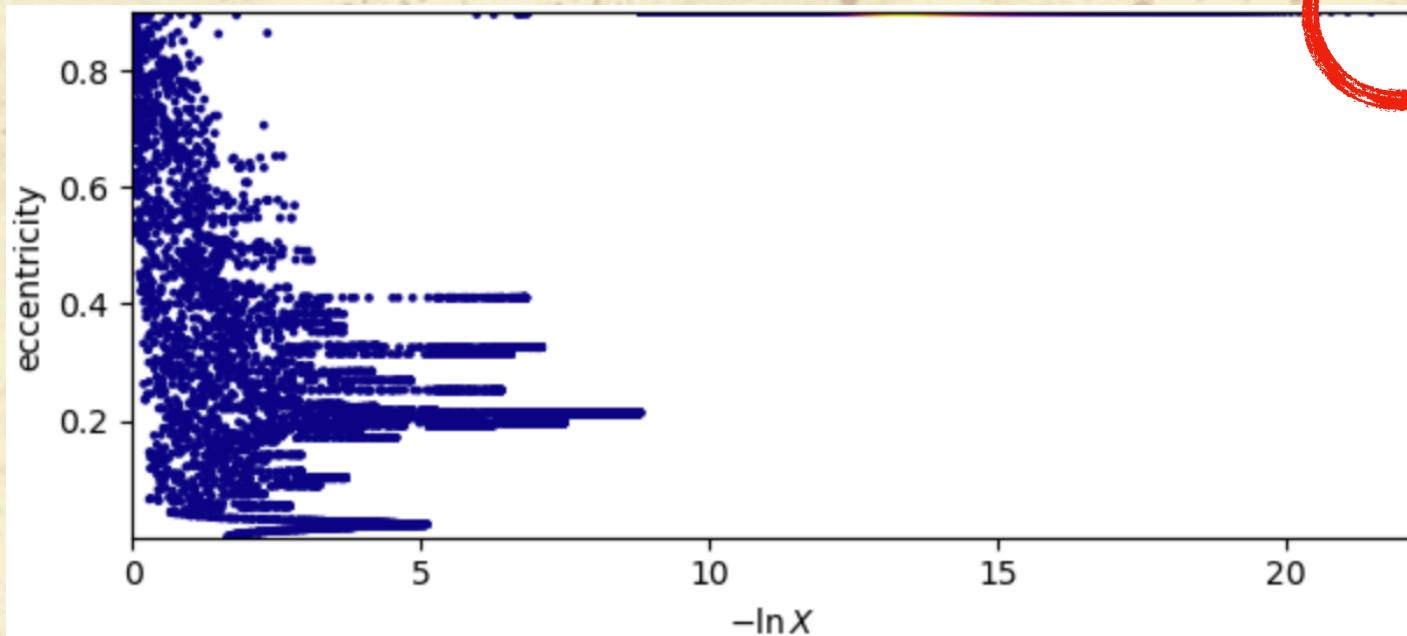
True ecc 0.5

Precision 97.4%

% Error -2.6%

Enhanced eccENTric seaRch mOdel (eENTRO)

- **Bilby implementation**



PEAK!

Total Mass: 43.3 solar masses
Mass Ratio: 0.7
Luminosity Distance: 1000 Mpc

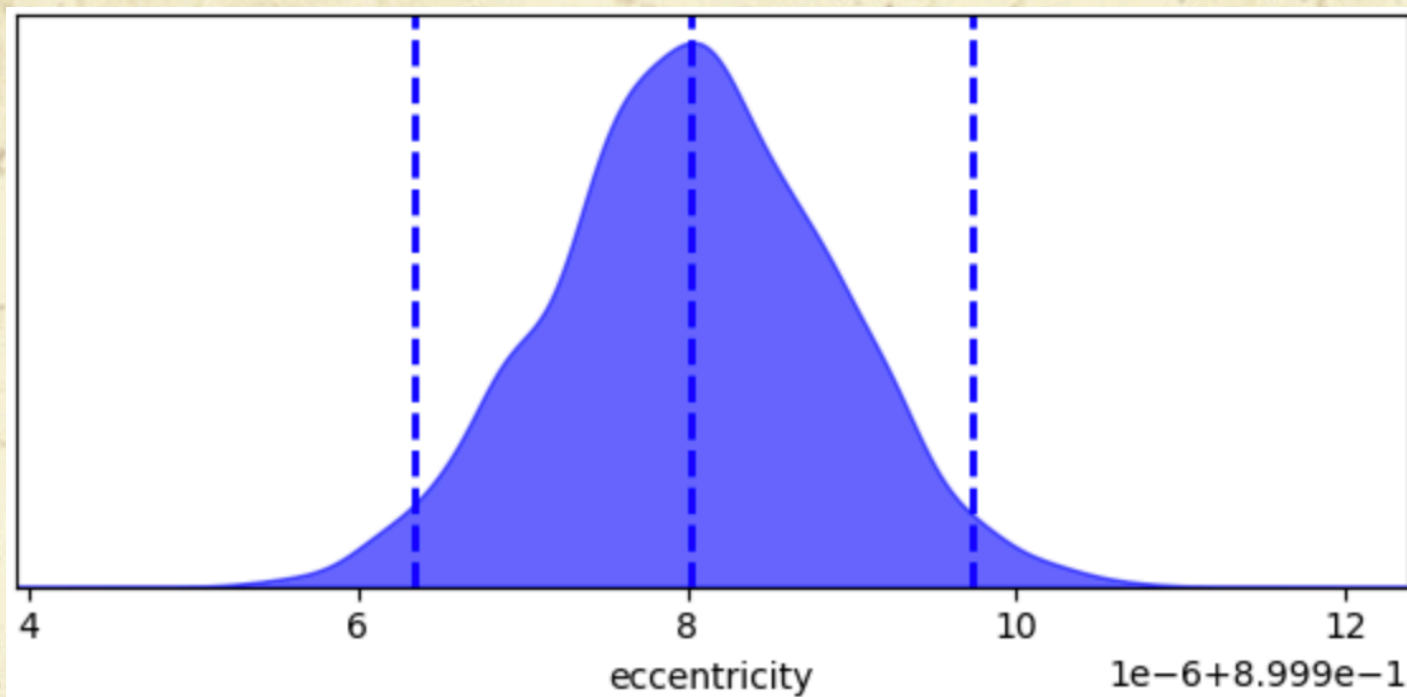
5th Trial Run:

Recovered ecc 0.899908

True ecc 0.9

Precision >99.9%

% Error ~0.0%





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PE on real data using Bilby

Parameter estimation eccENTric seaRch mOdel (PENTRO)

- PE on real data using Bilby
- Take **'LIGO Livingston', 'LIGO Hanford'** into the estimation

Let's see if we could find
eccentric waveform in real data!



Aidan Chong



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LIGO



CALTECH
Student-Faculty Programs

Thank You For Listening!

Special Thanks to:

NSF REU

Caltech SFP

Alvin Li

Rhiannon Udall

All other mentors

NSF LIGO

Alan (My mentor!)

Sarah Habib

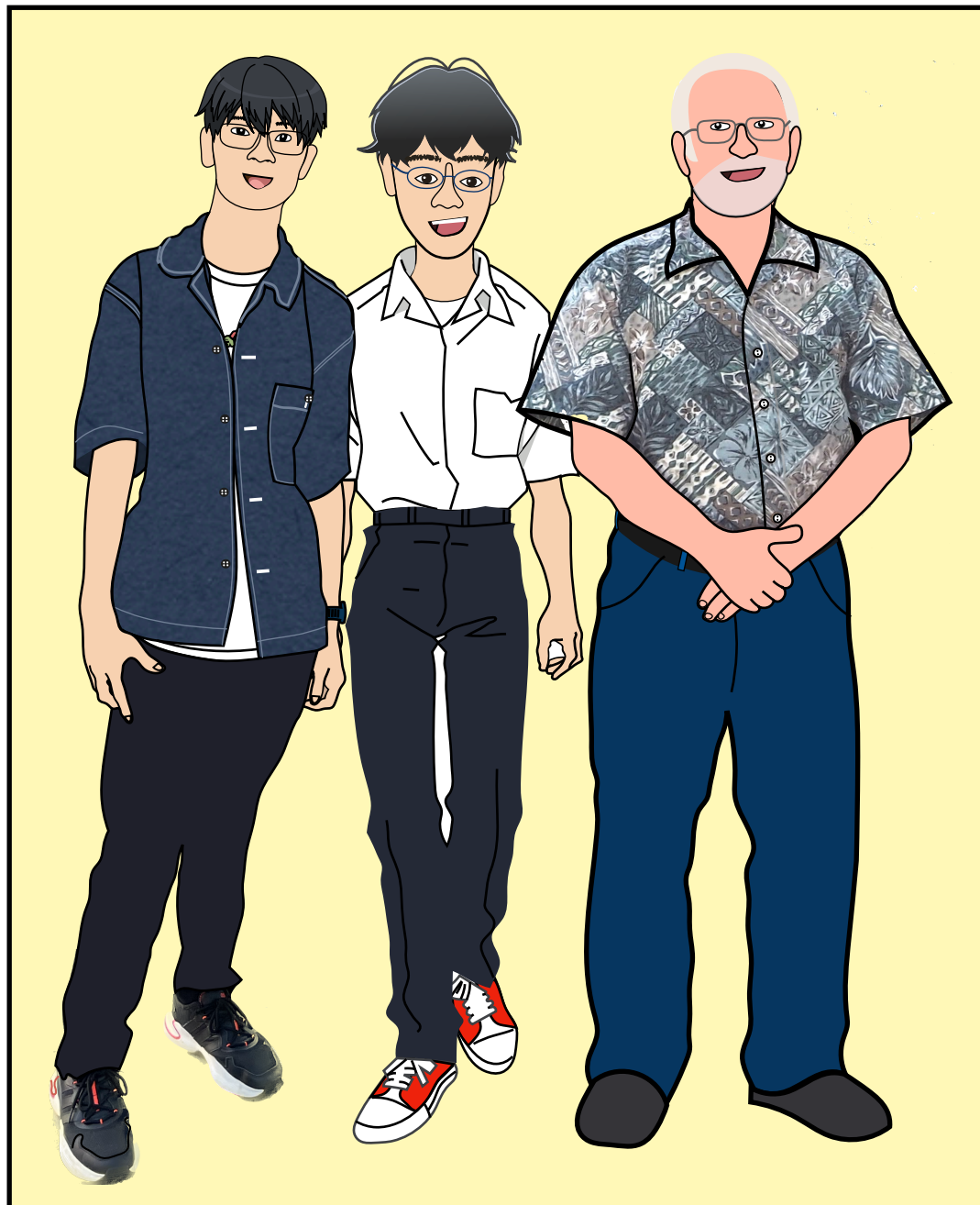
Aidan Chong

All my SURF friends



AND...Alvin would also like to thank Alan...

Picture to be taken :)



- For the first time in 4 years...
 - ✓ Alvin can finally celebrate his birthday, **NOT ONLY WITH OUR FIRST BNS MERGER GW170817**, but also **with his dearest brother.**



- ✓ Alvin and Elwin will be **forever grateful to Alan!**