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**TEOBResumS**  
**Pre-review Study**  
**P231102**

# **TEOBResumS**

## **Pre-review Study Presentation**

**Date : 2 November 2023**

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**TEOBResumS**  
**Pre-review Study**

## During the Reviewing:

- **TEOBResumS Git Branch “eccentric” is used**
- **All the waveforms are being tapered starting from 16Hz**

**Note: We have not yet run these tests in the latest version of TEOBResumS Eccentric.**



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## The Three Reviewing Notebooks

### Notebook 1:

- **Region of Parameter Space where TEOB passes sanity check**
- **Feasibility of TEOB**
- **Sanity Check with eyeballs**

### Notebook 2 & 3:

- **Diversity of TEOB**
- **TEOB vs Other Waveforms**
- **Quantity Check with waveforms matches**

\*Link to the three Notebooks: [Notebook 1](#)  
[Notebook 2](#)  
[Notebook 3](#)



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**Notebook 1**

## Notebook 1:

- **Region of eccentricity**
- **Region of total mass**
- **Region of mass ratio**
- **Aligned spin tests**
- **Extreme cases** of the integration of eccentricity, masses, and mass ratio





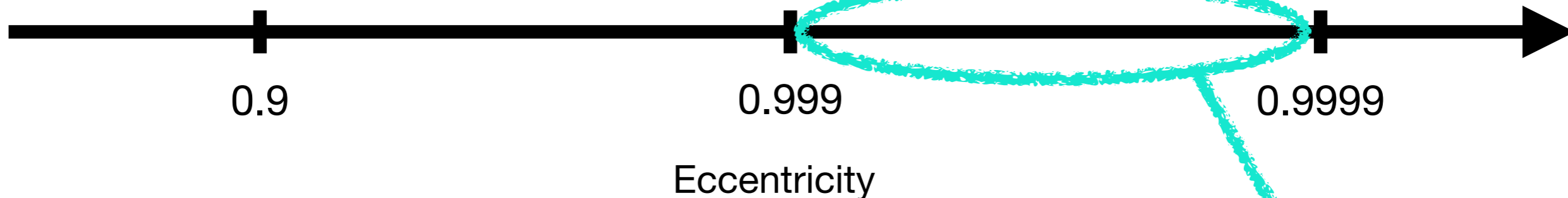
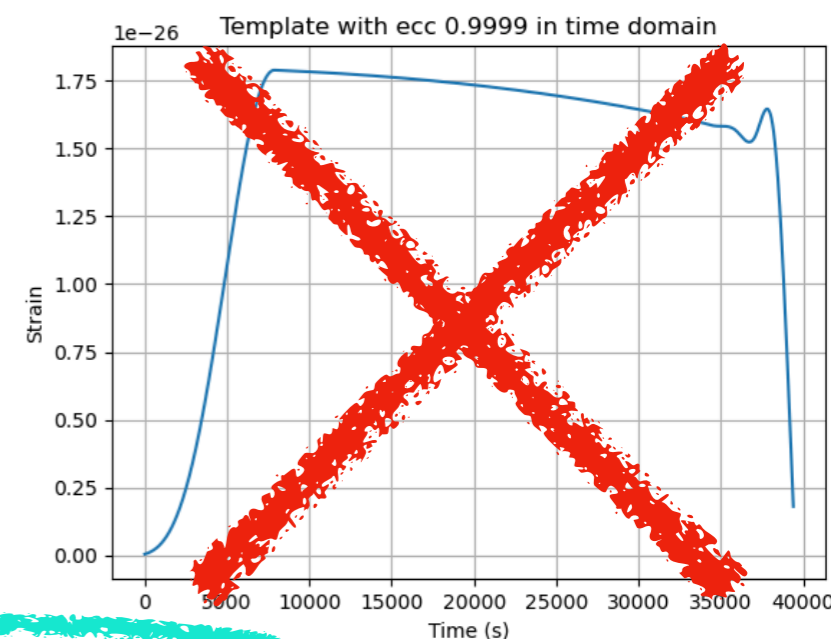
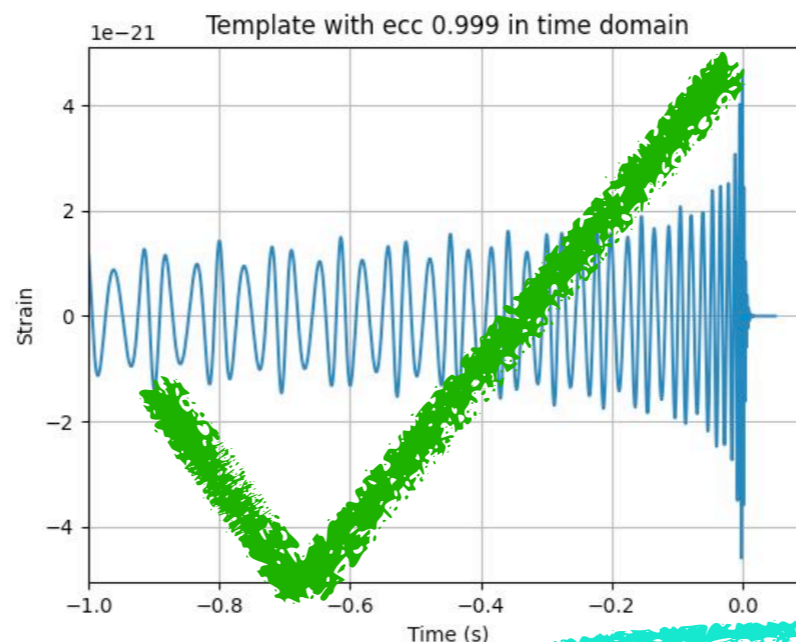
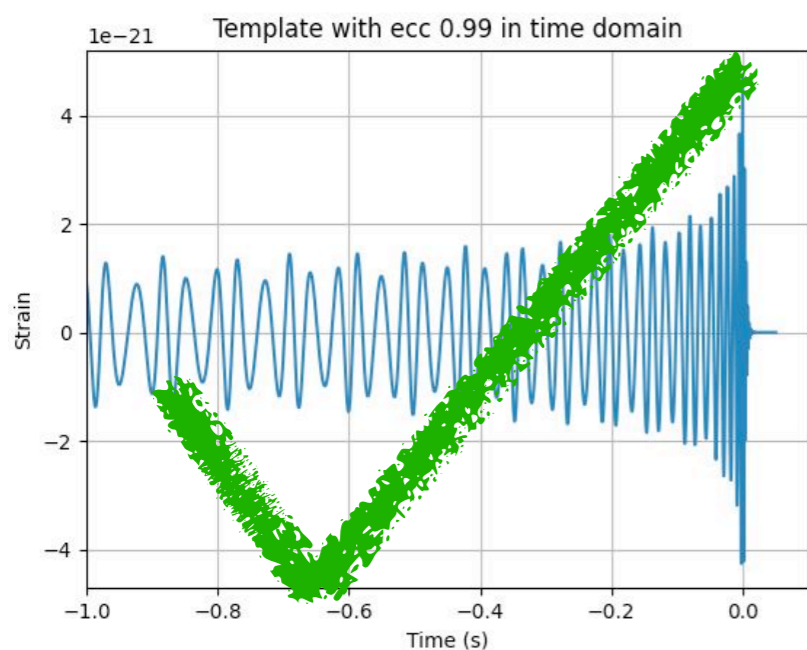
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# Notebook 1: Upper Limits of Eccentricity

## Region of validity of Eccentricity

Total Mass :  $40 M_{\odot}$   
 Mass Ratio : 1  
 → Eccentricity : varied  
 Spin : 0.0  
 Polarization : +



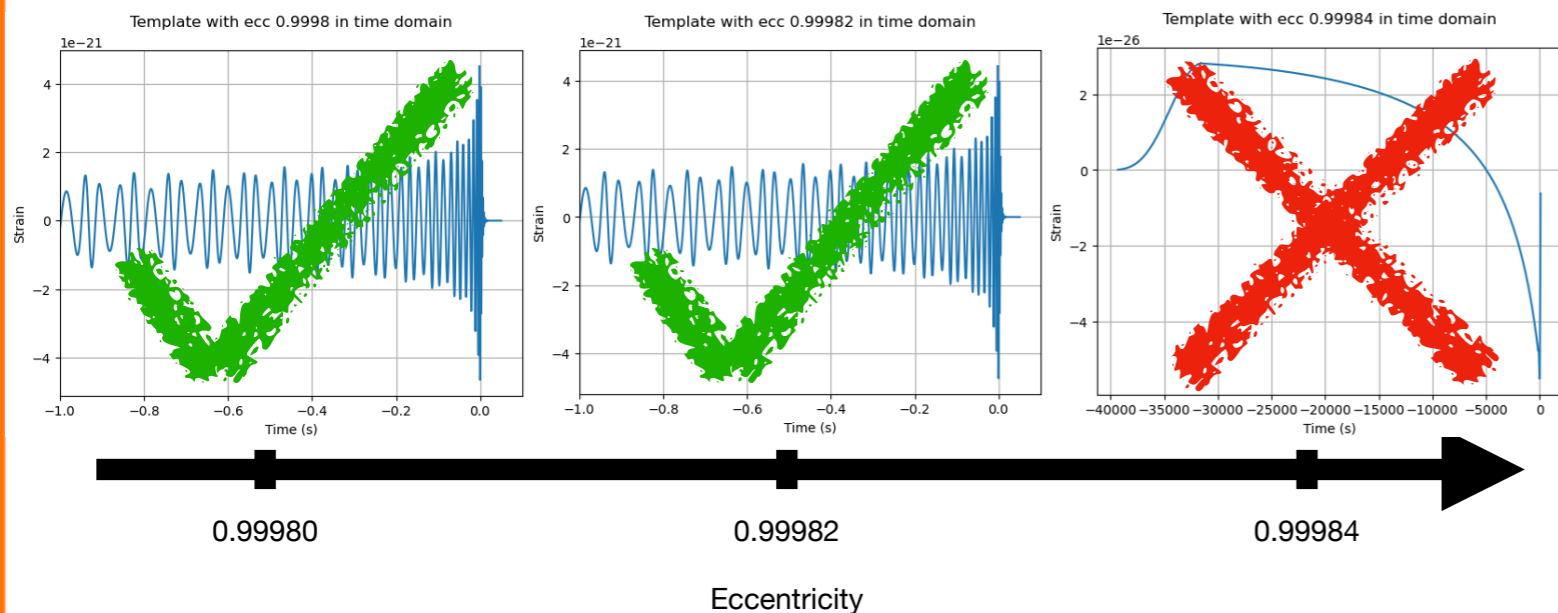


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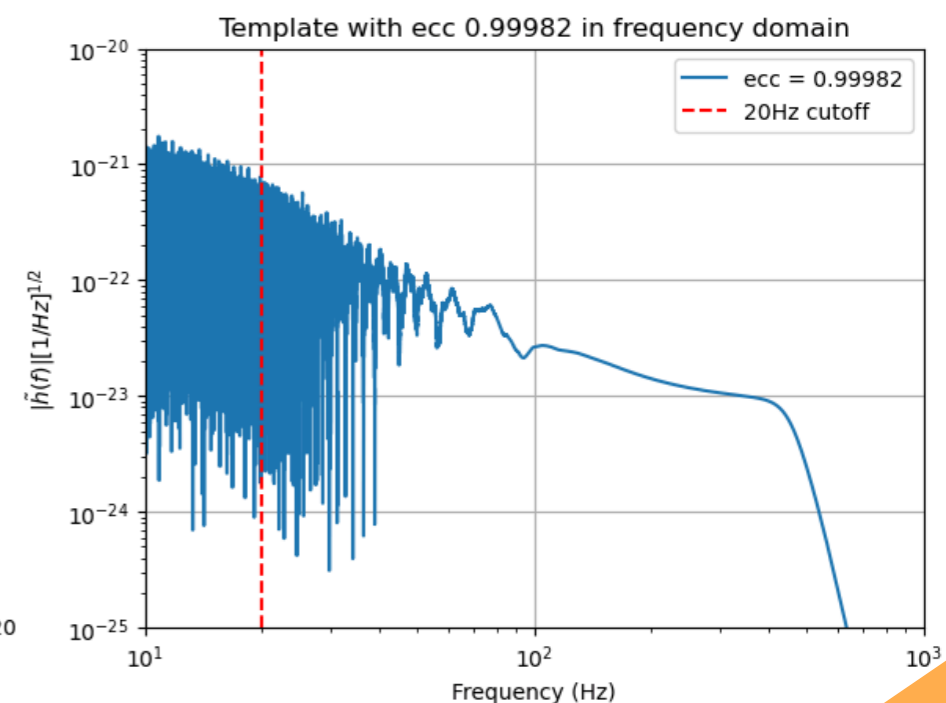
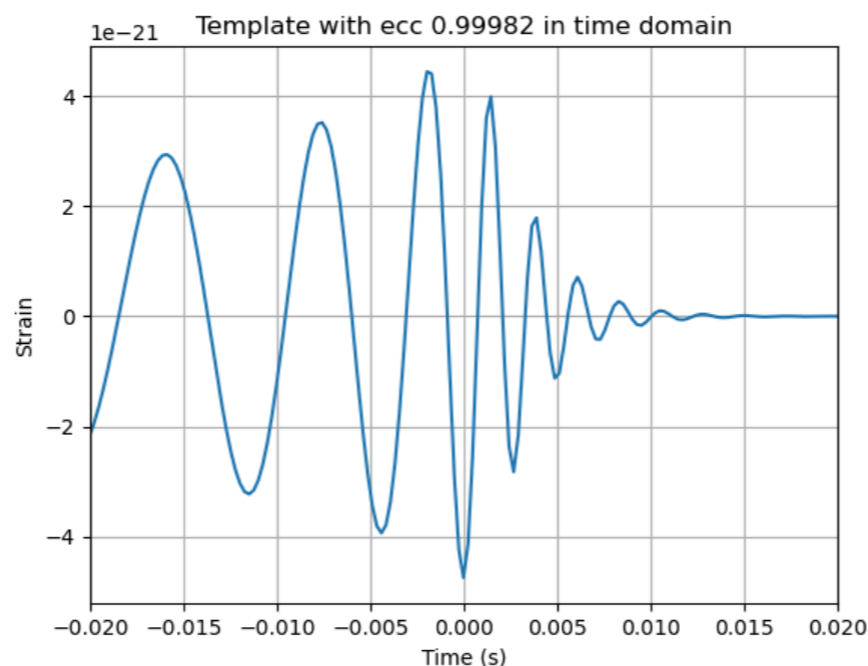
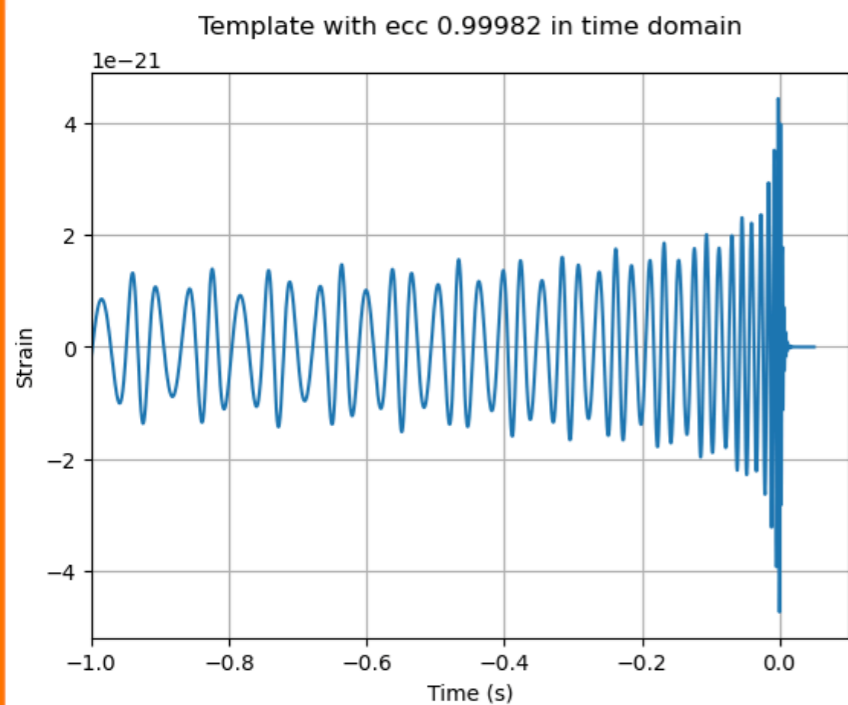


# Notebook 1: Upper Limits of Eccentricity

## Region of validity of Eccentricity



Total Mass :  $40 M_{\odot}$   
 Mass Ratio : 1  
 → Eccentricity: varied  
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 Polarization: +





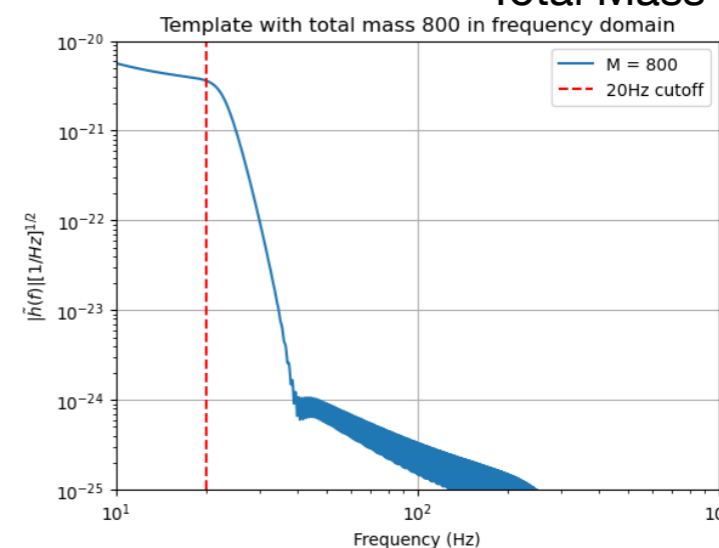
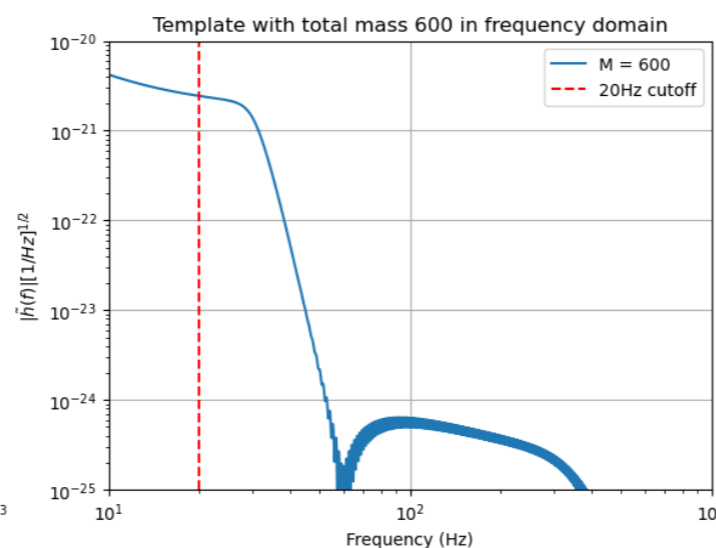
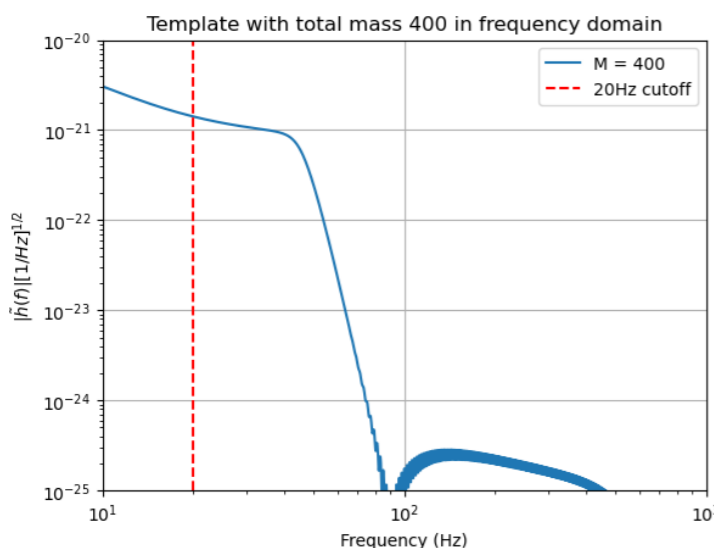
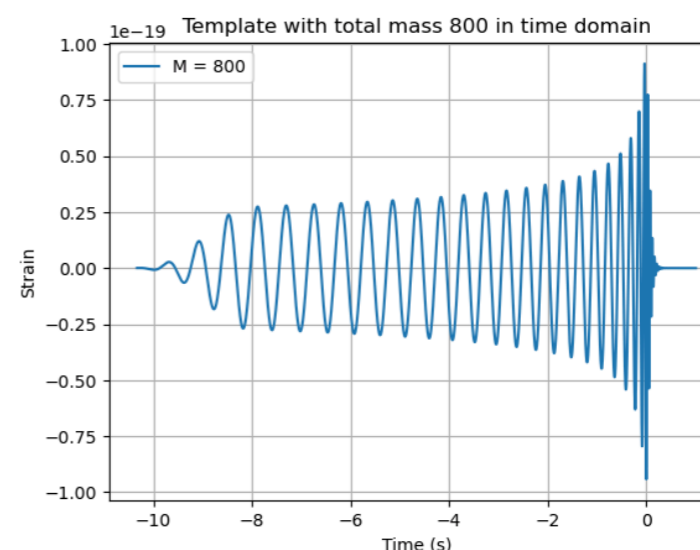
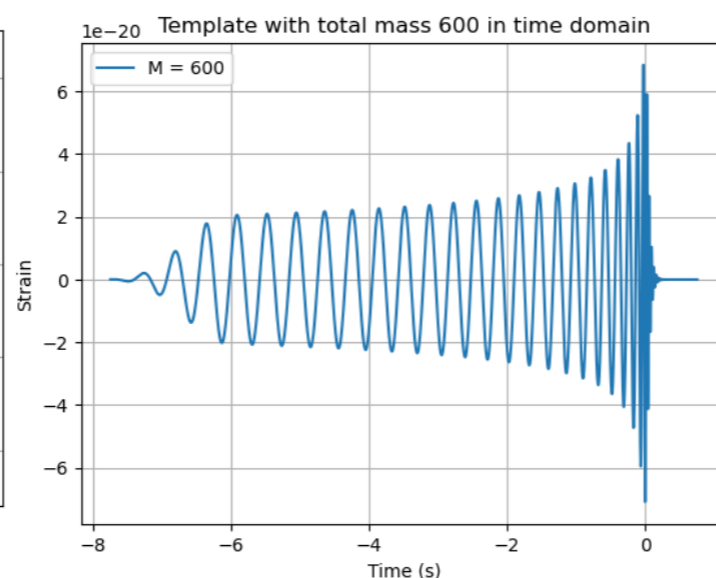
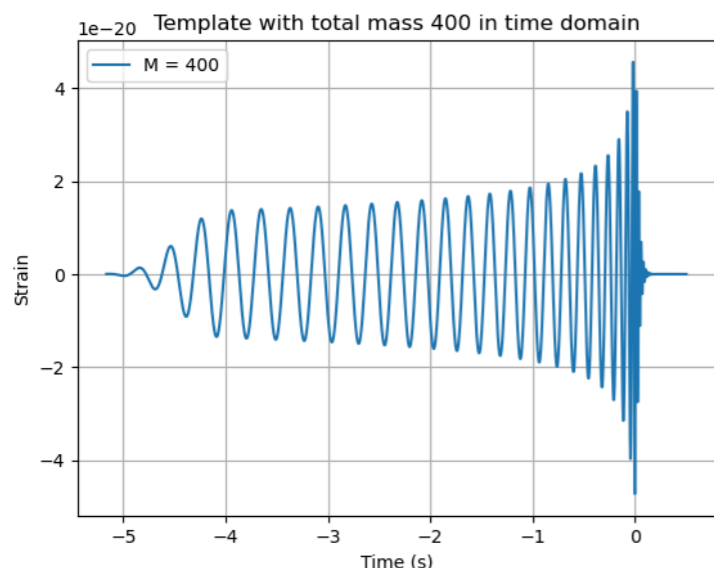
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# Notebook 1: Upper Limits of Total Mass

## Region of validity of Total Mass

→ Total Mass : Varied  
 Mass Ratio : 1  
 Eccentricity : 0.0  
 Spin : 0.0  
 Polarization : +





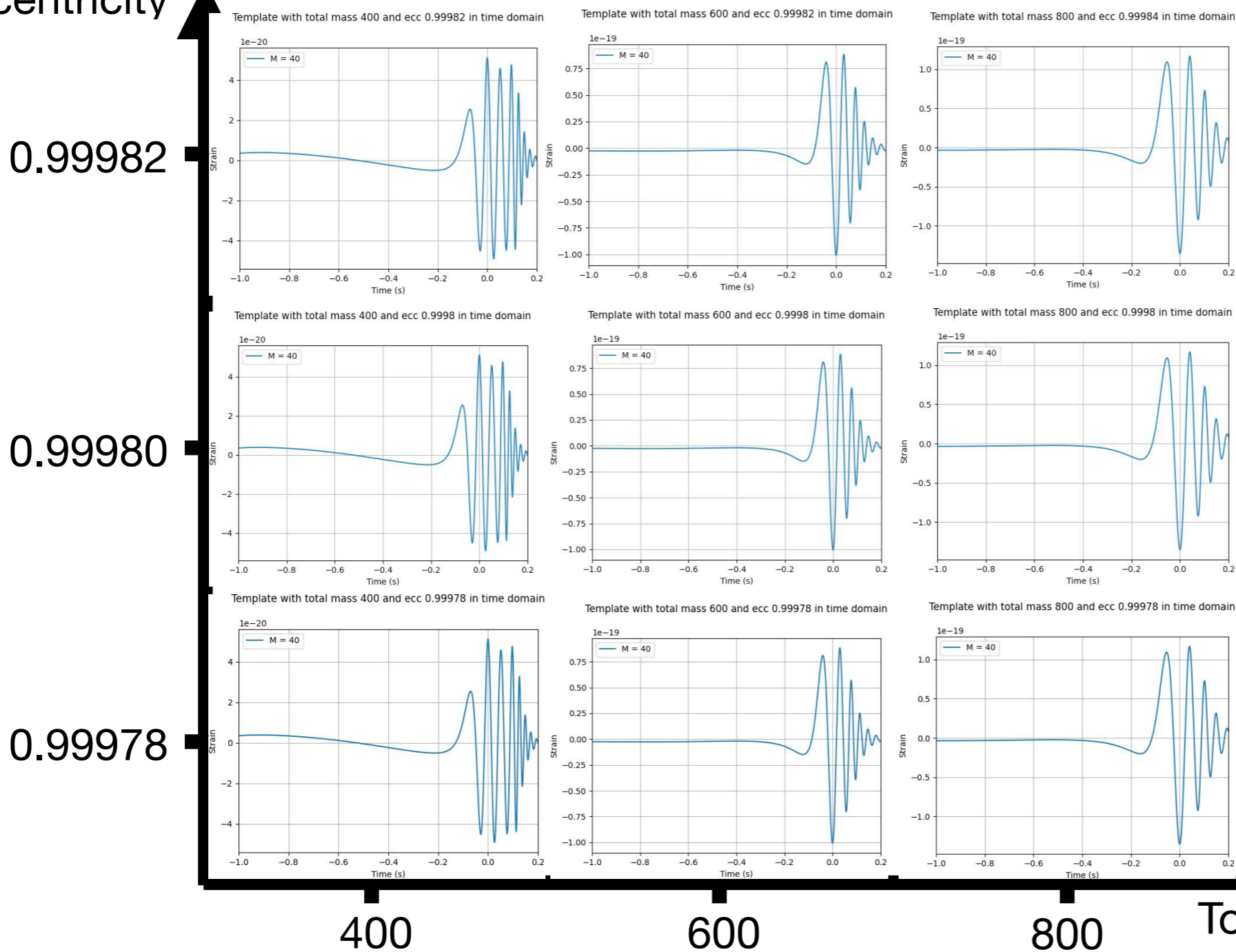
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# Notebook 1: Total Mass and Eccentricity

## Region of validity of Total Mass with Eccentricity

Eccentricity



- Total Mass : Varied
- Mass Ratio : 1
- Eccentricity : Varied
- Spin : 0.0
- Polarization : +





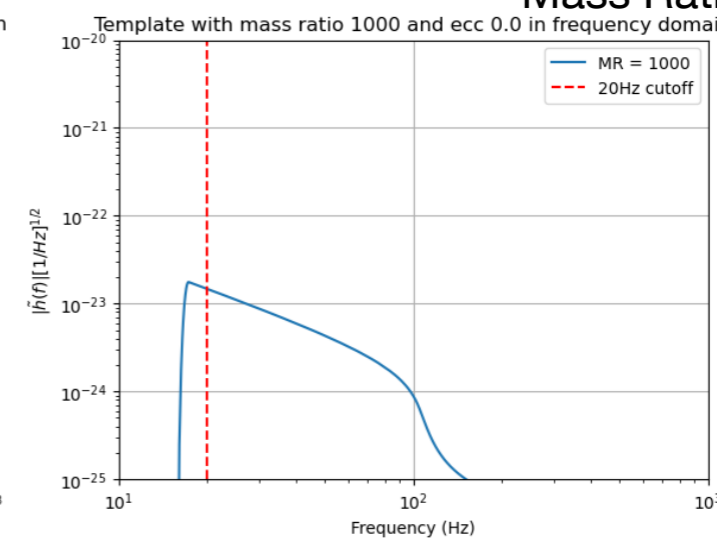
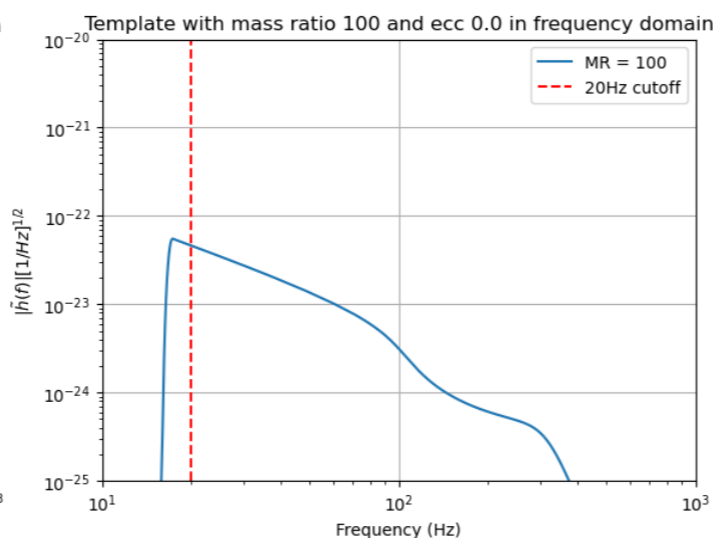
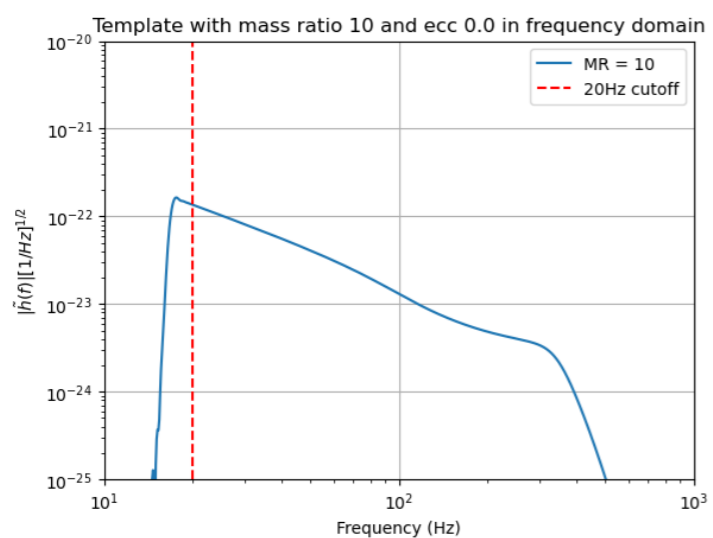
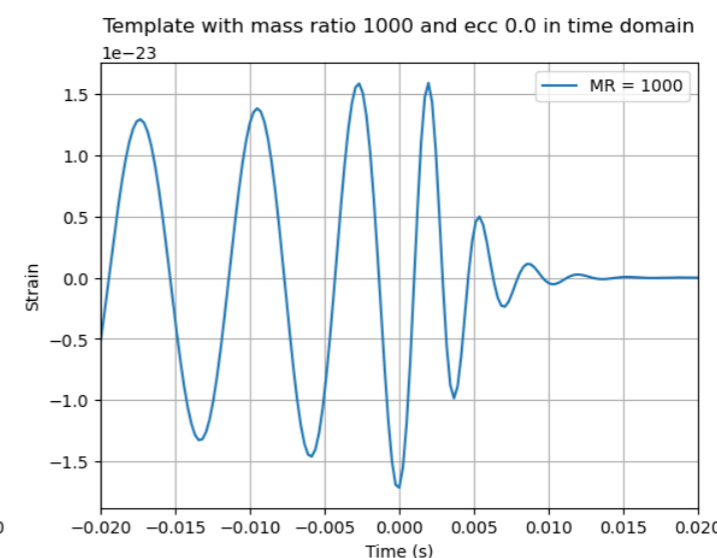
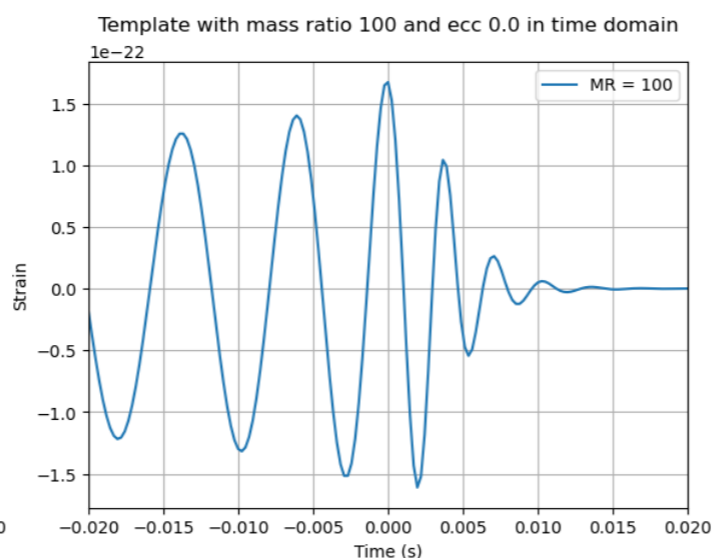
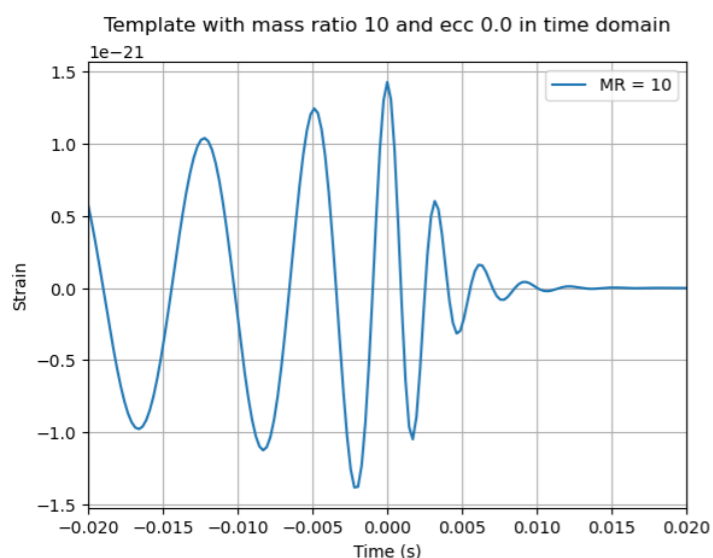
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# Notebook 1: Upper Limits of Mass Ratio

## Region of validity of Mass Ratio

Total Mass :  $300 M_{\odot}$   
 → Mass Ratio : Varied  
 Eccentricity: 0.0  
 Spin : 0.0  
 Polarization: +





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# Notebook 1: Mass Ratio and Eccentricity

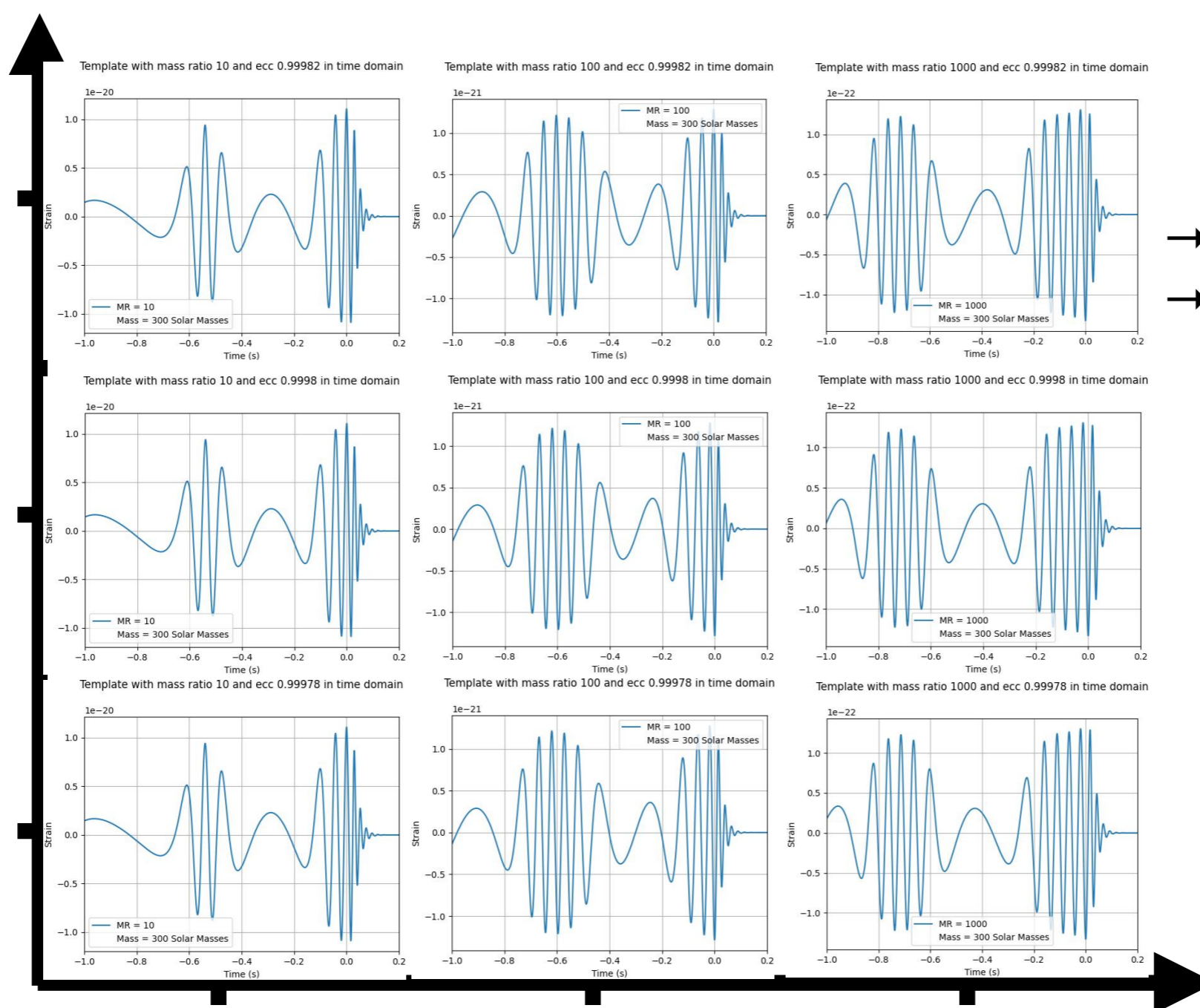
## Region of validity of Mass Ratio with Eccentricity

Eccentricity

0.99982

0.99980

0.99978



10

100

1000

Mass Ratio

Total Mass :  $300 M_{\odot}$   
 → Mass Ratio : Varied  
 → Eccentricity : Varied  
 Spin : 0.0  
 Polarization : +



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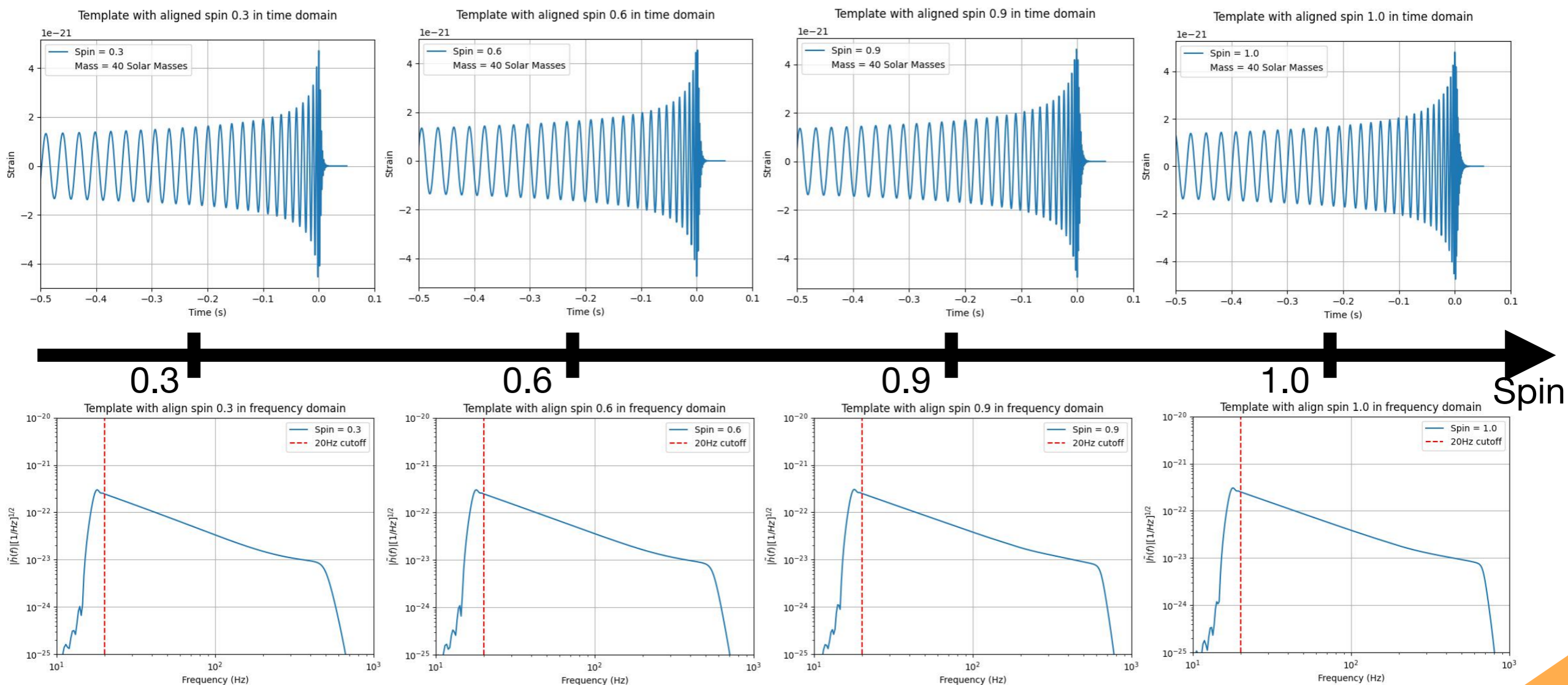


# Notebook 1: Aligned Spin

## Compatibility of Aligned Spin Waveform

Can you see the evidences of **orbital hang-up**?

Total Mass :  $40 M_{\odot}$   
Mass Ratio : 1  
Eccentricity : 0.0  
→ Spin : Varied  
Polarization : +







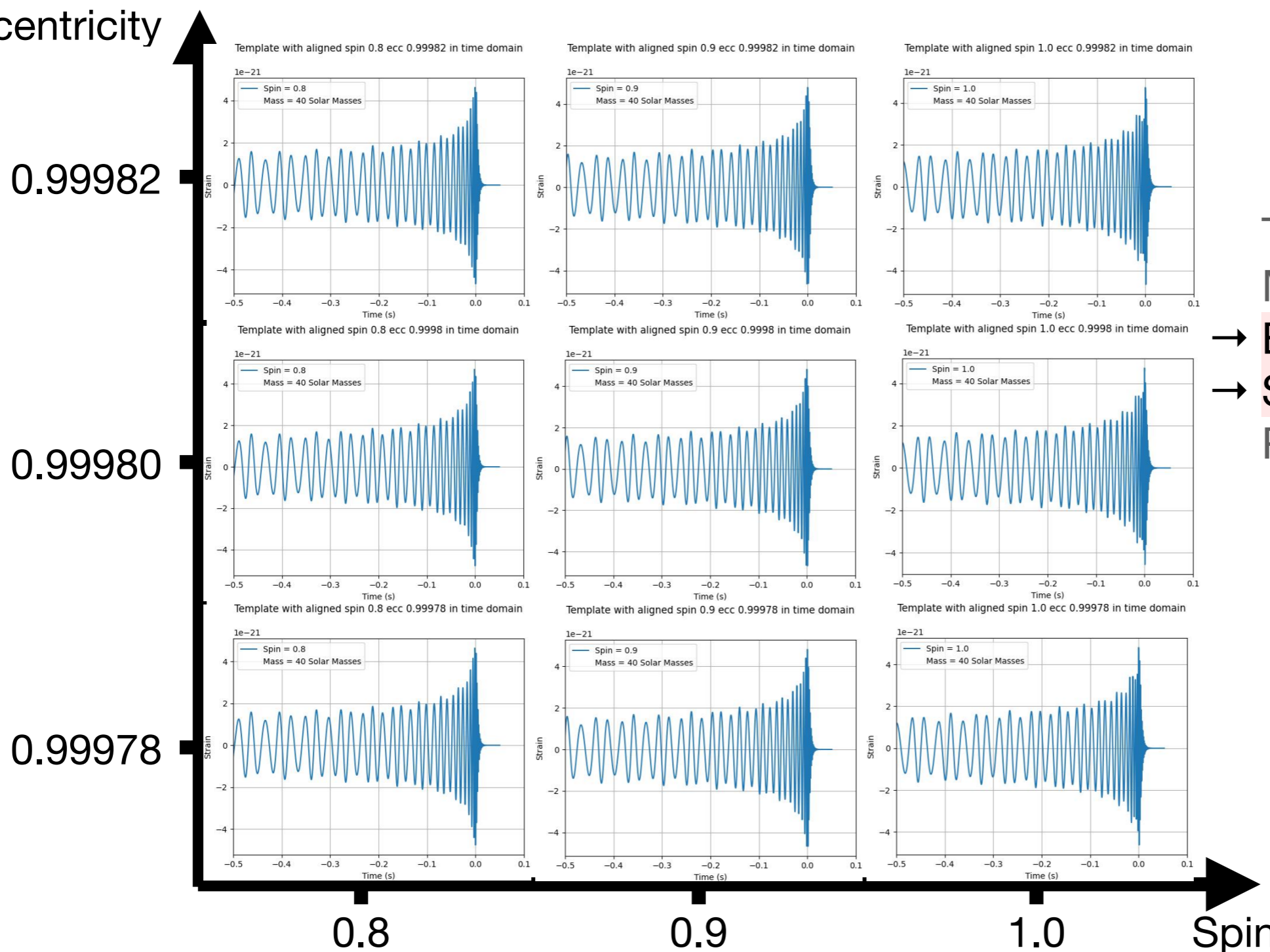
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# Notebook 1: Aligned Spin and Eccentricity

## Region of validity of Aligned Spin with Eccentricity

Eccentricity



Total Mass :  $40 M_{\odot}$

Mass Ratio : 1

→ Eccentricity : Varied

→ Spin : Varied

Polarization : +





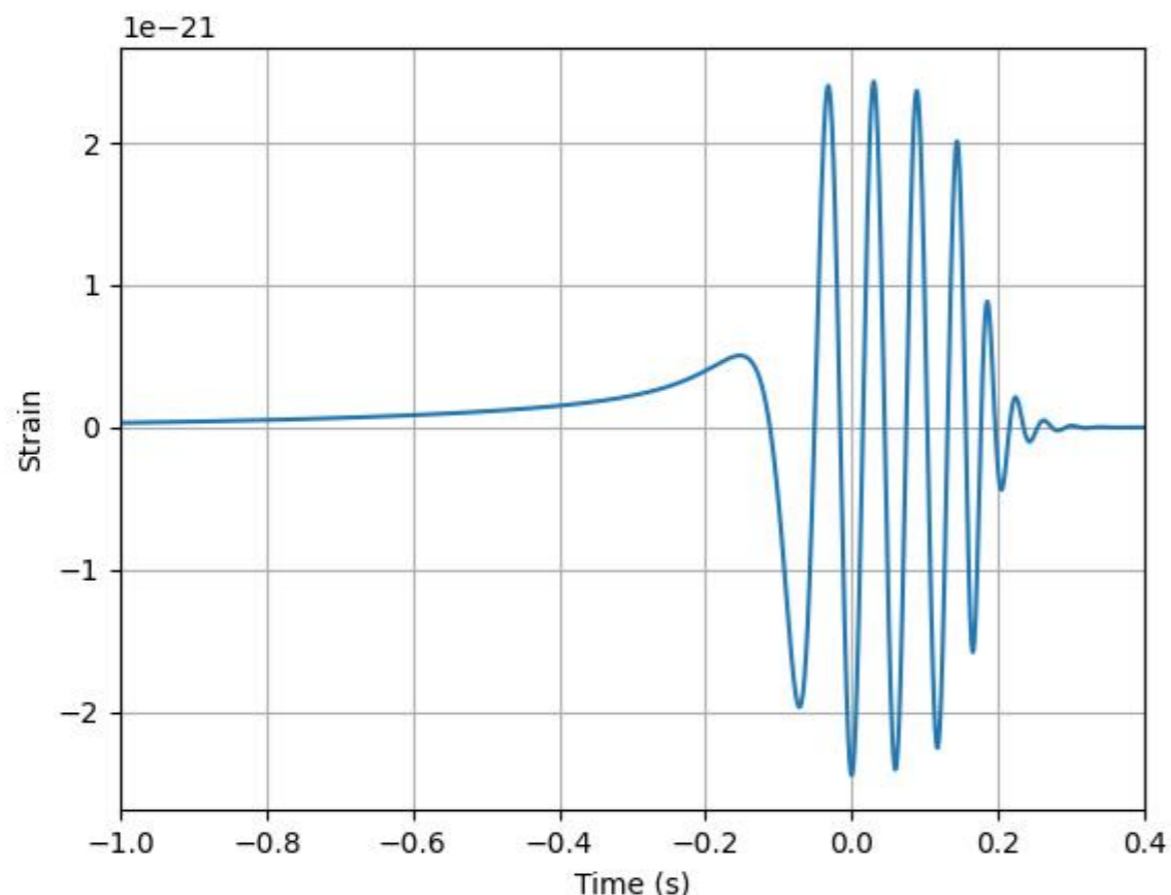
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# Notebook 1: Extreme Case

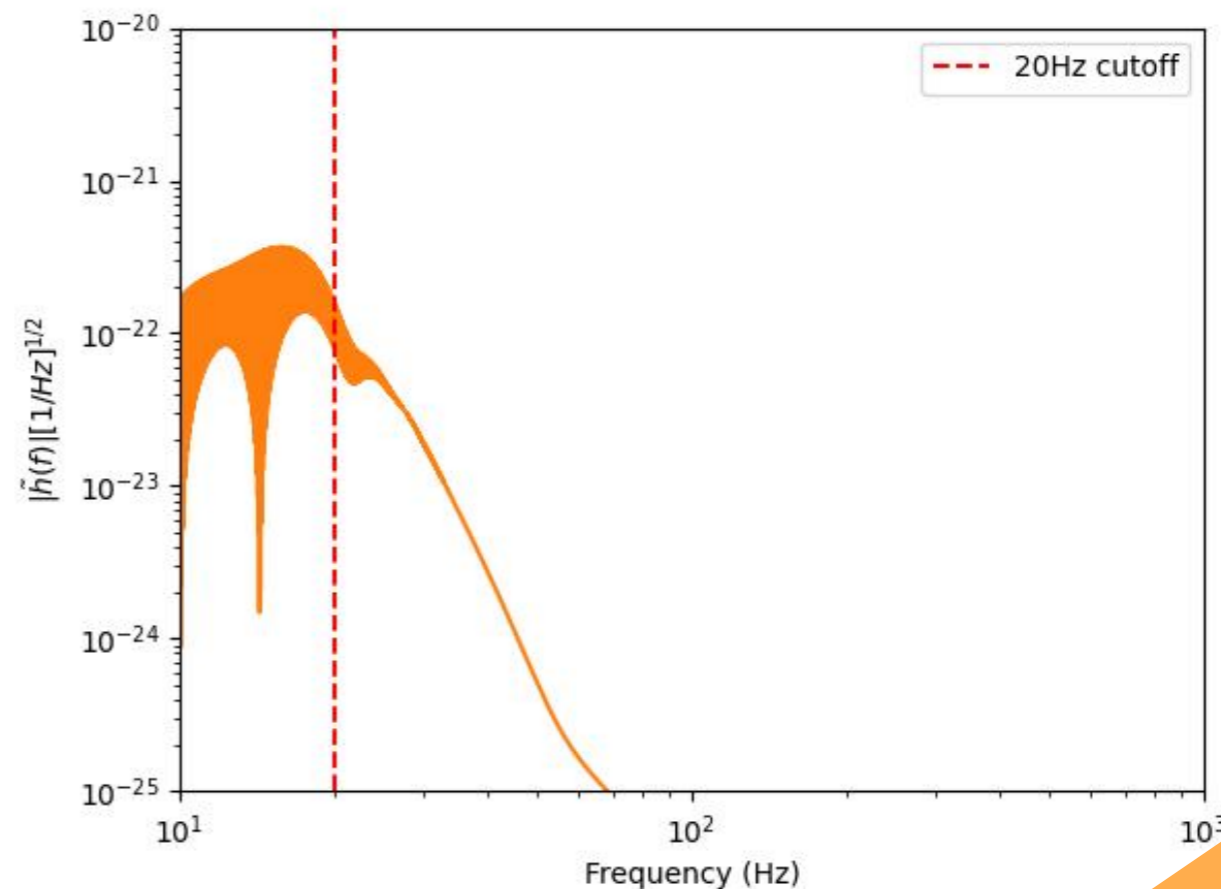
## Extreme Case with highest Mass, Mass Ratio and Eccentricity

Template with mass 470 mass ratio 100 and ecc 0.99982 in frequency doma



- Total Mass : Varied
- Mass Ratio : Varied
- Eccentricity: Varied
- Spin : 0.0
- Polarization: +

Template with mass 470 mass ratio 100 and ecc 0.99982 in frequency doma





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What's next?

## Looking good...but what's next?

- The region of validity that TEOB can reach is satisfyingly high!
- TEOB **passes** individual **sanity checks**.
- How about comparing TEOB with **other waveforms with eccentricity?**





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**Notebook 2 & 3**

## Notebook 2 & 3:

- **Eccentric TEOB vs Eccentric SXS waveforms**
- **Eccentric TEOB vs TaylorF2Ecc (PN)**
- **Eccentric TEOB vs EccentricFD (PN)**



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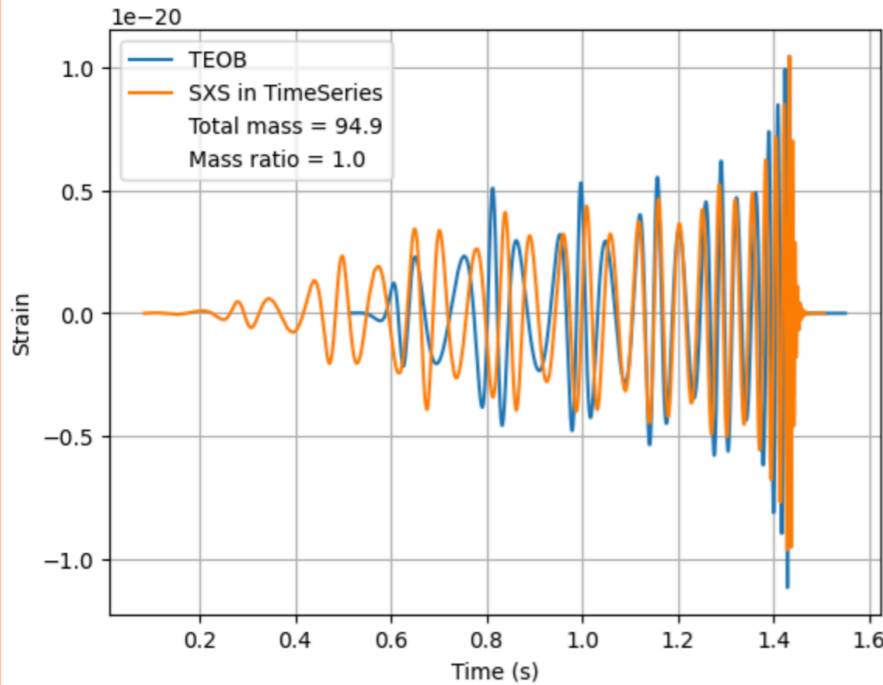
## Notebook 2 & 3:

- **Align spin `TEOBResumS` vs align spin `IMRPhenomXPHM` (at zero Eccentricity)**
- **Eccentric `TEOB` with zero precession vs **Precessing `IMRPhenomXPHM` with zero eccentricity****

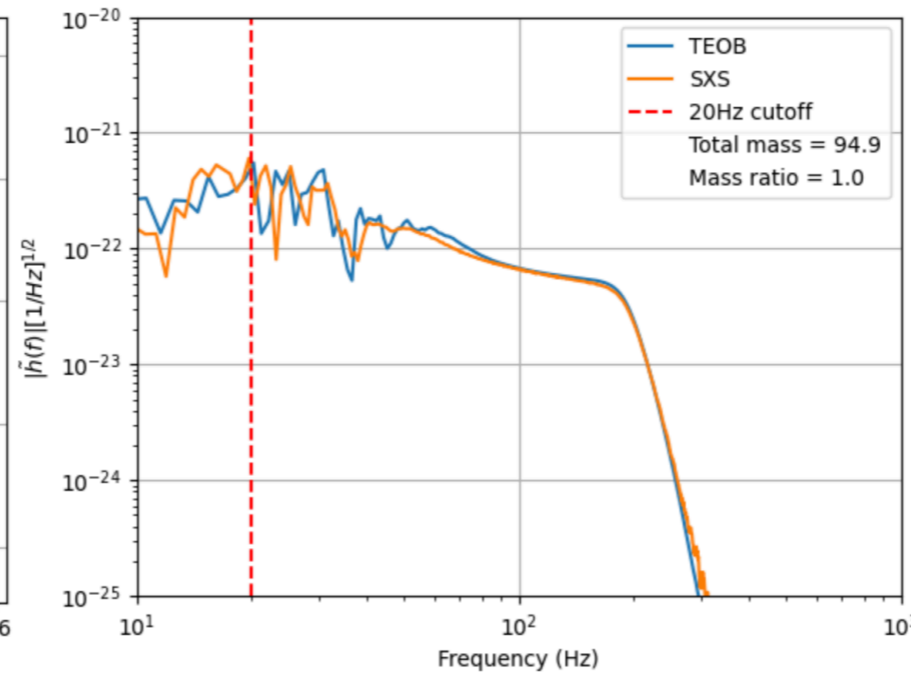
To see how similar they are

# Eccentric TEOB vs Eccentric SXS

TEOB vs SXS BBH 1360 with ecc = 0.3636 in time domain

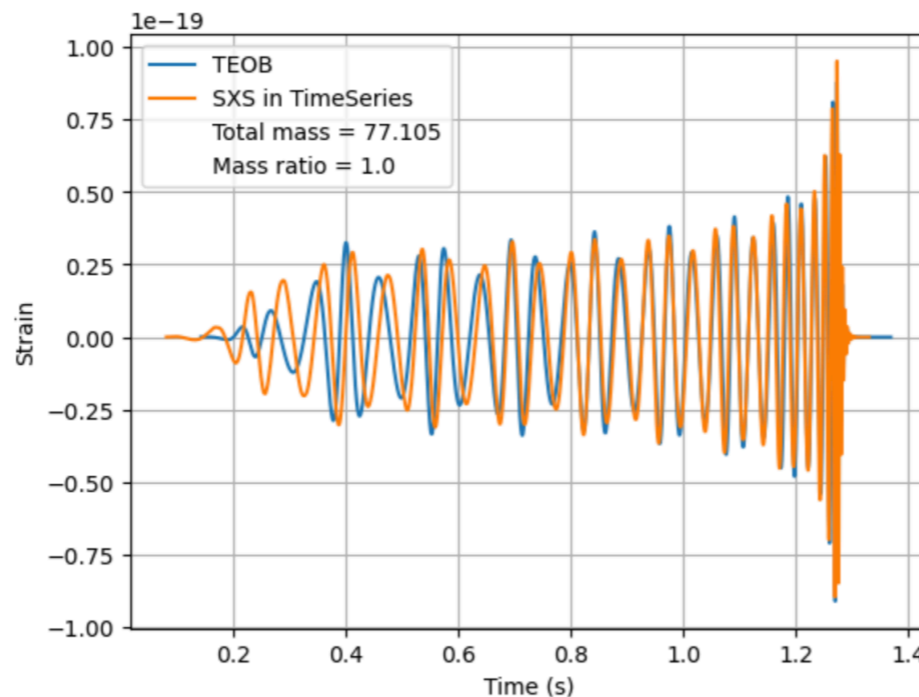


TEOB vs SXS BBH 1360 with ecc = 0.3636 in frequency domain

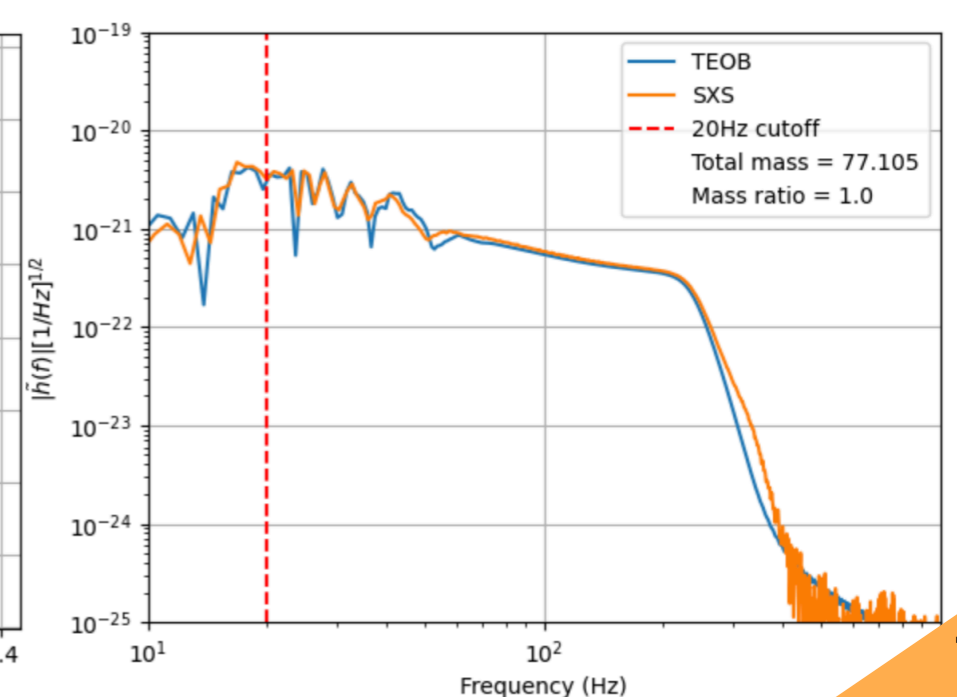


Match in TD: 85.8%  
Match in FD: 85.8%  
Sampling Rate: 4096.0

TEOB vs SXS BBH 1358 with ecc = 0.2186 in time domain



TEOB vs SXS BBH 1358 with ecc = 0.2186 in frequency domain

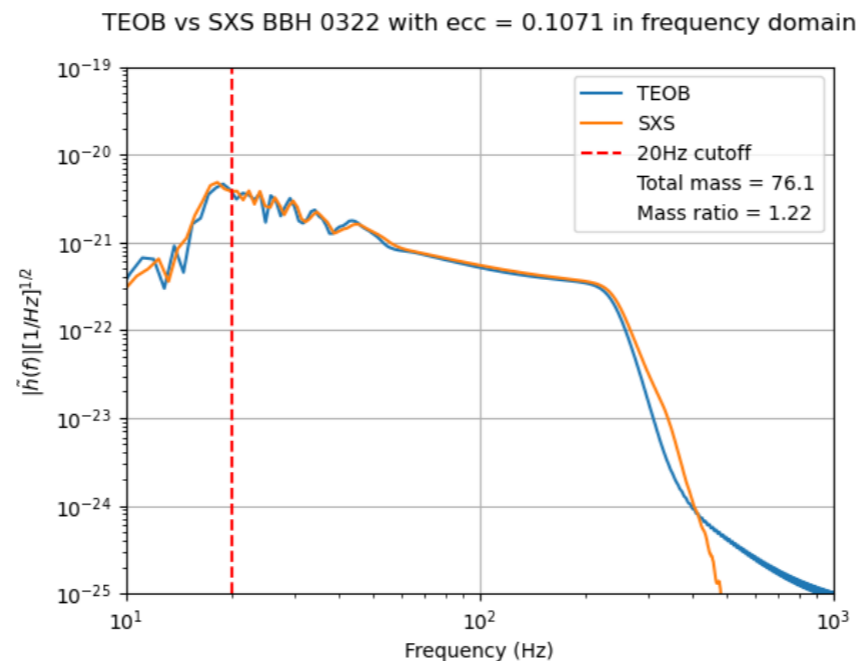
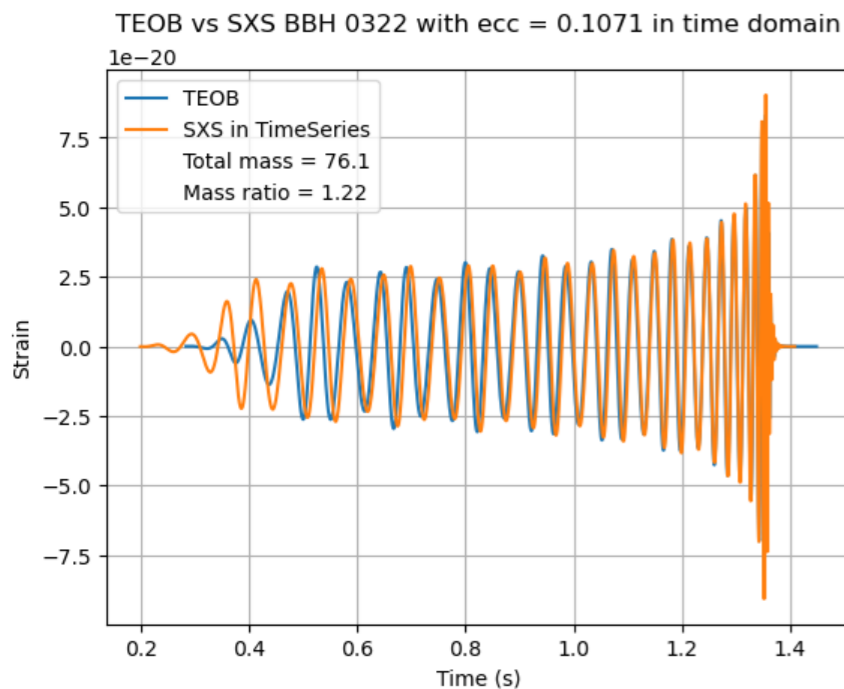
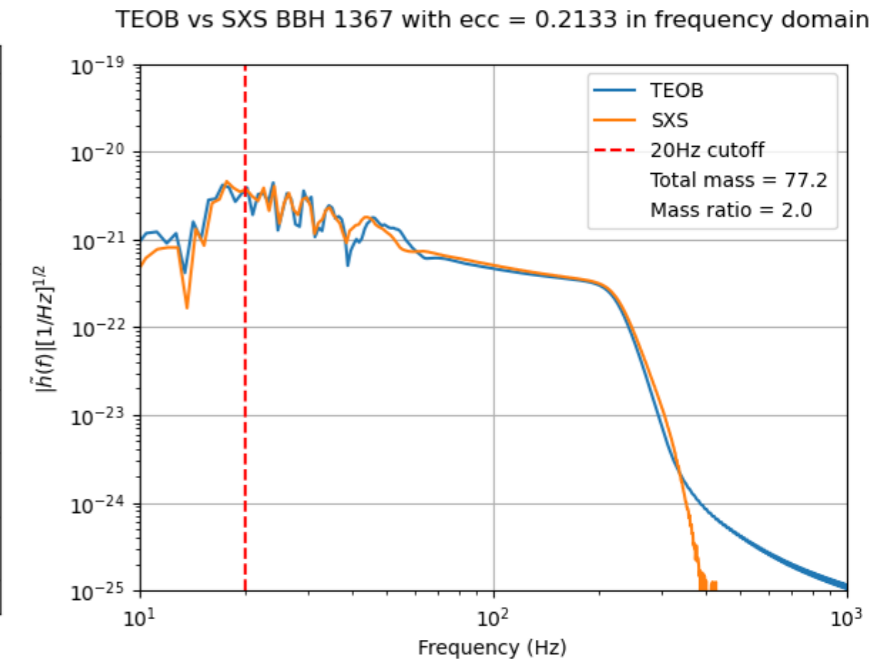
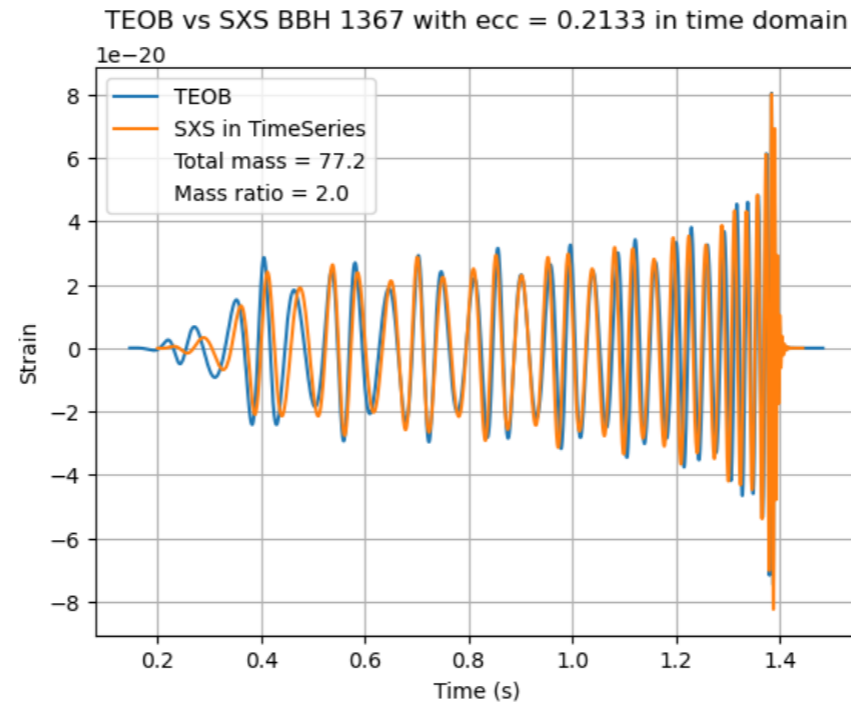


Match in TD: 95.0%  
Match in FD: 95.0%  
Sampling Rate: 4096.0



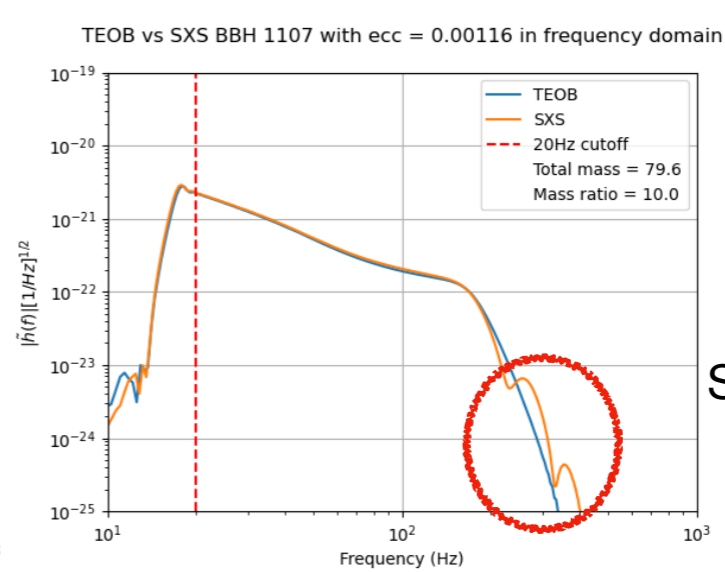
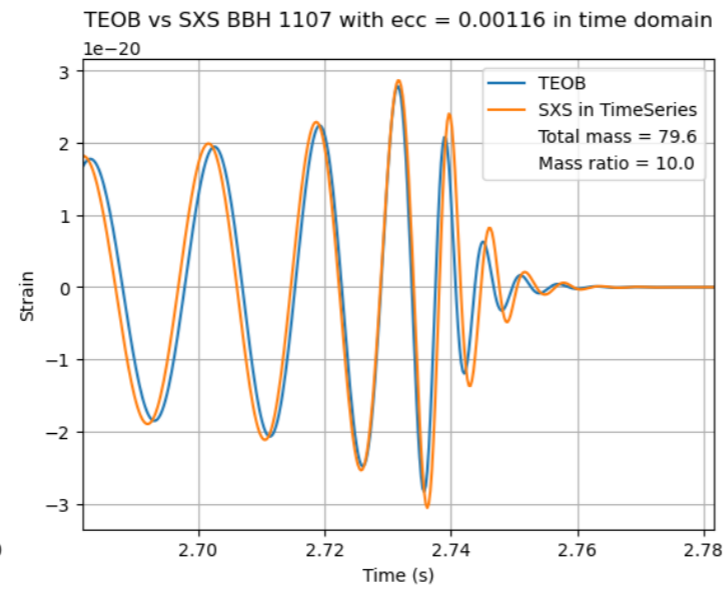
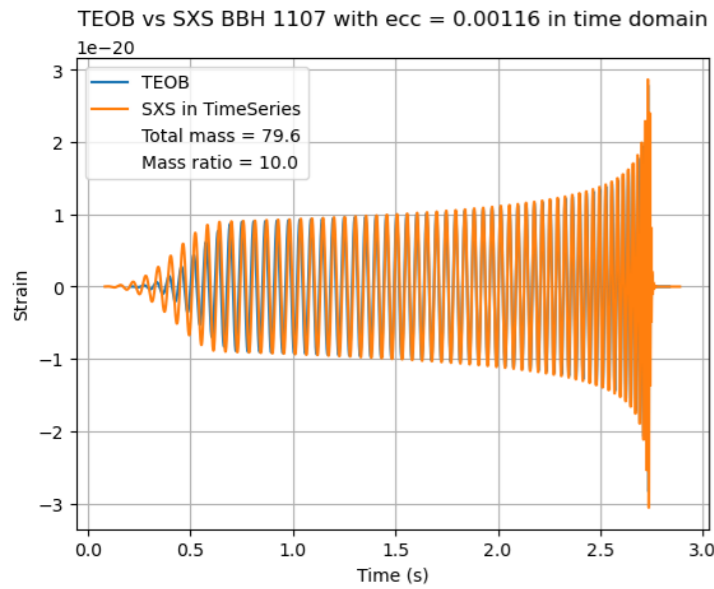
# Eccentric TEOB vs Eccentric SXS

Match in TD: 94.5%  
Match in FD: 94.4%  
Sampling Rate: 4096.0



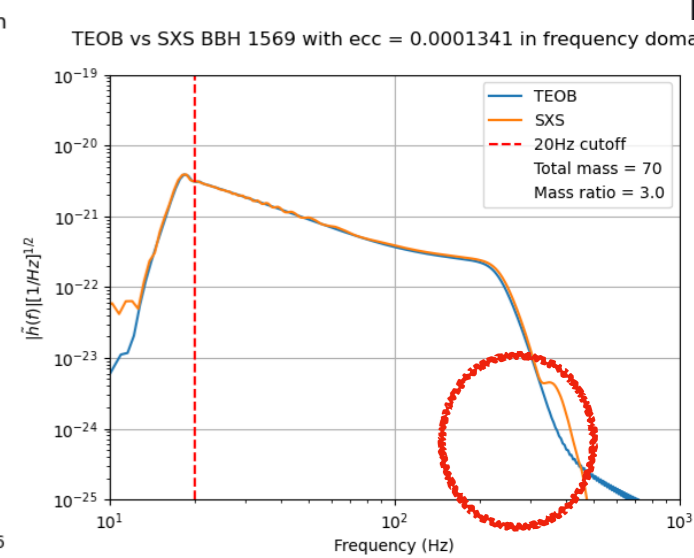
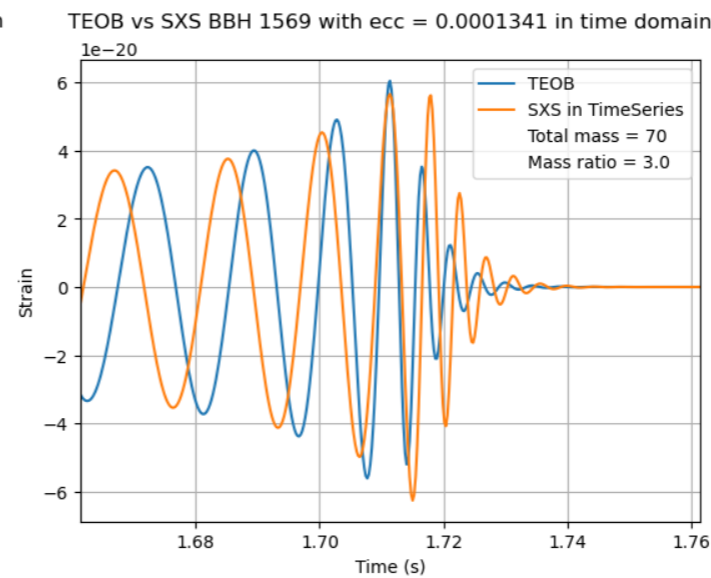
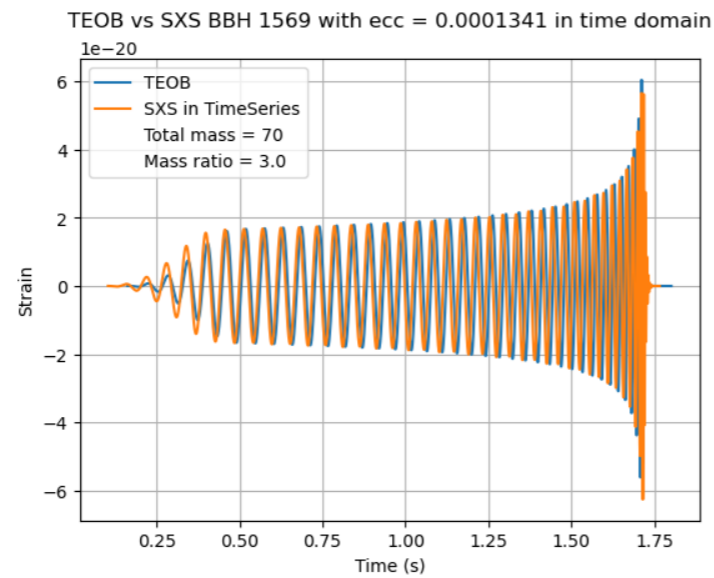
Match in TD: 97.1%  
Match in FD: 97.1%  
Sampling Rate: 4096.0

# Eccentric TEOB vs Eccentric SXS



Match in TD: 98.2%  
Match in FD: 98.3%  
Sampling Rate: 4096.0

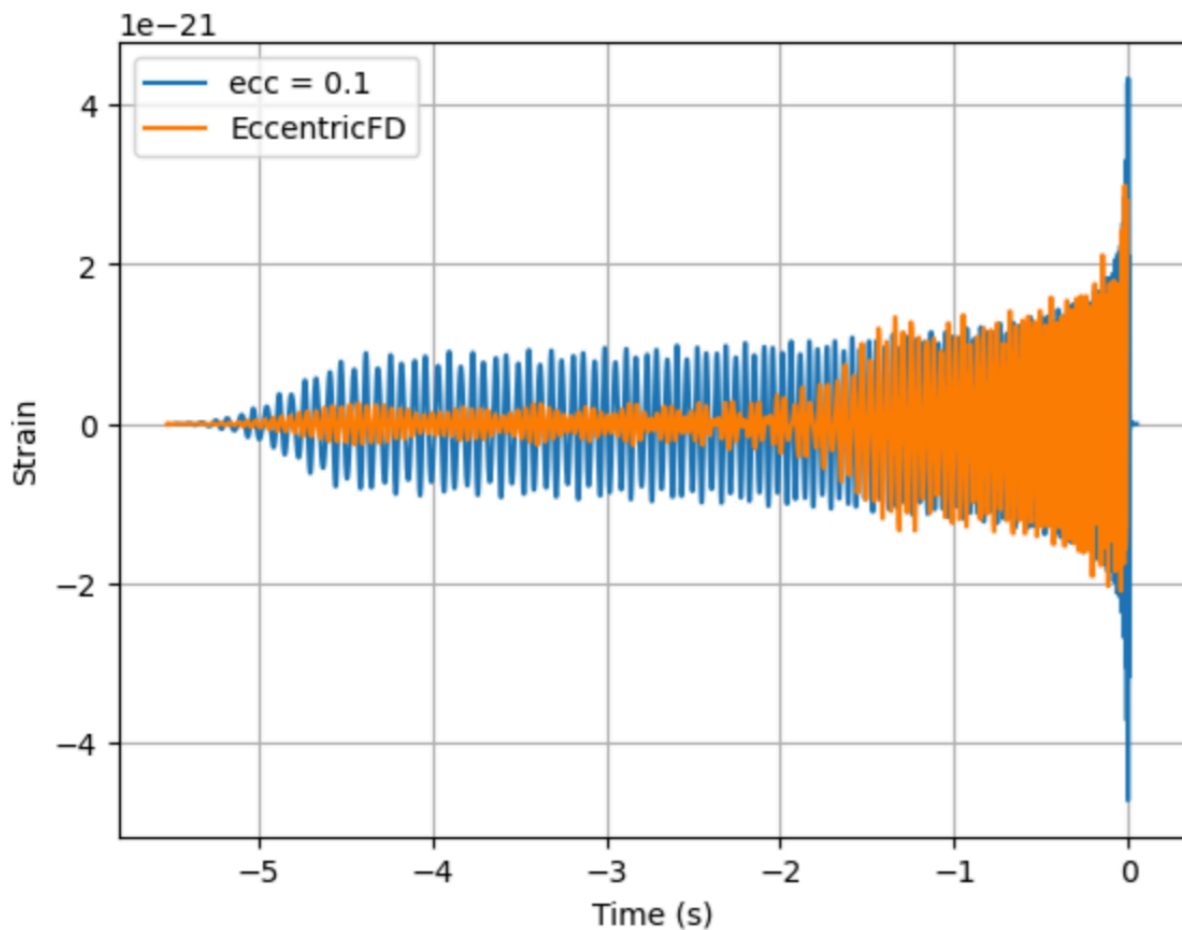
Match in TD: 95.3%  
Match in FD: 95.3%  
Sampling Rate: 4096.0



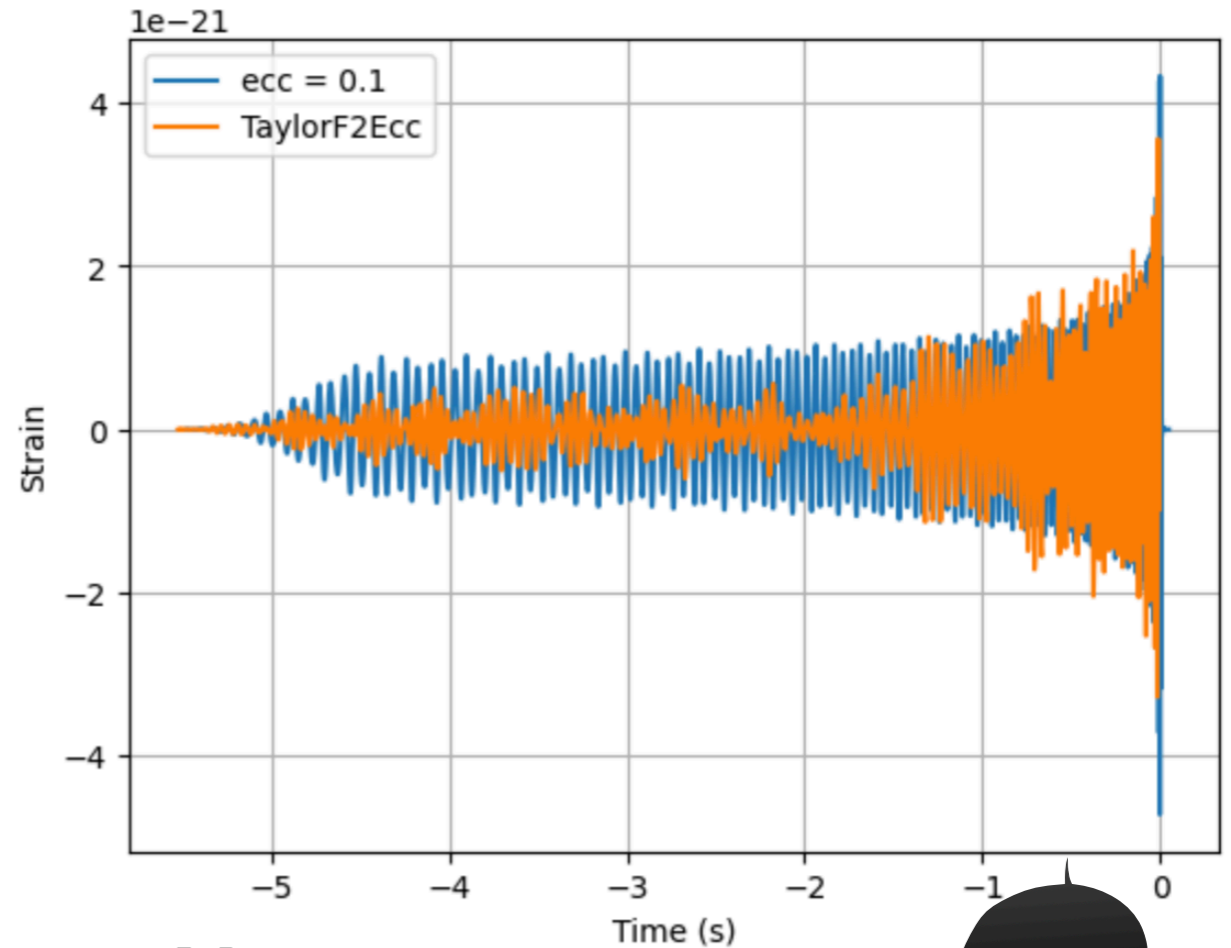
**Match  $\geq 85\%$  in both TD and FD!**

## 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



Total Mass:  $40M_{\odot}$   
 Mass Ratio: 1  
 Spin: 0.0  
 Eccentricity: 0.1

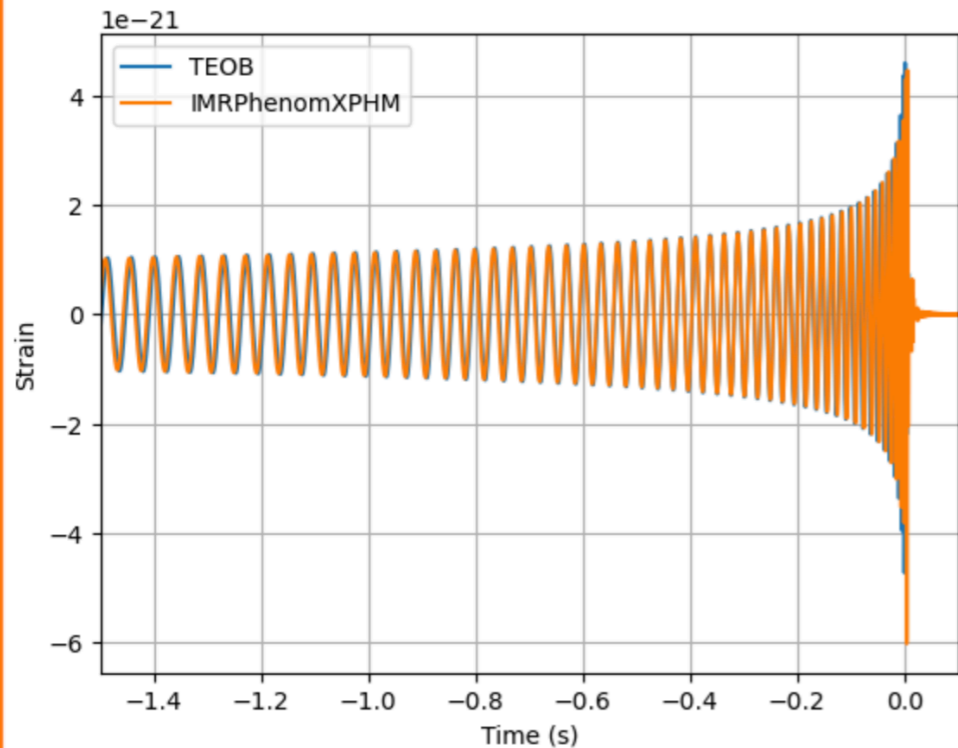
**EccentricFD/TaylorF2Ecc are instead not accurate!**





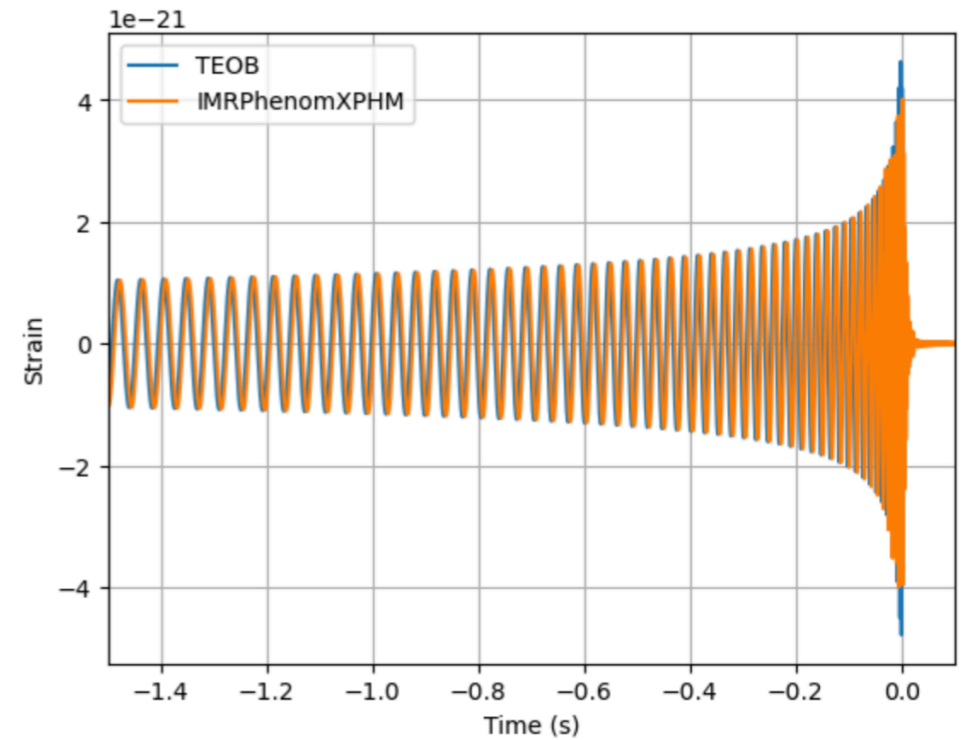
TEOB vs IMRPhenomXPHM (Aligned Spin with no Eccentricity)

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



Total Mass:  $40M_{\odot}$   
 Mass Ratio: 1  
 Eccentricity: 0.1

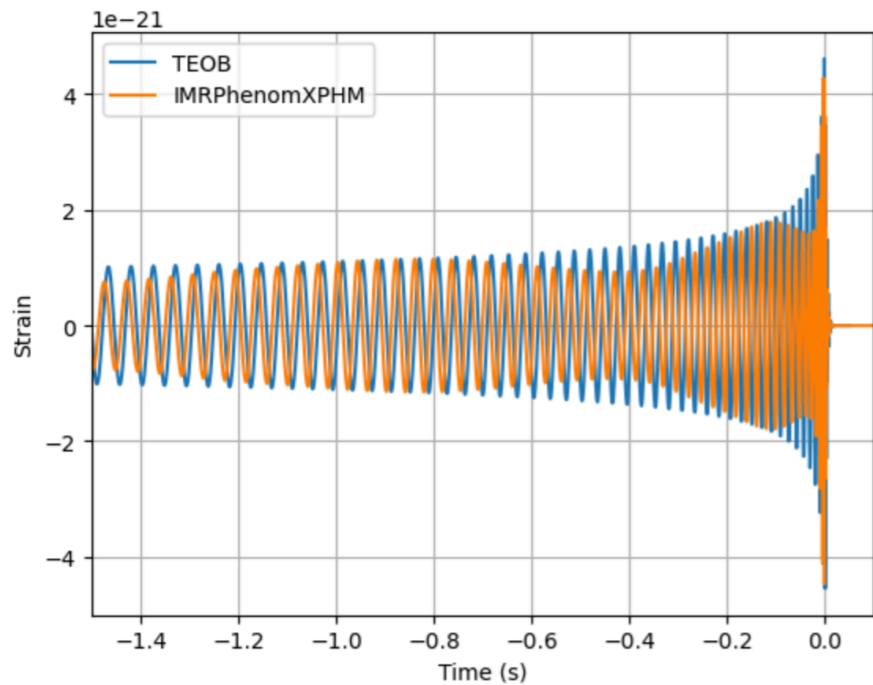
IMRPhenomXPHM Spin1 = 0.9, Spin2 = 0.9 Vs TEOB in time domain



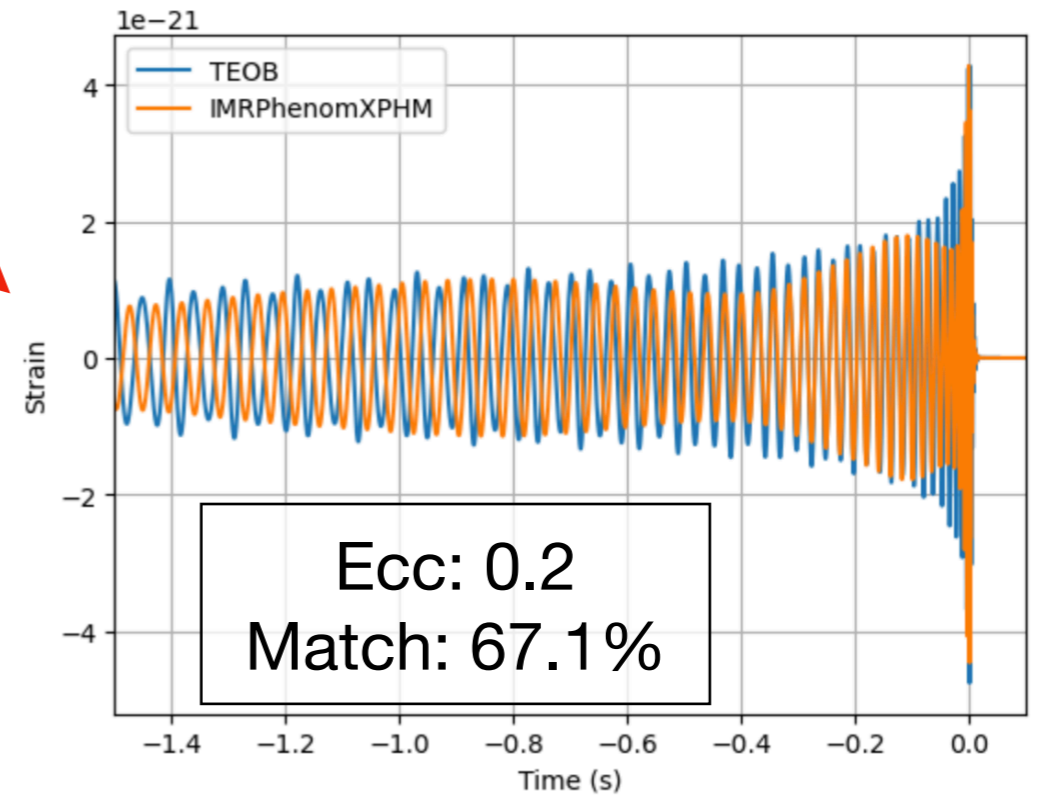
95%  
MATCH

# Eccentric TEOB vs Precessing IMRPhenomXPHM

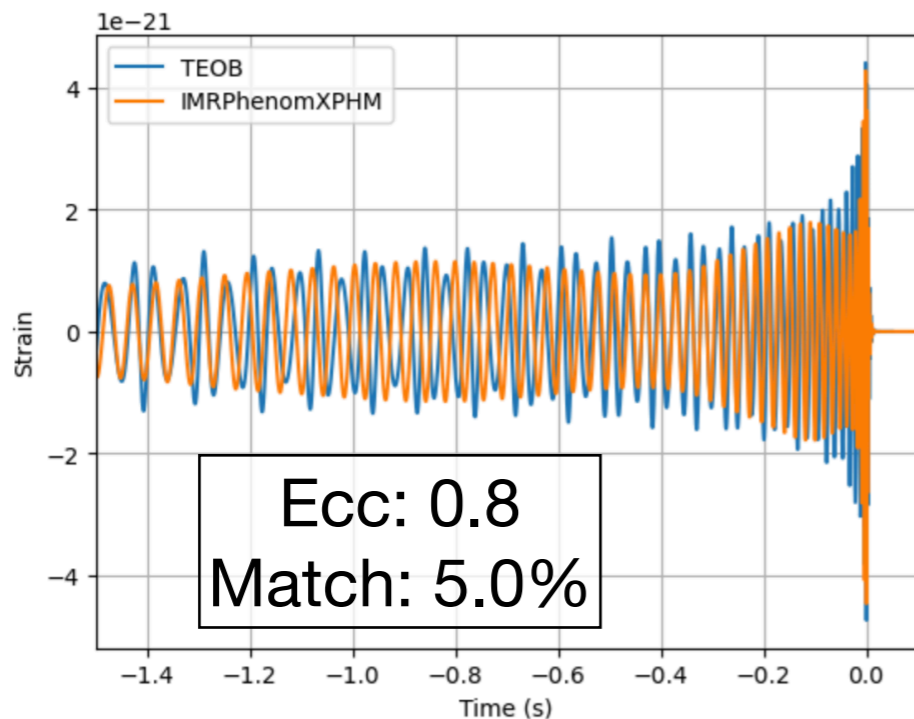
IMRPhenomXPHM Spin  $x_{1,2} = 0.7$  Spin  $y_{1,2} = 0.7$  Vs TEOB Ecc = 0.0 in time domain



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

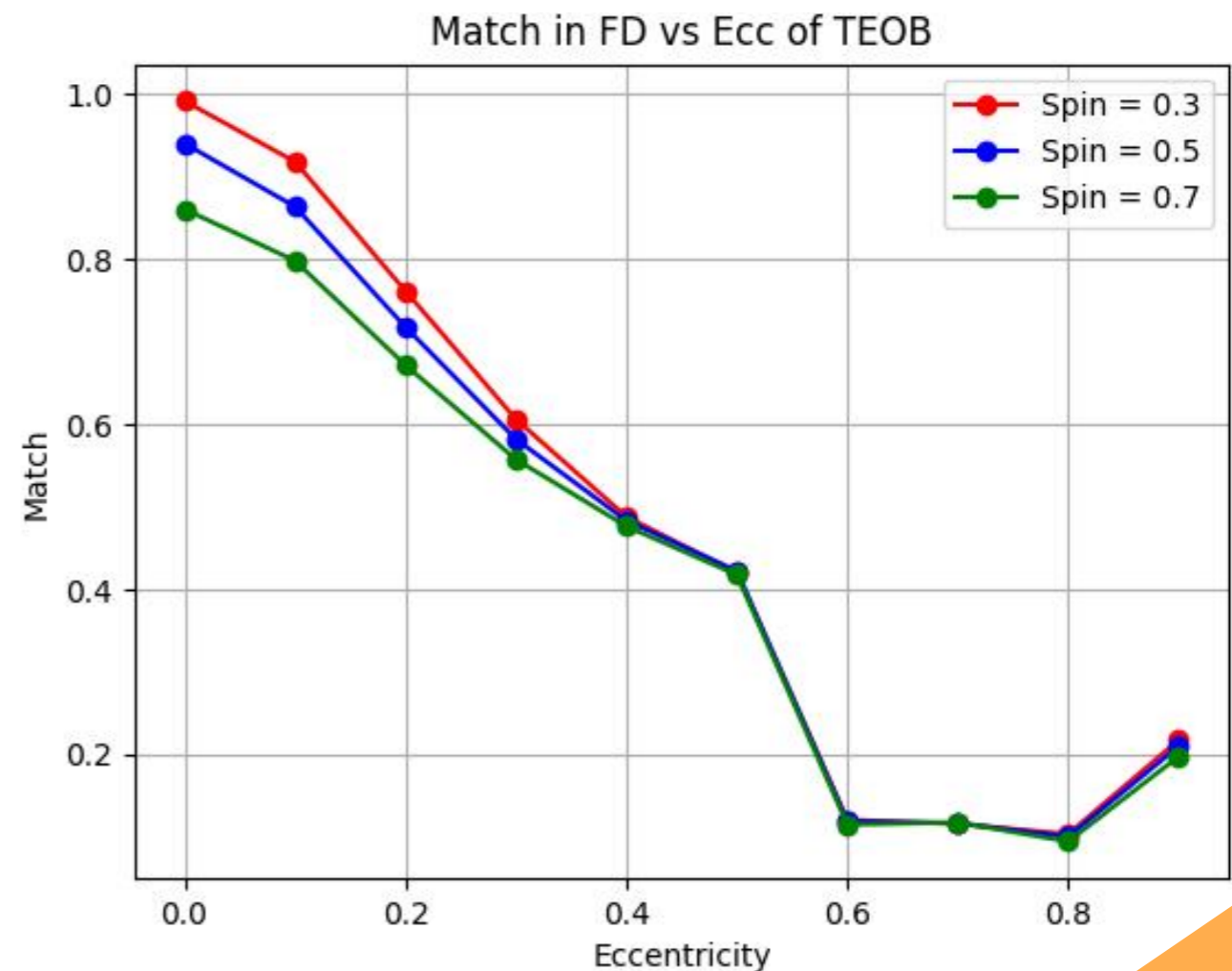
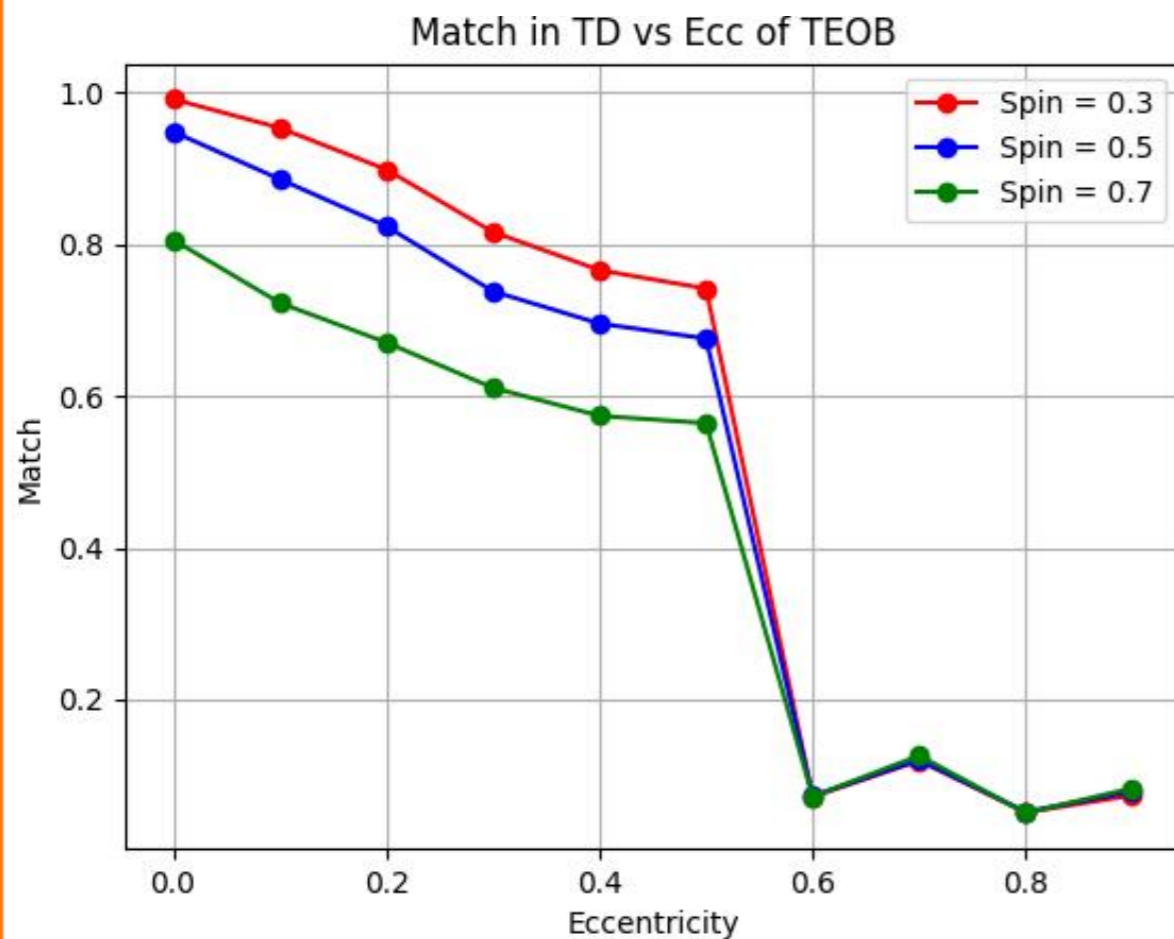


They are different in Amplitude Modulation!

## Eccentric TEOB with no Precession

VS

## Precessing IMRPhenomXPHM with no Eccentricity





## Results:

- ✓ **Eyeball Sanity Check → Looks Good!**
- ✓ **Comparisons and Matches with other waveforms → Good!**



**TEOBResumS Eccentric waveform family looks good for use by LVK!**



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Conclusion

Thank you!

TEOBResumS Group

Alan

Caltech SFP

LIGO Waveform Group

LIGO Lab

Everyone who gave suggestions



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**Thank you very much for listening!**