Core-Collapse Supernova Waveform Generation Using Machine Learning

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Introduction

Excellent Talks Covering Fundamentals of CCSN !!!

Motivation

- CCSN simulations are computationally expensive.
- Looking for an alternate method to quickly generate the waveforms across EOS and other physical parameter.
- Potential application in parameter estimation.
- An approach to combine the current CCSN models for further application.

Workflow

- Prepare a CCSN GW data.
- Choose the required physical parameter space.
- Built the neural network.
- Perform training, test and validation.
- Generate waveforms with the neural network.
- Verify the results with measured values.

Data

Data has been adopted from Richers et al. 2017 https://zenodo.org/records/201145

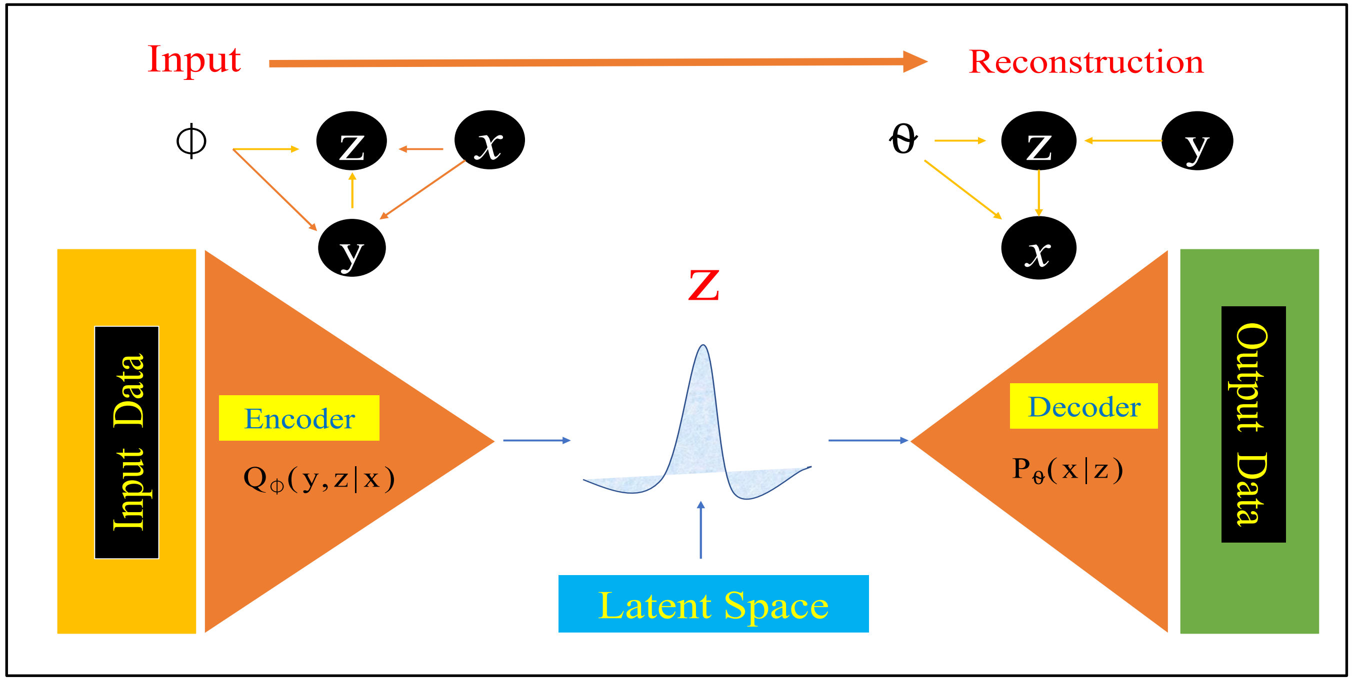
- 2D GR Hydrodynamic Simulation.
- 12-M_0 progenitor model.
- 18 different EOS
- 98 different rotational profile with differential rotation and maximum rotation.

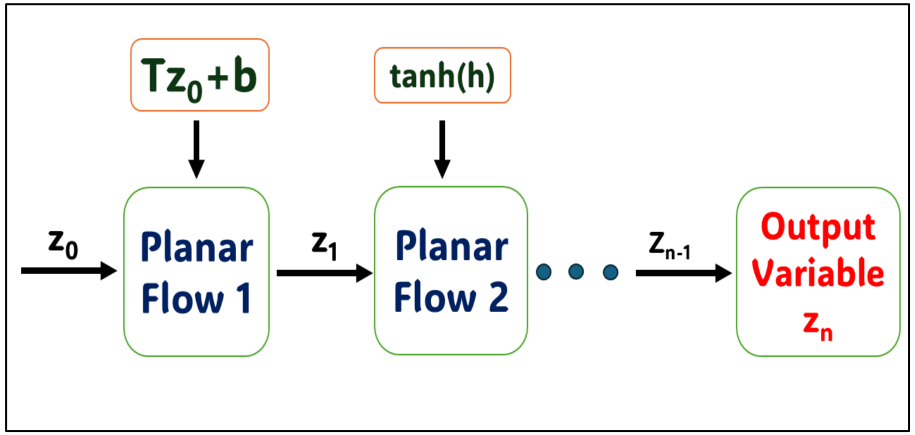
Selected Data

- **EOS Considered:** HDSS2, SFHo, GShenNL3, BHBLP, HSTMA, LS220, LS180, LS375, HSTMA, HSNL3, GShenFSU1.7, SFHx, SFHo_ecapture_0.1, SFHo_ecapture_1.0, SFHo_ecapture_10
- **Differential Rotation A** : 300, 467, 634, 1268 and 10000 (km)
- **Maximum Rotation Ω_0** : 0.5-15.5 rad/s
- **98 combinations** of physical parameter sets with A, Ω_0 for each EOS.
- Thus **98 waveforms** for each EOS.

Training Methodology

Conditional Variational Autoencoder + Planar Normalizing Flow (Generative Models)



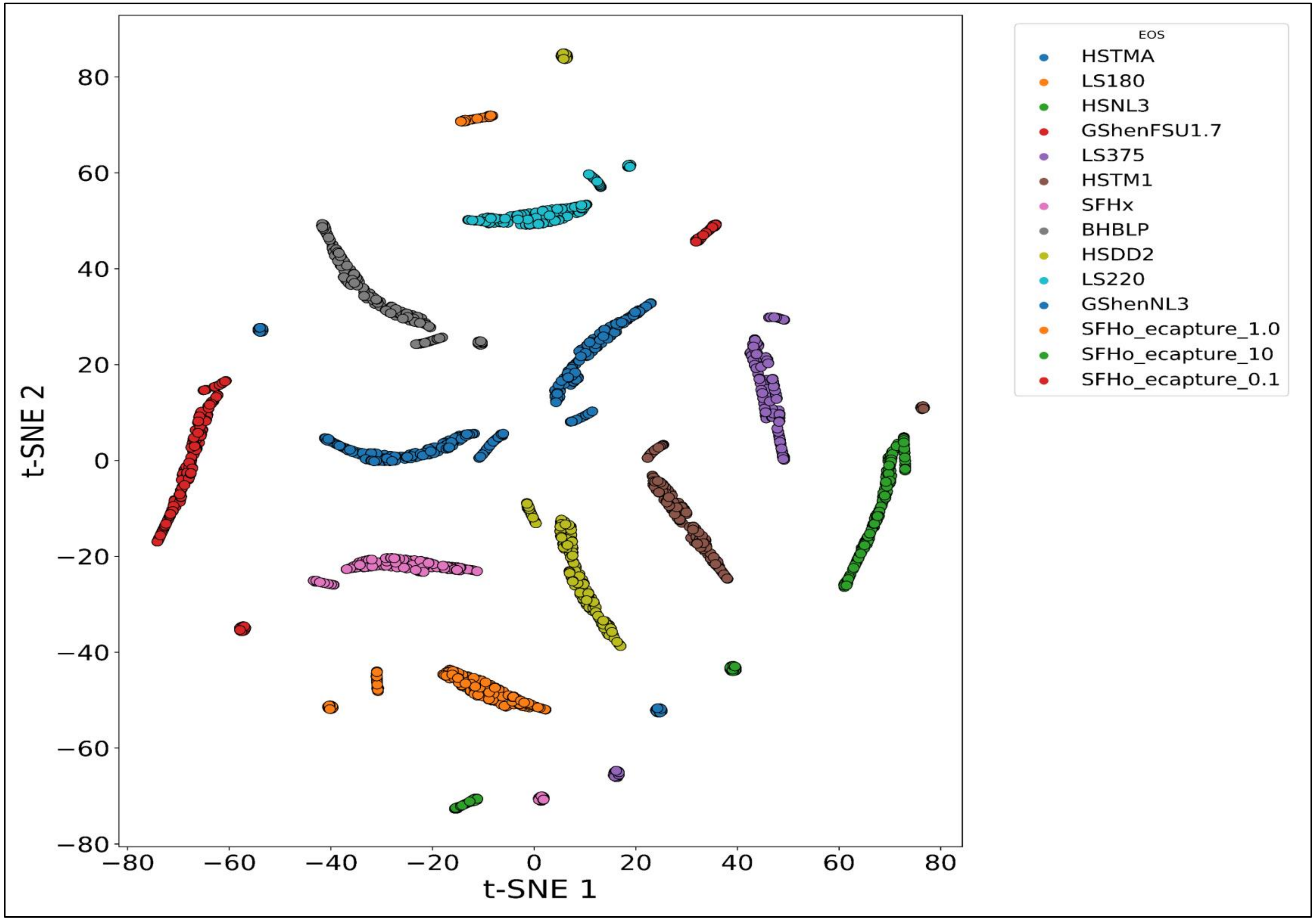


(Saha et al. 2024)

- **Train the waveforms being conditioned on EOS, A and Ω_0**
- **Generate 1000 GW waveforms for selected parameter set.**
- **Compare the true and generated waveforms visually and with other metrics.**

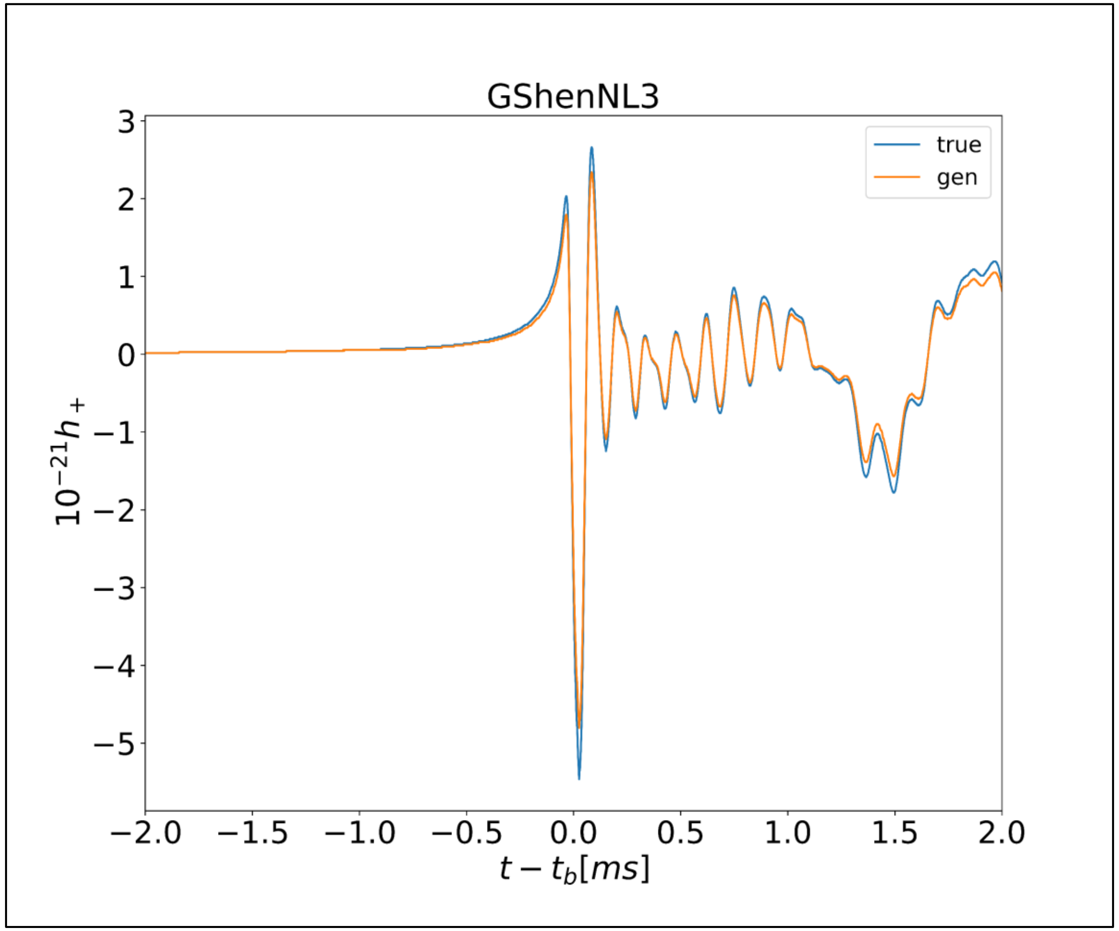
Results 1

t-SNE Plot

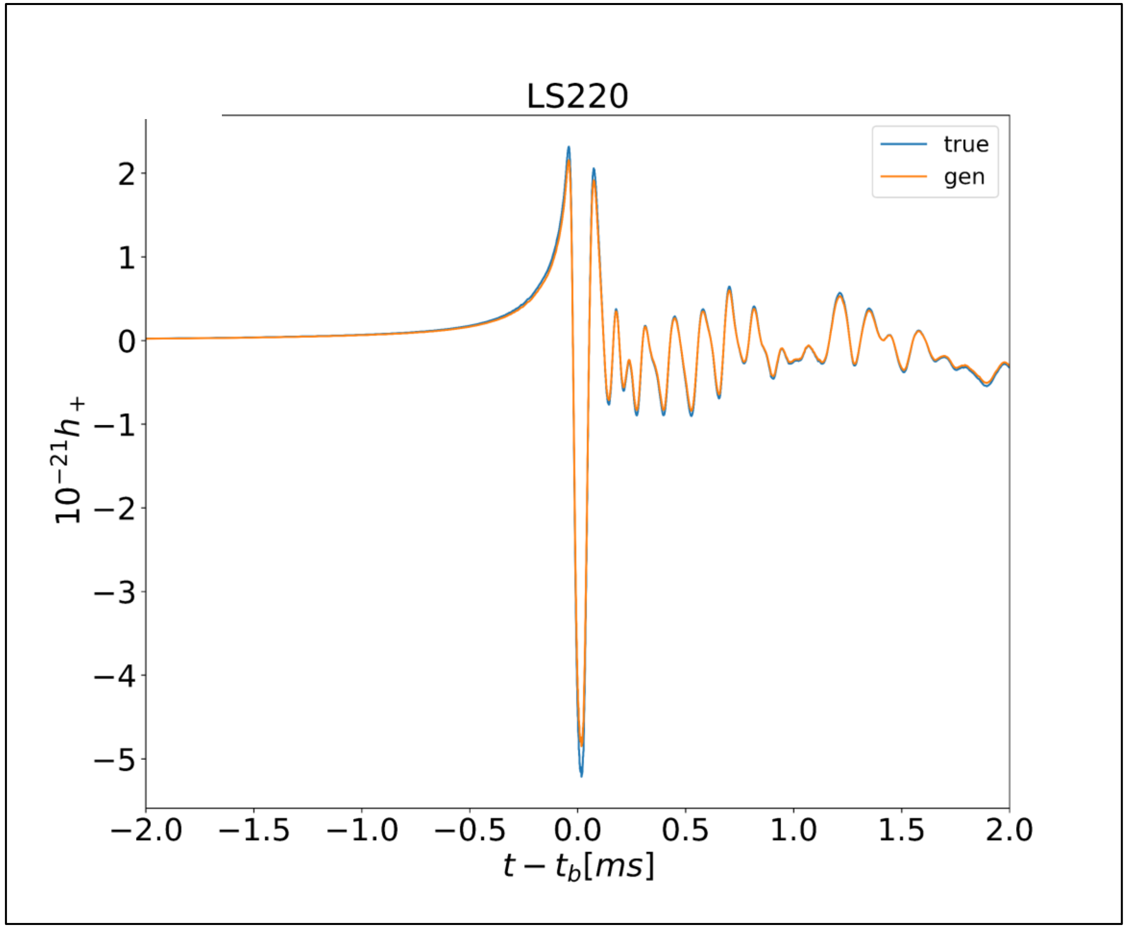


Results 2

GShenNL3, A = 467 km, Ω_0 = 6 rad/sec



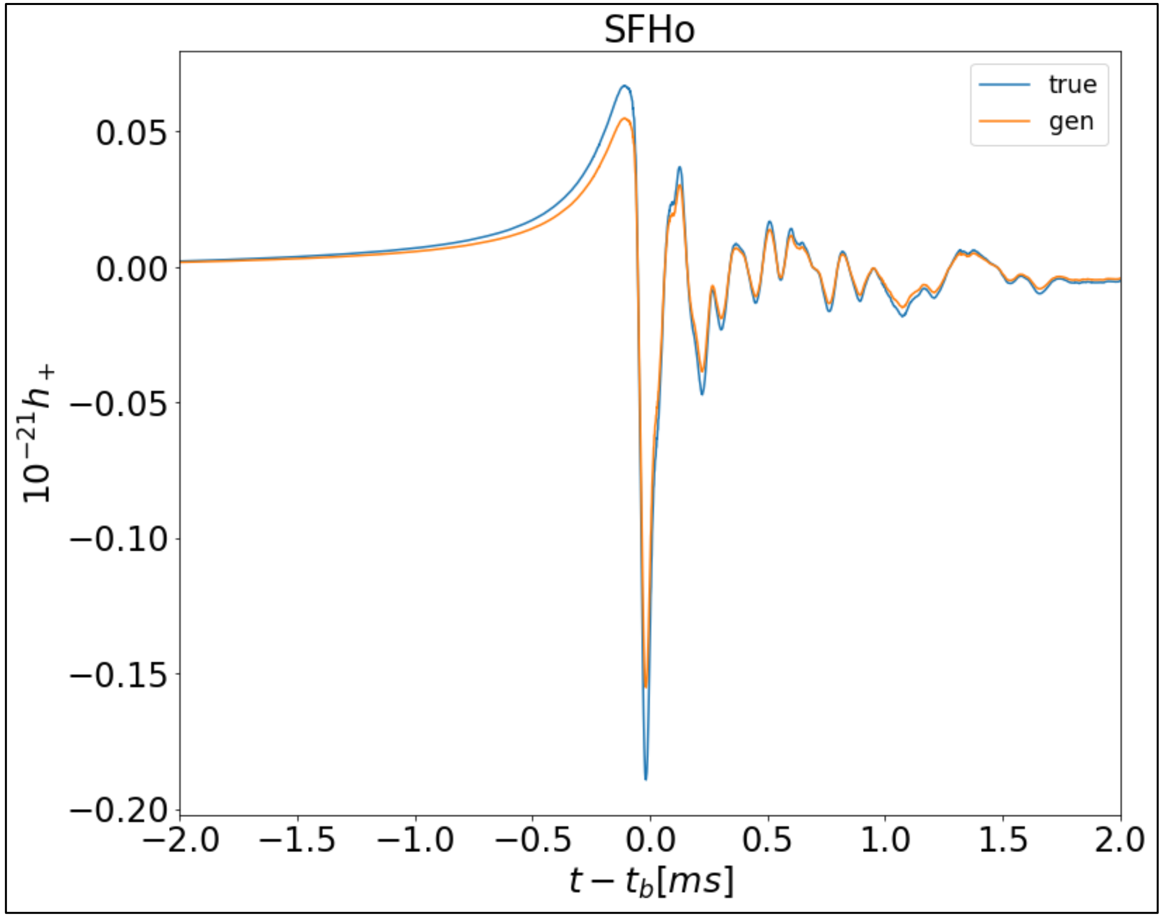
LS220, A = 634 km, Ω_0 = 6 rad/sec



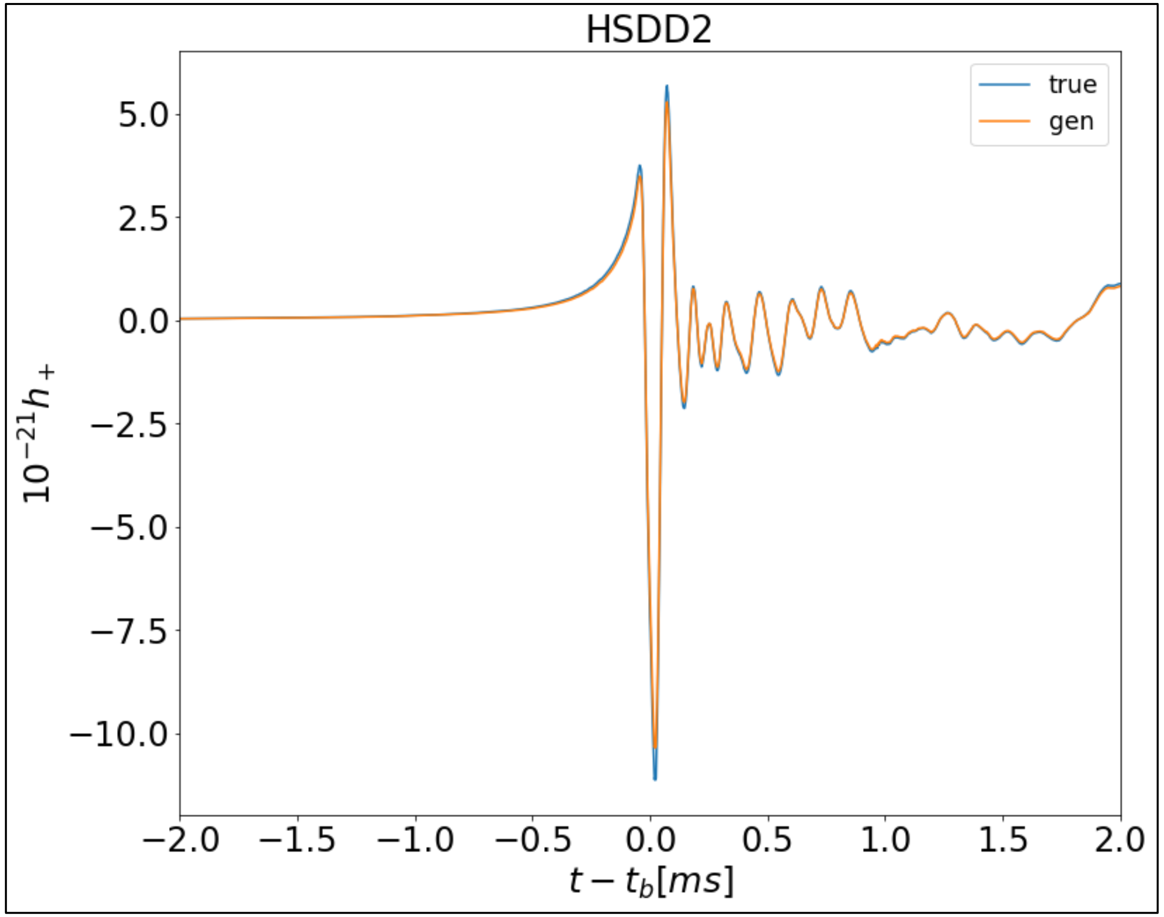
Extent of overlap between the true and generated waveforms

Results 3

SFHo, A = 634 km, Ω_0 = 9 rad/sec



HSDD2, A = 467 km, Ω_0 = 6 rad/sec



Extent of overlap between the true and generated waveforms

Results 4

Calculated values of mean squared error and MAPE between the true and generated waveform across EOS

EOS	Range of MSE [1e-41]	Range of MAPE (%)
HSDD2	0.0083~0.0088	1.5~2
GShenNL3	0.0077~0.0080	0.8-1.2
BHBLP	0.007~0.0073	0.9~1.25
SFHo	0.008~0.009	1.32~1.75
HSTMA	0.0065~0.0072	0.7~1.1
LS220	0.0092~0.0097	1.12~1.5
LS180	0.006~0.0065	1.09~1.45

Summary

- Currently, training takes ~2 hrs.
- Generation of waveforms take ~milliseconds.
- MSE and MAPE provide evidence for accurate generation.

Future Works

- Include CCSN waveforms from other models.
- Generate waveforms across other models based on EOS.

Thank You For Your Attention