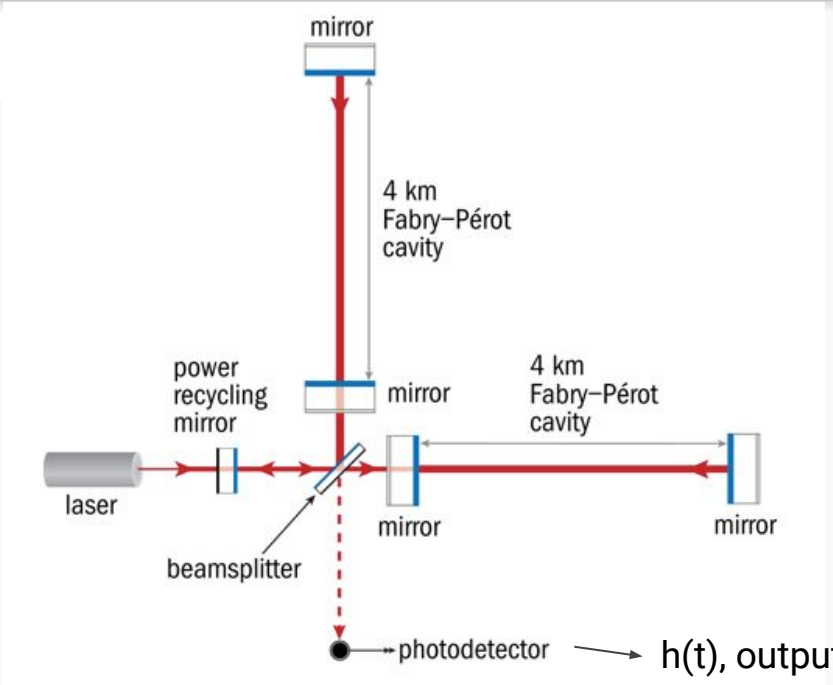
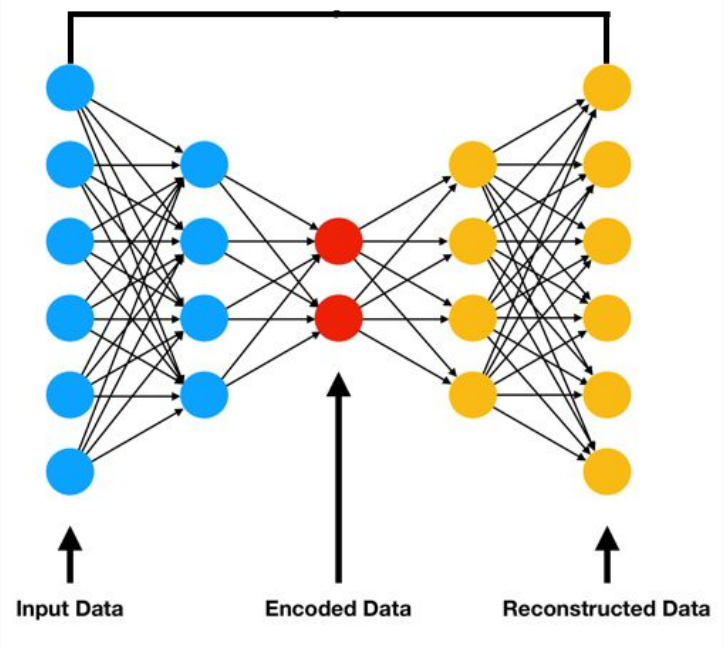
Quasi-Anomalous Gravitational Wave Detection With Recurrent Autoencoders

Ryan Raikman[1, 3], Eric Moreno[2], Phil Harris[2], Erik Katsavounidis[1,2], Ethan Marx[1,2], Alec Gunny[1,2], Deep Chatterjee[1,2]
MIT LIGO Laboratory[1], MIT[2], Carnegie Mellon University[3]

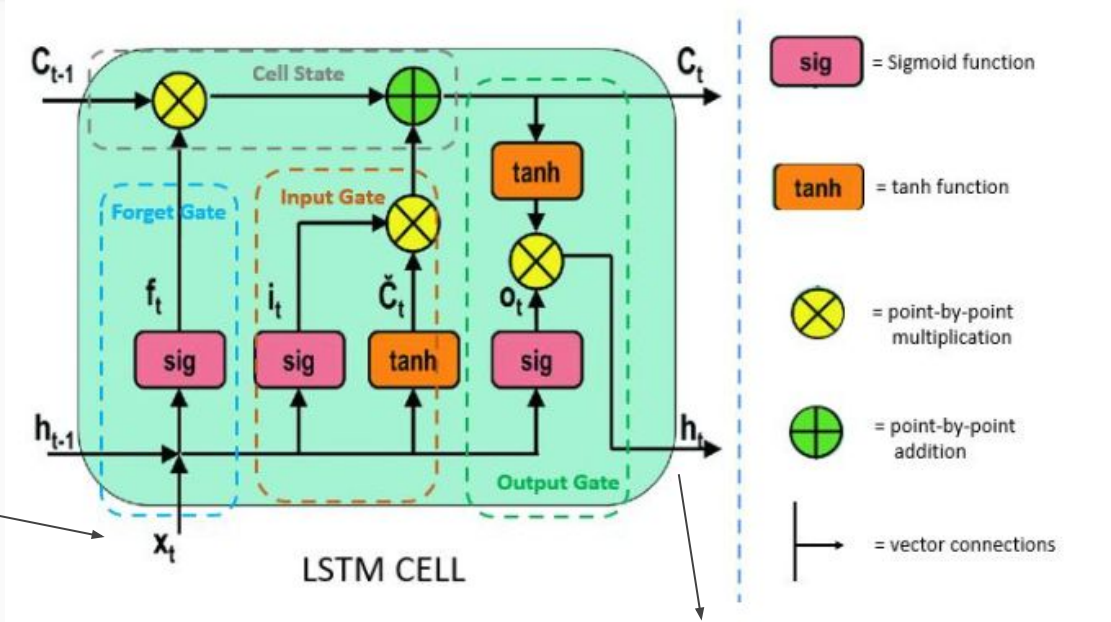
LIGO - Gravitational Wave Observatory



Autoencoders



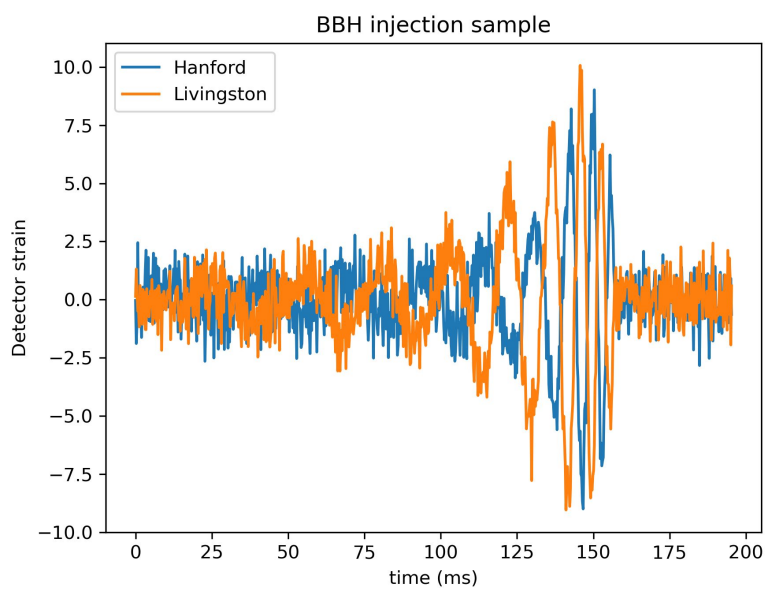
LSTM units

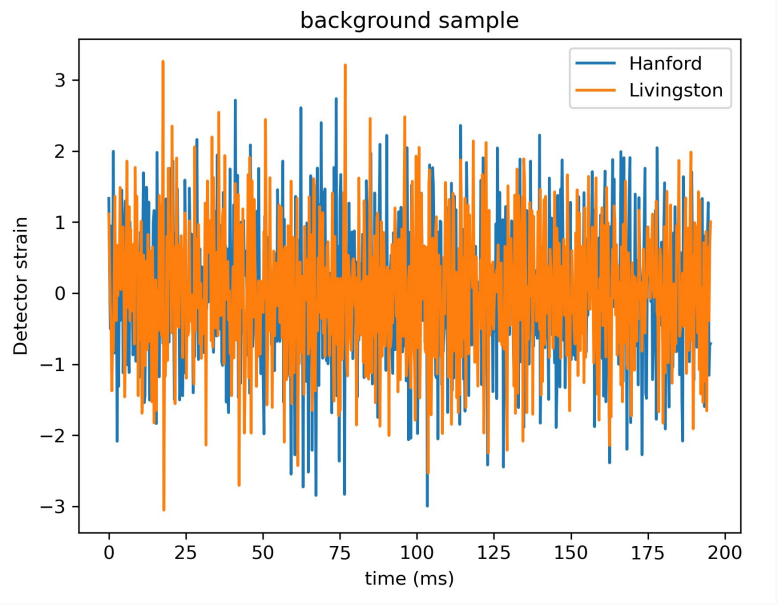


data: $\{x_1, x_2 \ldots x_N\}$

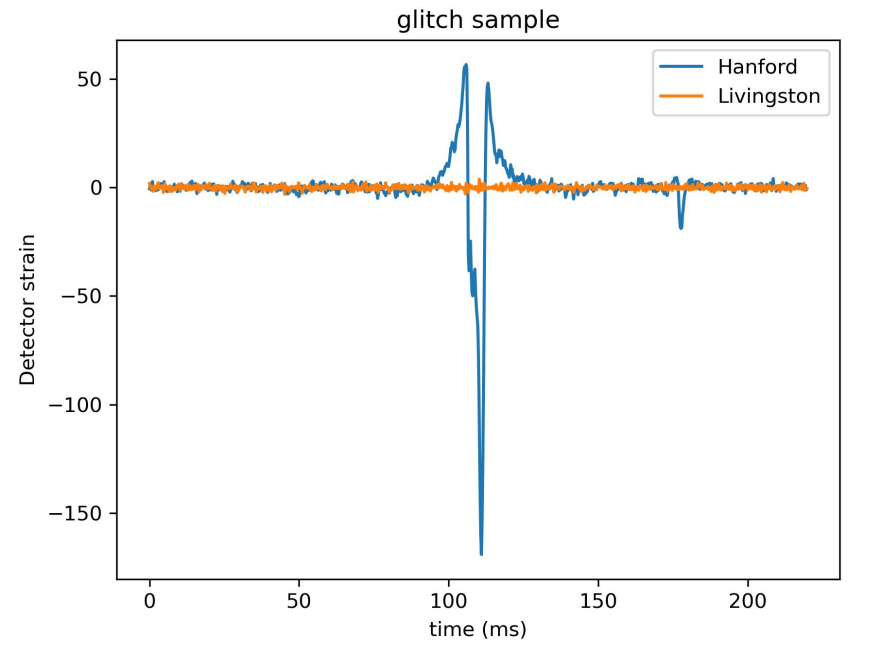
output: $\{h_1, h_2 \ldots h_N\}$

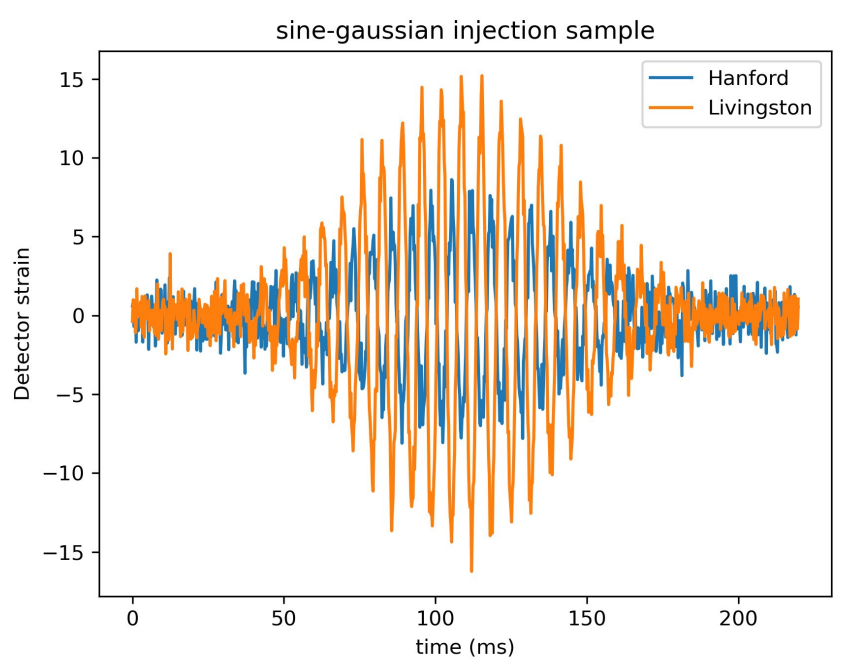
Training dataset





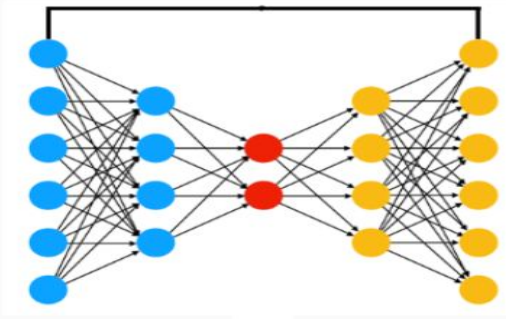
Training dataset



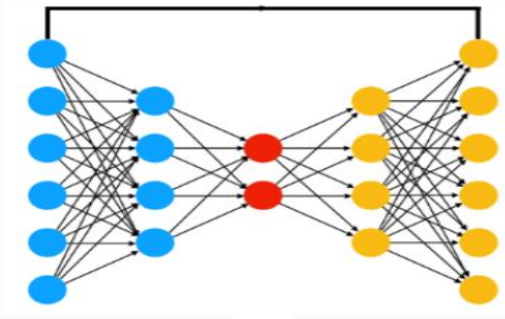


Idea: train a model for each data class

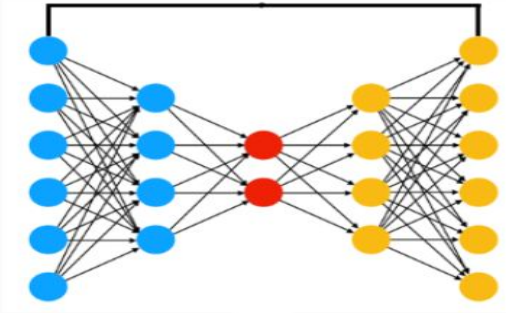
BBH autoencoder:



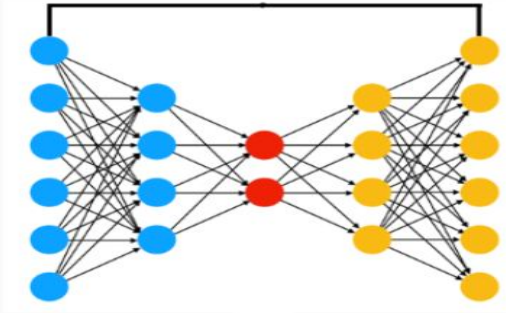
Glitch autoencoder:



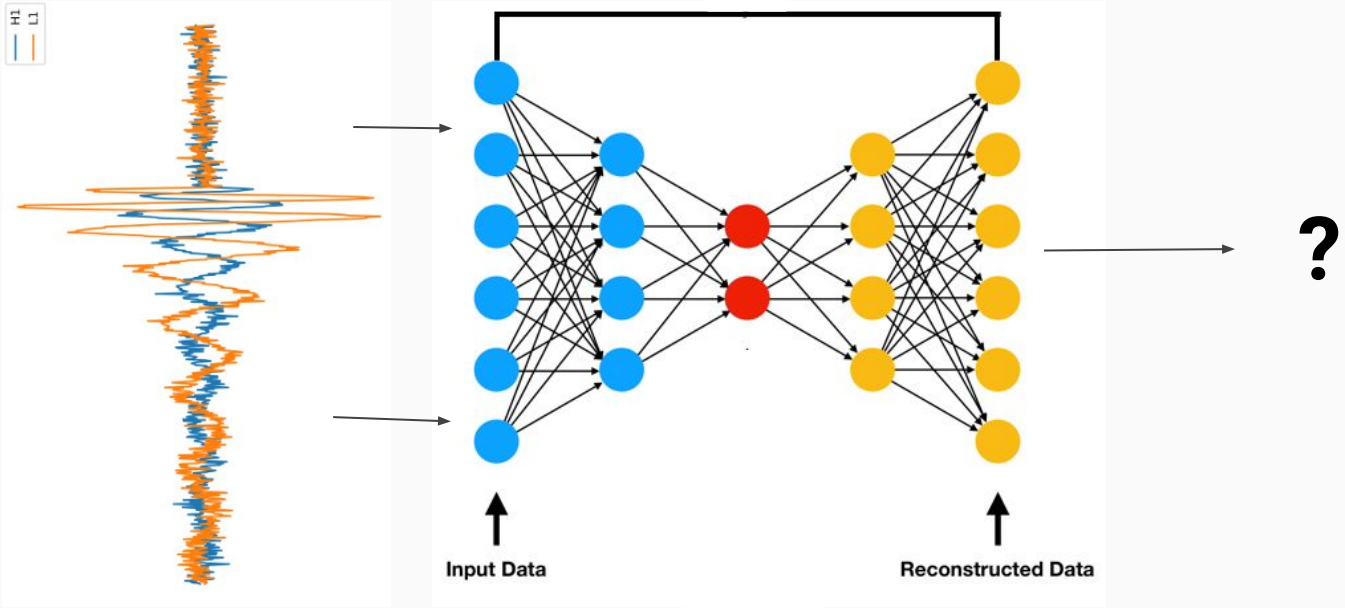
Sine-gaussian autoencoder:



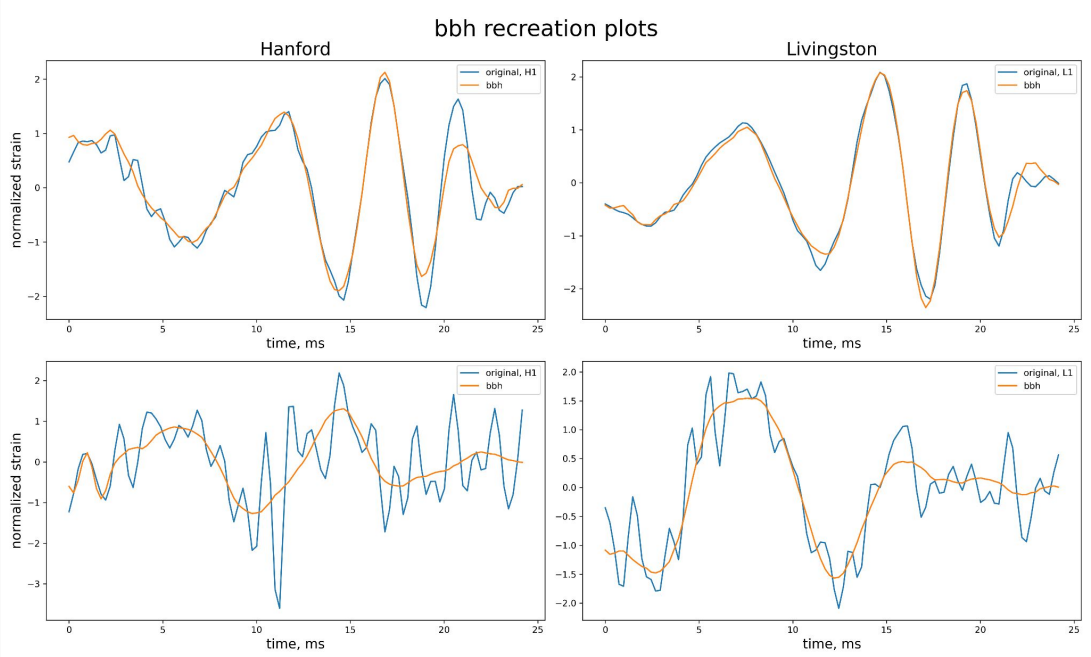
Background autoencoder:



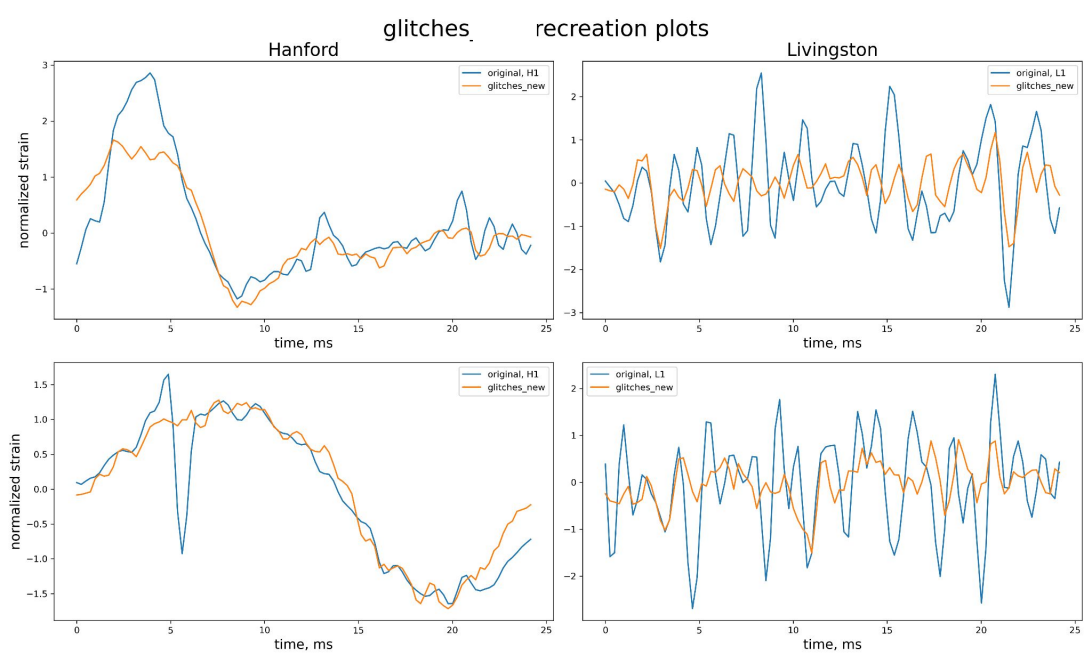
What does the reconstruction look like?



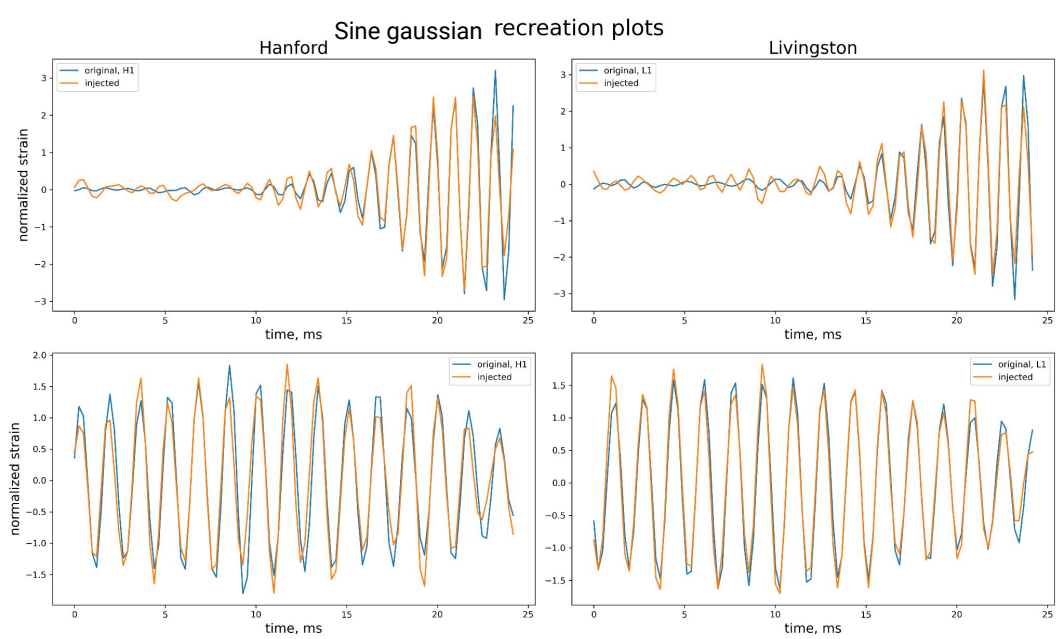
BBH autoencoder on BBHs



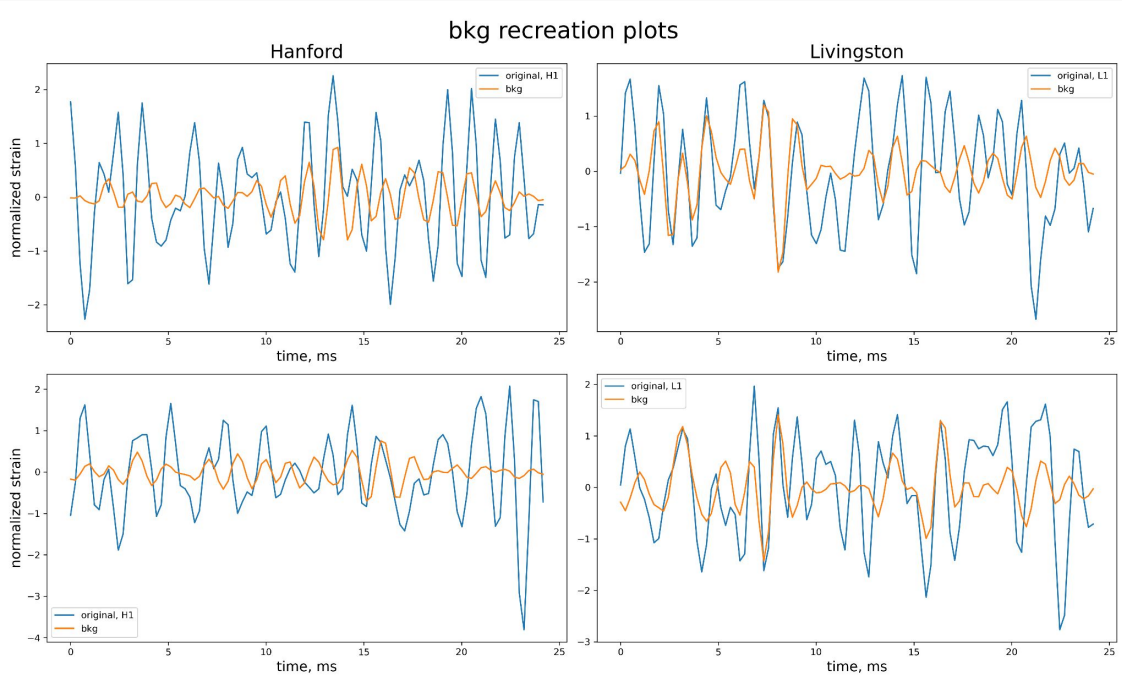
glitch autoencoder on glitches



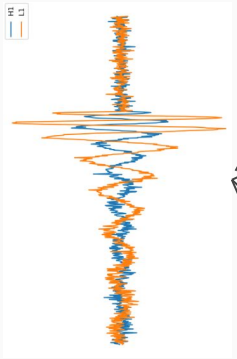
SG autoencoder on sine-gaussians



background autoencoder on background



analyzing unknown signal



BBH:

SG:

BKG:

GLITCH:

Compute recreation loss

$$\frac{1}{n}\sum_{i=1}^{n}|y_i - \hat{y}_i|$$

Losses (ex.):

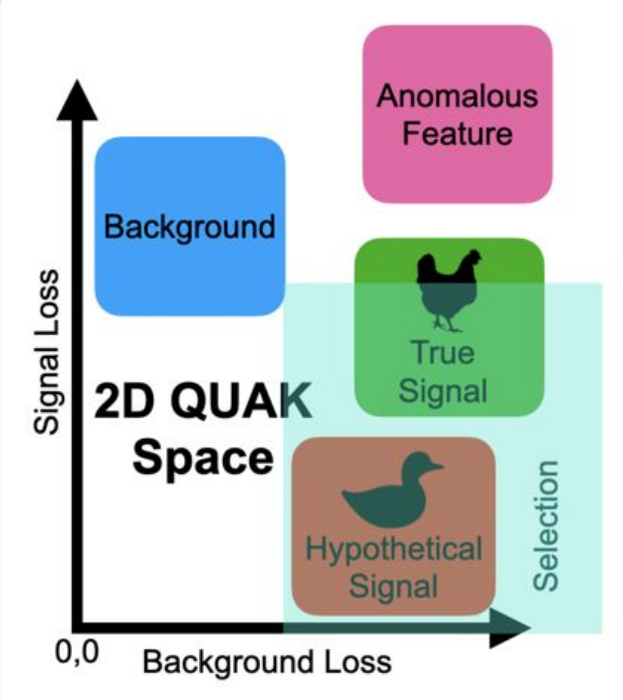
0.2

0.9

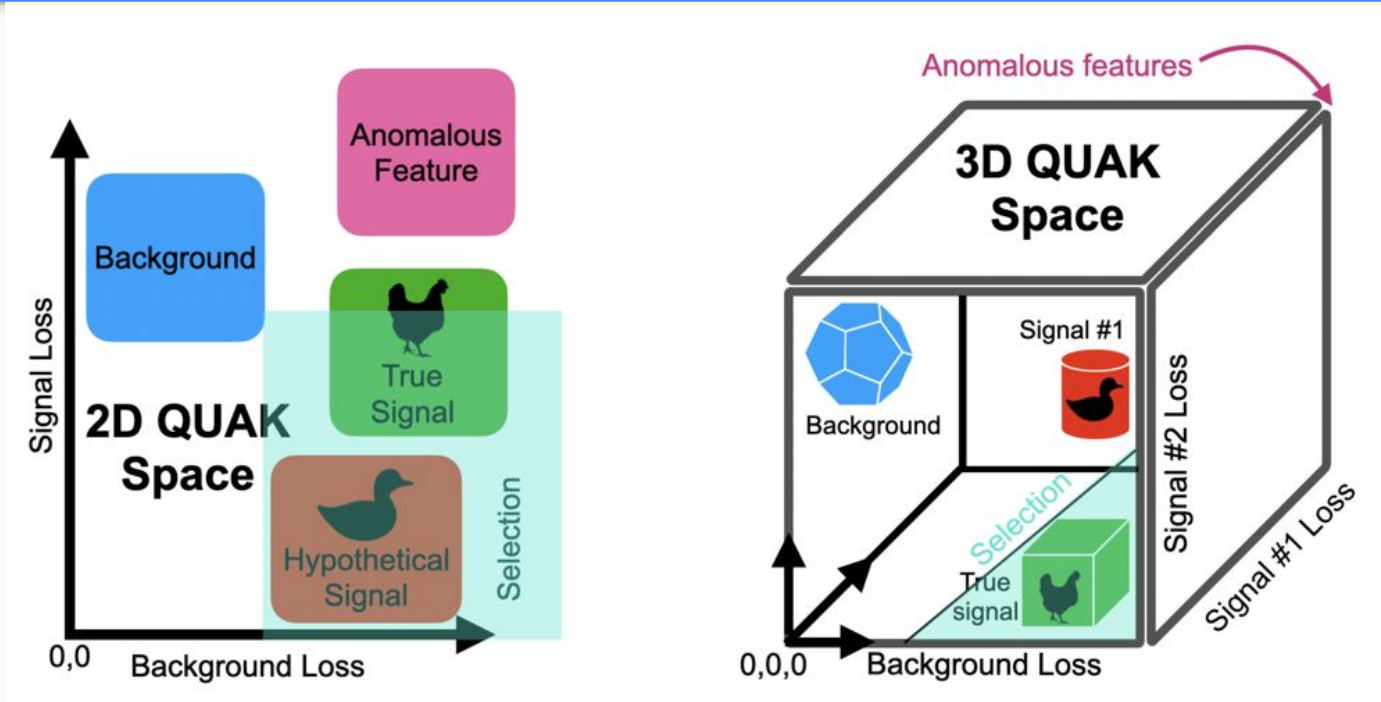
0.7

0.8

Quasi-Anomalous Knowledge - QUAK

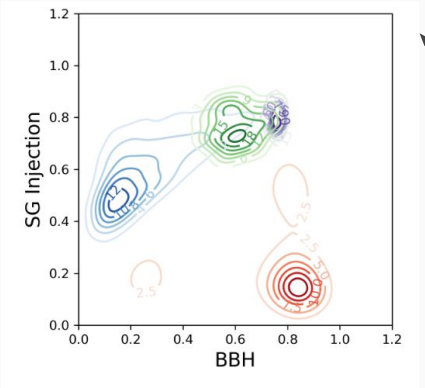


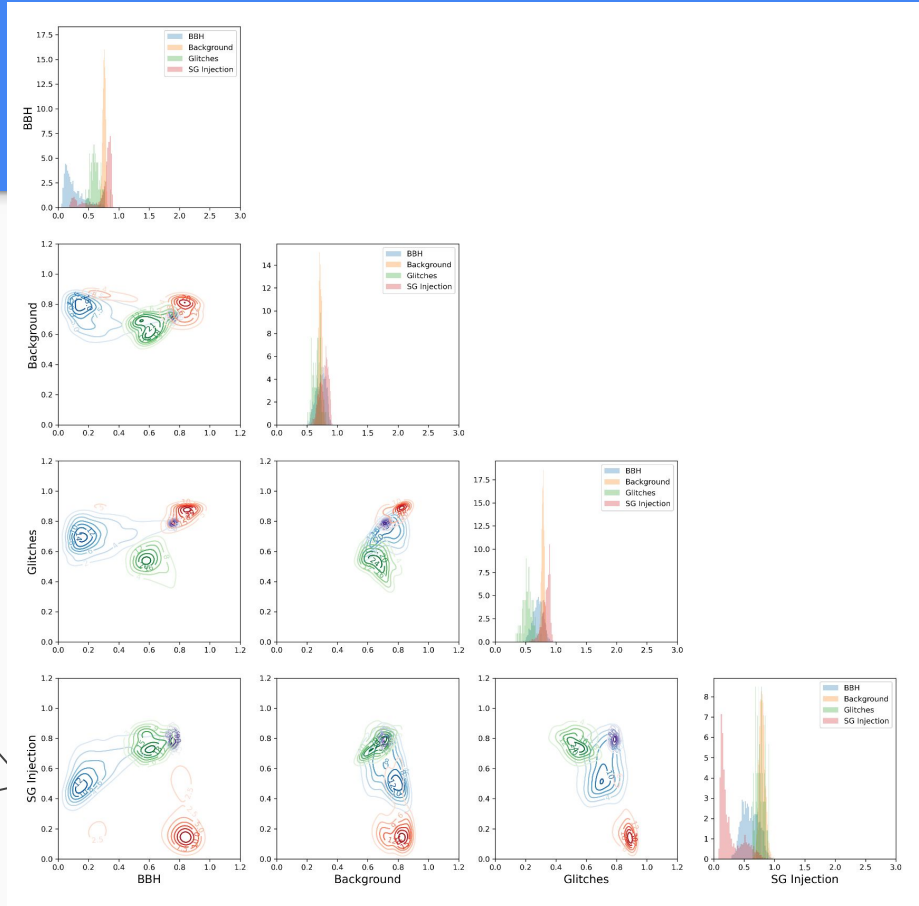
Quasi-Anomalous Knowledge - QUAK



Trained QUAK

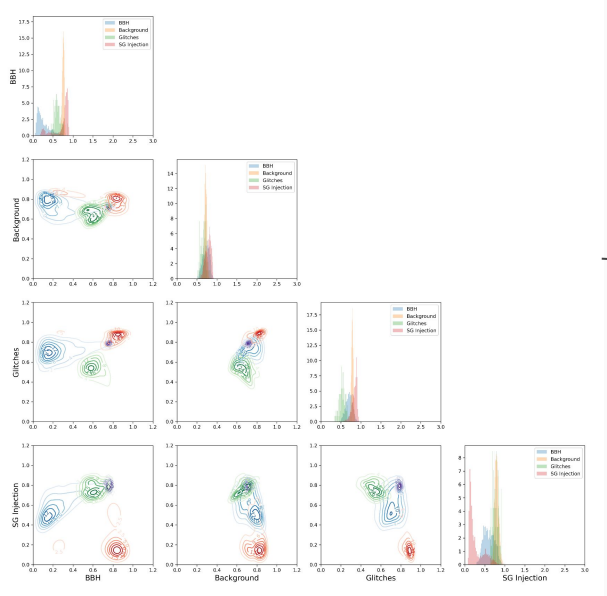
- BBH
- Glitches
- Sine gaussians
- Background





NN classifier

QUAK space ($\mathbb{R}^4$)



DNN, θ

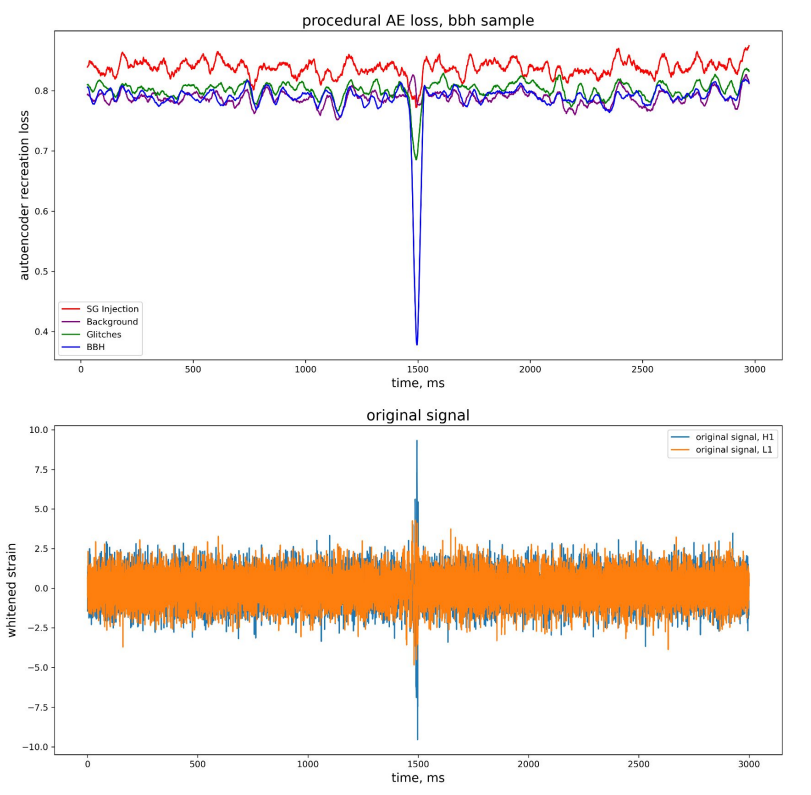
Softmax

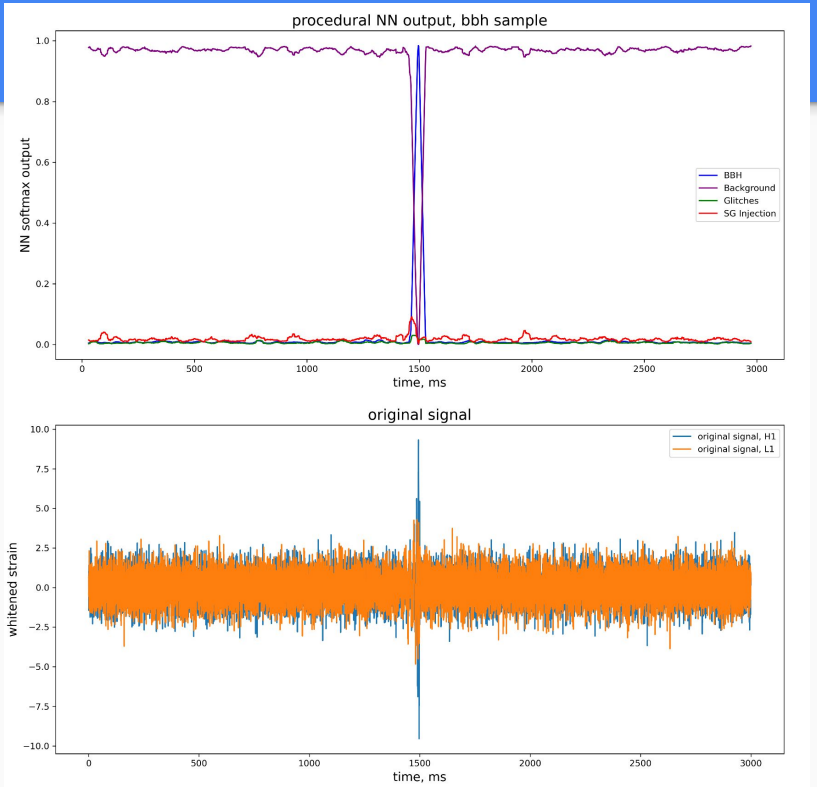
$$\sigma(\vec{z})_i = \frac{e^{z_i}}{\sum_{j=1}^{K} e^{z_j}}$$

Probability space ($\mathbb{R}^4$)

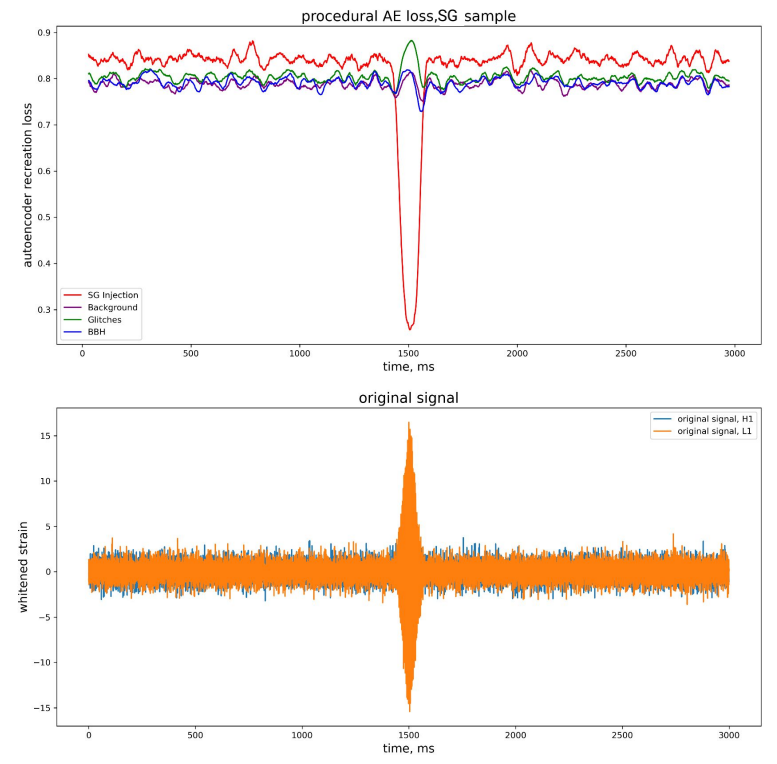
[
P(BBH),
P(BKG),
P(SG),
P(GLITCH)
]

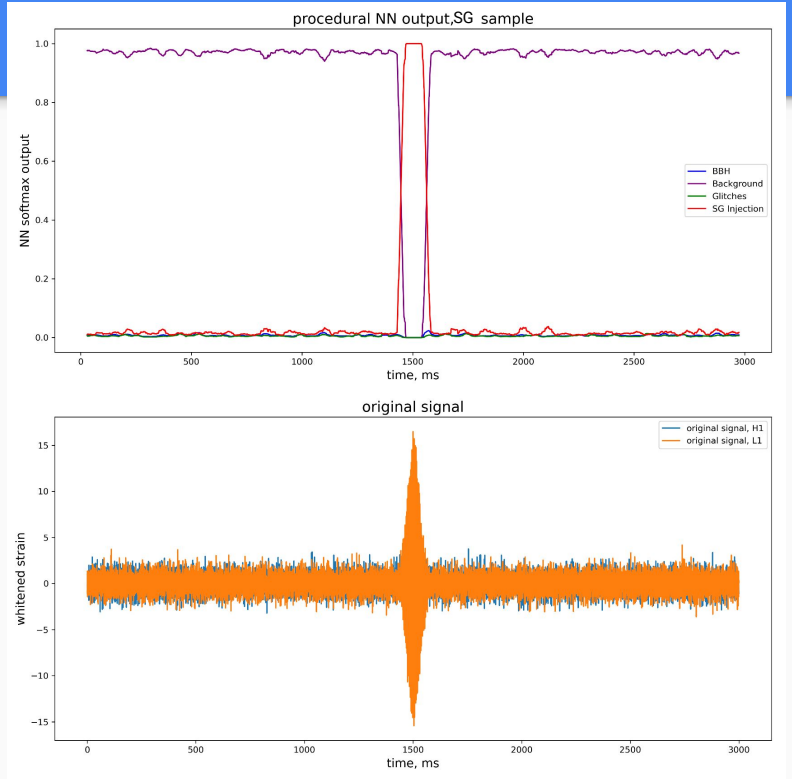
BBH Event


procedural AE loss, bbh sample
autoencoder recreation loss
time, ms
SG Injection
Background
Glitches
BBH
original signal
whitened strain
time, ms
original signal, H1
original signal, L1

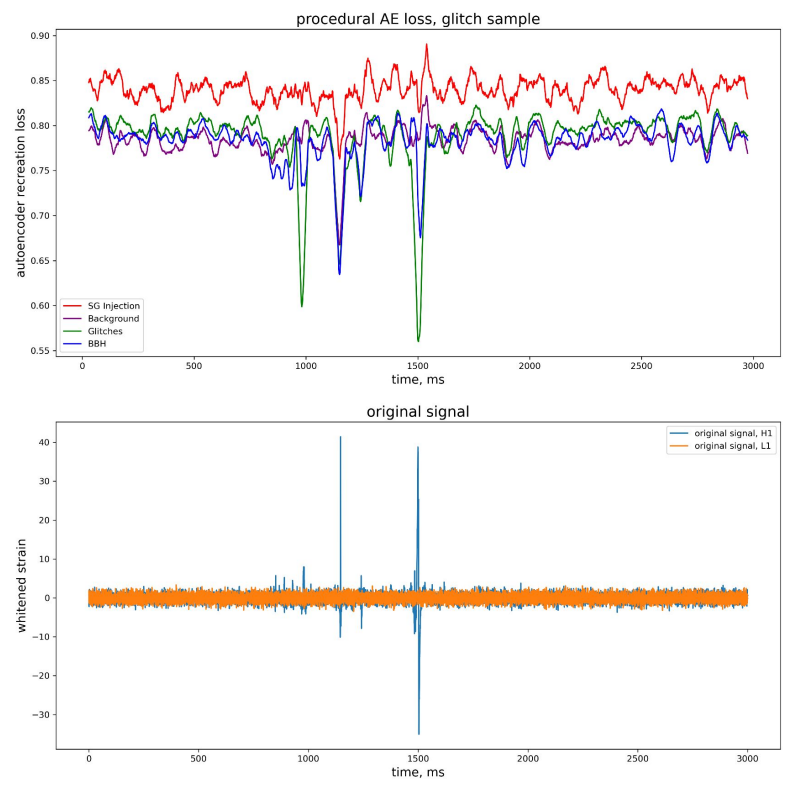

procedural NN output, bbh sample
NN softmax output
time, ms
BBH
Background
Glitches
SG Injection
original signal
whitened strain
time, ms
original signal, H1
original signal, L1

Sine-gaussian event





Glitch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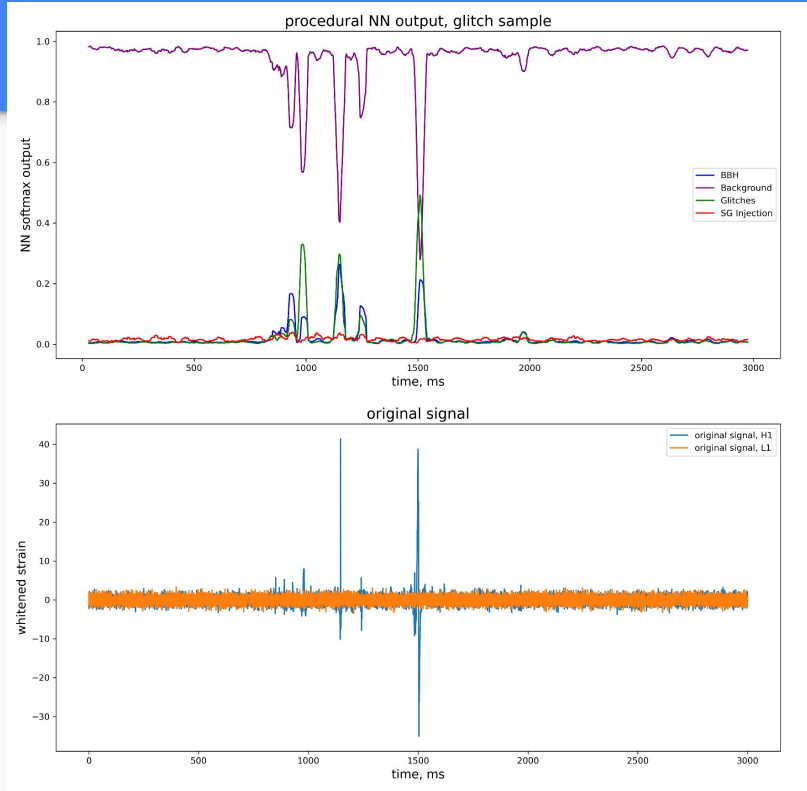
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time, ms
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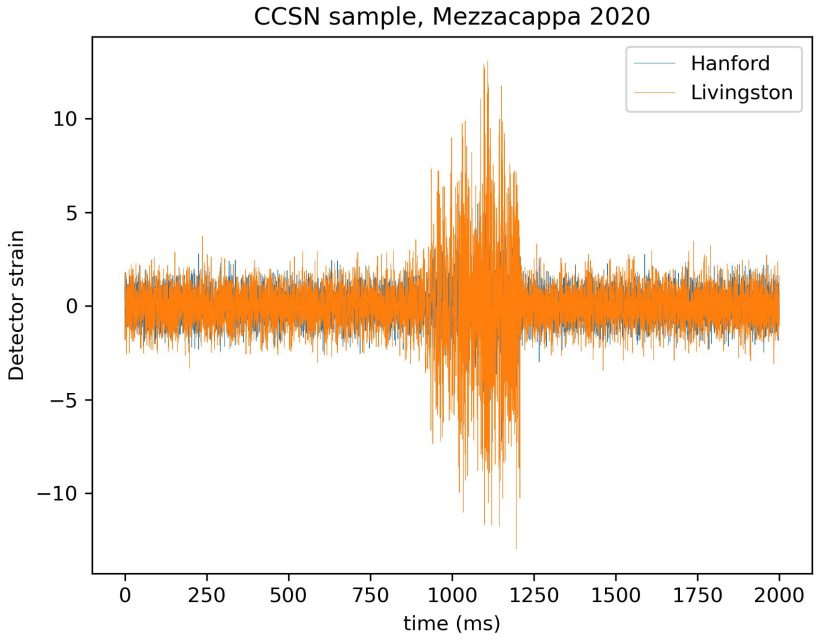
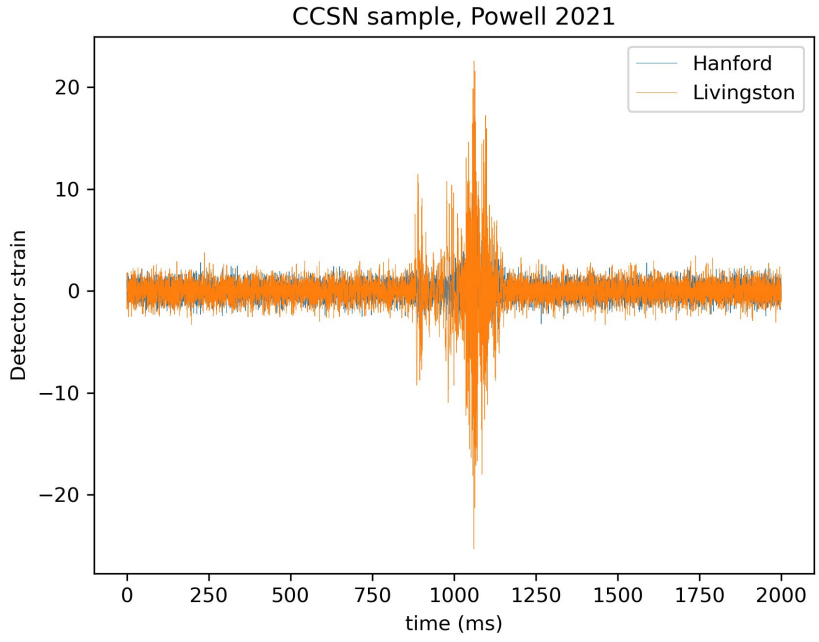
Glitches
SG Injection
original signal
whitened strain
time, ms
original signal, H1
original signal, L1

Anomalies - CCSN waveforms

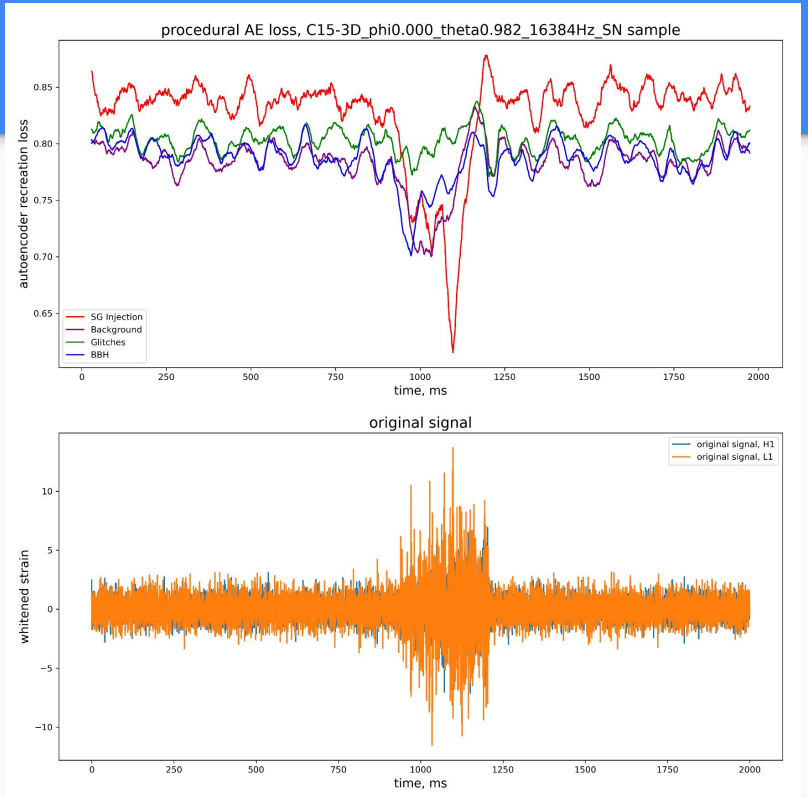


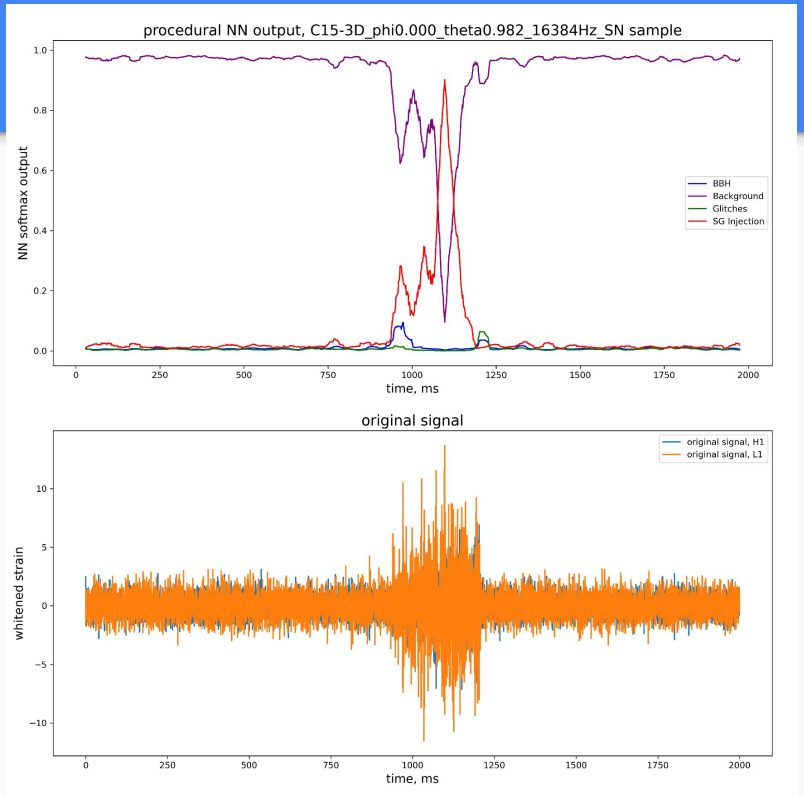
Mezzacappa et al. , Phys. Rev. D **102**, 023027



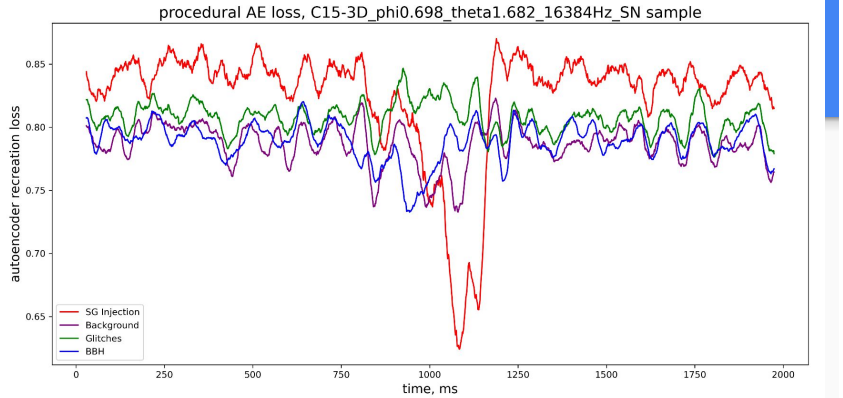
Powell et al, arXiv 2101.06889

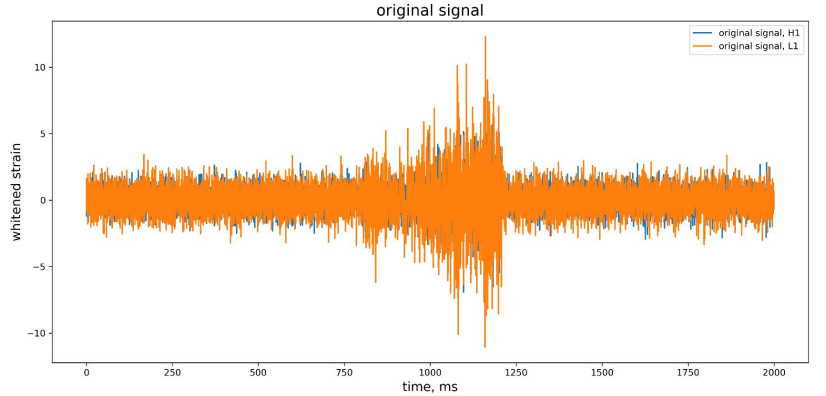
CCSN evaluation, Mezzacappa model

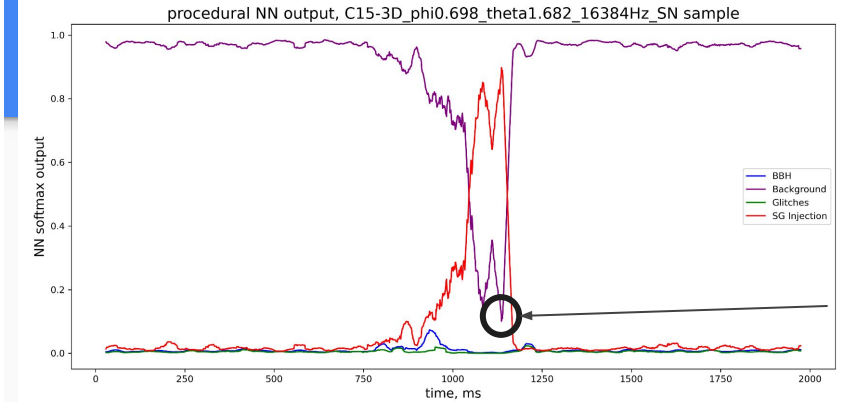




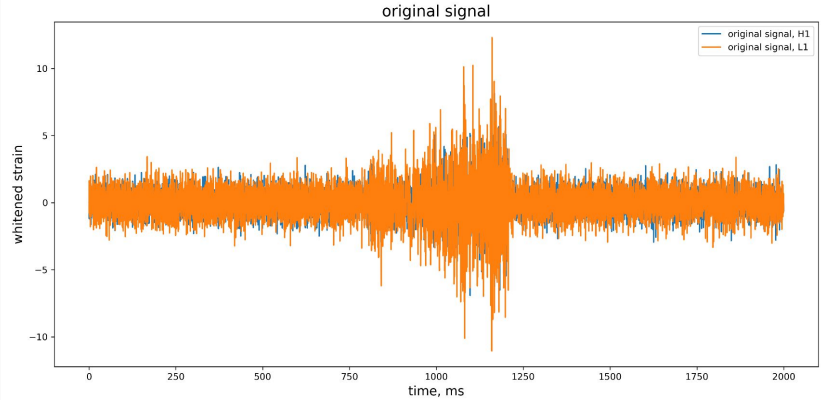
CCSN evaluation, Mezzacappa model





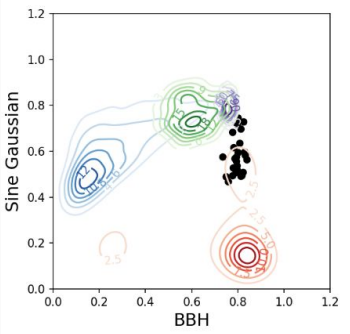


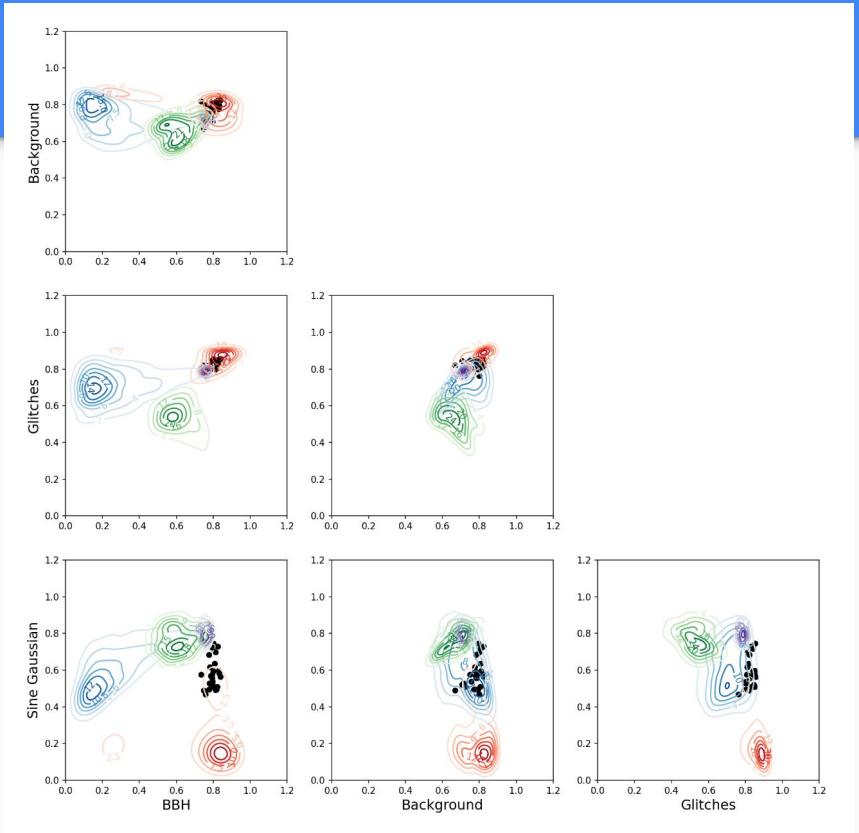
Sample here



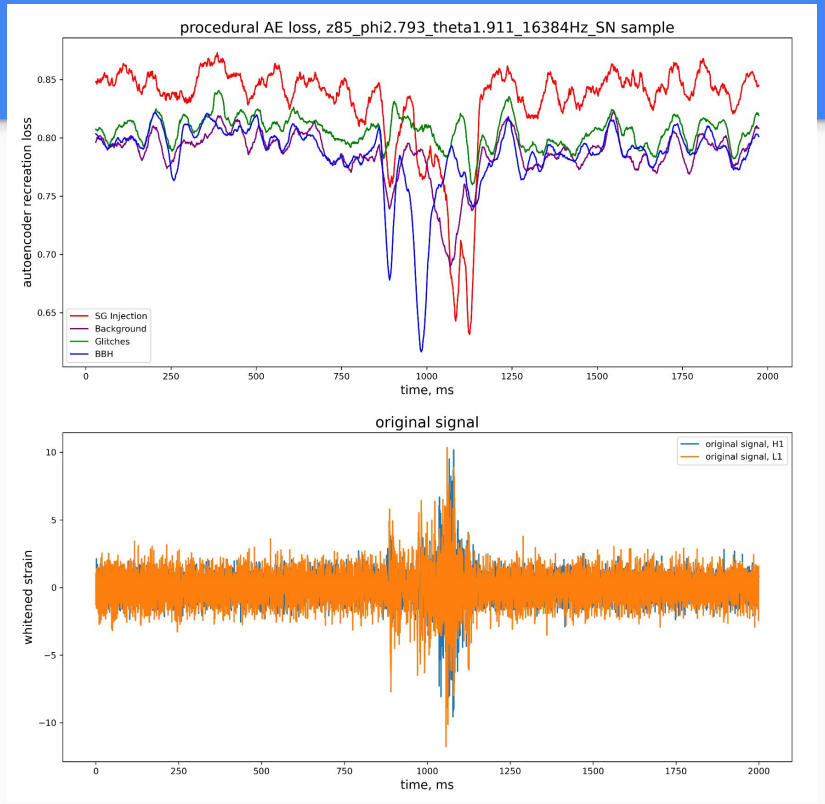
QUAK space, Mezzacappa Model

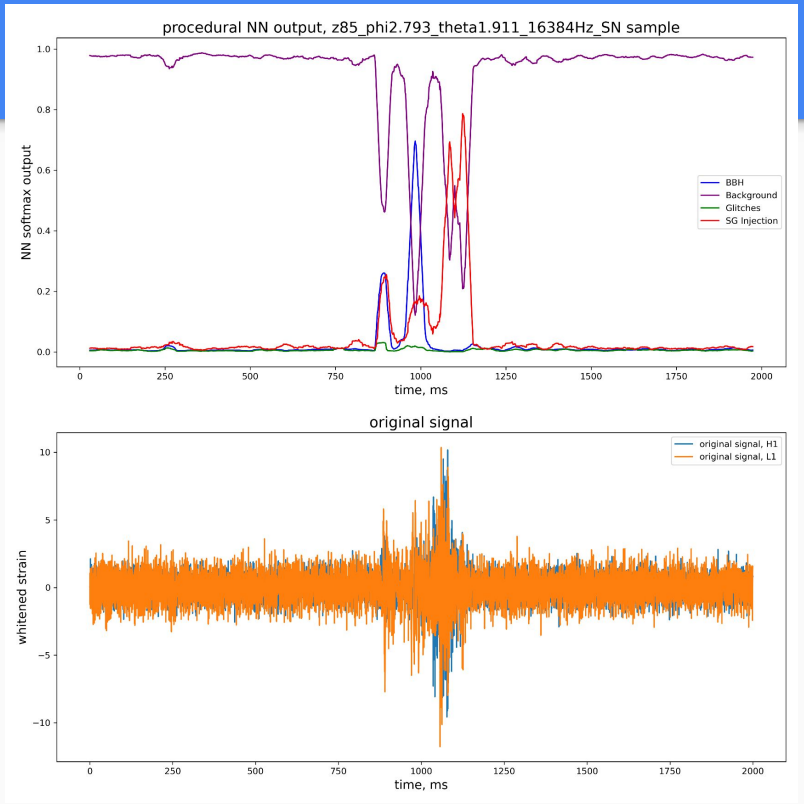
- BBH
- Glitches
- Sine gaussians
- Background
- CCSN



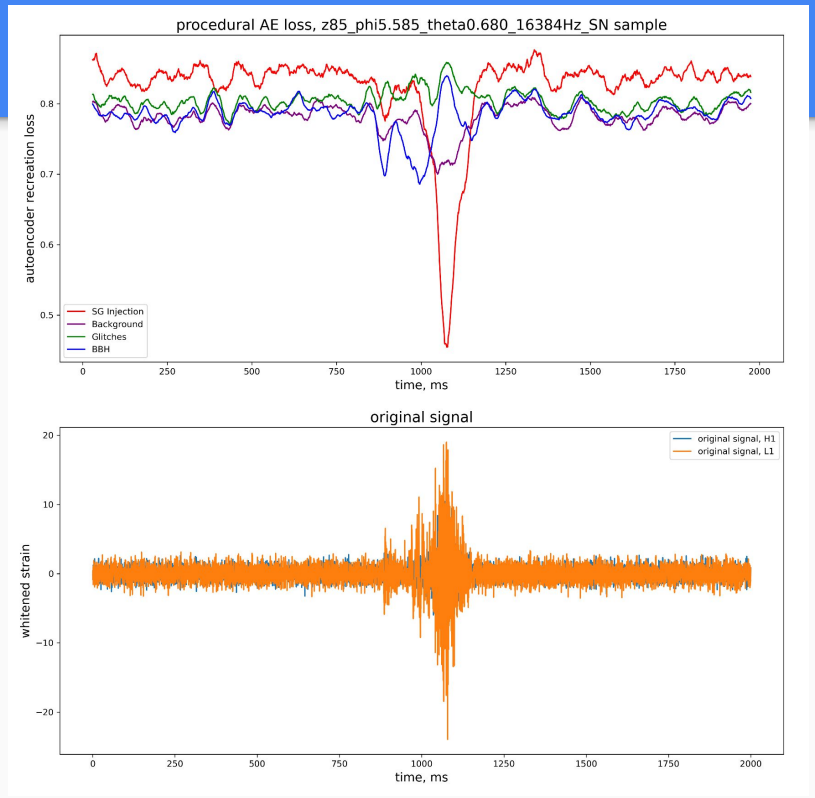


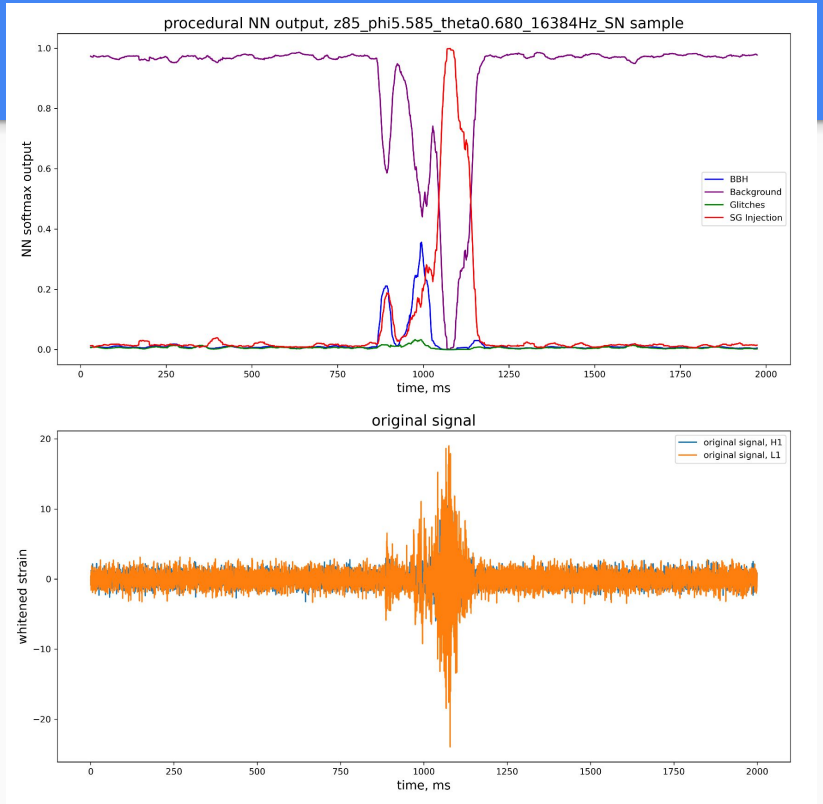
CCSN evaluation, Powell model





CCSN evaluation, Powell model





QUAK space, Powell Model

- BBH
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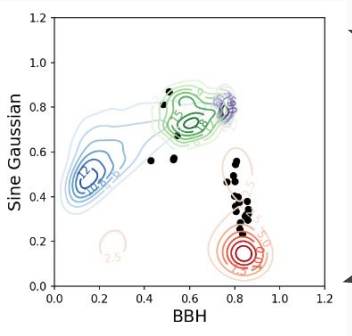

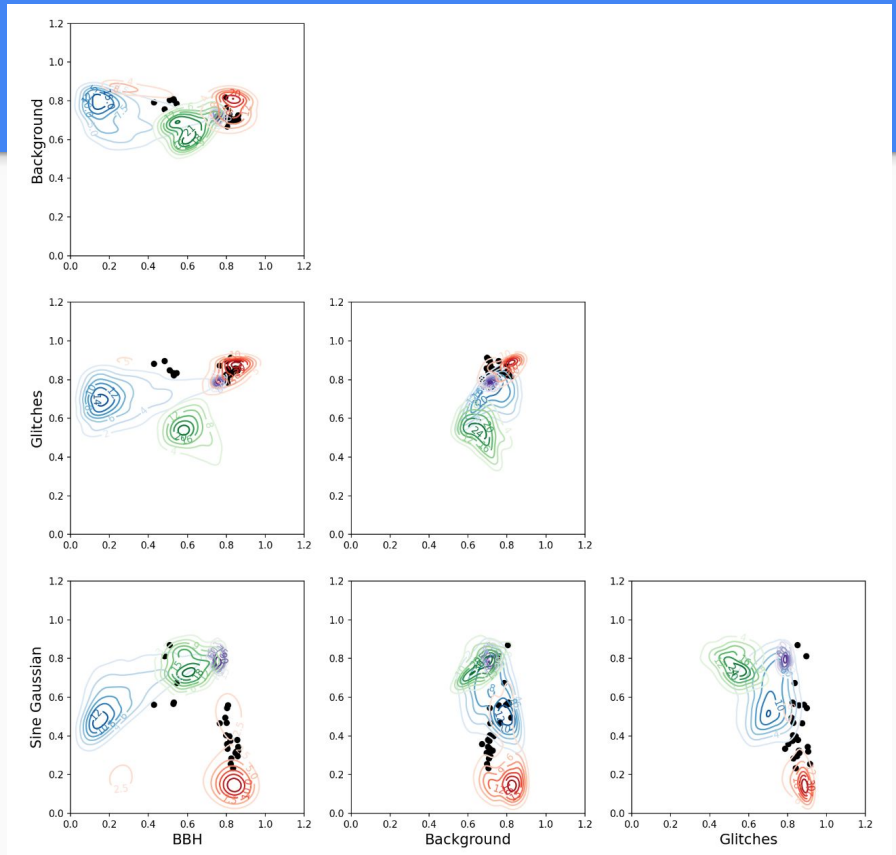

Further areas of improvement

- better, newer models: transformers
- more CCSN models: better representation of anomalies in QUAK space
- better CCSN models: realistic detection statistics

Thank you!

Big thanks to my collaborators, and MIT LIGO lab for sponsoring me!