

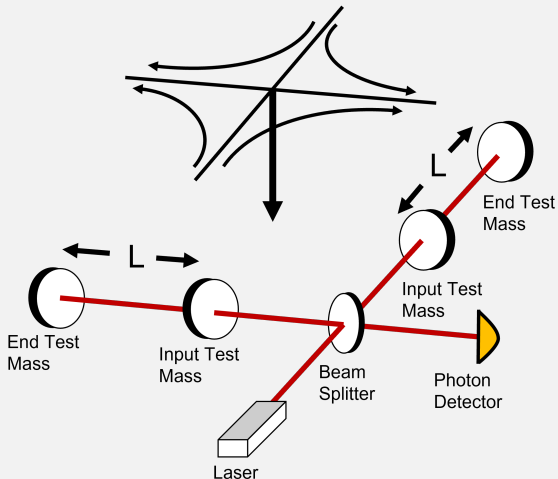
Noise Subtraction using Machine Learning on the Gravitational Data

Chia-Jui Chou

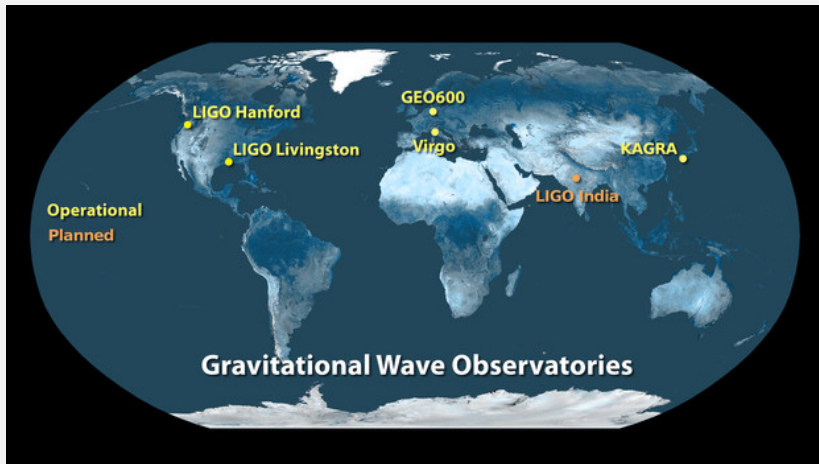
National Yang Ming Chiao Tung University, Taiwan

ASROC Annual Meeting@2025/05/17

Gravitational Wave Detector



Gravitational Wave Detectors

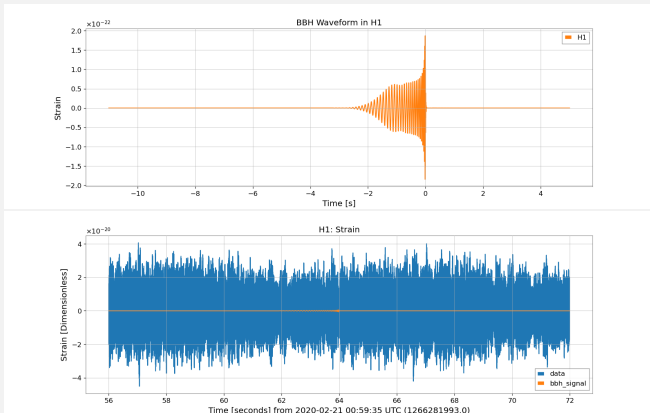


Sources of Gravitational Waves

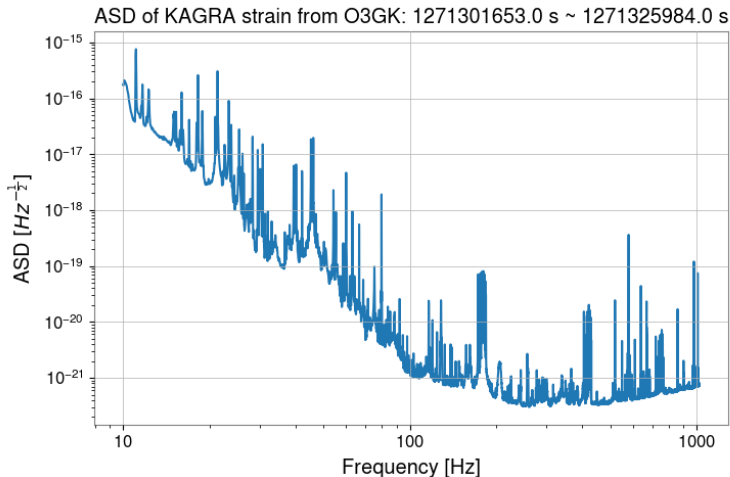
- **Compact Binary Coalescence:**
 - Black Hole-Black Hole Mergers,
 - Neutron Star-Neutron Star Mergers,
 - Black Hole-Neutron Star Mergers.
- **Bursts:**
 - Core-collapse Supernovae, Fast Radio Burst, Gamma Ray Burst, etc.
- **Continuous Waves:**
 - Spinning Neutron Stars, etc.
- **Stochastic Background:**
 - Cosmological background, Astrophysical background, etc.

Gravitational Waveforms and Background Noise

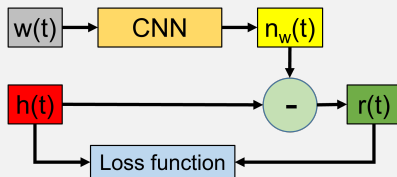
GW strain: $h(t) = \frac{\Delta L(t)}{L} \sim 10^{-22}$.



Noise in KAGRA



DeepClean



- $w(t)$: witness channels
- $p(t)$: predicted noise
- $h(t)$: raw strain
- $r(t)$: cleaned strain

- Loss function:

$$J = \alpha J_{asd} + (1 - \alpha) J_{mse}$$

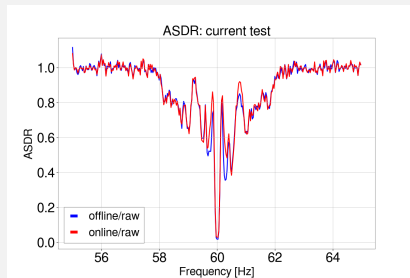
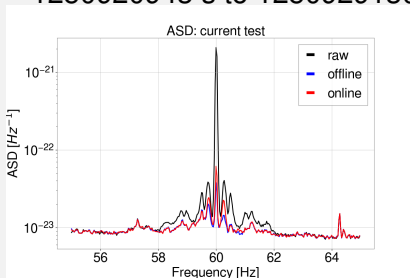
$$J_{asd} = \frac{1}{M} \sum_{i=0}^{M-1} \sqrt{\frac{S[r, r][i]}{S[h, h][i]}},$$

$$J_{mse} = \frac{1}{N} \sum_{i=0}^{N-1} r[i]^2,$$

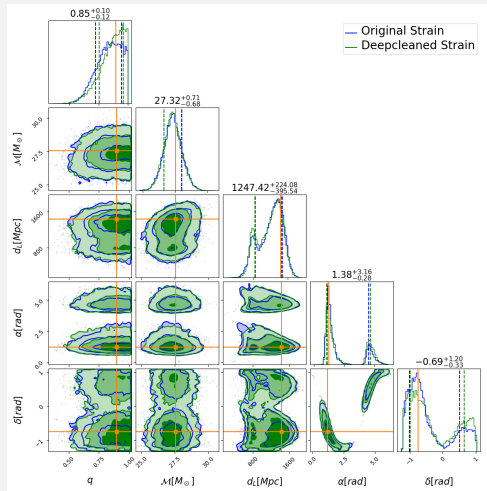
Online DeepClean

Comparison of offline and online cleaning on
H1:GDS-CALIB_STRAIN from O3a.

Trained from 1250916844 s to 1250920940 s. Tested from
1250920943 s to 1250929130 s.



Evaluation of Cleaning Results



Evaluation of Cleaning Results

- Review by CBC group, Burst group, Stochastic group, CW group, Mock Data Challenge of K1 data, etc.

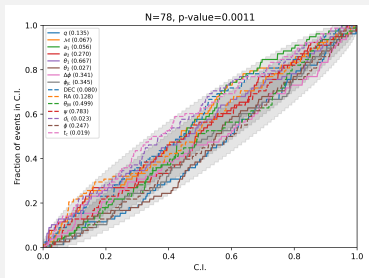


Figure: PP-plot of the parameters of the 78 BBH events injected to the raw strain.

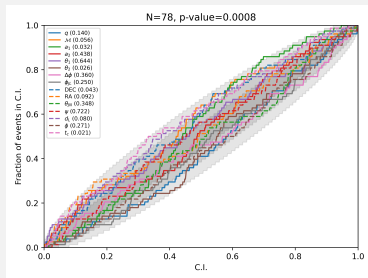
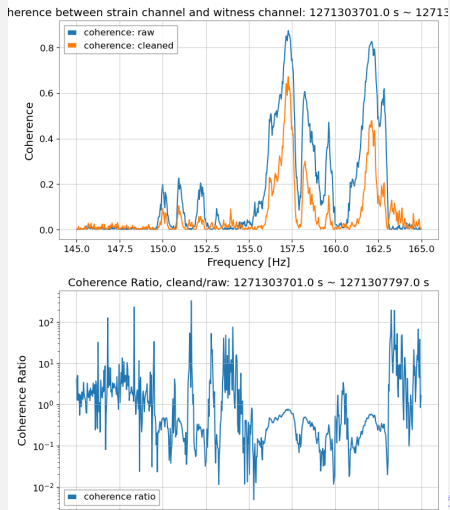
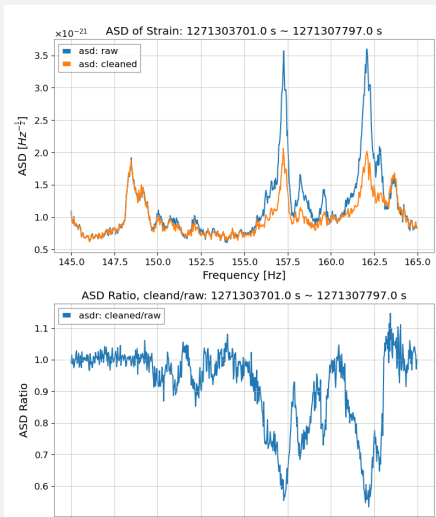


Figure: PP-plot of the parameters of the 78 BBH events in the cleaned strain.

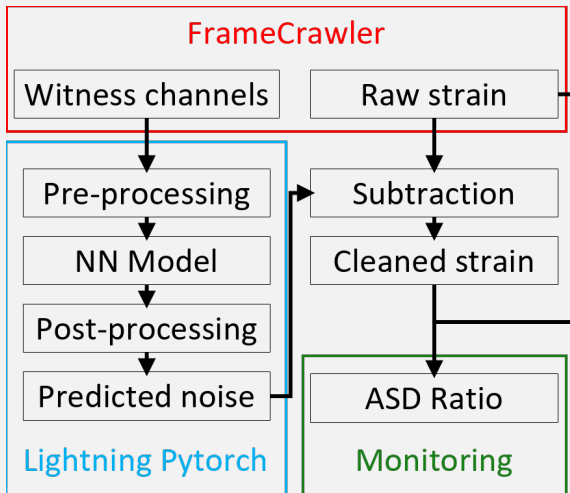
Demo: DeepClean on KAGRA O3GK Data



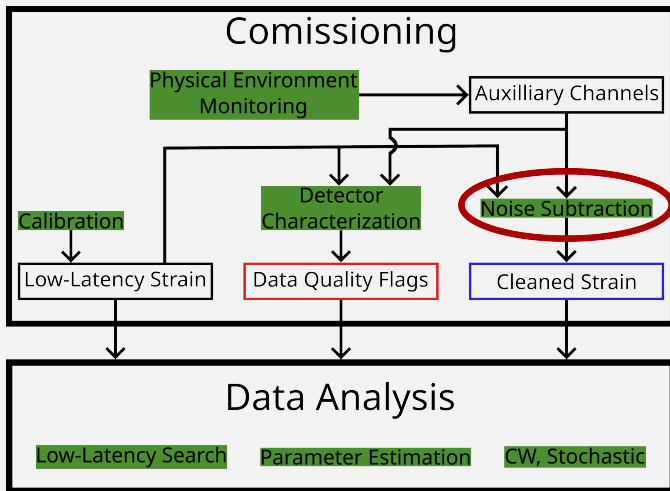
Demo: DeepClean on KAGRA O3GK Data



Online DeepClean



Noise Subtraction Group



Summary



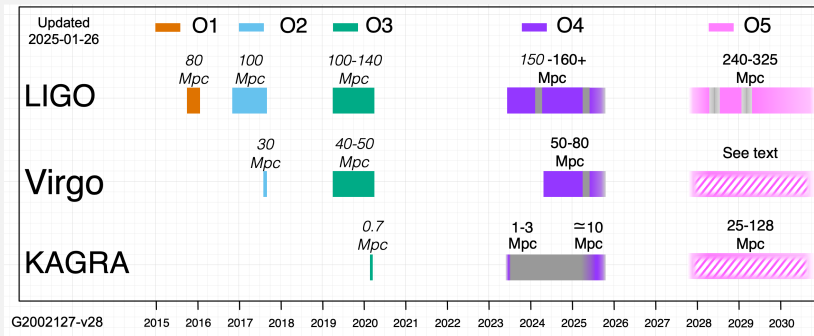
- Machine Learning applications are capable of rapid computation which is suitable for low-latency GW data analysis and Multi-Messenger Astronomy (MMA).
- The designed ML pipeline contains noise subtraction ([DeepClean](#)), modeled search ([Aframe](#)), parameter estimation ([AMPLFI](#)) and unmodeled search ([GWAK](#)) orchestrated by [ML4GW](#).

Summary

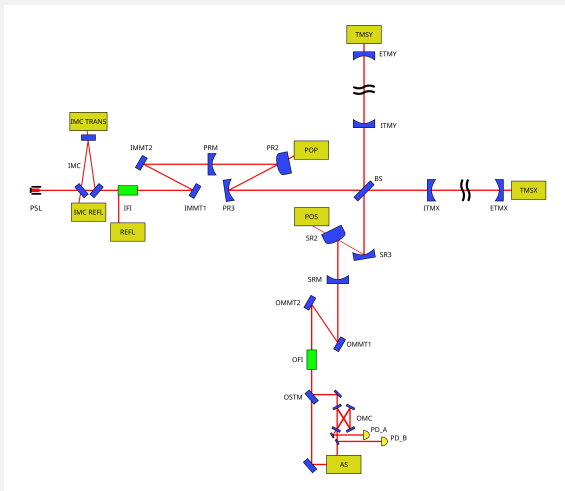
- DeepClean will be used to clean LIGO and KAGRA data in O4c. We are identifying subtraction problems and optimize DeepClean to provide cleaned frame data.
- In KAGRA, we will also use Independent Component Analysis (ICA, [1908.03013](#), [2206.05785](#)) method to clean KAGRA's data.
- Mock Data Challenge (MDC) will be prepared using O4a data, noise subtraction methods will be tested by comparing the matched filtering and parameter estimation results of the raw and cleaned data.

Thank you

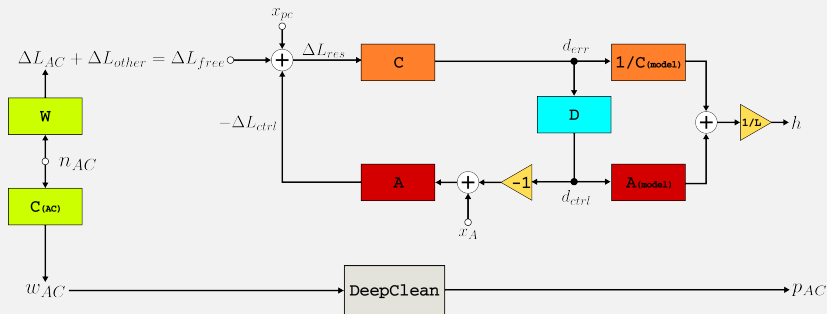
Observation Runs



Gravitational Wave Detector

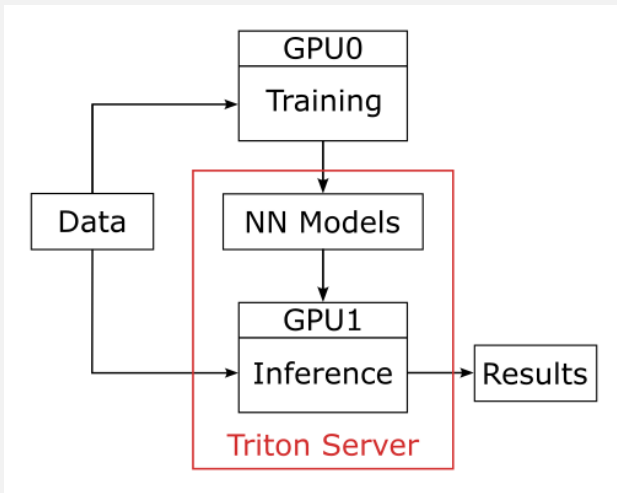


DeepClean



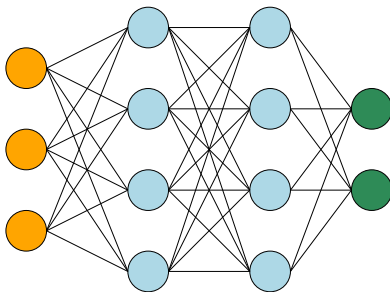
- ΔL_{free} : Displacement of the test masses,
- h : Reconstructed strain by calibration,
- n_{AC} : Noise source,
- p_{AC} : Predicted noise by DeepClean,

Online DeepClean



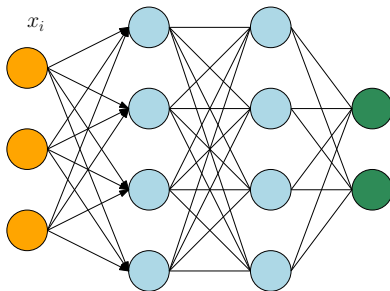
Machine Learning

Input Layer Hidden Layers Output Layer



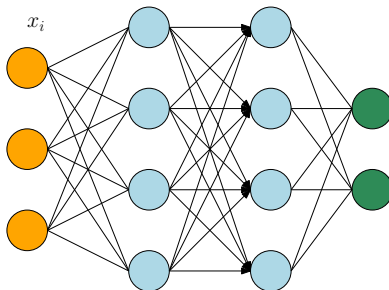
Machine Learning

$$y_i^{(1)} = F\left(W_{ij}^{(1)}x_j + b_i^{(1)}\right)$$

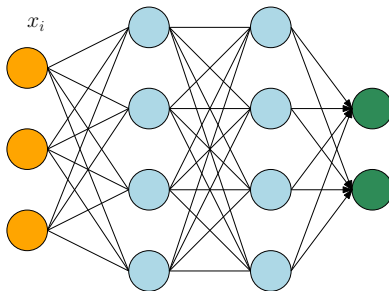


Machine Learning

$$y_i^{(2)} = F\left(W_{ij}^{(2)}y_j^{(1)} + b_i^{(2)}\right)$$



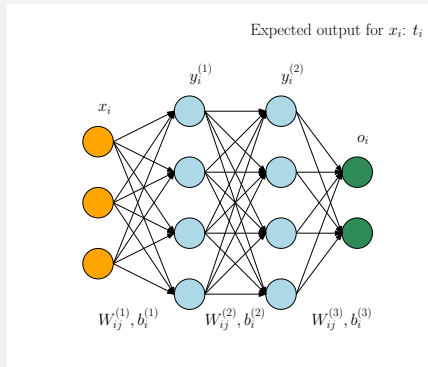
Machine Learning



$$o_i = F\left(W_{ij}^{(3)}y_j^{(2)} + b_i^{(3)}\right)$$

Machine Learning

- Loss Function: $E_{\text{total}} = \sum_i \frac{1}{2} (o_i - t_i)^2$
- Parameters to be adjusted: $W_{ij}^{(a)}, b_i^{(a)}$
- Optimizer: Gradient Descent, for example.



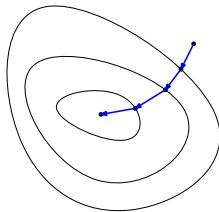
Machine Learning

- The change of loss function when varying $W_{ij}^{(3)}$:

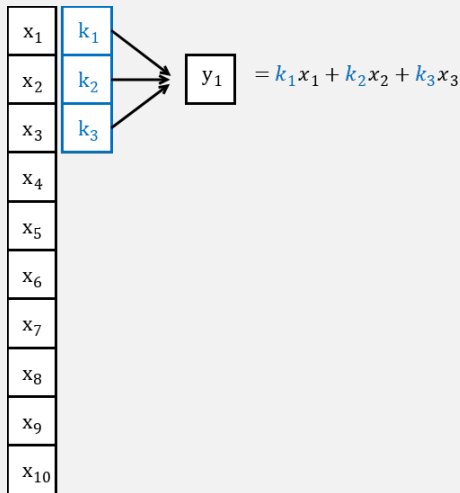
$$\frac{\partial E_{\text{total}}}{\partial W_{ij}^{(3)}} = \frac{\partial E_{\text{total}}}{\partial o_k} \frac{\partial o_k}{\partial F(y_i^{(2)})} \frac{\partial y_i^{(2)}}{\partial W_{ij}^{(3)}}.$$

- $W_{ij}^{(3)'} = W_{ij}^{(3)} - \eta \cdot \frac{\partial E_{\text{total}}}{\partial W_{ij}^{(3)}}.$

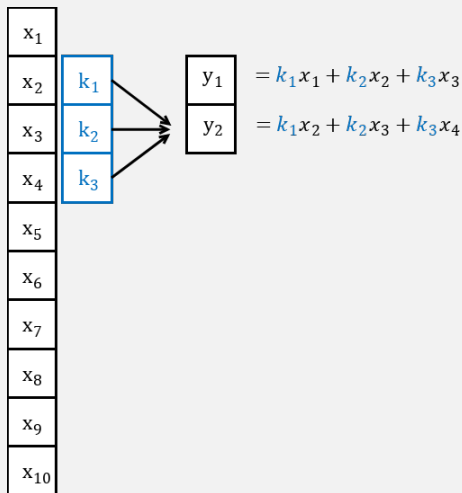
Contour Line of the Error Function in Parameter Space



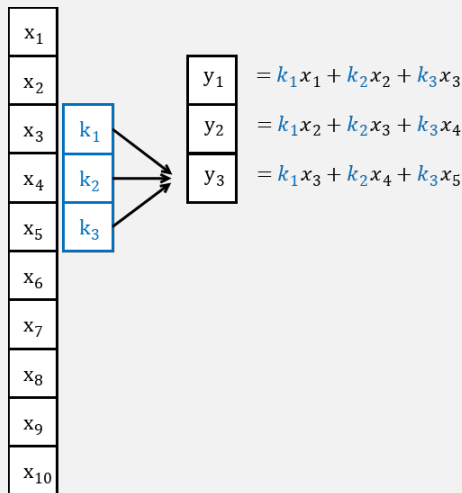
Convolutional Neural Network (CNN)



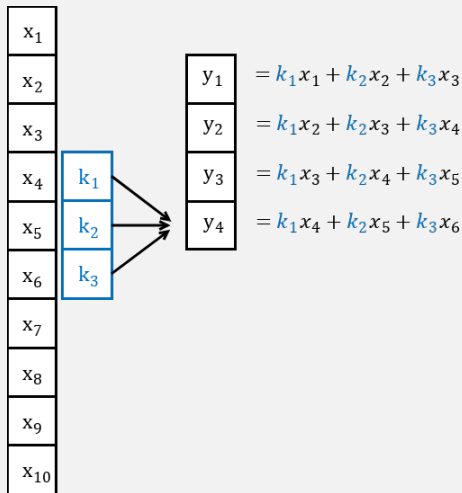
Convolutional Neural Network (CNN)



Convolutional Neural Network (CNN)



Convolutional Neural Network (CNN)



Convolutional Neural Network (CNN)

