



EUROPEAN COALITION FOR AI IN FUNDAMENTAL PHYSICS CONFERENCE

EuCAIFCon 2026

Anomaly Detection for Generic-Transient Gravitational Waves

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ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

24–28 August 2026 · Kirchhoff Institute for Physics (KIP), Heidelberg, Germany



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Motivation & TranAD Anomaly Detection

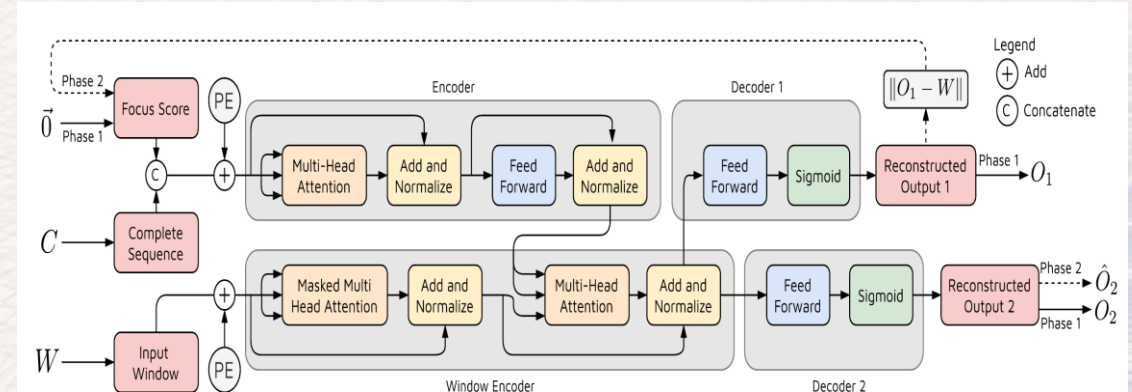
Why a model-agnostic search?

- Matched filtering is highly effective when accurate waveform templates are available.
- Generic or Burst GW signals may not have sufficiently accurate models.
- We investigate the model-agnostic method using H1-L1 coherence and Transformer based anomaly detection.

Objective

Identify previously unseen coherent transients by learning the normal Detector noise behaviour.

TranAD Architecture



1

TranAD Input:

Cross-correlation window

2

Two decoder

reconstruction

3

Reconstruction

deviation

4

Anomaly

score

Anomaly score

$$s = \frac{1}{2} \|O_1 - W\|_2 + \frac{1}{2} \|\hat{O}_2 - W\|_2$$

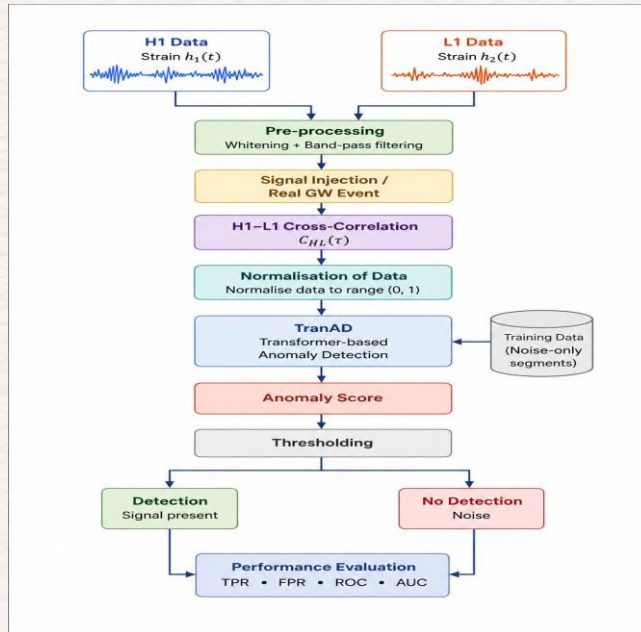
W : Input cross correlation window
 O_1, O_2 : decoder reconstructions
 $\|\cdot\|_2$: reconstruction error

Small $s \Rightarrow$ Noise like window
Large $s \Rightarrow$ Anomalous correlated window

Detection Pipeline & Noise-only Training

TranAD learns the normal H1-L1 cross-correlation background

Detection Pipeline



Dataset & Training Setup

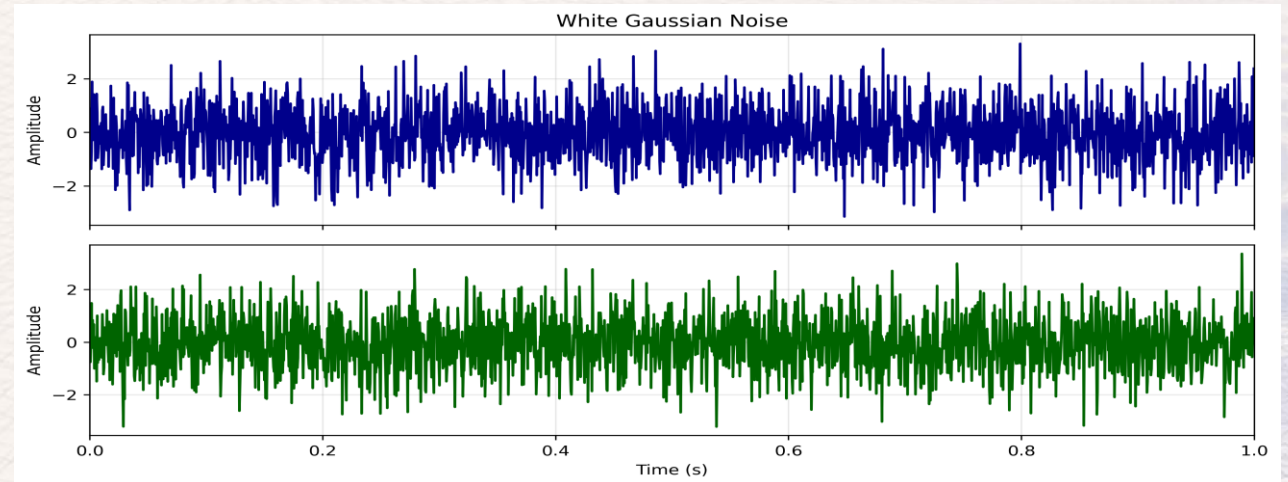
Noise Backgrounds: White Gaussian + Simulated LIGO noise.

Segment length: 1 Second

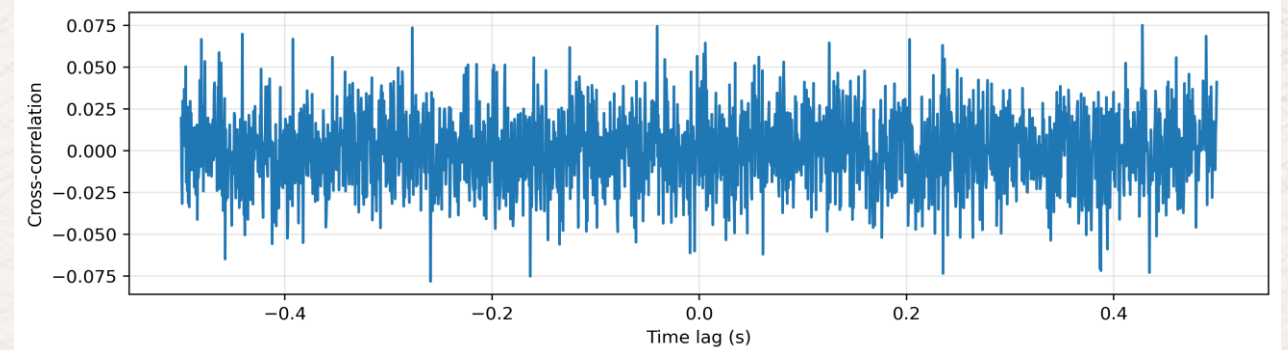
Training data: 100 x 1-s noise only segments

Testing data: 100 x 1-s noise + sine-Gaussian injections.

Noise-only Training Example



Corresponding H1-L1 cross-correlation

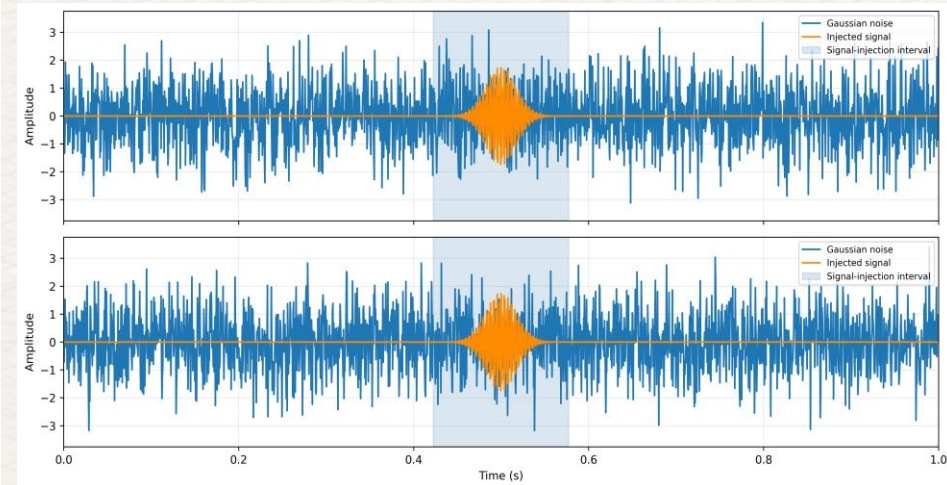


➡ The model learns noise-like cross-correlation behaviour.

Testing-data preparation: Sine-Gaussian injections

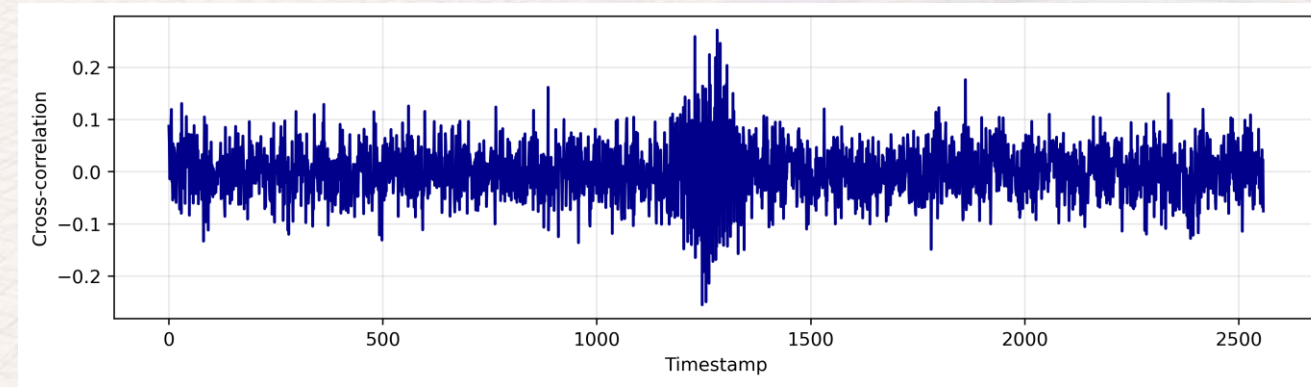
Coherent Sine-Gaussian injections and the resulting cross-correlation response

Injected Gaussian noise streams



cross-
correlation

Cross-correlation of the signal containing streams

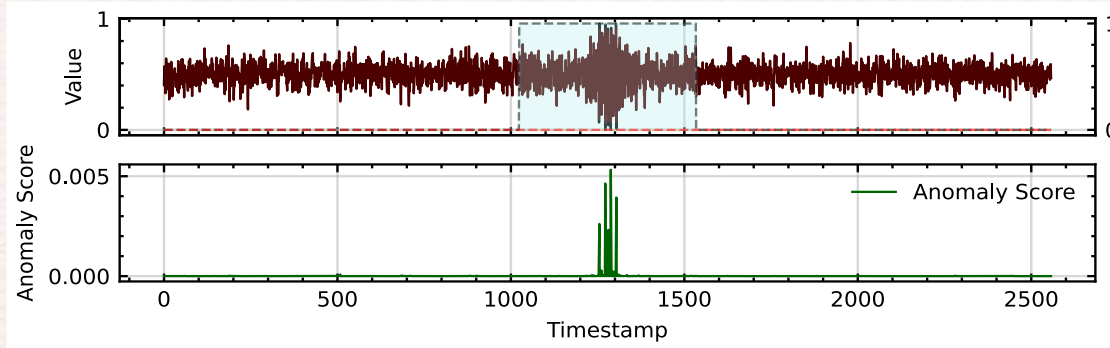


- A sine-Gaussian waveform represents a generic GW burst.
- The same waveform ($f_0 = 900$ Hz , Network SNR = 10) is injected coherently into two independent white Gaussian-noise streams.
- The signal is localised near the center of each 1s segment.

- The coherent transient produces a distinct localized feature.
- Independent noise contributes only background fluctuations.
- Cross-correlation retains signal content shared by both streams.
- Signal-containing regions are labelled as anomalies only for performance evaluation.
- The resulting sequence is passed to TranAD for anomaly detection.

Results I — White Gaussian Noise & model Optimization

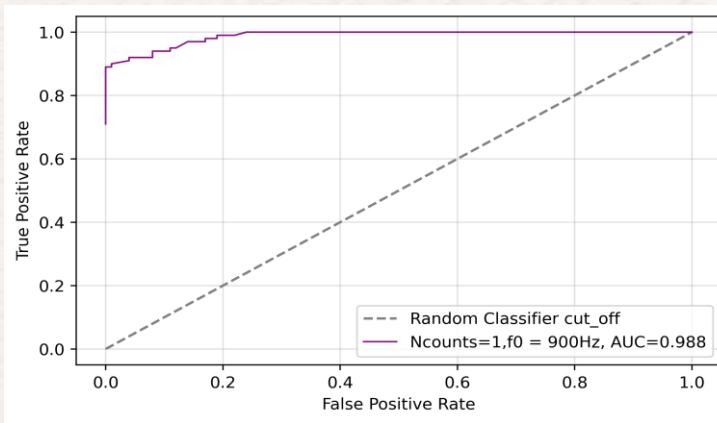
Sine-Gaussian injections at $f_0 = 900$ Hz & Network SNR = 10



- A localised anomaly-score response coincides with the injected signal.
- The reconstruction error clearly separates the transient from the noise background.

Model Optimisation – Network SNR = 8

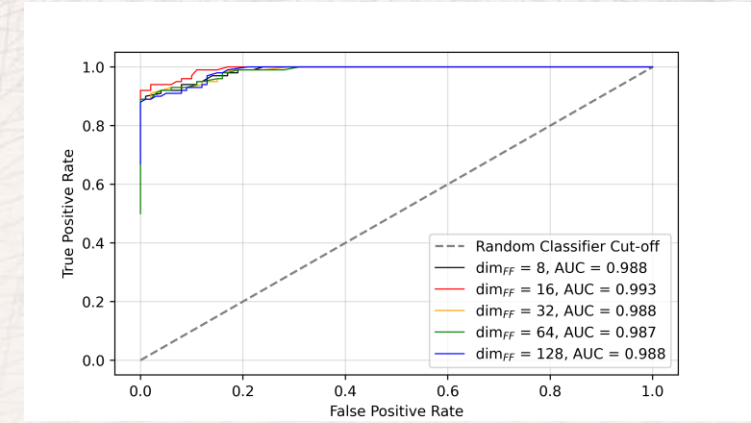
Baseline ROC: $n_{\text{counts}} = 1$



n_{counts}
Minimum number of anomaly-score samples that must exceed the chosen threshold.

Why $n_{\text{counts}} = 1$?
The Sine-Gaussian is short and produce a sharp, localised anomaly score peak. Requiring only one above threshold sample preserves sensitivity to short transients.

Feed-Forward Dimension



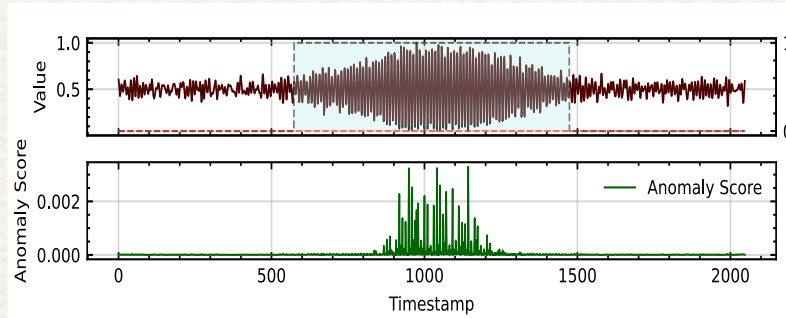
➡ The model performance remains stable across a Wide range of feed-forward dimensions.

Results II — LIGO Simulated Noise & Glitch Robustness

Sine-Gaussian Injections: Detection Performance (Network SNR = 15)

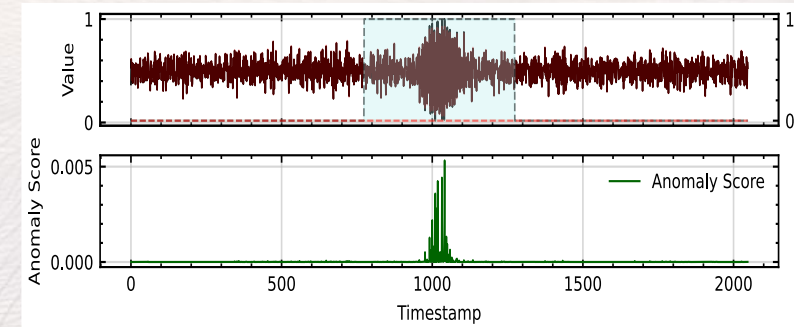
$f_0 = 200$ Hz

- Clear anomaly peak at the injected signal location.
- Strong response with minimal false alarms.
- Network SNR = 15 ensures robust detection.



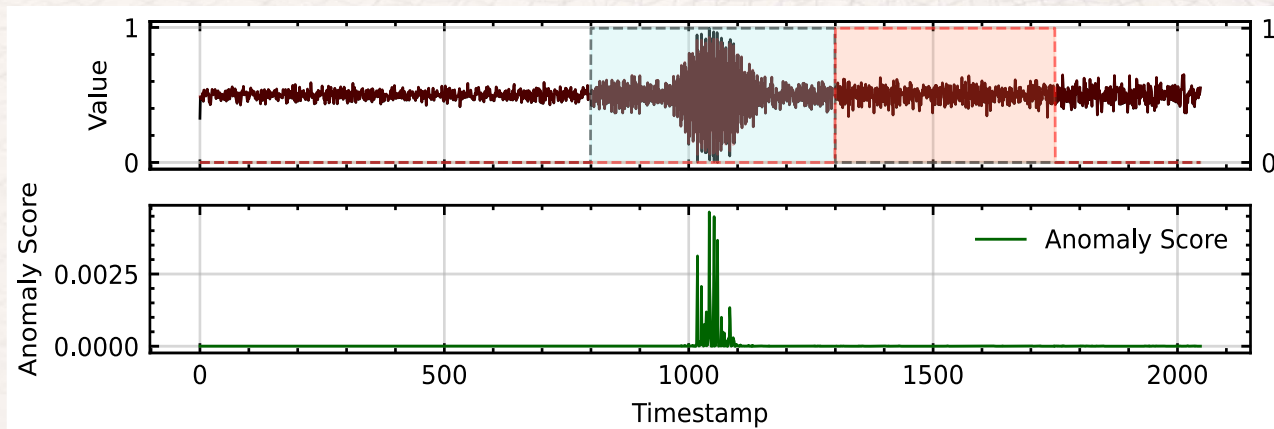
$f_0 = 900$ Hz

- Very strong and localized anomaly response
- Higher correlation peak compared to 200 Hz case
- Best overall detection consistency.



Glitch Robustness

- **Coherent Signal (H1 & L1)**
Produces strong cross-correlation peak and dominant anomaly score at the signal location.
- **Single Detector Glitch (H1 only)**
Does not produce a strong correlation peak and results in a suppressed anomaly response.



Coherent signal
(H1 & L1)

Glitch (H1 only)

Application to Real Gravitational-Wave Data: GW150914

TranAD response to the first observed binary black-hole merger

Real event dataset

- Public strain data from the LIGO **Hanford** (H_1) and **Livingston** (L_1) detectors
- The example shown corresponds to **GW150914**
- Off-source detector noise was used for model training and The event containing segment was used only during testing.

Pre-processing

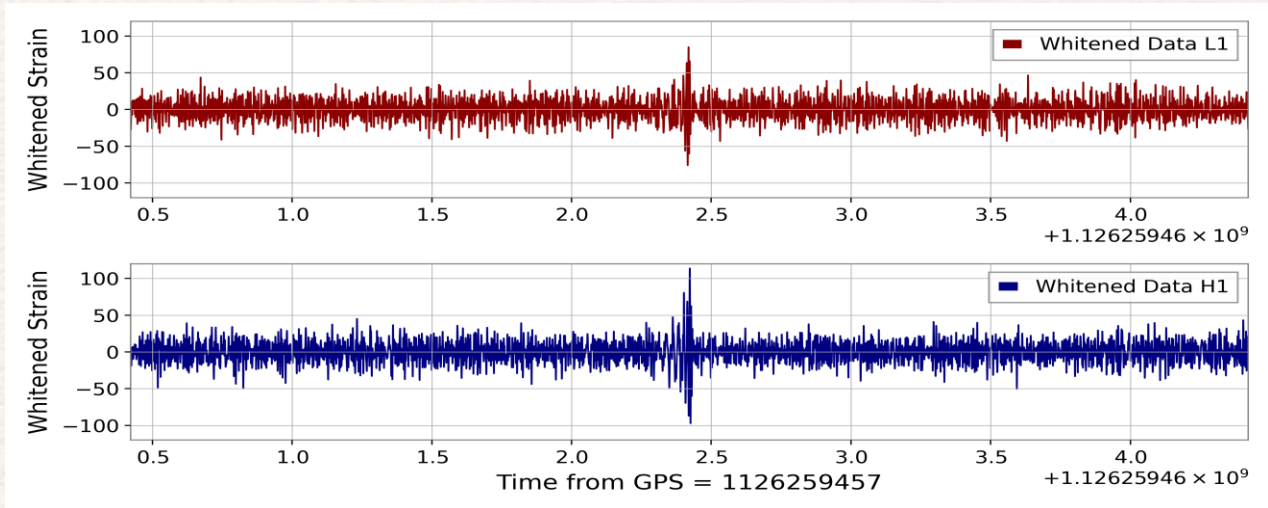
- Mean removal and detector specific **PSD** estimation.
- Frequency domain whitening
- Bandpass filtering between **30 and 300 Hz**
- H_1 and L_1 data alignend to accunt for the inter detector arrival time delay.
- The processed streams were cross-correlated beforebeing passed to **TranAD**

Whitenig in the frequency domain

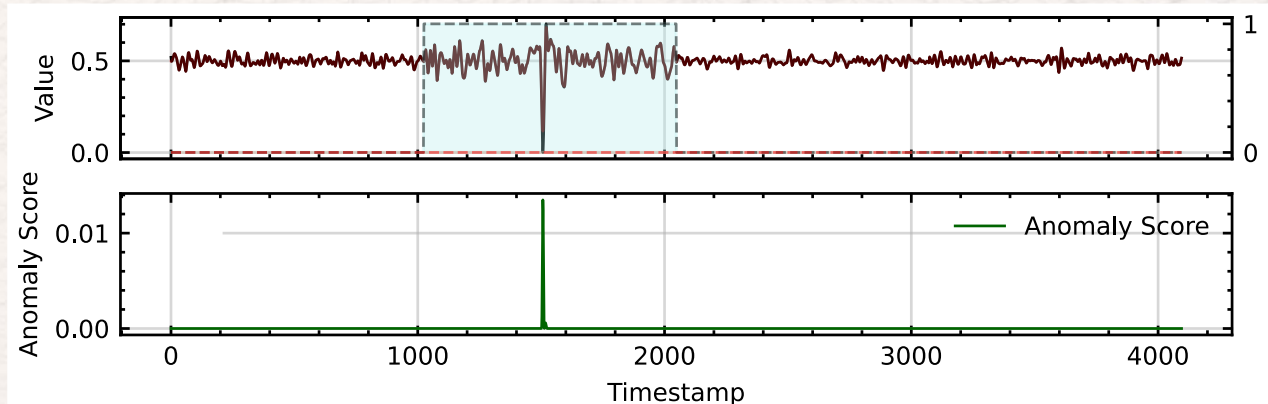
$$d(t) \xrightarrow{\text{FFT}} \tilde{d}(f) \xrightarrow{\text{Whiten}} \tilde{d}_W(f) = \frac{\tilde{d}(f)}{S_n^{1/2}(f)} \xrightarrow{\text{iFFT}} d_W(t)$$

$S_n(f)$: one sided noise power spectral density

Whitened H_1 and L_1 strain around GW150914



TranAD response to GW150914



Conclusion & Future Work

Cross-correlation and transformer-based anomaly detection provide a promising framework for transient gravitational wave searches

Conclusions

- The proposed pipeline combines **cross detector correlation** with the **TranAD** transformer model.
- Training on **noise only data** enables the model to identify coherent transient signals as anomalies.
- Detection performance improves with increasing **signal to noise ratio**, with strong performance for moderate and high SNR sine gaussian injections.
- The pipeline was tested on more realistic **Simulated LIGO noise**, using injections at $f_0 = 200$, 900 and SNR = 15 with successful detection at the optimal operating point.
- **Cross detector coherence** helps distinguish genuine signals from **single detector glitches**.
- The pipeline successfully detected confirmed real gravitational wave events **GW150914**.

Future Works

- Apply the method to more **GW events**.
- Extend the analysis to different **signal morphologies**.
- Optimise the network **architecture** and detection **threshold** to improve sensitivity.
- Investigate performance at **lower SNRs** and against a wider range of **detector artifacts/glitches**.