GWAK: Gravitational-Wave Anomalous Knowledge

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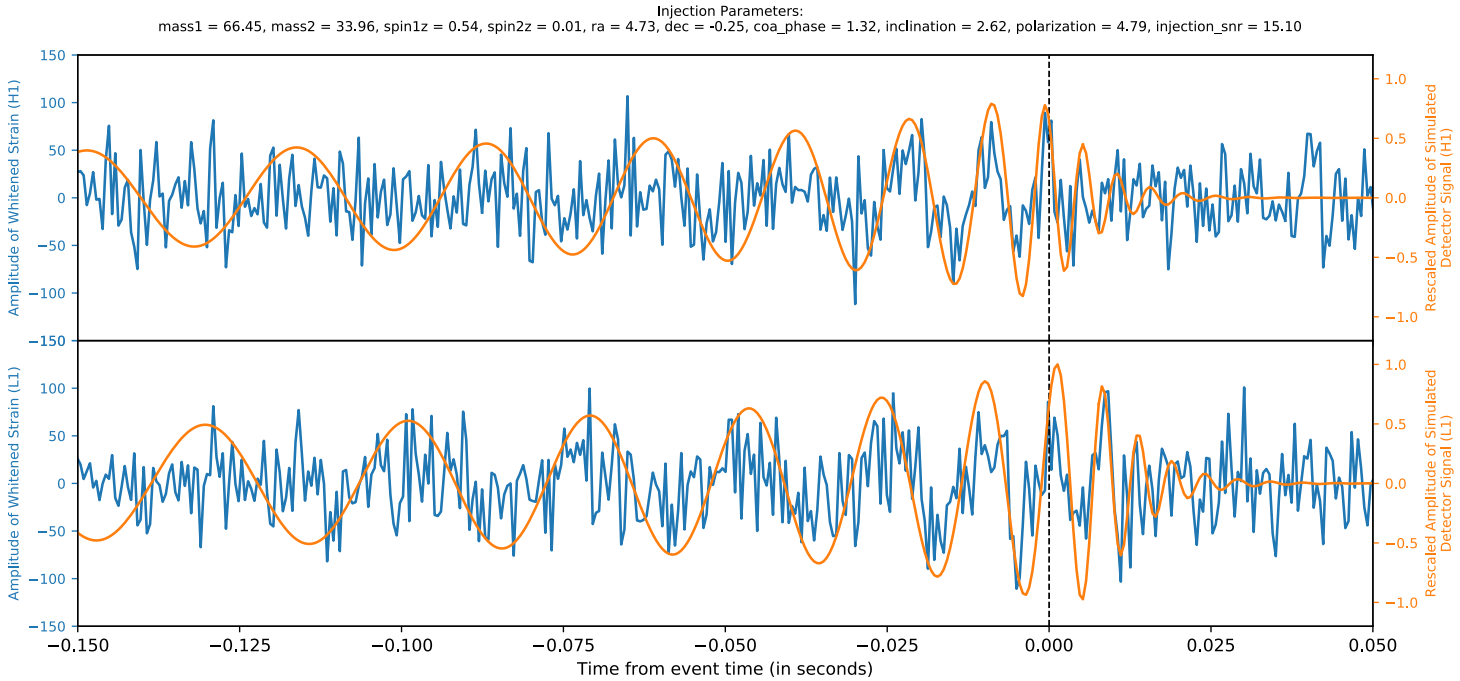
A3D3 MMA Subgroup - July 10th, 2023

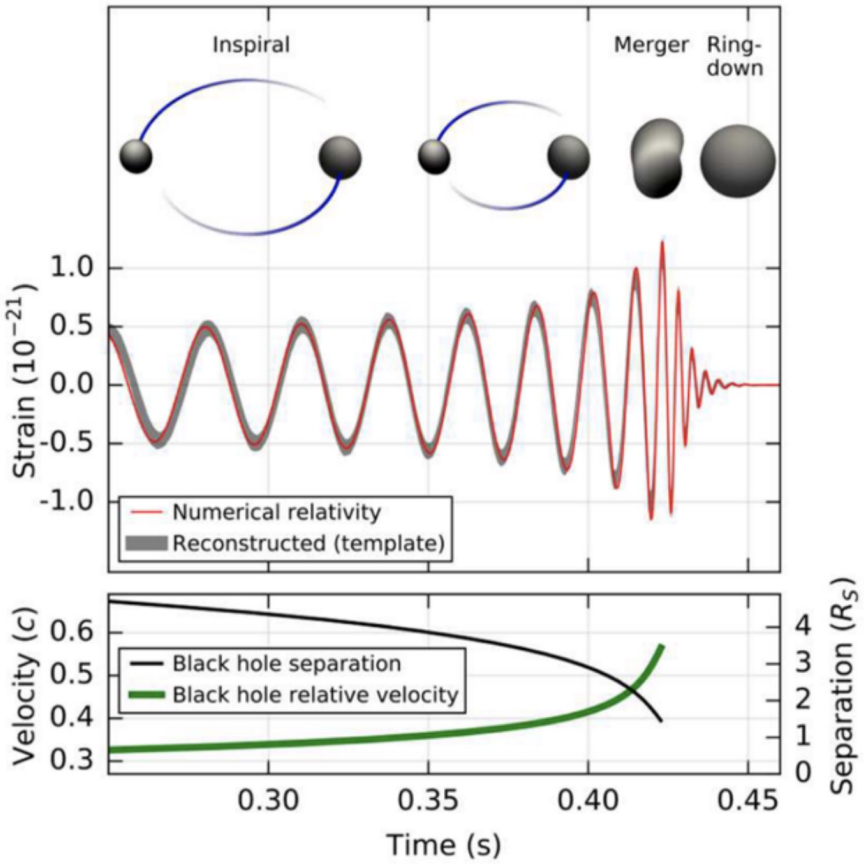
Binary Mergers

BBH Sample



Source: github.com/timothygebhard/ggwd, https://www.gw-openscience.org/data/

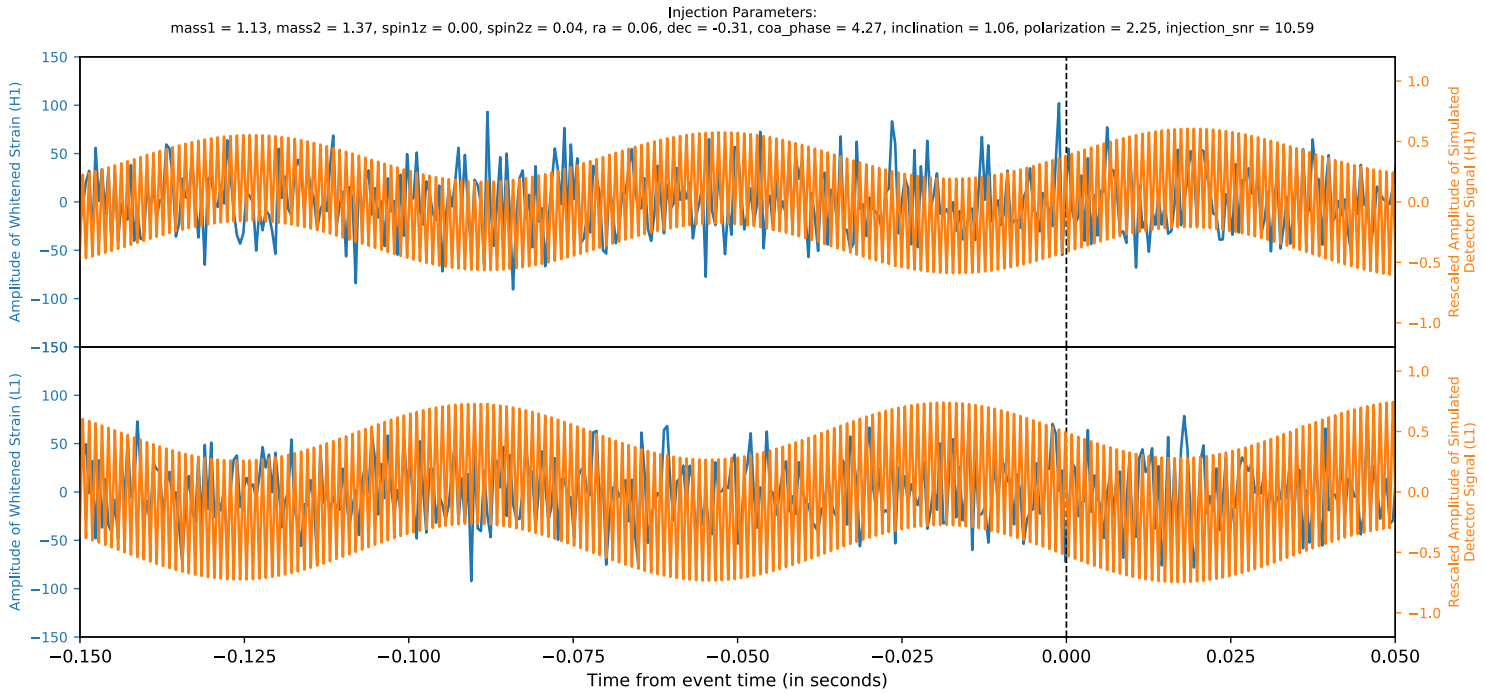
Figure: LIGO/Virgo



Produces: **time-series** [1-D strain + auxiliary channels]

Binary Mergers

BNS Sample



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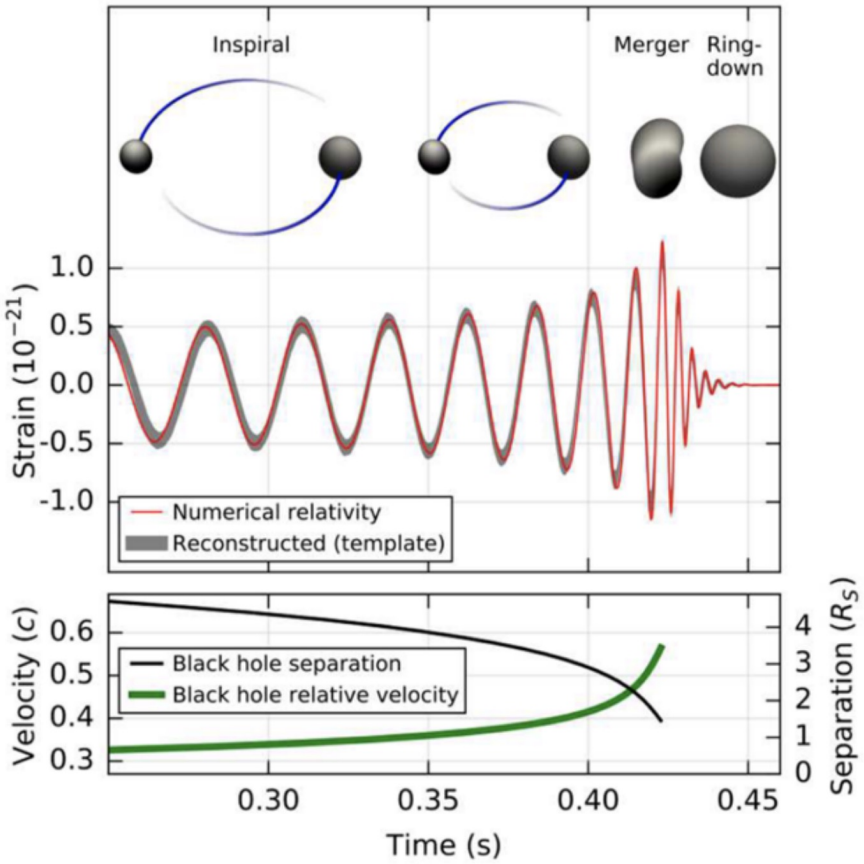

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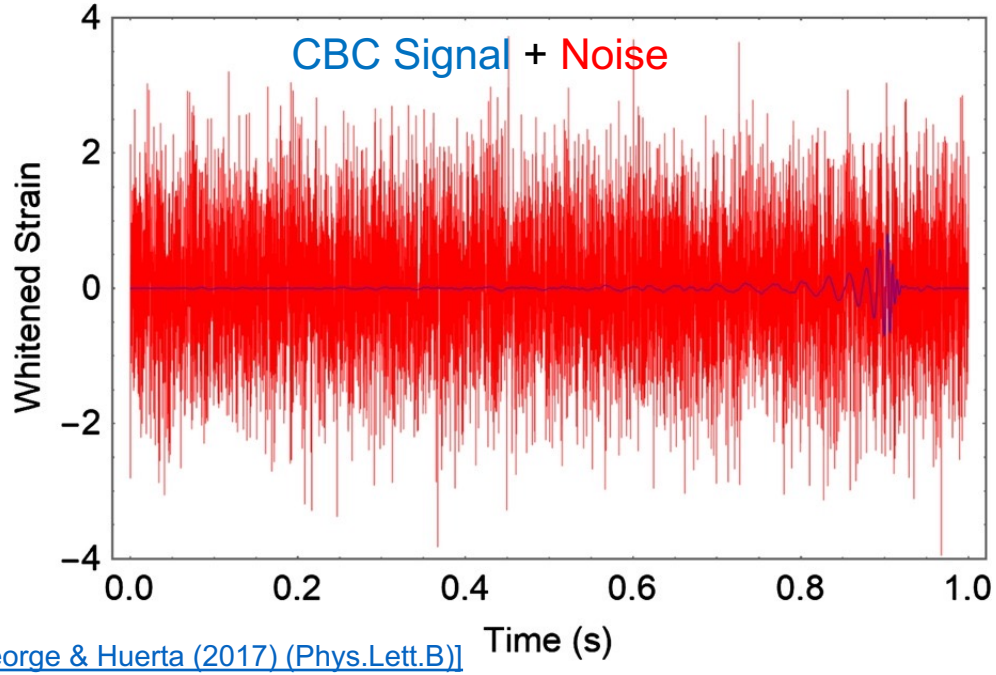
What are anomalies?

Anomalies are unmodelled waveforms

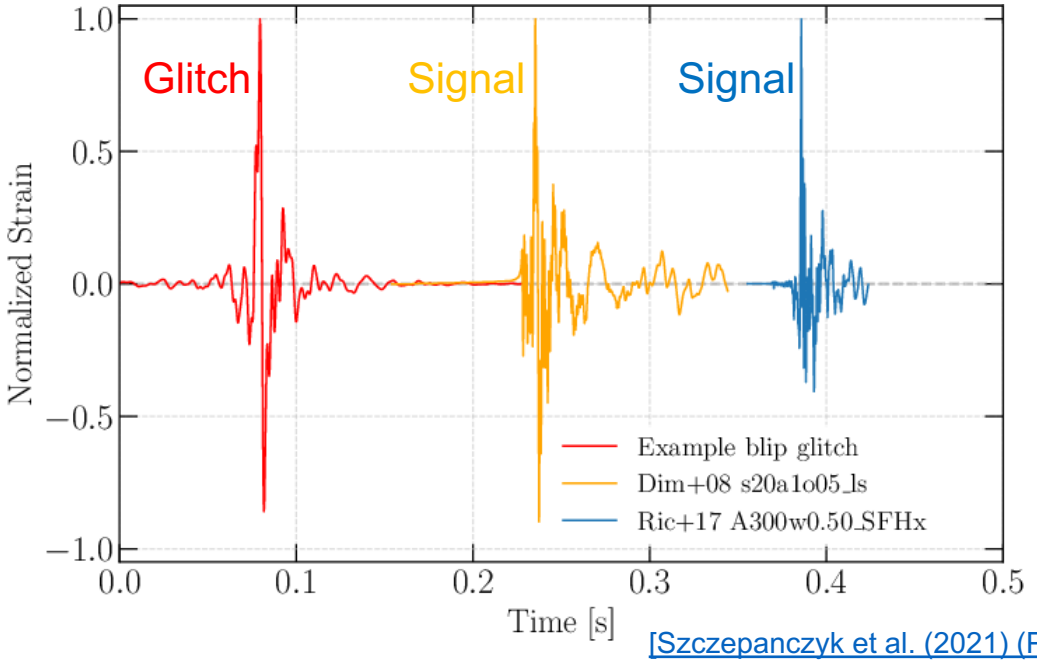
- GWs have been detected in Matched-Filter pipelines from:
  - Binary Black Holes (BBH)
  - Binary Neutron Stars (BNS)
  - Black Hole – Neutron Star (BHNS)
- Anomalous signals:
  - Core Collapse Supernovas (CCSNe)
  - Neutron Star Glitches
  - Cosmic Strings
  - NSs collapsing to BHs
  - Gravitational Bremsstrahlung
  - Other stochastic processes

GW Dataset - Nontrivial

- Length measurements are ~ $10^{-22}\ m$
- Constantly changing detector noise usually clouds signal
- Detector glitches occur every O(10 sec) – resembling GWs in excess power!



[George & Huerta (2017) (Phys.Lett.B)]

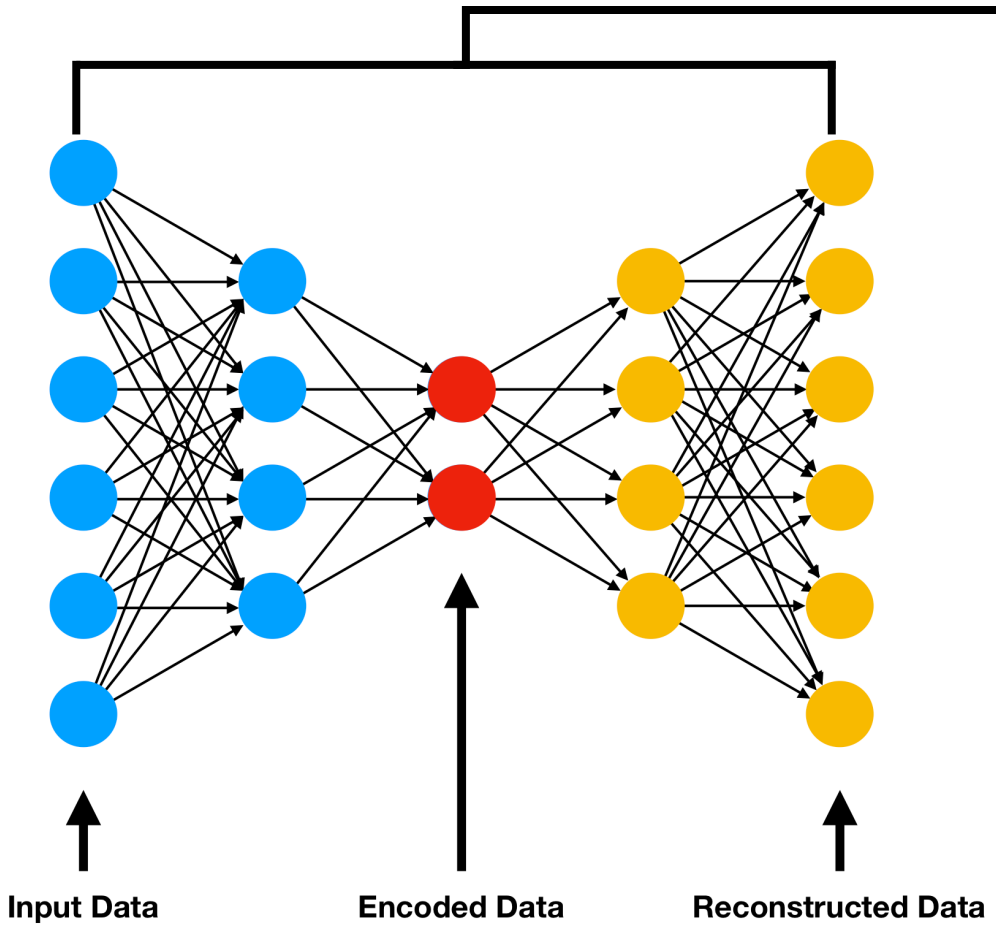


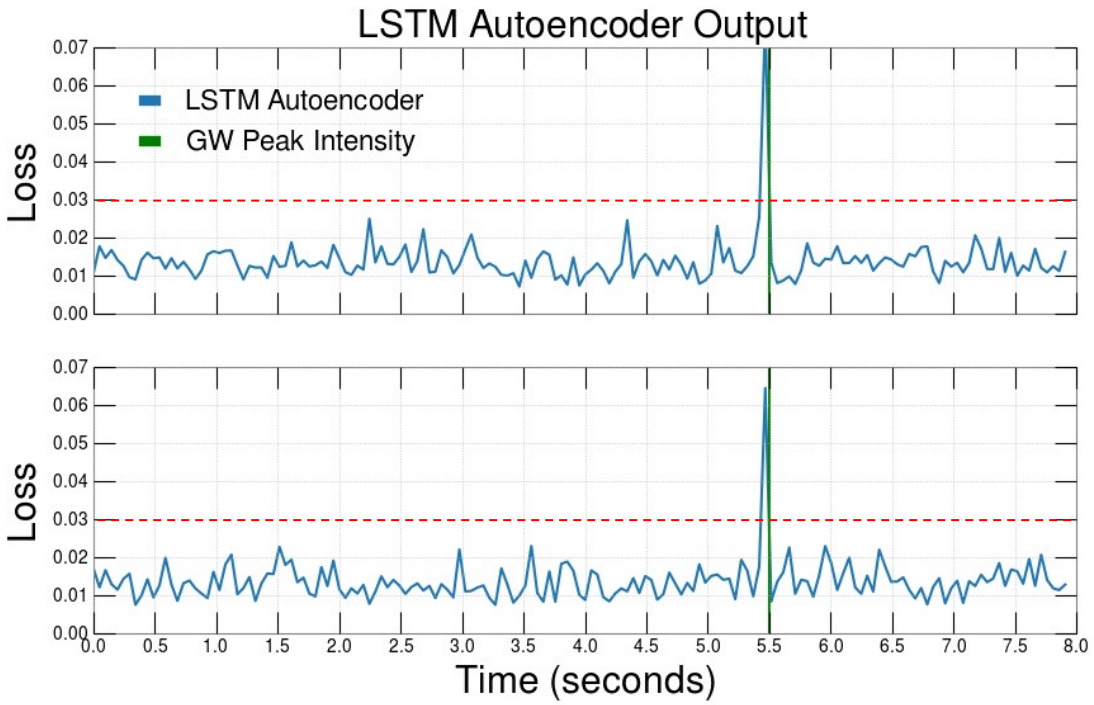
[Szczepanczyk et al. (2021) (Phys.Rev.D)]

Unsupervised Learning: Detection

[Moreno et al. (2022) (MLST)]

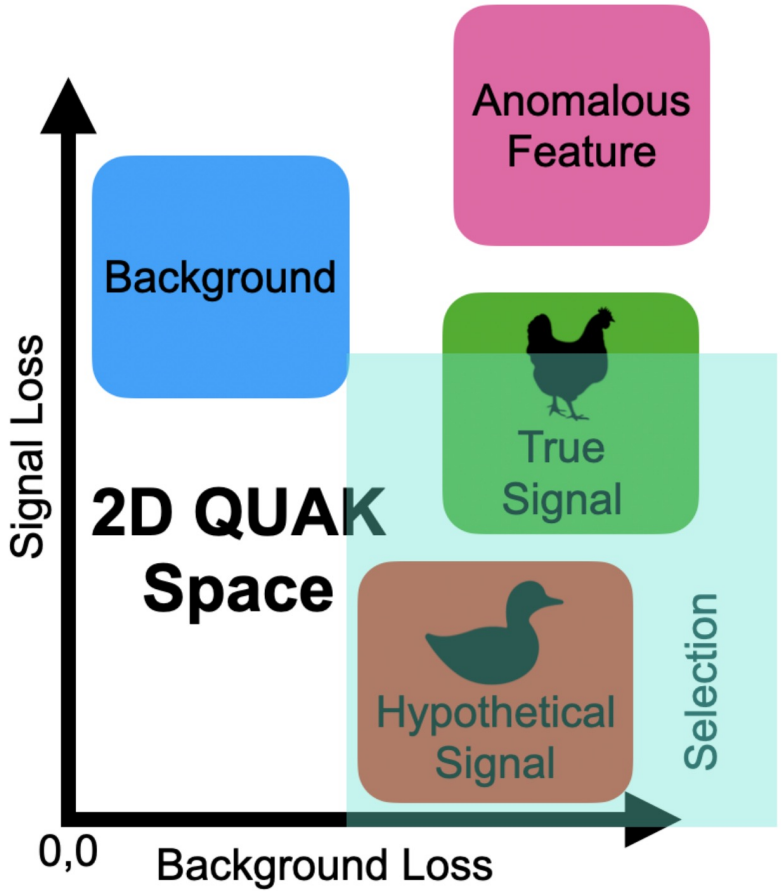
Comparing input and reconstructed data gives a model loss

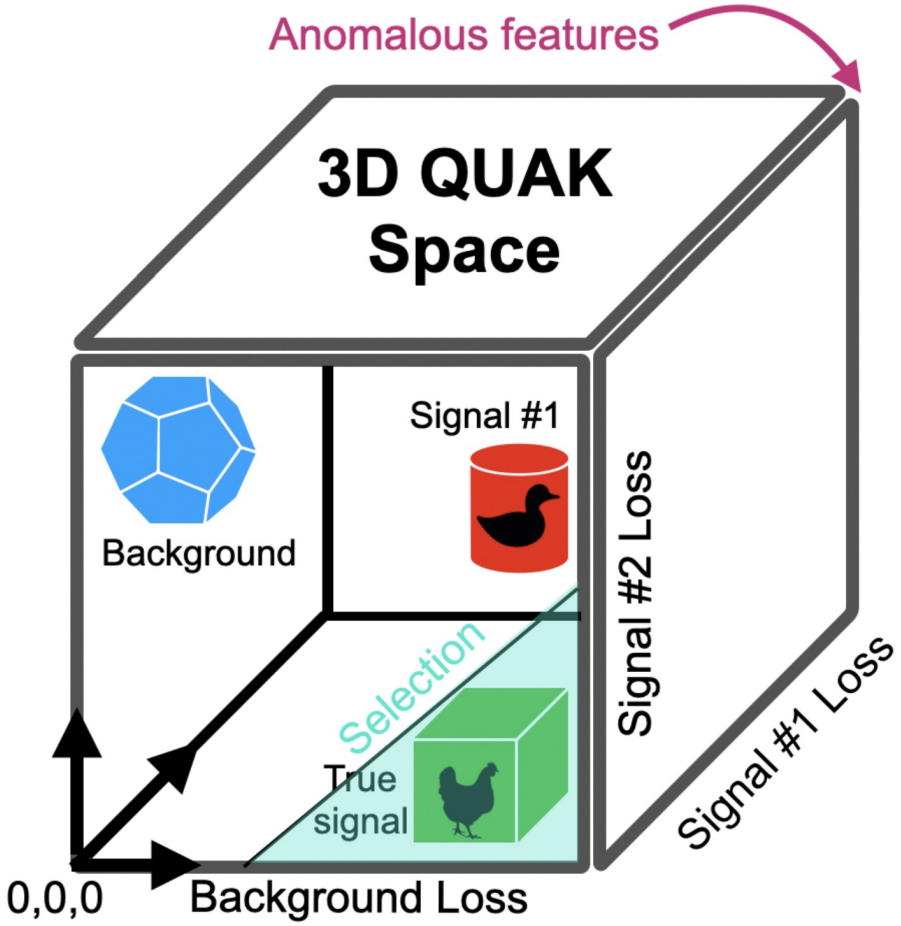




Quasi-Anomalous Knowledge - QUAK

[Park et al. (2021) (JHEP)]





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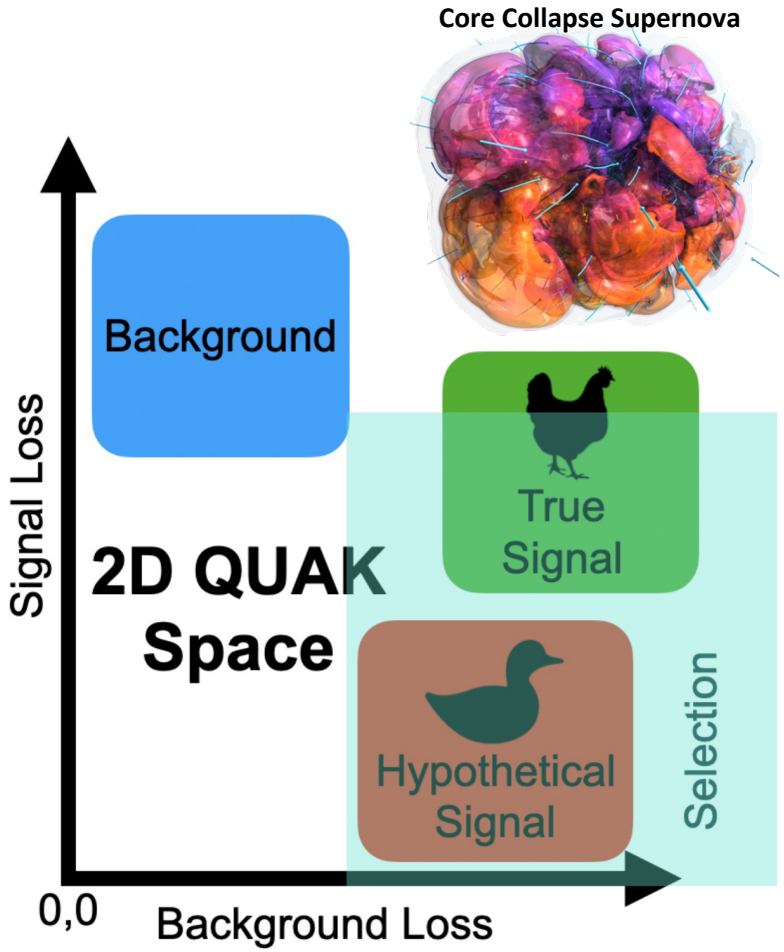
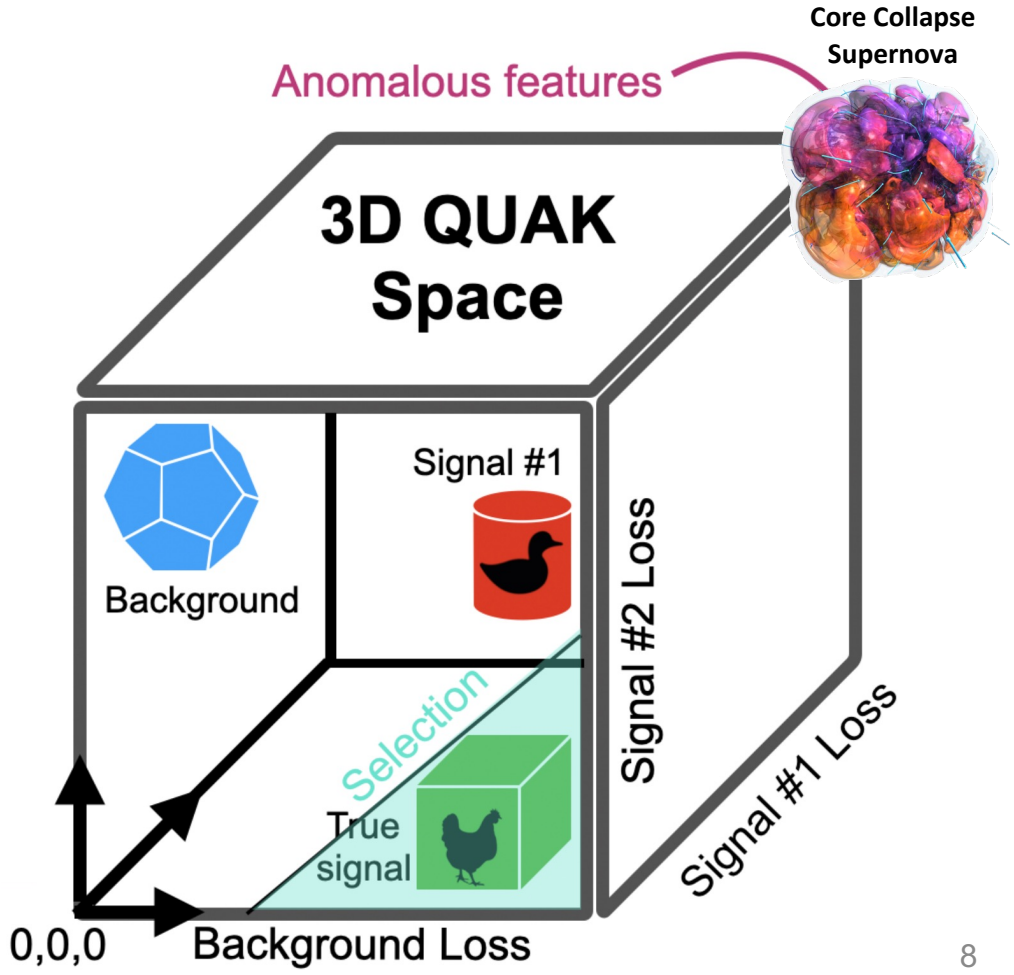
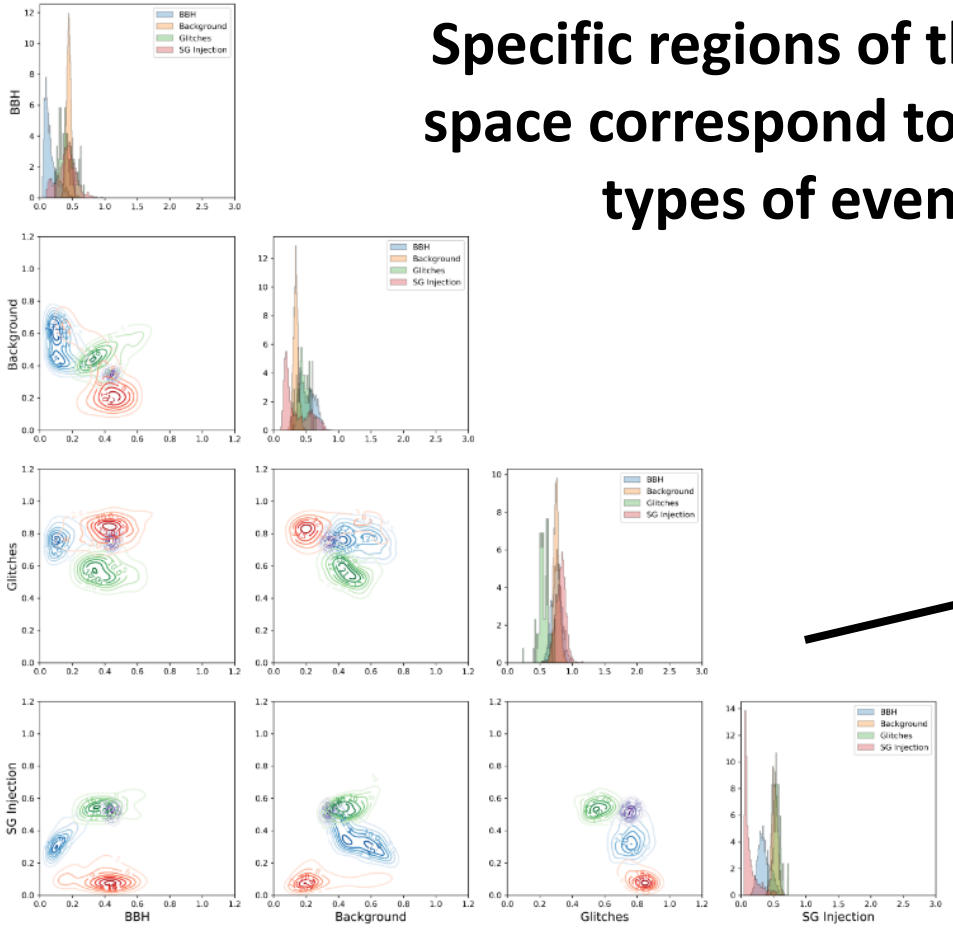
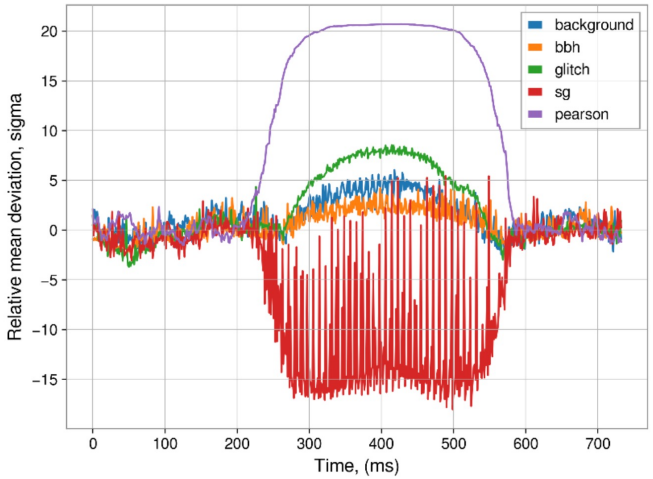


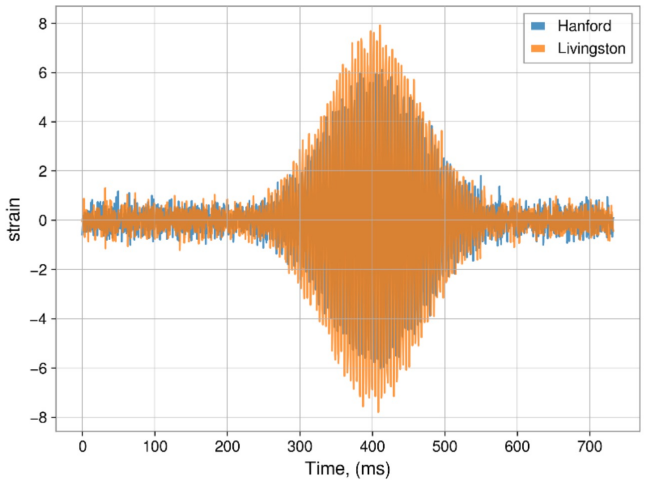


QUAK -> GWAK

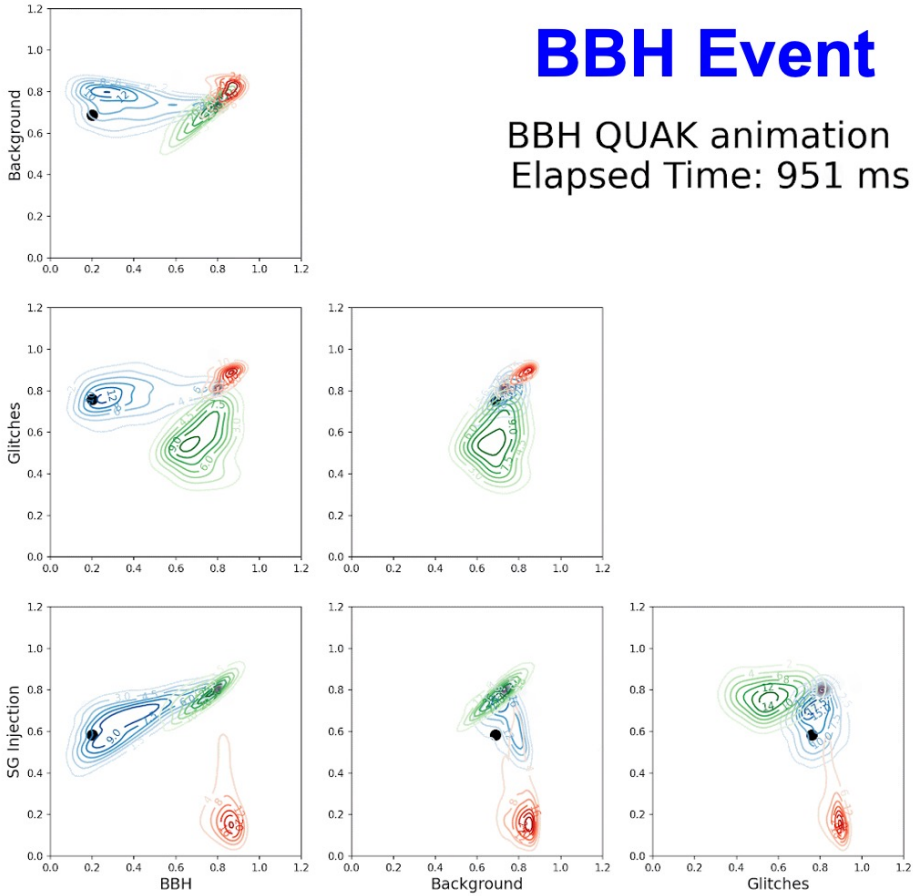
Specific regions of the GWAK space correspond to different types of events!





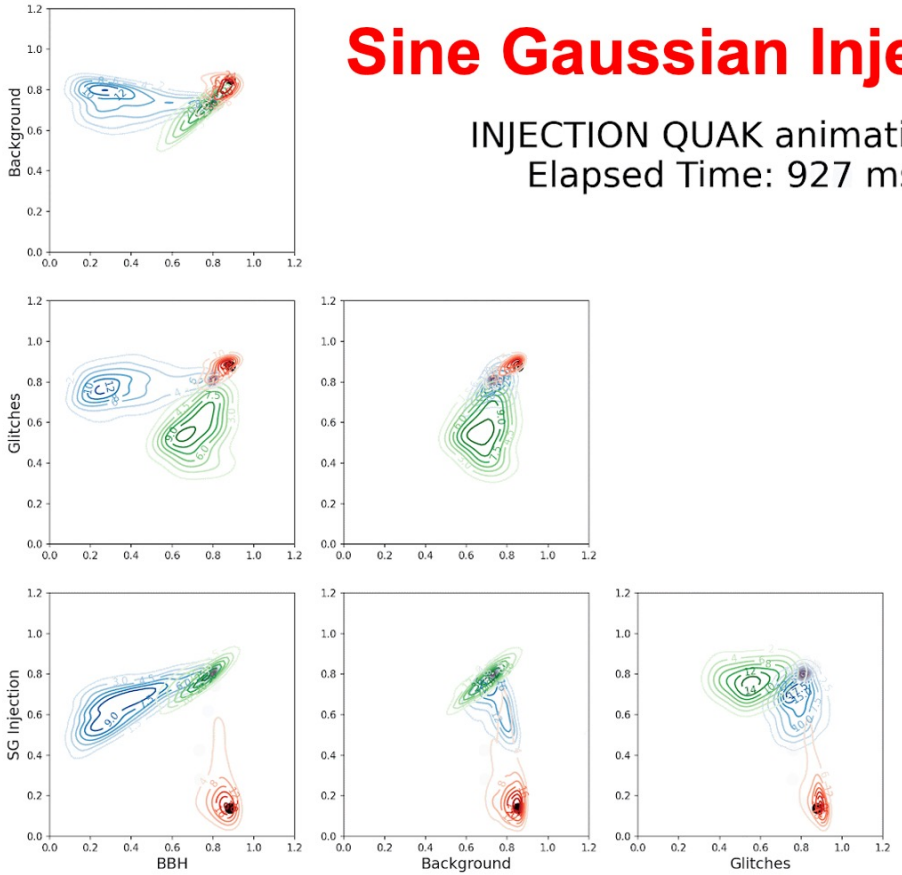


Real-Time Animations



BBH Event

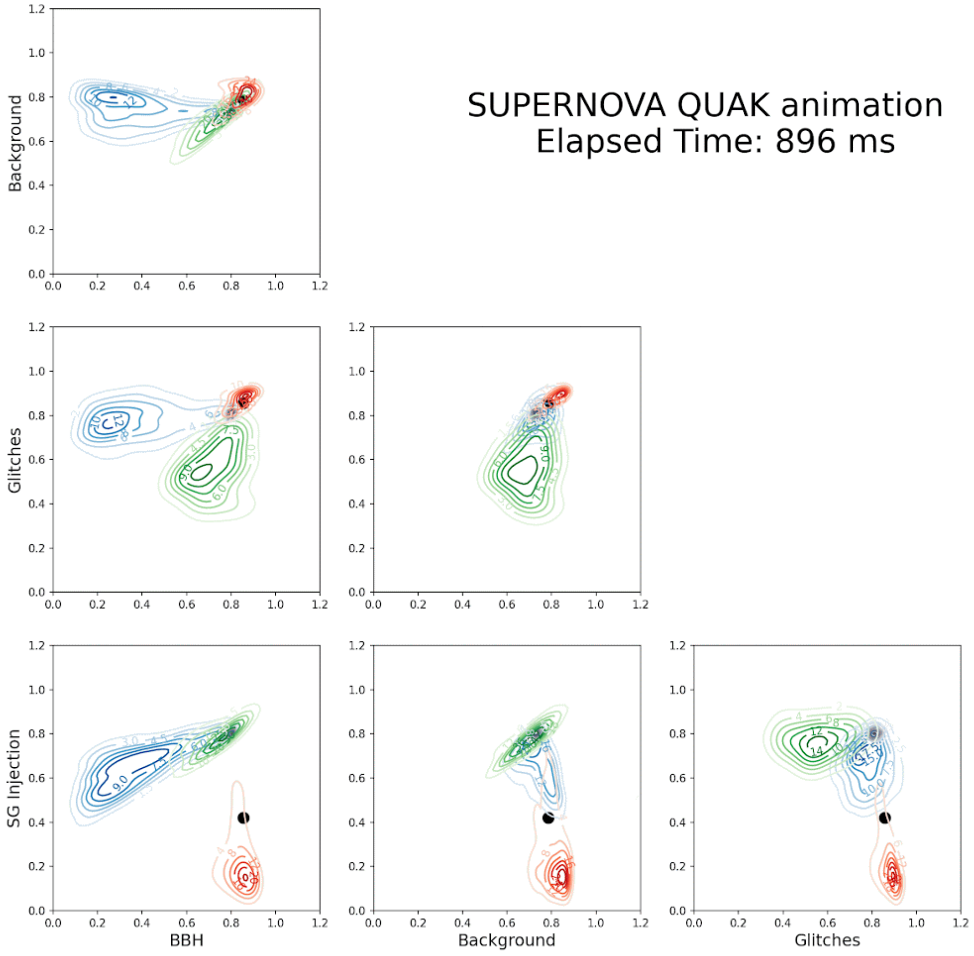
BBH QUAK animation
Elapsed Time: 951 ms



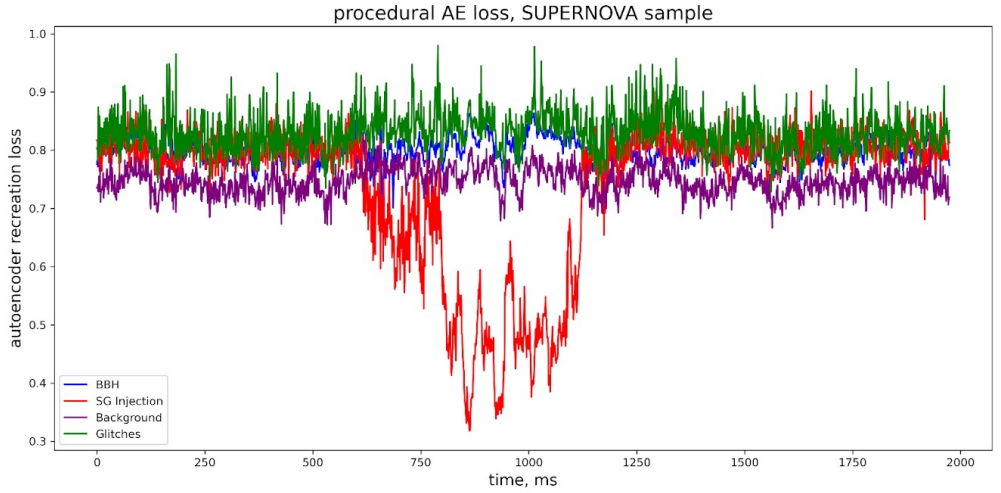
Sine Gaussian Injection

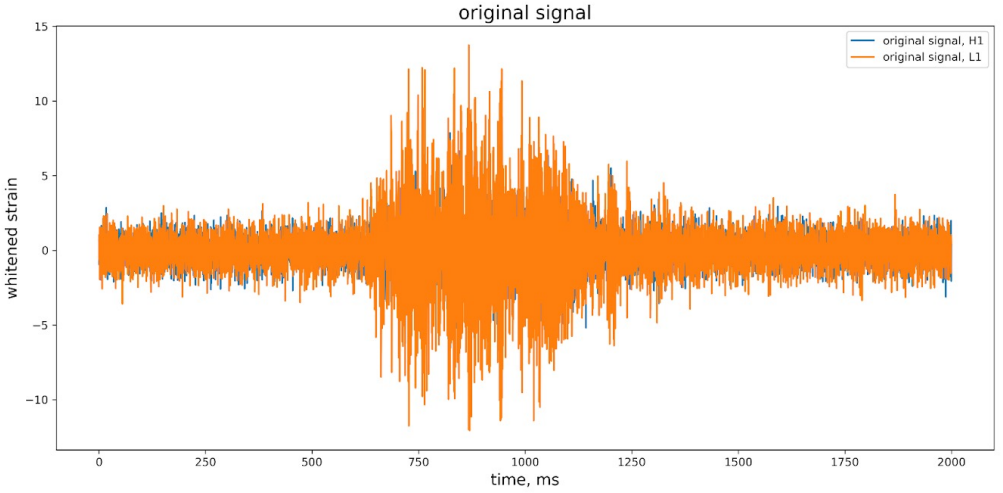
INJECTION QUAK animation
Elapsed Time: 927 ms

QUAK Spaces on Supernovae



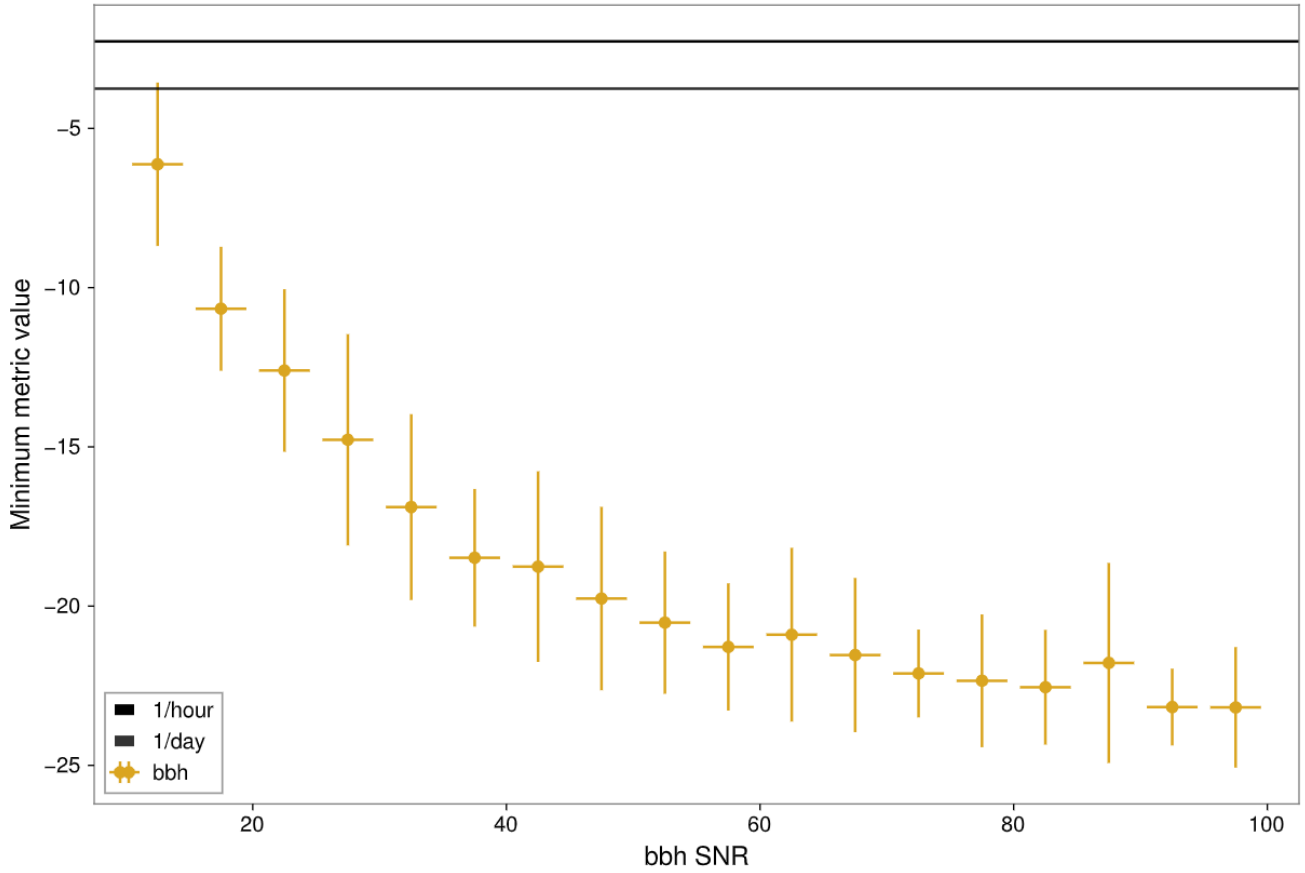
SUPERNOVA QUAK animation
Elapsed Time: 896 ms





Quantitative Results

- LSTM-AE currently best performing model
  - Model architecture input size favors shorter signals
- **Dedicated searches perform well at low-SNR**
- Able to **consistently identify mid-range SNR anomalies** at incredibly low FAR
- Test on full LIGO O(3) incoming
- Ideas for real-time O(4) in the works



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