Searching for Compact Binary Coalescences with Deep Learning

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Outline

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- Motivations
- Our Approach
- Binary Black Hole Detection
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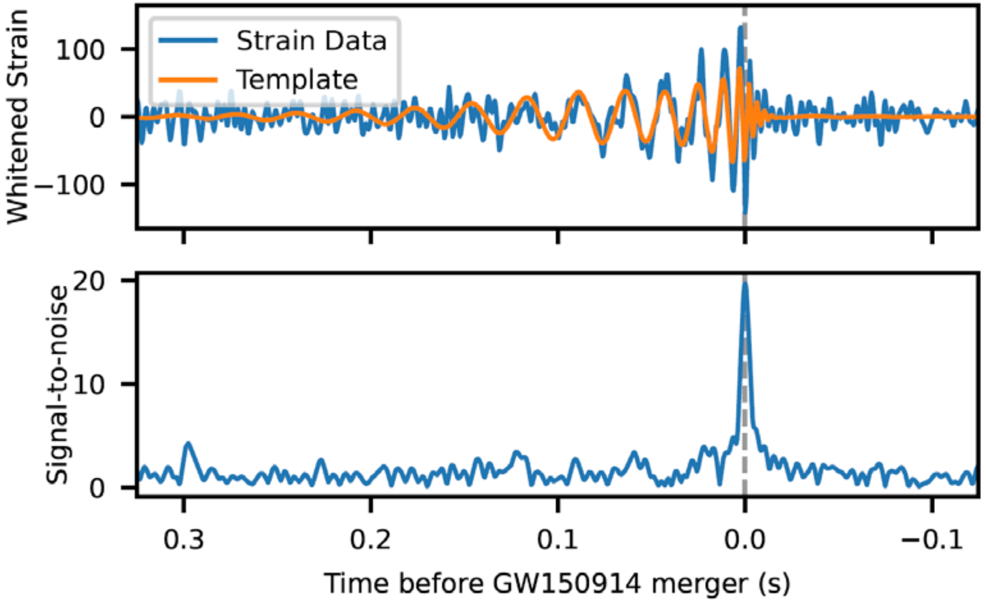
Background

- Compact binary coalescences (CBCs) involve binary systems with black holes and/or neutron stars that spiral into a merger and emit gravitational waves
- Gravitational waves (GWs) are detected using the LIGO and Virgo detectors
- Current search techniques involve matched filtering to identify signals
    - Considered the optimal method for detecting modelled signals in stationary noise
    - Use a bank of template waveforms to search for correlated signals

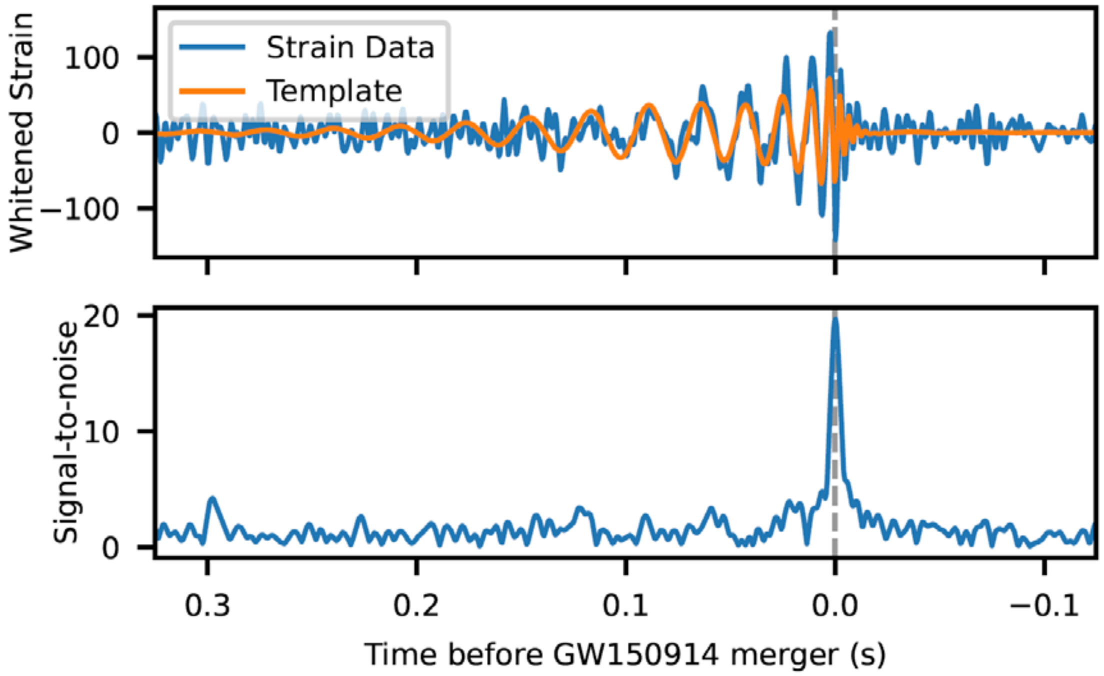


Motivation

- For large parameter spaces, search pipelines require a significant number of templates which adds latency to post-processing
  - Significant computational cost
  - Efforts being made to improve latency, but there is a limit
- Detecting events rapidly after merger, or pre-merger, can lead to multi-messenger astronomy to study these mergers
- Detector data is non-stationary, so the standard matched filtering is not optimal

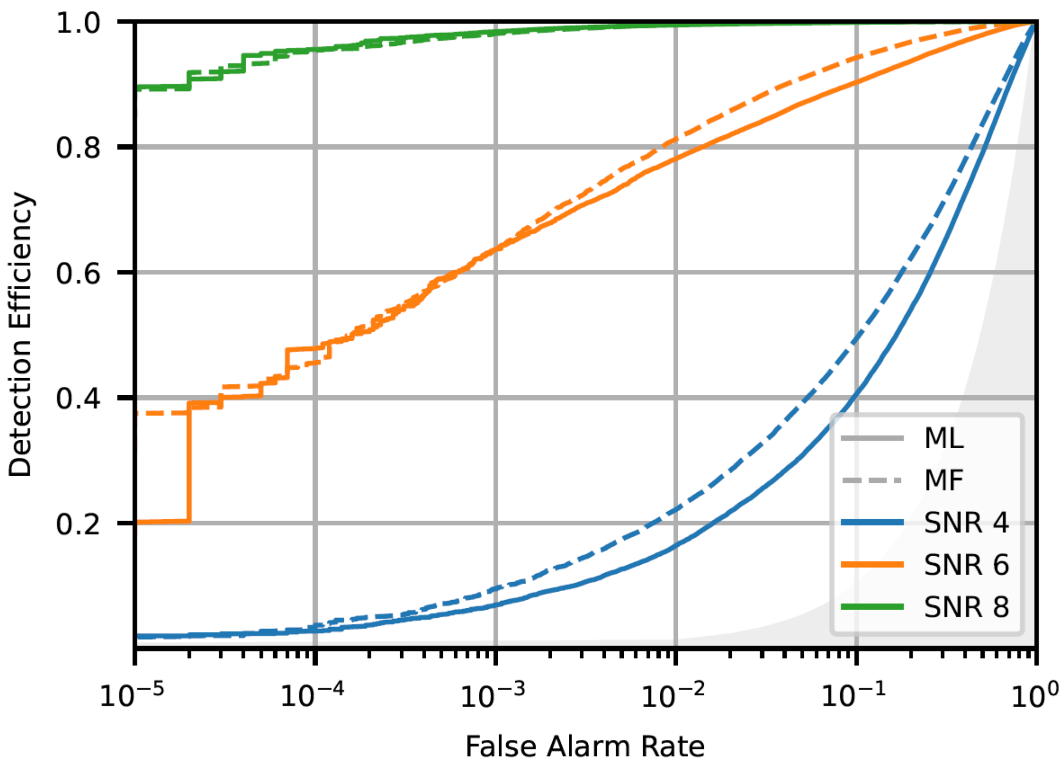
Our Approach

- Signal length increases for lower mass binaries
  - Difficult to design models searching for signals with varying durations
- We use SNR time-series from matched filtering as our networks input
- Proof of concept using Gaussian generated noise
- Use a combination of CNN, ResNet and LSTM layers



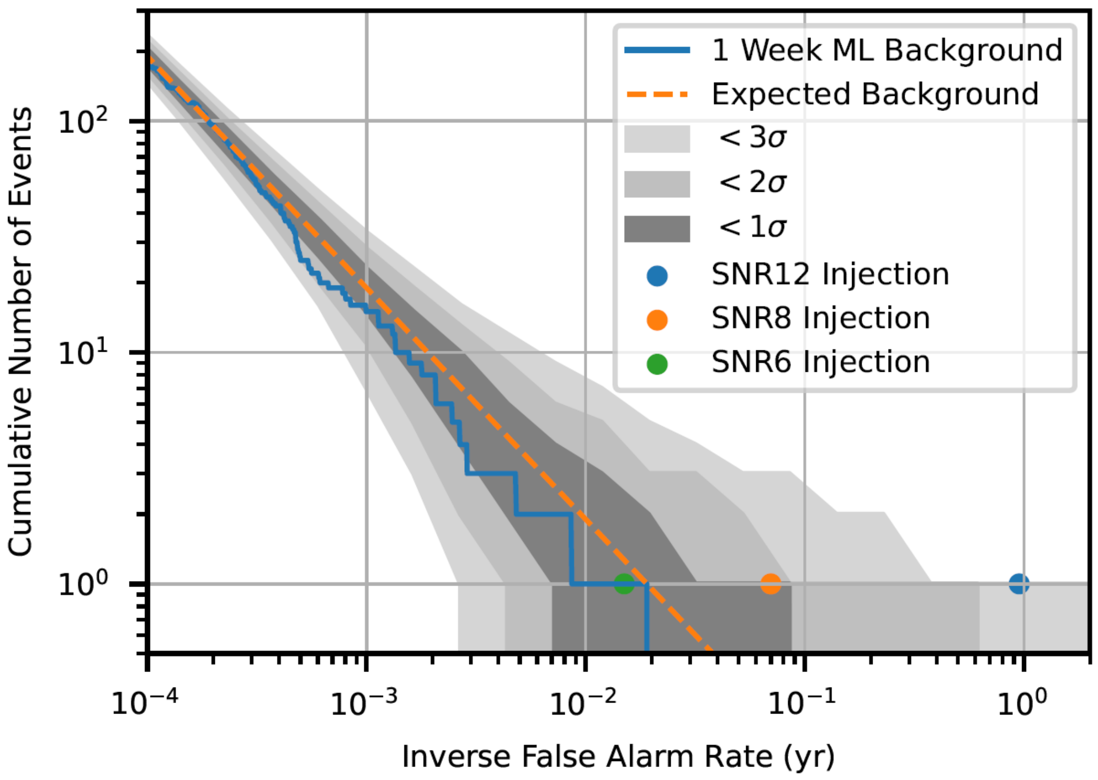
Binary Black Hole (BBH) Detection

- Train on a small set of template banks
- Sample lengths of 1s
- SNR range ∈ [5, 50]
  - Biased to lower SNRs
- Component Masses ∈ [10,80]
- Dimensionless spin (z-axis) ∈ [-1,1]



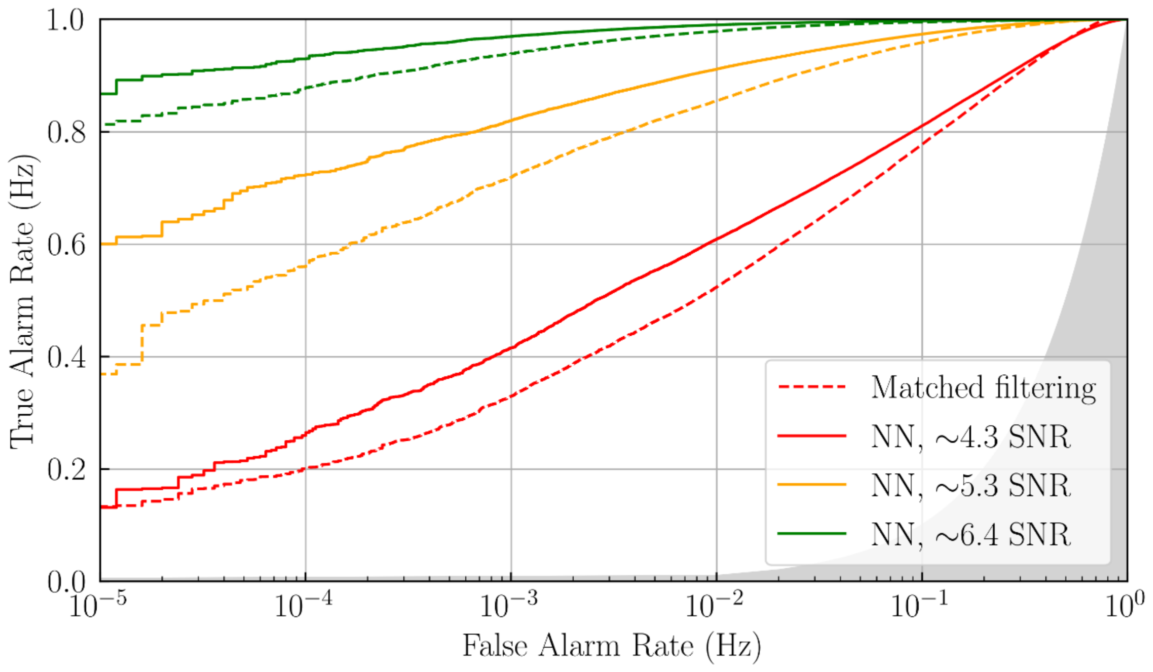
BBH Detection - Testing

- Remove final softmax layer from our model to unbound the ranking statistic
- Verify statistic with inference on 1 year of pure noise



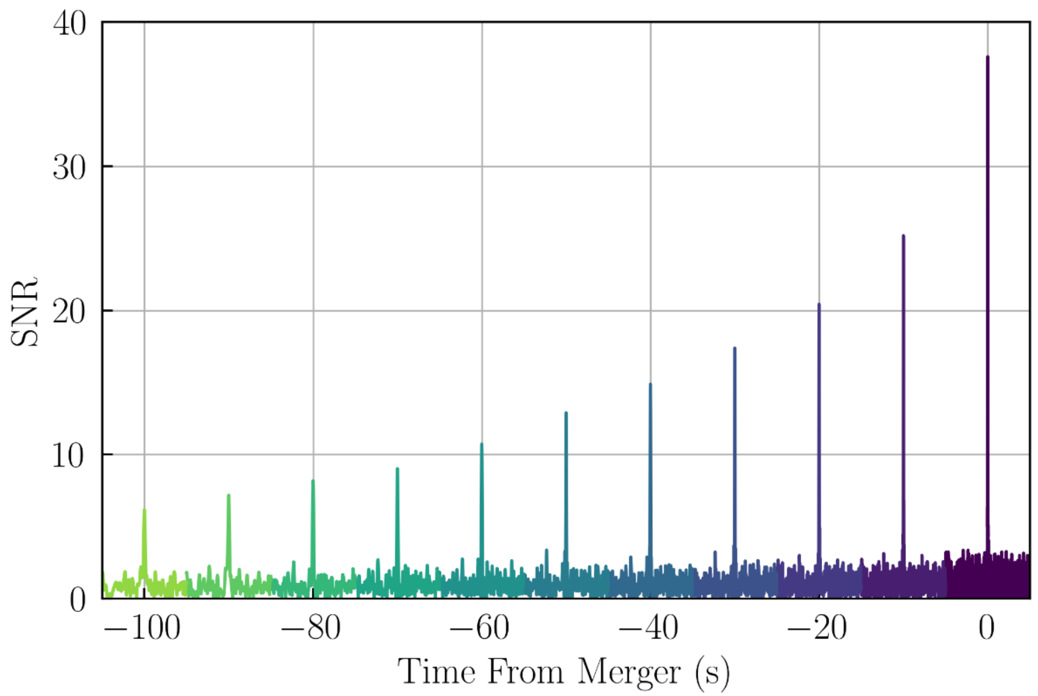
Binary Neutron Star (BNS) Detection

- We have begun similar work for BNS detection using the SNR time series input
- SNR time series response is dependent on signal chirp mass, so we include the template chirp mass as an input
- Tune in to Alistair’s talk on Wednesday for more



Pre-merger BNS Detection

- Feasible to conduct pre-merger detection as total signal strength is combined into a smaller window in the SNR time-series
- Goal is to confidently detect events prior to merger so they can be observed with EM telescopes



Challenges

- SNR time series data scales the disk usage linearly with the number of templates we train/test with
  - Cannot all be stored in memory for training

- Inference over many years of data to validate our model requires improved infrastructure

- Limitations when using real data in sample generation

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Future Work

- Expand detection to multiple detectors
- Improve data loading/generation infrastructure
- Pre-merger detection
- Implementation offline/online during detector operating runs
  - Integration into the SPIIR pipeline

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Summary

- Machine learning can be used to accelerate the detection of GWs from compact binary coalescences
- We have shown that using the SNR time series from matched filtering is a valid approach
- Can match the results of matched filtering search with stationary Gaussian background (where matched filtering is considered optimal)
- We plan to expand this work with real noise, multiple detectors, pre-merger detection, and eventually into online use