Form 8

Research Result Report
ICRR Inter-University Research Program 2025

Research Subject:
Low-Latency Localization and Parameter Estimation of Gravitational Waves Using Probabilistic Deep Learning

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Summary of Research Result :

In this research project, we aim to build a machine-learning-only pipeline that can detect, localize, perform fast parameter estimation with low latency, and estimate uncertainty. The pipeline consists of a denoiser as the general feature extractor, a model for rapid background estimation, and models for low-latency detection and parameter estimation.

In this fiscal year, we focused more on testing the relationship between denoised features and downstream tasks, as well as on developing a novel noise-background estimator. For the first part, we investigated the relationship between signal recovery and the performance of downstream tasks. The signal recovery was quantified using the overlap $\mathcal{O} = (h|s)/\sqrt{(h|h)(s|s)}$. We found that the model can make confident predictions when $\mathcal{O} > 0.2$ for BBH and NSBH signals, and 0.1 for BNS signals, as shown in Figure 1. However, we also found no significant improvement from integrating the denoiser, and poor denoising even degrades detection performance.

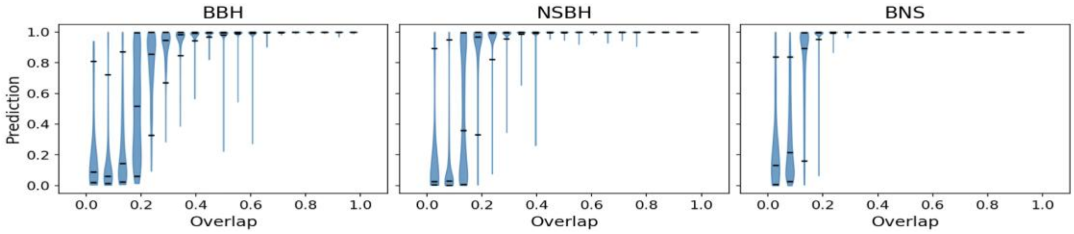

Figure 1. The relationship between signal recovery and the overall precision of the detection model

As for parameter estimation, although the PE model's loss decreased with increasing overlap, the overall performance remained poor. We will further improve the denoiser and the PE model in the next year.

In the second part of this fiscal year, as we worked to improve the denoiser's performance, we found that whitened data sometimes exhibits dips in the spectrum, causing the denoiser to generate noise. We suspected the dips were due to nonstationary line noise in the previous segments. Therefore, based on our experience developing the denoiser, we developed a self-supervised ML model to estimate the power spectral density of background noise directly from the data power spectrum we are analyzing. We used a blind-spot U-Net and trained the model with O3b and O4a strain data. Figure 2 shows that our method can improve the matched-filter SNR overall, and Figure 3 compares PSDs around the event GW200224_222234. We will conduct more tests in the next year.

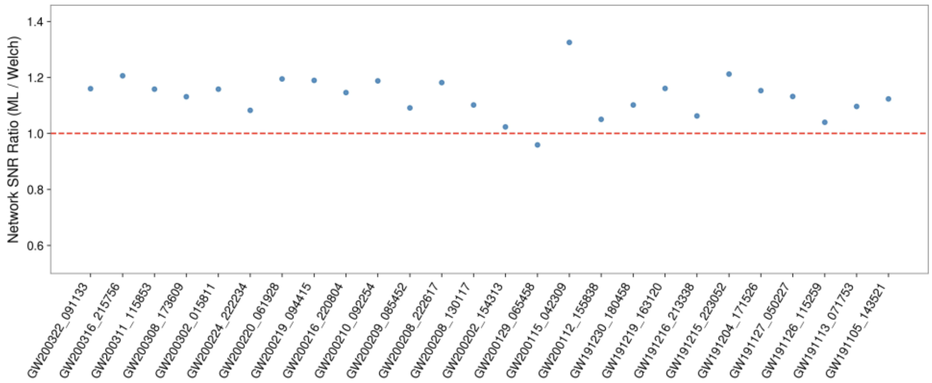

Figure 2. The ratio of the matched-filter SNR of O4a events between the noise background estimated by our method and the traditional Welch method

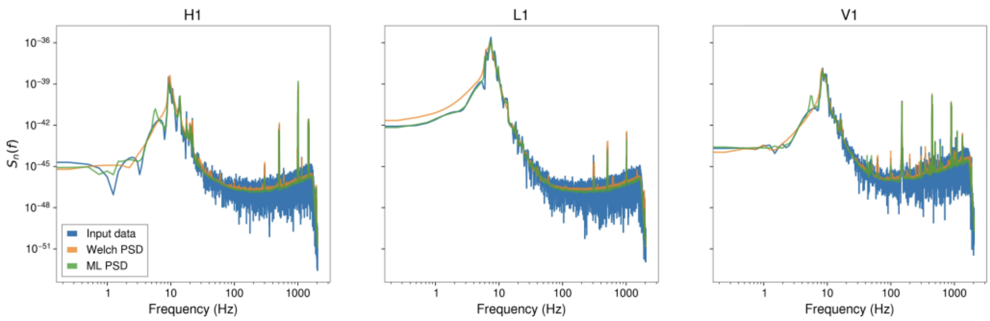

Figure 3. The comparison between the PSDs estimated by our method in a 4-second window around the event GW200224_222234 and the Welch method estimated from a 128-second segment before the data window of the event.