Deep Learning Parameter Estimation of Black Hole Mergers from LIGO Data

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*Note: All diagrams/images created by author unless otherwise noted

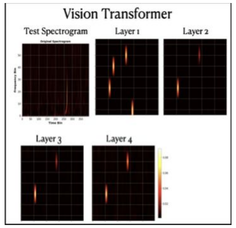
Research Question

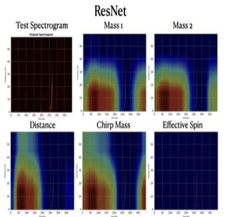
Problem: Traditional gravitational wave analysis methods are computationally intense.
Research Question: **How do convolutional networks and vision transformers compare in estimating black hole merger parameters from gravitational wave spectrograms?**
Aim: To determine whether **vision transformers** or **convolutional neural networks** more effectively estimate **black hole merger parameters** from gravitational-wave spectrograms.
Hypothesis: Convolutional networks and vision transformers will achieve comparable parameter estimation performance when trained on identical LIGO data.

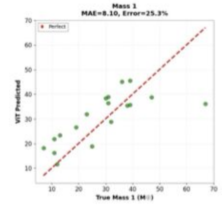
Methodology

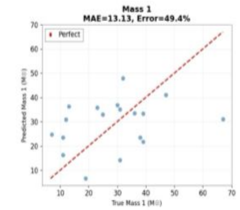
- ➢ Gravitational wave data from 54 confirmed black hole merger events was obtained from the Gravitational Wave Open Science Center (GWOSC). Spectrograms were extracted from both LIGO detectors separately.
- ➢ Additional training samples were generated through data augmentation, including temporal shifts, frequency shifts, noise addition, and intensity scaling
- ➢ A vision transformer and a convolutional architecture based on ResNet-18 were trained on the spectrograms
- ➢ After training interpretability techniques examined what each architecture actually learned
- ➢ The vision transformer and ResNet-18 model's performance was compared

Data Analysis & Results









- ➢ Model performance was evaluated for five parameters - primary mass, secondary mass, luminosity distance, chirp mass, and effective spin.
- ➢ Vision transformer (ViT) achieved an average median error of 38.0% while the ResNet achieved 35.7%.
- ➢ Both architectures focus on signal-containing regions; they employ different spatial organizations: ViT: more temporal localization; ResNet: broad selection of frequency bands.

Interpretation & Conclusions

- ➢ The hypothesis that both architectures would achieve comparable performance was supported. Both architectures had very similar overall performances only differing by a few percentage points in average.
- ➢ Neither architecture consistently outperformed the other across all parameters.
- ➢ Scatter plots of predicted vs true values show that both vision transformer and ResNet learned relationships between spectrograms and physical parameters with predictions generally clustering around the diagonal line representing perfect prediction
- ➢ Convolutional networks and vision transformers can be used to accurately process LIGO gravitational wave data while minimizing computational energy.