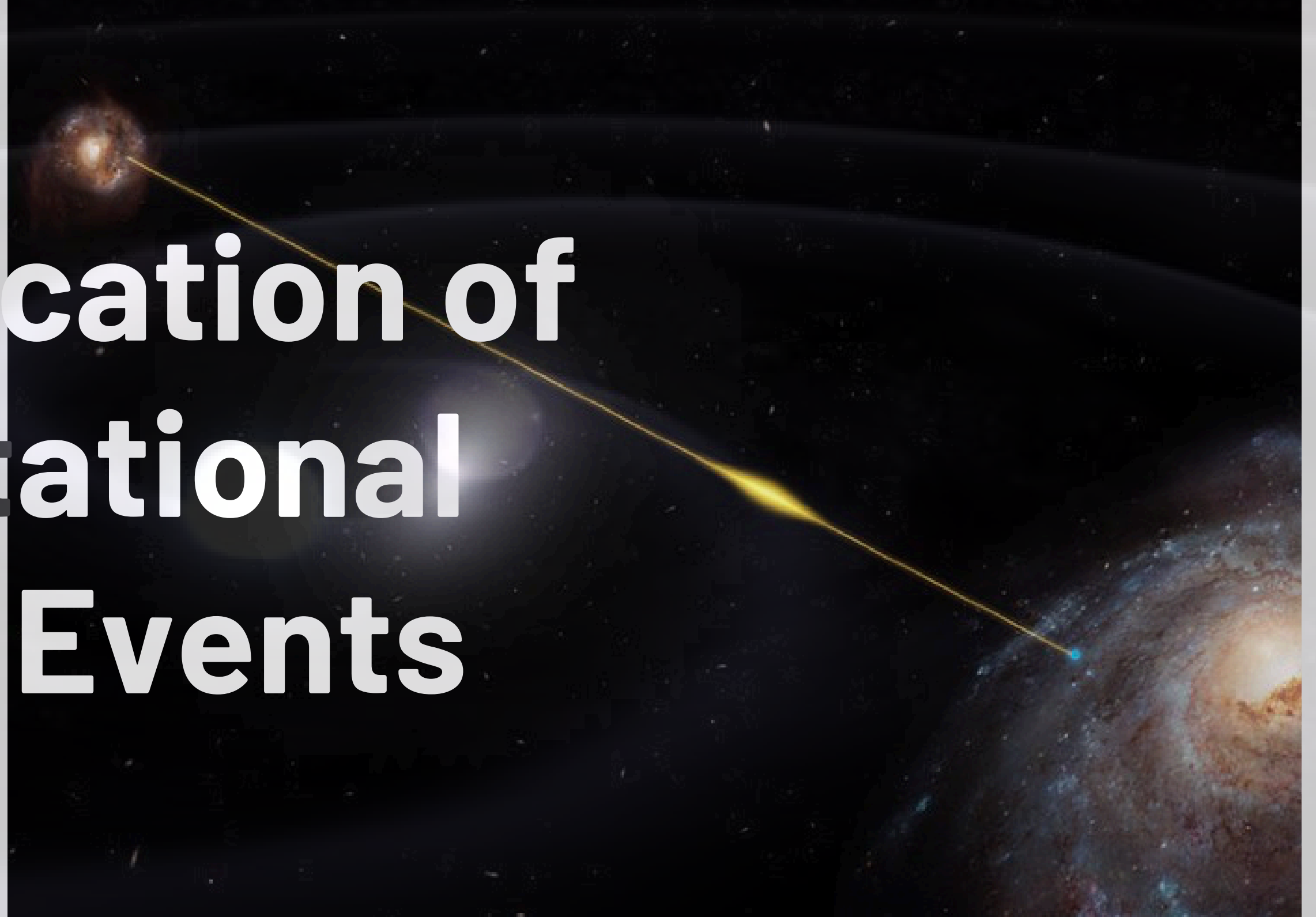


Classification of Gravitational Wave Events



Motivation: Understanding Cosmic Events through Gravitational Wave Analysis

WaveBusters's Members



Arzu Nur Köroğlu
090220708



Ayberk Bulut
090180164

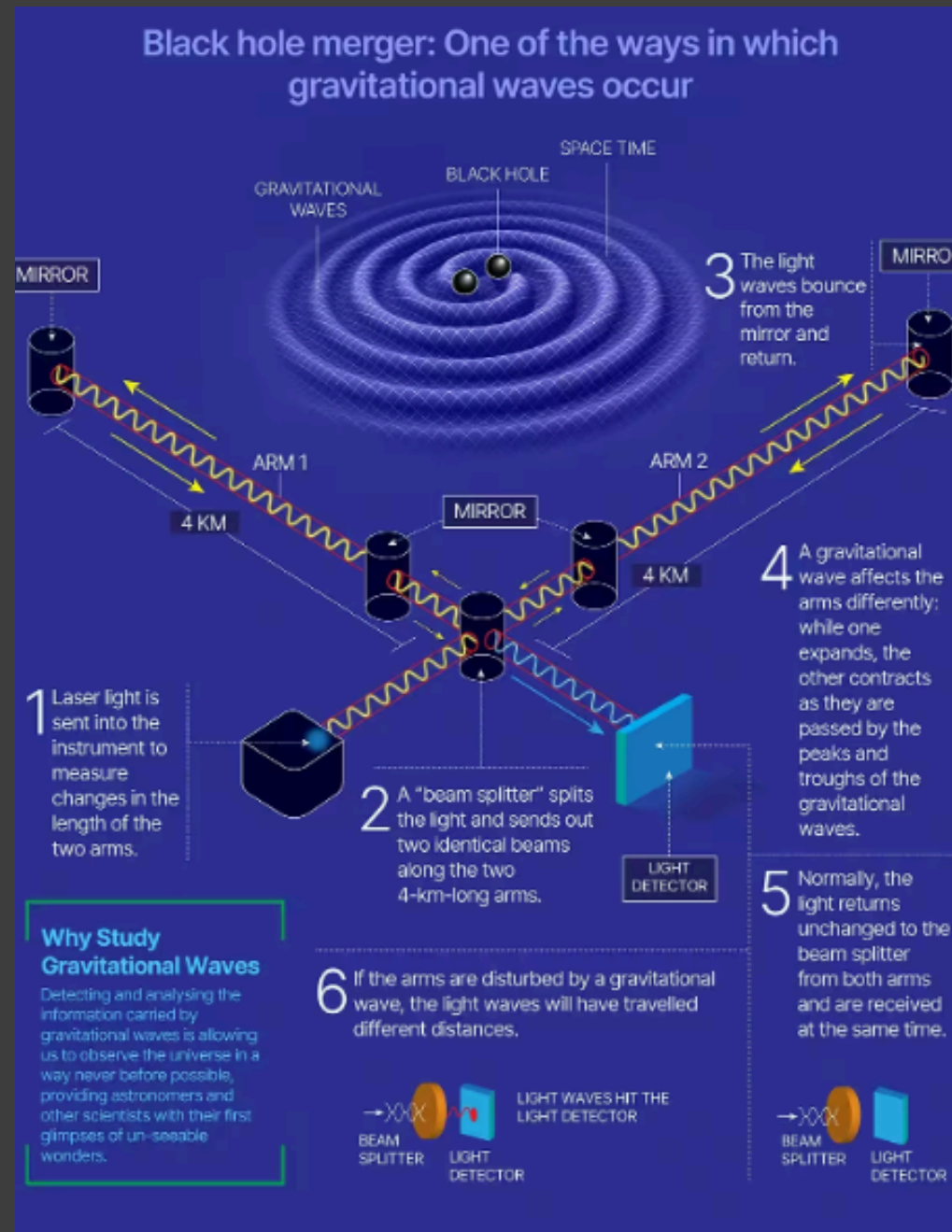


Ayça Yerlikaya
090200165

Motivation of the Project

Fast and accurate detection of gravitational waves

- The first direct gravitational waves detection in 2015 by LIGO
- 01, 02 and 03 observations LIGO and Virgo
- The GW170817 event
- New field: Multi-Messenger Astrophysics (**MMA**)
- Traditional methods: Matched Filtering & Burst search



LIGO- A Gigantic Interferometer

Importance for Physics

- Understanding the structure and secrets of the universe
- Importance of detection and analyzing black hole and neutron star mergers
- Increase in detected events with advanced gravitational wave detectors
- Critical role of deep learning projects in big data analysis

Literature Search

- Detection of 11 GW signals in O1 - O2 observing (BBH, BNS mergers)
- O3 and GWTC-3 catalog: 90+ events, including BNS and NSBH mergers
- Need for efficient and rapid analysis with increasing GW events
- Models capable of recognizing signals at low signal-to-noise ratios (SNR)

Current Situation

- O4 began in March 2023
- LISA (-2030) opens low frequency gravitaional universe
- Higher detector sensitivity expected to increase detection rates
- Anticipation of millions of events per year with Einstein Telescope and Cosmic Explorer
- Need for enhanced data analysis capacity and techniques with rising detection rates

Research Paper

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Journal of Astronomy and Space Sciences

Classification of Gravitational Waves from Black Hole-Neutron Star Mergers with Machine Learning

Nurzhan Ussipov, Zeinulla Zhanabaev, Almat Akhmetali¹, Marat Zaidyn, Dana Turlykzohayeva, Algerim¹ *Abolmomen T. H. M. Khamis*

Department of Solid State Physics and Non

Machine Learning Applications in Gravitational Wave Astronomy

Nikolaos Stergioulas

Abstract Gravitational wave astronomy has emerged as a new branch of observational astronomy, since the first detection of gravitational waves in 2015. The current number of $O(100)$ detections is expected to grow by several orders of magnitude over the next two decades. As a result, current computationally expensive detection algorithms will become impractical. A solution to this problem, which has been explored in the last years, is the application of machine-learning techniques to accelerate the detection and parameter estimation of gravitational wave sources. In this chapter, several different applications are summarized, including the application of artificial neural networks and autoencoders in accelerating the computation of surrogate models, deep residual networks in achieving rapid detections with high sensitivity, as well as artificial neural networks for accelerating the construction of neutron star models in an alternative theory of gravity.

Deep learning detection and classification of gravitational waves from neutron star-black hole mergers

Richard Qiu^{a,b,c}, Plamen G. Krastev^{d,e,*}, Kiranjyot Gill^{a,e}, Edo Berger^{a,e}

^a Center for Astrophysics | Harvard & Smithsonian, 60 Garden Street, Cambridge, MA 02138-1516, USA
^b Department of Physics, Harvard University, 17 Oxford Street Cambridge, MA 02138, USA
^c John A. Paulson School of Engineering and Applied Sciences, Harvard University, 130 Western Ave, Allston, MA 02134, USA
^d Faculty of Arts and Sciences Research Computing, Harvard University, 52 Oxford Street, Cambridge, MA 02138, USA
^e The NSF AI Institute for Artificial Intelligence and Fundamental Interactions, USA

INFO

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ABSTRACT

The Laser Interferometer Gravitational-Wave Observatory (LIGO) and Virgo Interferometer Collaborations have now detected all three classes of compact binary mergers: binary black hole (BBH), binary neutron star (BNS), and neutron star-black hole (NSBH). For coalescences involving neutron stars, the simultaneous observation of gravitational and electromagnetic radiation produced by an event, has broader potential to enhance our understanding of these events, and also to probe the equation of state (EOS) of dense matter. However, electromagnetic follow-up to gravitational wave (GW) events requires rapid real-time detection and classification of GW signals, and conventional detection approaches are computationally prohibitive for the anticipated rate of detection of next-generation GW detectors. In this work, we present the first deep learning based results of classification of GW signals from NSBH mergers in real LIGO data. We show for the first time that a deep neural network can successfully distinguish all three classes of compact binary mergers and separate them from detector noise. Specifically, we train a convolutional neural network (CNN) on $\sim 500,000$ data samples of real LIGO noise with injected BBH, BNS, and NSBH GW signals, and we show that our network has high sensitivity and accuracy. Most notably, we achieve a detection rate of $\sim 90\%$ for NSBH mergers in real LIGO data (GW191219 and GW200115) together with $\sim 90\%$ of all alog. GWTC-3. These results are an multi-messenger astronomy. This article under the CC BY license <https://creativecommons.org/licenses/by/4.0/>. Funded by SCOAP³.

International Astronomy and Astrophysics Research Journal

3(2): 1-9, 2021; Article no.IAARJ.66617

Deep Learning Techniques to Make Gravitational Wave Detections from Weak Time-series Data

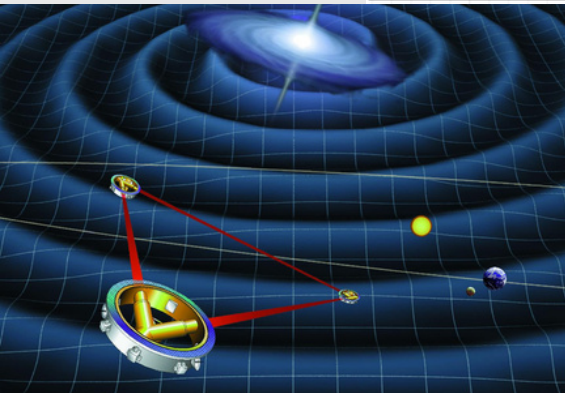
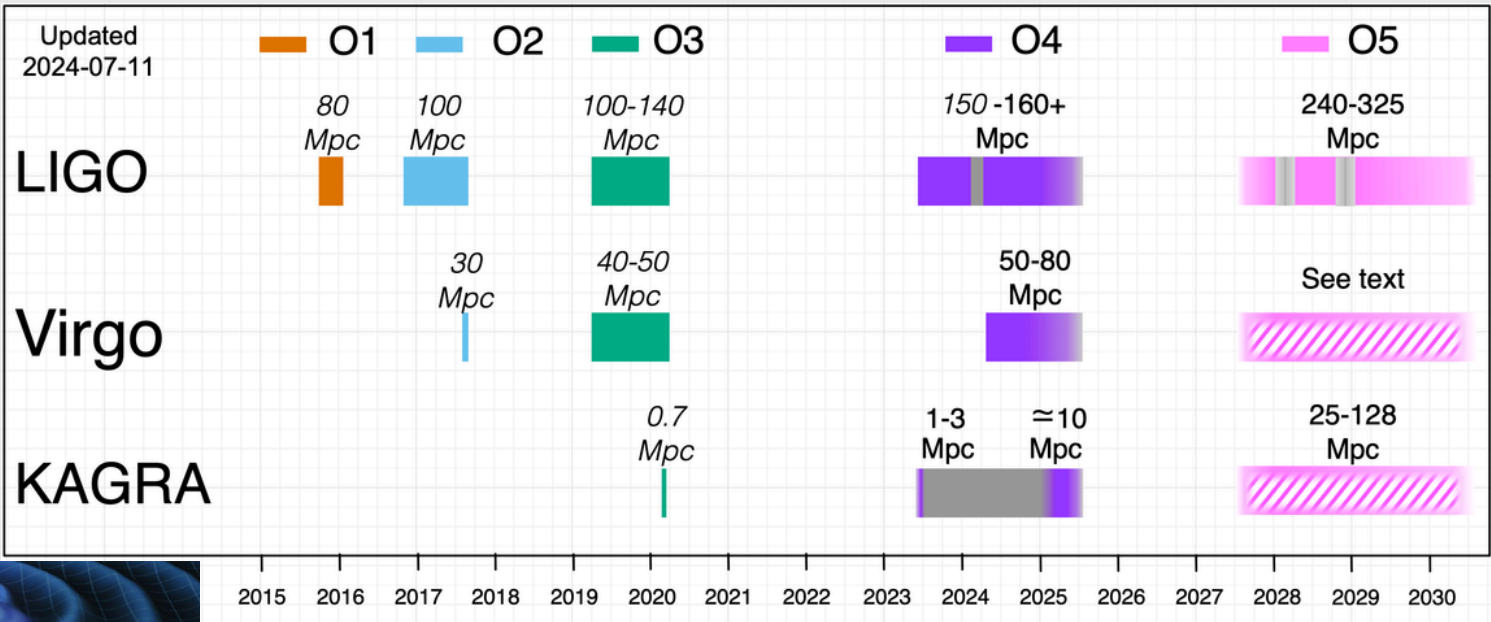
Yash Chauhan^{1*}

¹The International School of Bangalore (TISB), Bangalore, India.

Author's contribution

The sole author designed, analyzed, interpreted and prepared the manuscript.

Article Information



About the Data

O3b Data Release

O3b Time Range: November 1, 2019 through March 27, 2020

Detectors: H1, L1 and V1

GEO Data around FRBs

Time Range: April 28, 2020 through Dec 2, 2022

Detectors: GEO600 (Select times only)

O2 Data Release

O2 Time Range: November 30, 2016 through August 25, 2017

Detectors: H1, L1 and V1

O3a Data Release

O3a Time Range: April 1, 2019 through October 1, 2019

Detectors: H1, L1 and V1

Dataset

Training Data: Gravitational wave signals will be generated using PyCBC, with noise added to these signals. Noise will either be generated synthetically or sourced directly from pre-existing data on [GWOSC](#).

Testing Data: Real data from GWOSC, categorized as follows:

- FRB events: 4 instances
- Observing Runs 01 & 02: Total of 11 events (10 BBH, 1 BNS)
- Observing Runs 03a-b: Total of 70 events (1 BNS, 2 NSBH)

BBH: 2-95 M_{\odot} - SEOBNRv4

BNS: 1-2 M_{\odot} - TaylorF2

NSBH: 1-2 M_{\odot} ve 2-35 M_{\odot} - SEOBNRv4_ROM_NRTidalv2_NSBH

Data Soruces

Data is sourced from the [GWOSC website](#).

Data Structure

The dataset is structured as time-series data.

Size Details

Initial testing will use a small dataset, with plans to expand as accordingly.

Analysis Details

Project Goal

An optimized Neural Network Architecture to classify GW events .

Model Structure

Possible Architectures:

- RNN
- CNN
- Transformers
- Physics Informed NN

ML Libraries

- PyTorch
- TensorFlow

Data Processing Libraries

- Pandas
- Polars
- Dask
- Prophet
- Statsmodels
- TSLearn

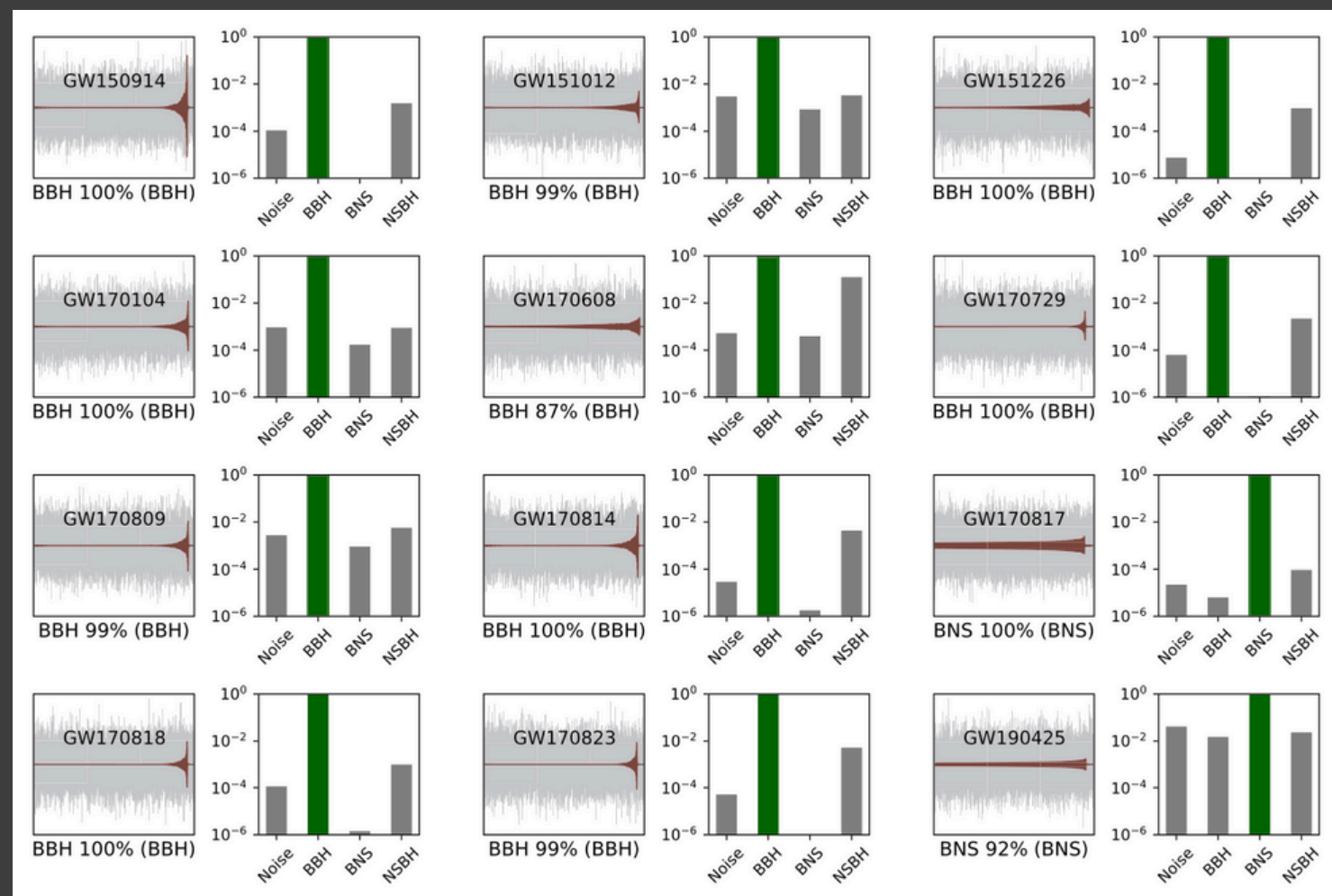
Dev Tools and Environments

- Ray
- JobLib
- Kubernetes
- GCP
- Azure

Task	Week
<div><div>Data Preparation</div><div><div>• Generate synthetic data</div><div>• Add noise to data</div><div>• Prepare data for model</div></div></div>	1-3
Model Training	4-6
Model Fine-Tuning	7-8
Paper Writing	9
Presentation Preparation	10

Project Timeline

Possible Outcomes



Project Objective: Develop a model capable of accurately classifying gravitational wave events into four main categories:

- FRB (Fast Radio Bursts)
- BBH (Binary Black Hole Mergers)
- BNS (Binary Neutron Star Mergers)
- NSBH (Neutron Star - Black Hole Mergers)

Expected Outcome: The model is anticipated to accurately classify a total of 18 events as follows:

FRB: 4 events
BBH: 10 events

BNS: 2 events
NSBH: 2 events

Performance Evaluation: The model's success will be evaluated based on its accuracy and reliability across each class. Our goal is to achieve a high-precision classification model that can distinctly differentiate between event types.

Scientific Contribution: This model is expected to provide new insights into the classification of gravitational waves, offering a deeper understanding of the unique characteristics of each event type and contributing to knowledge advancement in this field.