M.Sc - Artificial Intelligence and Machine Learning in Science

SPC720P

Research Project in Data Science

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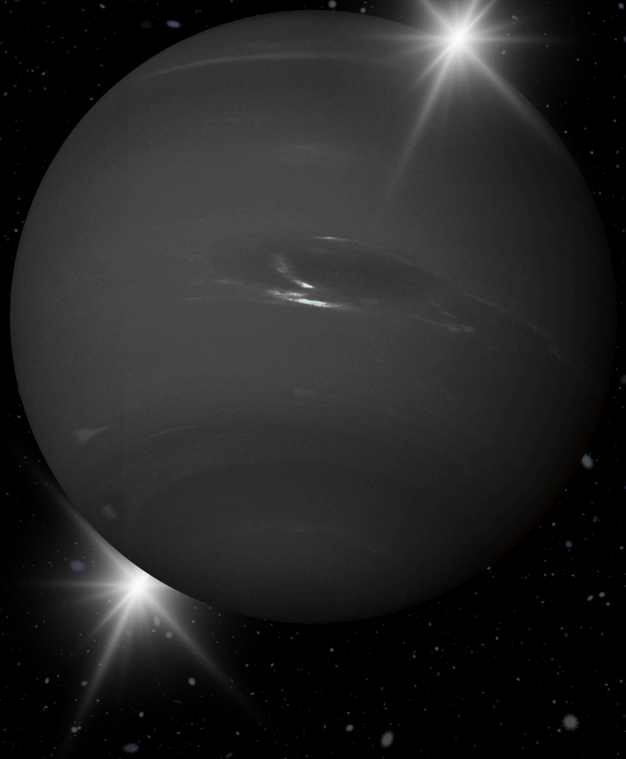
INTRODUCTION OF THE PROJECT



EXPLORING GRAVITATIONAL WAVE DATA

To analyze gravitational wave data from GWOSC.

Motivation:

- **The nature of compact objects in the universe — black holes, neutron stars, and exotic alternatives — is still under active exploration.**
- **Gravitational wave signals carry rich information about these events.**

Aim:

- **To build a computational framework (Bayesian or ML-based) to analyze and classify gravitational wave signals.**
- **Two promising directions currently under evaluation.**

1.BLACK HOLES VS BOSON STARS

Based on:

Constraining Exotic Compact Object Mergers with Gravitational Waves – INSPIREHEP

Goal:

- **Use Bayesian inference to distinguish between binary black holes and boson star mergers.**

Approach:

- **Use waveform templates for both BH-BH and BS-BS mergers.**
- **Apply Bayesian model selection to real/simulated GW data.**
- **Tools: Bilby / PyCBC Inference.**
- **Key Event: Possibly work on GW150914 or GW170104.**

Outcome:

- **Posterior parameter estimation**
- **Bayes Factor comparisons to evaluate which model better explains the signal**

Known methods : Bayesian methods with waveform fitting

Gaps/ Scope : Few real detections, relies on accurate waveform modeling

Future Impact : Pushes the boundary of exotic compact object detection,
can help constrain the existence of new forms of matter.

2.CLASSIFYING BNS REMNANTS USING MACHINE LEARNING

Based on:

Classifying Binary Neutron Star Merger Remnants with Machine Learning – INSPIREHEP

Goal:

- **Train a supervised ML model to classify the post-merger remnant of binary neutron star events.**

Remnant Categories:

- **Stable Neutron Star**
- **Supramassive NS**
- **Hypermassive NS**
- **Prompt Black Hole**

Approach:

- **Simulate BNS signals.**
- **Extract time-frequency features (e.g., spectrograms).**
- **Train CNN or RNN-based models.**
- **Evaluate performance using confusion matrix, accuracy, ROC, etc.**

Known Methods : Machine Learning using time-frequency analysis

Gaps/ Scope : Still experimental, can be extended to real-time use

Future Impact : Potential use in real-time classification pipelines.

TOOLS & METHODOLOGY

BOTH IDEAS RELY ON A MIX OF GW DATA TOOLS, SIGNAL PROCESSING, AND EITHER ML OR BAYESIAN METHODS AS MENTIONED BELOW

Task	Tools/ Techniques
Waveform Generation	Bilby Templates / Others
Bayesian Interface	Bilby, PyCBC Inference
ML Classification	Python, Tensorflow/ Pytorch
Signal Processing	Spectograms, PSD Estimation
Data Source	GWOSC/ Simulated data

CURRENT TASKS & NEXT STEPS

Current Status

- Two strong project directions shortlisted:
  - Boson Star vs Black Hole (Bayesian approach)
  - BNS Remnant Classification (ML-based approach)
- Completed literature review for both ideas.
- Explored gravitational wave datasets from GWOSC.
- Tools identified (Bilby, PyCBC Inference, ML frameworks), but simulation workflows yet to be explored.

Next Steps

- Finalize project direction after supervisor discussion.
- Begin dataset preparation: explore waveform simulation or pre-existing datasets.
- Set up initial codebase and preprocessing pipeline.
- Build and test baseline model (Bayesian or ML).


THANK YOU!