Expanding computational resources for gravitational wave detection pipelines in medium-latency and beyond

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November 8, 2023

Expanding computational resources for gravitational wave detection pipelines in medium-latency and beyond

Timeframe (6 months & extension)

Start Date: March 1, 2023

End Date: November 8, 2023

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Overview

With the next observing run of LVK (O4) having begun in May 2023, the importance of increased computational resources for gravitational wave (GW) detections is key to detect a larger population and more sensitive events. By expanding those resources for medium-latency events, we are improving the evaluation of the efficiency of these detections to produce results faster.

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Background - Gravitational Waves

Gravitational waves (GWs) are 'ripples' in space-time caused by some of the most violent and energetic processes in the Universe. Einstein's mathematics showed that massive accelerating objects (things like neutron stars or black holes orbiting each other) would disrupt space-time in such a way that 'waves' of undulating space-time would propagate in all directions away from the source. These cosmic ripples would travel at the speed of light, carrying with them information about their origins, as well as clues to the nature of gravity itself.

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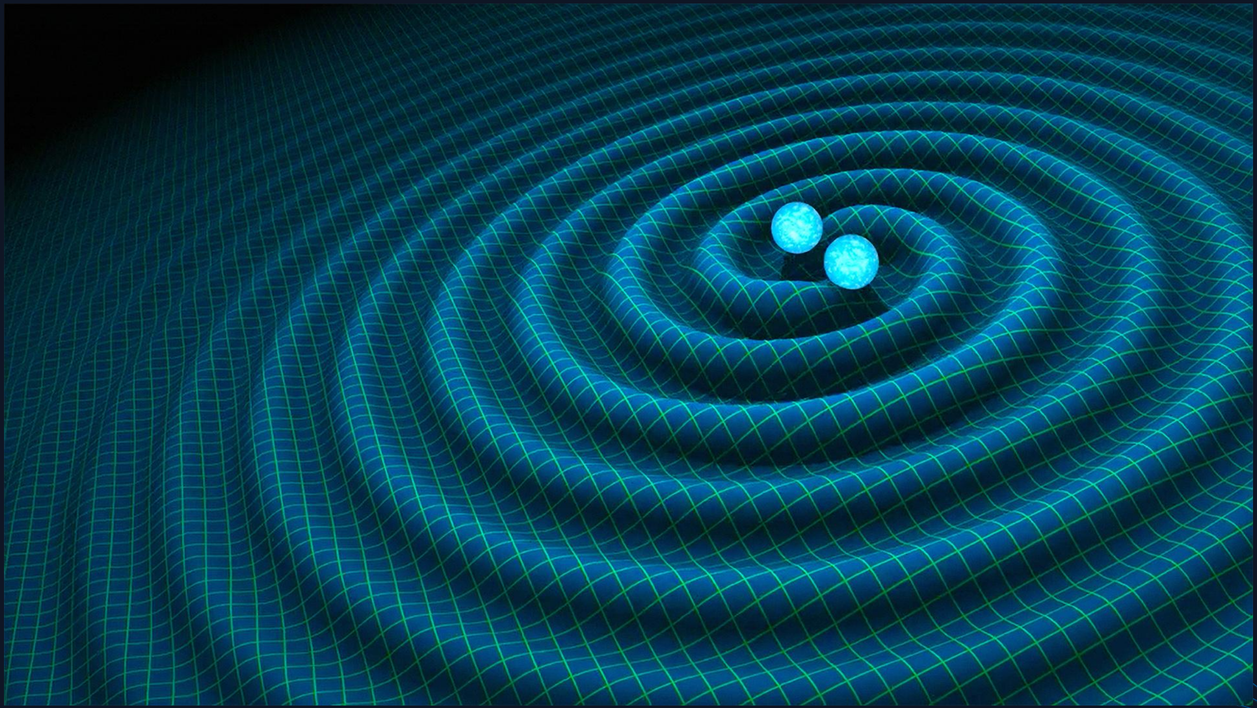

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Background - Detection

Before, scientists have relied almost exclusively on electromagnetic (EM) radiation (visible light, x-rays, radio waves, microwaves, etc.) to study the Universe. Each of these 'messengers' of information provides scientists with a different but complementary view of the Universe. GWs, however, interact very weakly with matter (unlike EM radiation, which can be absorbed, reflected, refracted, or bent by gravity itself), they travel through the Universe virtually unimpeded, carrying information about their origins that is free of distortion.

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Background - Gamma Ray Bursts

Gamma ray bursts (GRBs) are short-lived bursts of gamma-ray light, the most energetic form of light. Lasting anywhere from a few milliseconds to several minutes, GRBs shine hundreds of times brighter than a typical supernova and about a million trillion times as bright as the Sun. Evidence from recent satellites like Swift and Fermi indicate that the energy behind a gamma-ray burst comes from the collapse of matter into a black hole.

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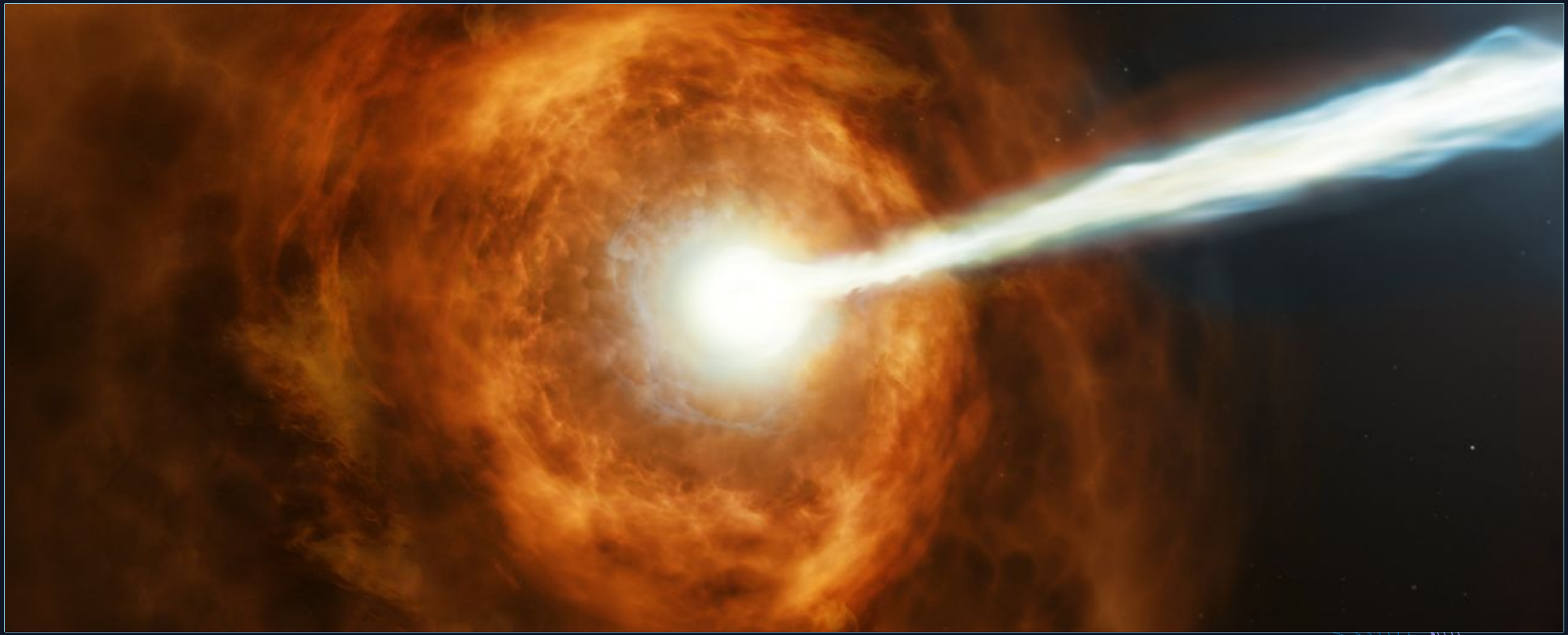

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Background - PyCBC

PyCBC is a software package used to explore astrophysical sources of gravitational waves. It contains algorithms that can detect compact binary coalescences (CBCs) and measure the astrophysical parameters of detected sources. PyCBC was used in the first direct detection of gravitational waves by LIGO and is used in the ongoing analysis of LIGO and Virgo data.

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Background - PyGRB

PyGRB is a coherent matched-filtering search that looks for CBC signals associated with external triggers, such as GRBs. The version of PyGRB we're working with is based on PyCBC, which is publicly available and able to be run on non-LIGO clusters. Hence, PyGRB is basically a workflow generator, or a series of scripts that set up PyCBC to specifically look at GRBs.

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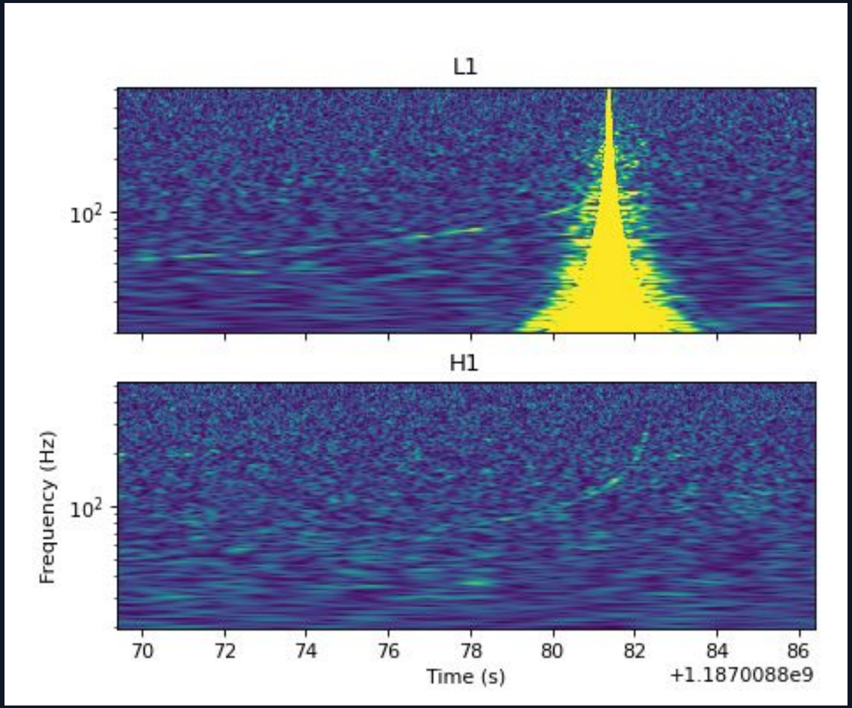

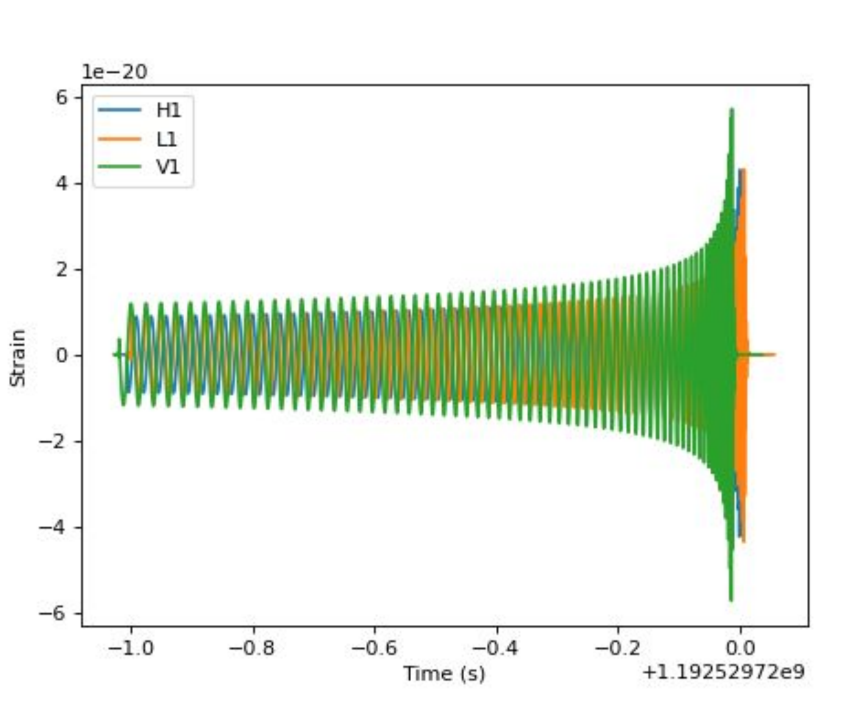

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Background - Expanding Computational Resources

By having medium-latency analysis run on Unity instead of LIGO, there will be available computational resources to immediately analyze the data that otherwise would not happen. Currently, LVK's HPC systems are dedicated to time-sensitive analysis due to the computational needs outpacing the availability of resources and persons. This inadequacy has negatively impacted development of archival analysis pipelines, including PyGRB.

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Background - Unity Cluster

One of the goals of this research is using local HPC resources to offload those non-time-critical development tasks. URI has access to the Unity cluster hosted at the Massachusetts Green High Performance Computing Center (MGHPCC).

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Goals

- Evaluate optimization options and develop strategies
- Expand computational resources for GW detection
- Implement some optimizations
- Perform extensive testing

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Goals (Pivot)

- PyGRB development stalled due to the lead developer not resolving the issues present
- Use parent software, PyCBC, to analyze the root behavior on Unity

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Accomplishments

- Learned how to use LSC's GraceDB Playground (Gravitational-Wave Candidate Event Database)
- Became familiar with Unity, Jupyter notebooks, GIT Repository, and Command Line

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Accomplishments

- Installed PyCBC and PyGRB onto Unity
- Ran PyGRB offline with test cases
- Attended weekly remote meetings for LVK GRB/FRB/Magnetar discussions

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Accomplishments

- Signed up to join LVK's "Rapid Response Team" and receive training on PyGRB and X-Pipeline
- Received access to the Caltech cluster and the LIGO Data Grid (LDG)

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Accomplishments (Pivot)

- Ran PyCBC on Unity and generated gravitational waveforms using waveform approximants
- Analyzed how waveform changes with binary masses and distances; created plots to show signal frequency

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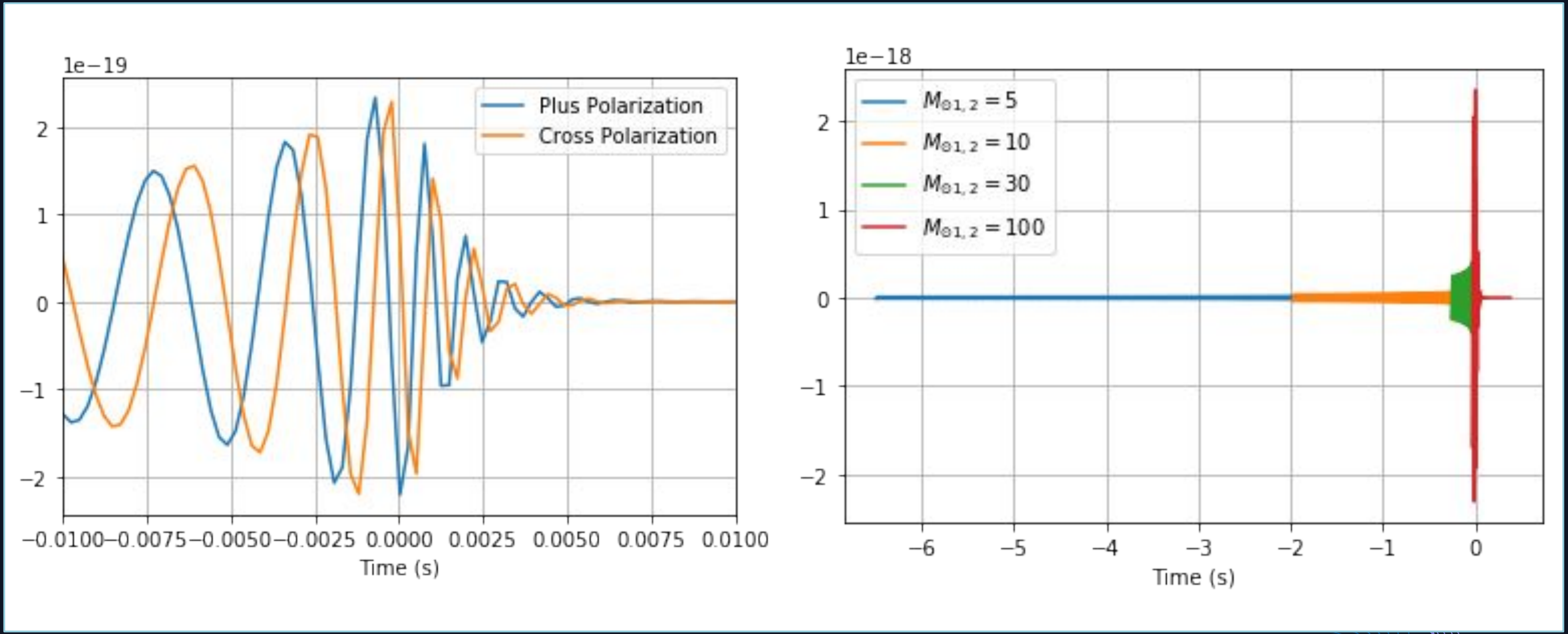

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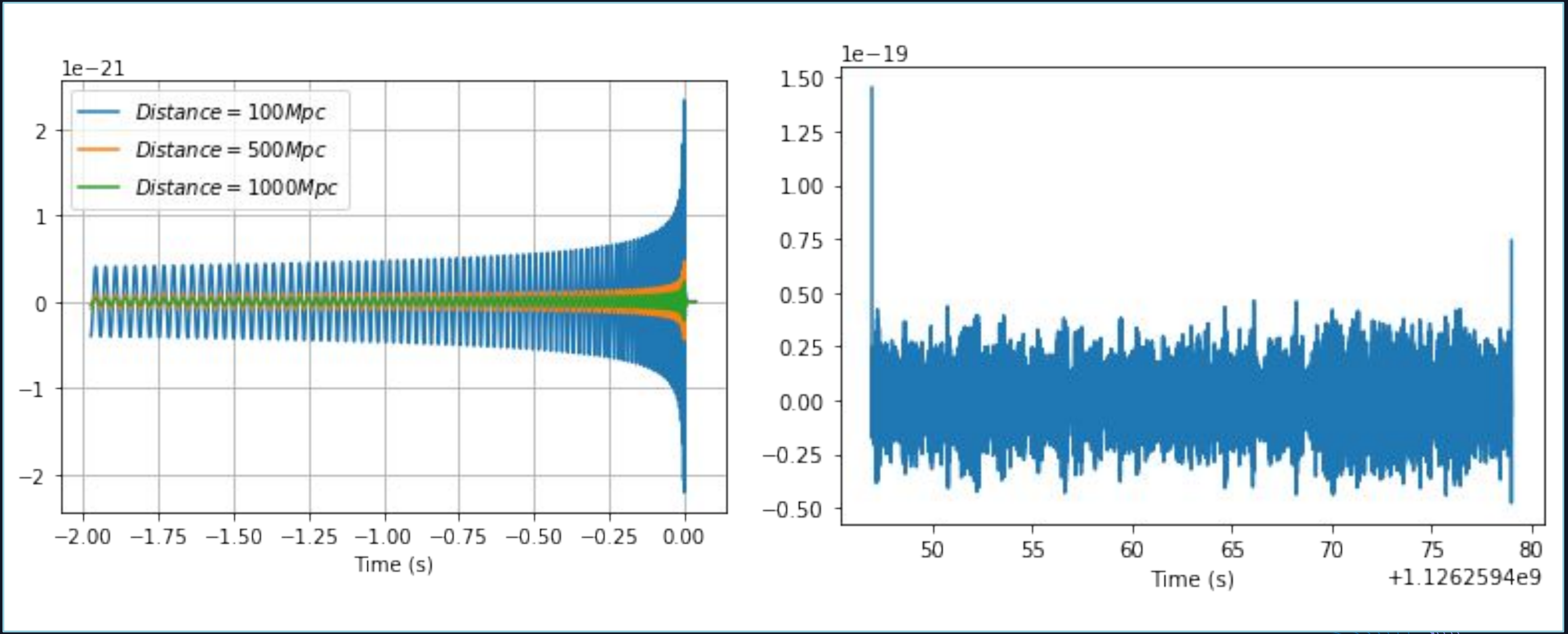

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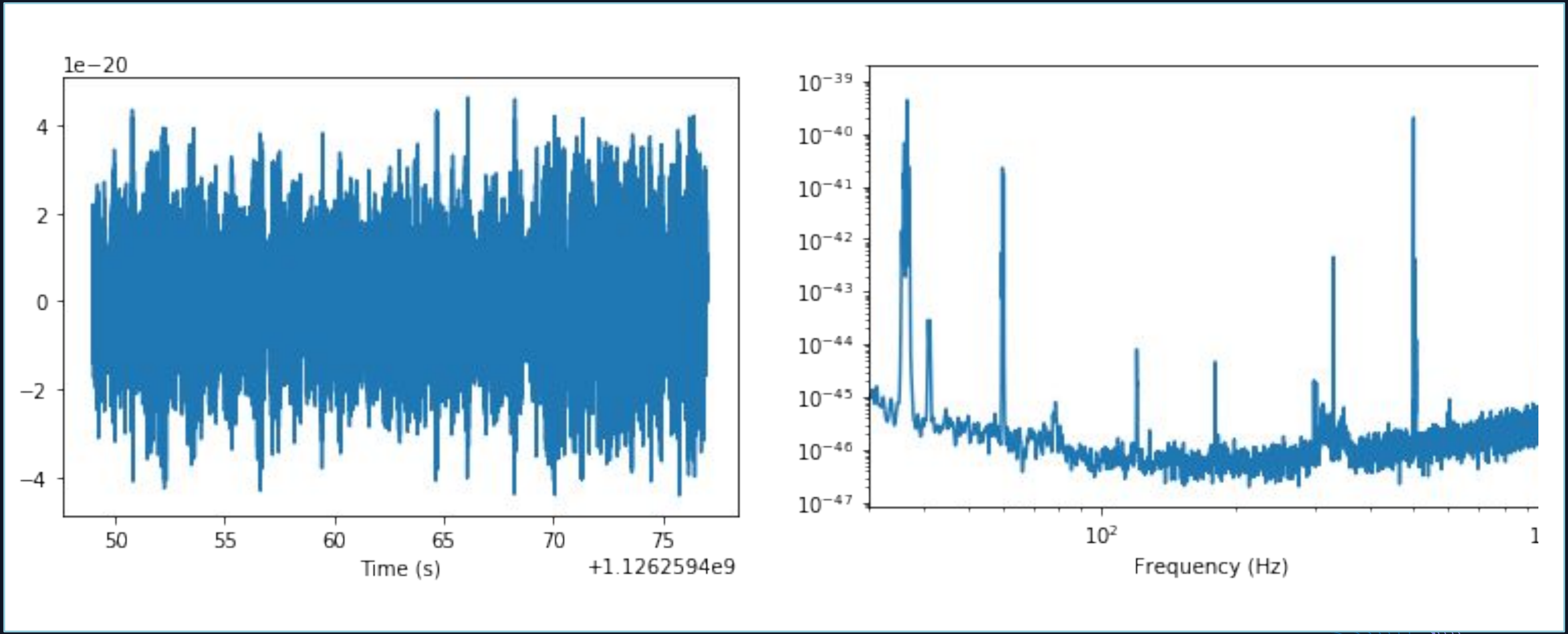

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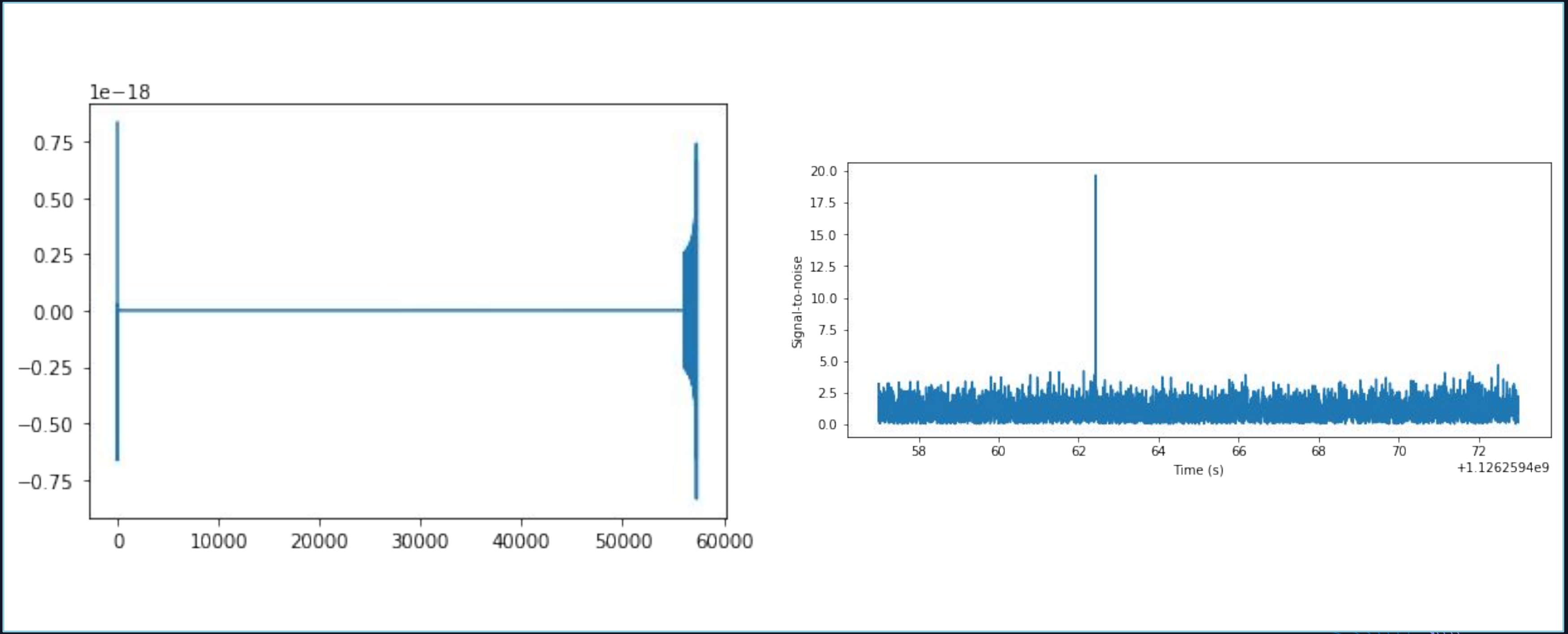

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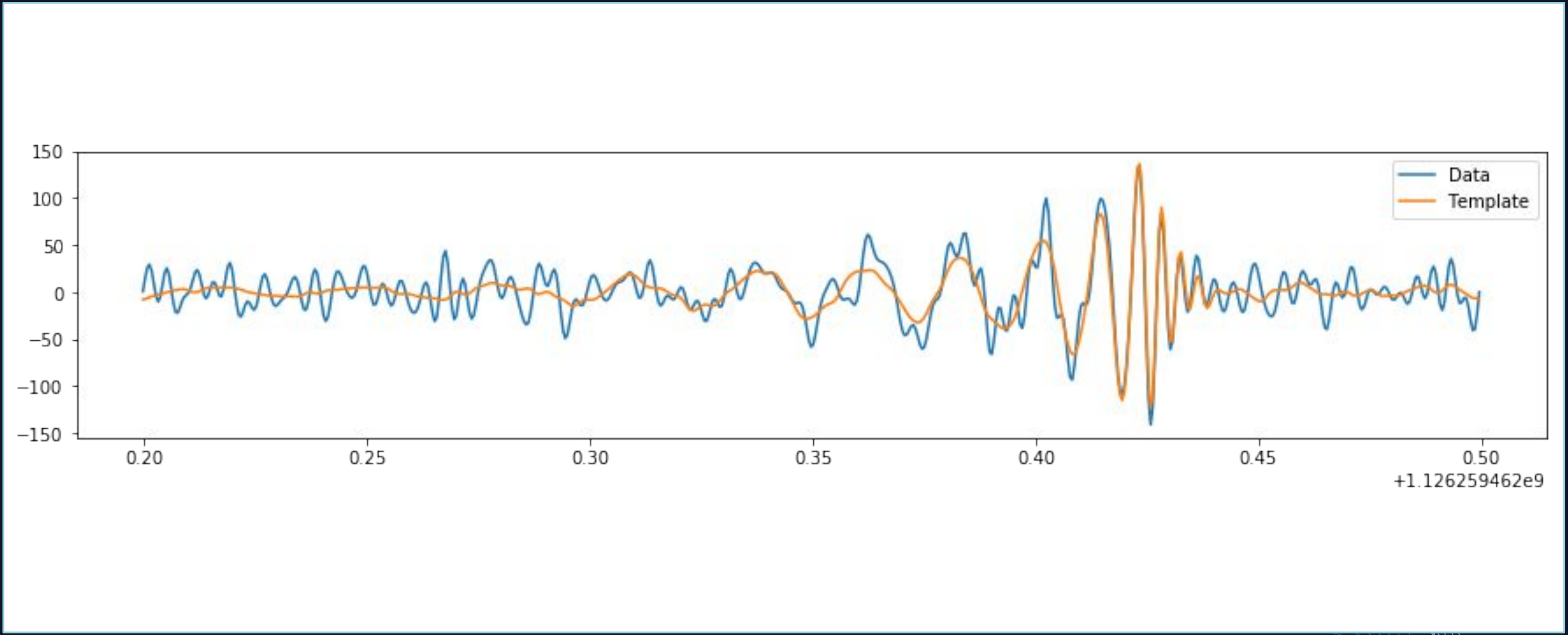

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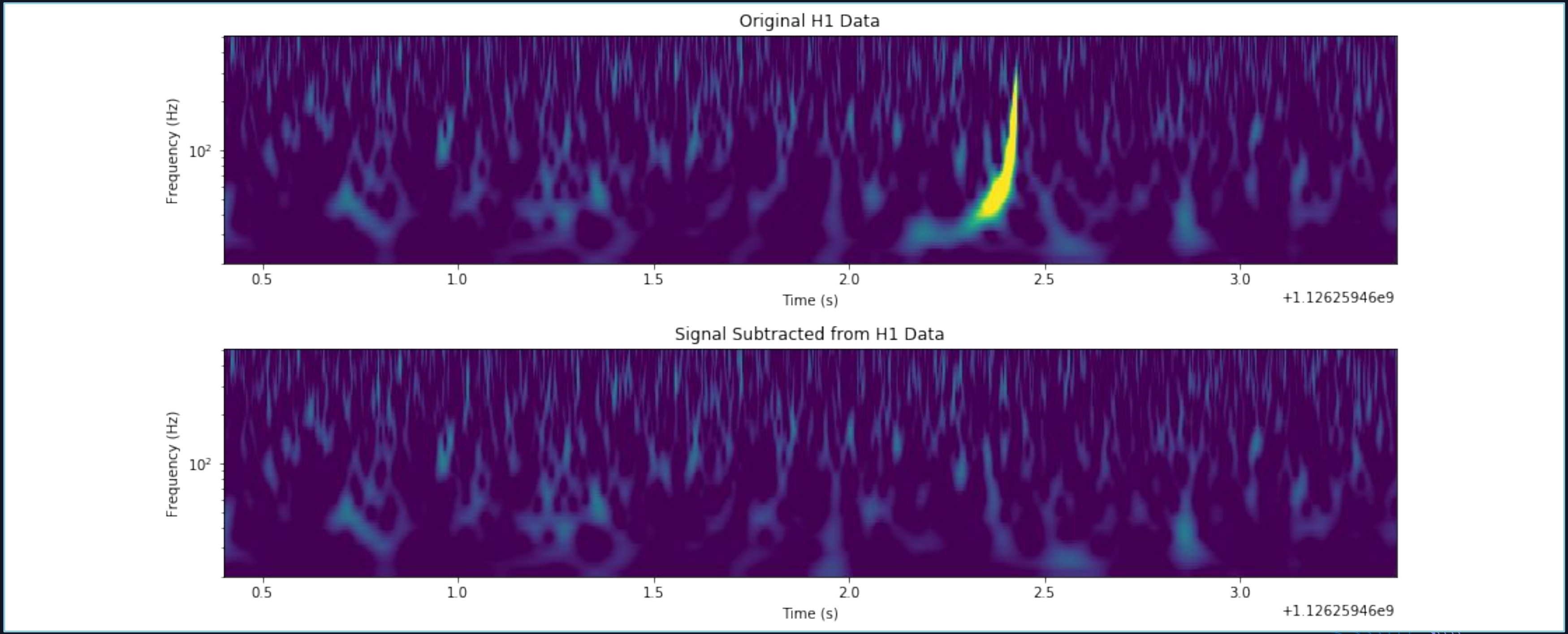

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Difficulties

- Temporary data in the GraceDB Playground is only stored for a brief period of time
- Environment not working; fatal errors while testing
- Lead developer not resolving issues with PyGRB

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Lessons Learned

- Learning the process for running GW analysis
- Becoming familiar with LVK/G resources such as GraceDB and LDG
- Understanding how to use GIT Repository, Unity, Jupytr Notebooks, and Google Colab

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Lessons Learned

- Prioritize communicating more effectively with code errors; more frequent check-ins with PI
- Review basic coding commands and error meanings
- Some issues will be outside of your control; learn how to pivot and still complete your goal

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Contributions & Continuations

NASA RI Space Grant Graduate Fellowship

LIGO-Virgo-KAGRA Meeting - March 2024

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