Exploration of Gravitational Waves Due to Super Massive Cosmic Merging Events

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Abstract -

Applying the principles of general relativity it was predicted that certain cosmological events with rough mass could create a change in space time. Events such as this would include the merging of neutron stars and blackholes. By using the two LIGOS detector labs measurements of the remnants of these events can be recorded and studied to further our understanding of space time.

1. Introduction

The warping of spacetime (that we can currently measure) is a fascinating byproduct of supermassive bodies. These bodies once close enough fall into each other's orbits which causes the bodies to orbit at increasing velocities (and decreasing distance in respect to each other). This amount of energy and force create an impulse large enough to create a “ripple” in time space. If an event is of large enough magnitude and close enough to earth we can detect these ripples at the LIGOS facilities. Using a high powered laser beam that is split into two tangent beams the ripples warp the laser beam over a 4 km distance that then returns to the lab to be analyzed.

2. Process

There have been a number of events recorded in the recent years, though we specifically chose to study three in particular. The events studied were GW190521_074359, GW200311_115853, and GW150914. The data for these experiments is collected from the GWOSC database for GW events [1], this data is then uploaded to a google colab journal where the data is processed.

The processing data to remove the noise is critical due to how small the disturbances of gravitational waves are compared to the noise of the data. To filter the data we first removed the obvious inconsistencies relating to noise from the electrical aspects of the lab, these caused spikes at 60, 120, and 180 Hz.

```
#Imports library to filter data
from gwpy.signal import filter_design
bp = filter_design.bandpass(50, 250, hdata.sample_rate)
```

```python
#Defines 'notches' of data to remove
notches = [filter_design.notch(line, hdata.sample_rate) for
           line in (60, 120, 180)]

#Stores the combination of filters used
zpk = filter_design.concatenate_zpks(bp, *notches)

#Filters out data
hfilt = hdata.filter(zpk, filtfilt=True)
```

This part of the code [2] defines the mentioned spikes as "notches" that are then stored in the notches variable to be filtered out later.

Once filters have been used the same process is then repeated using data from one of the sister facilities to compare the data to confirm the event. These labs overlap their data with a respective time correction (due to their large distance apart, gravitational waves arrive at different times) to get a composite set of data showing the gravitational waves.

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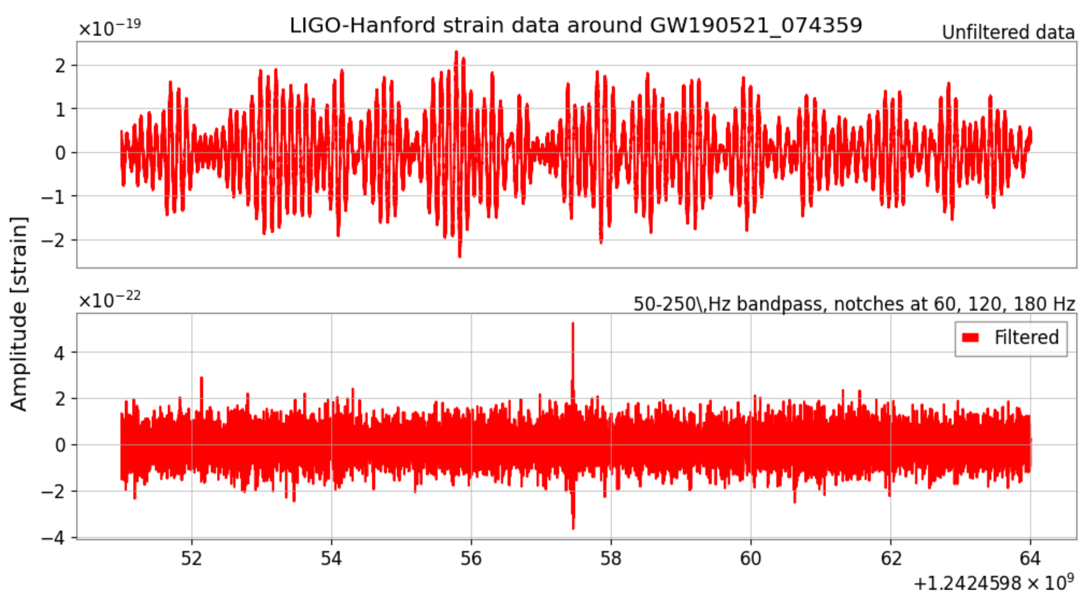
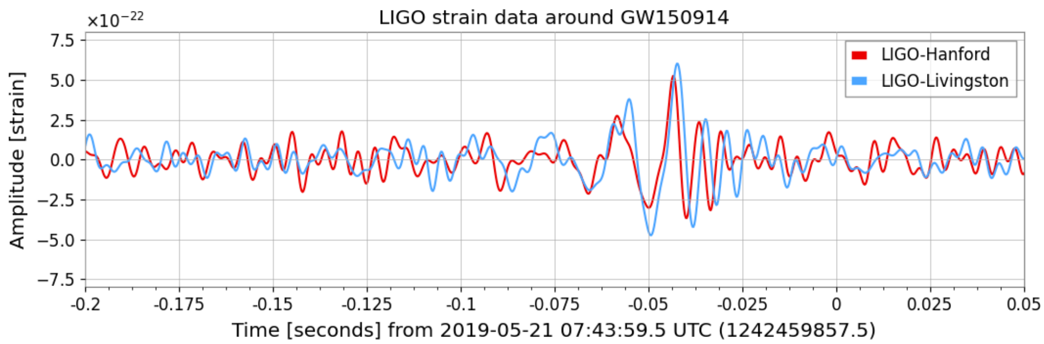
3. Results

Once the data is cleaned and trimmed we get the following figure [3].



This data shows one very clear spike around the ~57.5 range of the x-axis. This is a very good indicator of a gravitational wave event. Once we see a spike like figure 1 has is when a comparison of data is then initiated. We used the same filters as the Hanford data on the Livingston data set for consistencies and over layed the findings [4].



There was an overlap of great significance indicating the presence of a gravitational wave event. Along with that there is a behavior pattern that matches the theoretical predictions. This sudden increase then drop in the strain shows clear evidence of gravitation wave distortion.

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4. Discussion

These findings are of great importance to the study of general relativity. In recent years we have improved our technology to detect more gravitational events which allows a more indepth comparison and understanding of how these events traverse through our universe. This specific study will be a critical aspect to understanding and measuring the effects of general relativity.

In the figures above the event used the event GW190521 which has the black hole masses to be approximately 42.2 (+5.9, - 4.8), and 32.8 (+5.4, -6.4), with a distance of 1240 Mpc (+400, -570). This is above the average of the events which might have been a good indicator why it has a clear signal. Another good possibility could be that there were ~3.7 solar masses during the process of merging creating the gravitational waves that we detected. Using E = mc^2 we can calculate E = 2 x 10^30 (one solar mass) * 3.7 * (3x10^8)^2 to be the total energy which equates to 6.66x10^47 J.

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5. Conclusions

By using the LIGOS detectors we have been able to detect and study the effects of gravitational waves. More improvements need to be made with the scientific equipment currently used to have a better understanding of neutron star mergers along with better sensitivity to detect more events. In collecting more data we can test our theories of general relativity to strengthen our current understanding of the folding of space time.

References

[1] - GW data set, Event List (gwosc.org)
[2] - GravitationalWave.ipynb,In (21) Everett Helm
[3] - GravitationalWave.ipynb,In (41) Everett Helm
[3] - GravitationalWave.ipynb,In (46) Everett Helm

AI Statement

Our group did have assistance with generative AI through Gemini AI, this was used in the coding aspect of the project to help look up how certain functions work. There was no notable or heavy reliance on AI to create any specific code, and such no inquiries or prompts were used. AI was used to look up certain syntax issues and to explain bugs in the code when debugging.

Work Statement

Work was evenly distributed with both members working on all aspects of the project. To cater to each group members strengths each group member specialized as we saw fit, this distribution is as follows:

Everett was the lead in the written report with a majority of the written components and formatting. It was also his responsibility to proofread and correct the slides for the oral presentation.

Ember was the lead on the oral report slides and presentation preparations. In addition most code referenced is Ember's code for this project. It was also her responsibility to proofread and correct the written report.

Both group members helped each other on their respective part of the project to ensure the best product we could produce.