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Gravitational Waves and The Study of GW200224_222234

Scientific Importance and Motivation

The existence of gravitational waves was first predicted by Einstein's theory of general relativity in 1915. The theory of general relativity describes gravity as the curvature of spacetime due to mass and energy. Gravitational waves are ripples in spacetime which are caused by the acceleration of massive objects. Gravitational waves carry information about the most energetic astrophysical events, such as black hole mergers. The detection and analysis of gravitational waves rely on advanced mathematical techniques and technologies to help unlock the secrets to the universe.

LIGO

Detecting Gravitational waves involves extremely precise instruments, such as those at the Laser Interferometer Gravitational-Wave Observatory (LIGO). LIGO detects gravitational waves using a powerful laser light source that emits a single-frequency light beam. The laser is split and each beam travels down two long vacuums that are several kilometers long. A mirror is at the end of these tunnels that reflects the beams back to the splitter, and there is a detection when the beams do not perfectly overlap.

There are observatories in Livingston, Louisiana and Hanford, Washington. Having two detectors allows LIGO to distinguish gravitational waves from environmental factors or instrumental error. That is, only a true gravitational wave would appear in both detectors.

Data

The Gravitation Wave Open Science Center (GWOSC) provides the full list of gravitational waves captured by LIGO. There have been 93 events recorded by GWOSC, which mostly consist of black hole mergers. For my research, I will study GW200224_222234 with GPS time of 1266618172.4. The individual masses of the black holes are 40.0 Solar Masses and 32.5 Solar Masses, with a resulting mass of 72.2 Solar Masses. The mass of a black hole can be calculated using the equation of the Schwarzschild Radius, $R_s = 2GM/c^2$, where R_s is the Schwarzschild radius, G is the gravitational constant, M is the mass of the black hole, and c is the speed of light. To find the mass of a black hole, rearrange the equation to solve for M. That is, $M = (R_s)(c^2)/(2G)$. When two black holes merge, the mass of the resulting black hole mass is the sum of the black holes, assuming that no mass is lost as gravitational waves during the merger. The sum of the two black holes is an approximation, as we can see that some mass was lost as gravitational waves.

Method

My goal for the study of GW200224_222234 is to produce a sound file to replicate the noise of the black hole merger. The raw data provided from the 'gwpy' package is first edited by filtering out unwanted signals such as environmental or instrumental noise (Figure 1). The data is then mapped to the time domain for further analysis. To confirm that the detection is indeed a gravitational wave, I used data from LIGO-Hanford and LIGO-Livingston (Figure 2). Both observatories captured this event, which confirms that this event was a gravitational wave. To convert the gravitational wave into a sound file, I mapped the frequencies into audible frequencies to create a continuous sound (Figure 3). The resulting sound file is not a direct representation of the gravitational wave but rather a replica designed to be accessible to the human ear. Gravitational waves are of extremely low frequency, so the sound file is an artificial representation.

Results

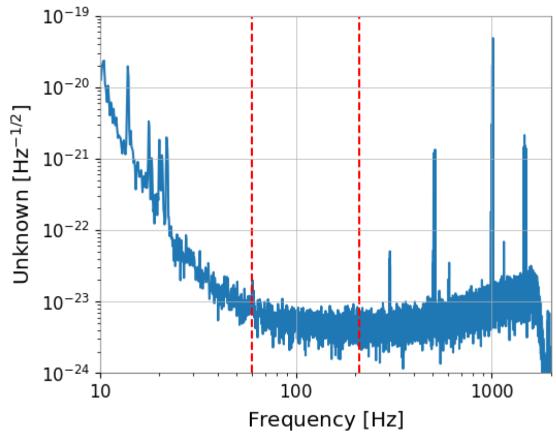

Figure 1: Filtering Out Unwanted Frequencies

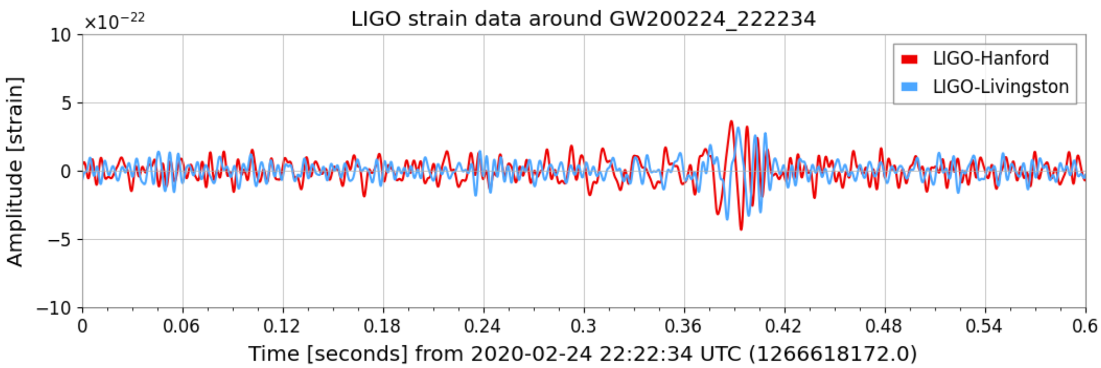

Figure 2: Data from both LIGO Observatories

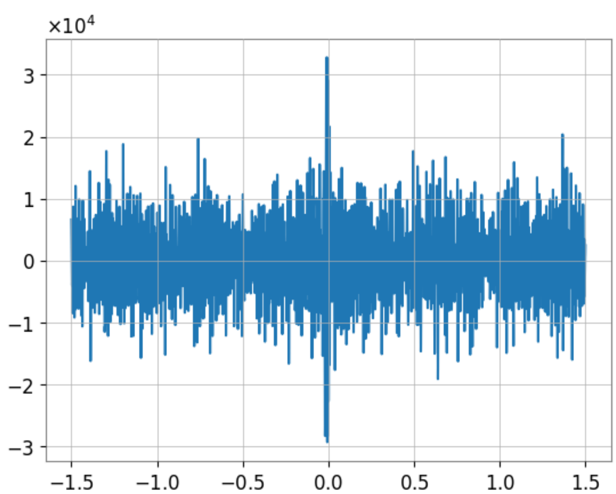

Figure 3: Graph of Sound Wave

Conclusion

The discovery and study of gravitational waves have introduced a new understanding of the universe. These "ripples" in spacetime were first observed in 2015 and validated Einstein's theory of general relativity. Additionally, it has opened the door to a new field of astronomy, enabling us to study events like black hole mergers in this report and even star collisions. As wave detectors such as those at LIGO become more advanced, gravitational waves will forever be a milestone in the study of astronomy.

References

1. **https://www.ligo.caltech.edu/**
2. **https://gwosc.org/eventapi/html/allevents/**