Scientific Importance and Motivation

In Newton’s view, the space is flat and static, but Einstein’s theory of General Relativity first stated that the space is curved and changeable. In Einstein’s view, space have moving riddles, which are called “Gravitational Wave”. The study of Gravitational Wave is an important topic for both physics and astronomy since Gravitational Wave provide a new way for scientists to view and understand the universe. Before Gravitational Wave, the only method that scientists have to study the universe is through EM radiation which had a lot of limitations such as can be absorbed, reflected, refracted, or bent by gravity itself 1. While gravitational waves can bring almost original information traveling long distance since they don’t have strong interaction with any matter. Through capturing the signal of gravitational waves, we could get the duration, distance of events that caused the gravitational waves, the mass, and the radius of the objects. Given all the advantages gravitational waves have, one thing we still have to considered is that how do we test whether gravitational waves exist? According to Einstein, gravitational waves are “ripple” in the space-time, and massive accelerating objects will disrupt space-times, then result in gravitational waves that travel at the speed of light2. One of the most power event in the universe is two black holes orbit around and merge with each other which would convert huge amount of mass in an extremely short time, which makes them the perfect events to cause gravitational waves. A gravitational wave event was captured by LIGO detectors in 2020-01-29 has a strong signal of gravitational waves, which makes it a great example to prove the existence of gravitational waves and Einstein’s theory of General Relativity.

Method and Math

Gravitational waves require highly sensitive equipment, such as Laser Interferometer Gravitational-Wave Observatory, also known as LIGO. Normally, a laser light will split into two arms of LIGO, reflected by two mirrors, and put together by a “beam splitter”, where they cancel each other out. When the two laser lights didn’t cancel each other out, it implied the presence of interferences such as gravitational waves. However, since LIGO is a highly sensitive equipment, it also will record tremors such as wind, or sound from other equipment, which means the first step of finding gravitational waves is to exclude the noise that recorded by LIGO, which will be achieved by a filter function in python. After excluding all the tremor noises recorded by LIGO, we could zoom in the data and check if there is still a spike data. If there is still a spike, we could confirm the existence of gravitational and Einstein’s theory. Then with the gravitational wave that LIGO recorded, we could calculate the information carried by gravitational waves, such as the masses merged black holes by using the formula and the distance between where these two black holes merge and earth since the distance that gravitational wave traveled is inversely proportional to the decay of strain h, which we could measure. Through python, we could also translate the gravitational waves into sound, then we will perform a Fourier transform to increase the frequency of gravitational waves sound so that it’s more audible. During the Fourier transform, we will increase the original index of each data by 3, which reducing the spacing between waves by 3, so the frequency is increased by 3.

Result and Interpretation

A graph of a red line

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Figure 1: Comparison of Data before and after the Filter

As mentioned before, LIGO is a sensitive equipment that will record a lot of noise. Figure1 portrays the comparison between date recorded by LIGO before and after the filter. The upper graph shows several spikes which are the noises, but after we filter out all the noises, there is only one spike left around 47 seconds into the data in the lower picture. We could zoom in the picture to better understand the spike.

A graph of a graph

Description automatically generated with medium confidence

Figure 2: Zoon-In of LIGO data after the filter

A graph showing a graph of a train

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Figure 3: Comparison of data from two LIGO Detectors after the filter

Figure 2 is when we zoom in the time period when LIGO record the interference and the picture shows a clearly spike which represents the gravitational wave. Figure 3 is the comparison of data recorded by two LIGO detectors located in Hanford and Livingston, which shows that the LIGO in Livingston also has recorded the spike and agree with the data recorded by LIGO-Hanford. The spike recorded by both LIGOs has proven the existence of gravitational waves and the theory of Einstein that the space is curved and dynamic since we could capture the “ripples” in the space. Then we use the gravitational wave to calculate the mass and distance of the merged black holes and perform sonification of the gravitational wave. We could get the period before merging is about 0.016 seconds, the δt we needed, and plug into the formula, we could get the mass of merged black hole is 64.625 solar mass. From figure2, we could also see the strain of the gravitational wave is about 4.2 \* 10-22 and we also knew the radius of the merged black hole can be calculated from mass, then we could divide the radius by the strain and get the merger events happened 7363 \* 106 parsec away.

A graph of a number of numbers

Description automatically generated with medium confidence

Figure 4: the Frequency of gravitational waves before and after Frequency Increase

Given the gravitational wave data recorded by LIGO, another thing that we could do is make the gravitational wave audible, so that we could hear the gravitational wave. The picture above in figure 2 is the 0.04 seconds window of frequencies recorded by LIGO around gravitational wave being captured, which we could see is the spike at around 0.03 seconds. However, we want to make this sound more audible, by which we did a Fourier transform and result in the picture below where the spacing between the waves is reduced by a factor of 3, which means the frequency is increased by 3.

Conclusion

This analysis tries to prove that gravitational waves are exist and perform a sonification of the gravitational wave based on the data that recorded by LIGO recorded of a black hole merging event at 2020-01-29. After excluding the noises that recorded during the time period, the spike that LIGO recorded represent the gravitational wave LIGO captured and the data from LIGO-Livingston agrees with the data from LIGO-Hanford. Then we perform the sonification of gravitational waves, and use Fourier transform to increase the frequency of gravitational waves so that we can hear the gravitational waves. In conclusion, the data recorded by LIGOs shows convincing evidence that the gravitational waves exist, and the space is dynamic and curved as Einstein stated.

References

1. “Why Detect Them?” Caltech. Accessed October 20, 2023. <https://www.ligo.caltech.edu/page/why-detect-gw>