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Research on the classifications of gravitational wave

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Abstract. In daily life, we can transmit and obtain information through mechanical waves and electromagnetic waves. For example, judging where the fish swims from the flooded water waves, and learns from the wonderful music to know what kind of instrument the musicians are playing and communicating through the radio waves. Gravitational waves, a fundamental prediction of Einstein's theory of general relativity, have revolutionized our understanding of the universe. This essay explores the background of research on gravitational waves, tracing their theoretical origins to the early 20th century and highlighting their recent detection in 2015. The research technique employed involves highly sensitive interferometers, such as LIGO and Virgo, which can detect the minuscule distortions in space-time caused by these elusive waves. By observing the gravitational waves emitted during cataclysmic cosmic events, scientists can now delve deeper into the nature of black holes, neutron stars, and the origin of our universe. In conclusion, the discovery of gravitational waves opens up new avenues for exploring the cosmos, providing unprecedented insights into the fabric of space-time itself.

Keywords: LGIO, signal, frequency, astronomical, gravitational wave.

1. Introduction

The quest for understanding and exploring our universe can be traced back to the moment a Neanderthal gazed upon the star-filled night sky. This encounter sparked a deep curiosity about the cosmos, serving as the impetus for advancements in astronomy and the continuous pursuit of improved techniques to capture clearer and more precise images of distant stars. Considerable amounts of capital and resources have been invested in developing astronomical instruments, acting as the "eyes" of humanity. However, despite these efforts, the outcomes have often left us somewhat dissatisfied. Gravitational waves present a promising avenue that may enable us to detect and study unique astronomical events more effectively, potentially offering a breakthrough in our understanding of the cosmos. This article will mainly discuss the defects of traditional ways of astronomical observation and possible applications of gravitational wave detection. The first part of this article will talk about the reason why traditional observation cannot cover all the requirements of astronomy research, and the second part of this article will precisely describe the definition, zoology, and inspiration of gravitational waves.

2. Definition and classification of gravitational wave

The percentage of lost and effectiveness of information transfer are heavily reliant on the chosen medium. For instance, traditional mail can take weeks to reach someone on the opposite side of the

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Earth, whereas the use of email can reduce this time interval to less than a second, thanks to its remarkable speed of 299,792,458 meters per second (based on the 1983 standard). Email has become one of the most efficient means of information exchange for humans. While many astronomical instruments are designed to capture electromagnetic waves emitted by stars, their reliability inevitably diminishes during interstellar travel. This decline can be attributed, in part, to the presence of interplanetary dust. These layers of minute silicon, carbon, and aluminum particles have the capacity to absorb light from distant objects. Consequently, some groundbreaking discoveries based on the analysis of electromagnetic waves can be easily disrupted by the obstructive nature of interplanetary dust [1].

2.1. Definition

In gravitational wave astronomy, the hindrances posed by dust clouds or other obstructions can be disregarded. While the field of traditional astronomy may encounter challenges such as the obstruction of an astronomical telescope's "sight" by a dust shadow, the instrument employed for the indirect detection of gravitational waves, the Laser Interferometer Gravitational-wave Observatory (LIGO), operates more akin to an "ear" than an "eye." In other words, LIGO functions as a receiver of vibrations, enabling it to bypass the issues typically associated with visual obstruction. The reliability of this technology has been preliminarily proved by comparing any observable black hole or other cosmic events with possible gravitational wave signals[2].

For example, as shown in figure 1, there is a plot showing the properties of gravitational-wave detections and their candidates. Scientists will compare any observable signals of radio waves, x-rays, or gamma rays from possible candidates with these gravitational wave signals [3]. On August 17, 2017, at 8:41 a.m., a gravitational wave signal, GW170817, was detected. The properties of this signal tell us that it should be gravitational waves from a pair of neutron stars. Almost at the same time, a gamma ray burst was detected by the Gamma-ray Burst Monitor on NASA’s Fermi space telescope, and then these two signals were put together to be analyzed by LIGO-Virgo analysis software. The result is that it was highly unlikely to be a chance coincidence, so it is the first time that a cosmic event has been observed with both gravitational waves and electromagnetic waves and given proof for the reliability of gravitational wave detection.

Figure 1. Photo of LIGO Livingston.

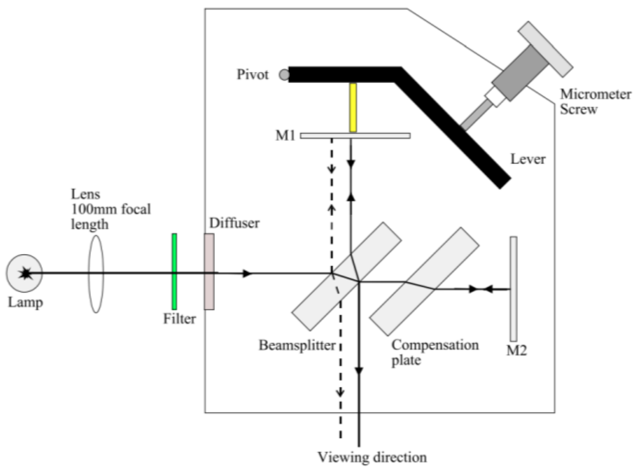

Figure 2. A Michelson Interferometer.

Back to the end of 17th century, at that time and age, what was called "force" was considered to only act between objects that directly contact each other or indirectly contact each other by substantial medium. Then, time comes to the point that is recorded in a famous story: Newton and the apple tree. In the story, while sitting under the tree, he observed an apple falling from the tree and started to imagine an invisible "rope" serving as the medium of such a king of force. Then he realized that the moon moving on its orbit must have been restricted by the same invisible "rope". Everyone knows the end of this story: Newton tried to find this mysterious "rope" and force, then he worked out the relationship between mass and this force called "gravitational force" by his calculation, which is that every object with mass has its own gravity field, and the magnitude of gravitational force is proportional to the mass of the object, which serves as the origin of the gravity field.

$$F = \frac{GM_1M_2}{R^2} \quad (1)$$

According to his prediction, when a mass changes its position, the gravitational field throughout the whole universe changes, and this transformation is instantaneous, meaning that resultant forces acting on every object in the universe change at the same time. However, when time comes to the 20th century, Einstein's Theory of General Relativity tells us that it is impossible for any form of information to transmit with a velocity higher than the light speed constant If four vectors, $q^2 < 0$ then separation in space must follow the equation that

$$S^2 > (C\Delta t)^2 \quad (2)$$

Means that no causal relationship is possible; there will be an inertial system where the events are simultaneous So, the variation of the gravitational field will go through the universe at the speed of light, and this information about the variation of the gravitational field is the gravitational wave.

2.2. Observation and LGIO

Gravitational waves are conduction of vibration of gravitational fields generated by movement of massive object. They are the fluctuations of space-time that travel at the speed of light and are very different from electromagnetic waves. Since this physics concept was proposed by Albert Einstein in the form of a hypothesis, there's no way to directly detect gravitational waves, but we can still find a solution to receive their energy with LGIO [3].

In comparison to astronomical telescopes or colossal physics instruments like the Large Hadron Collider, the structure and operation of LIGO are surprisingly straightforward. LIGO's key components include a laser source, a beam splitter that divides the laser into two beams of equal frequency, perpendicular to each other, two mirrors situated in separate "arms" at precise kilometer-scale distances from the splitter, and a laser detector. As depicted in Figure 2, the reflected beams recombine at the beam splitter. In perfect destructive interference, the detector remains photonless. However, when a gravitational wave traverses the entirety of the LIGO instrument, it induces a subtle distortion in spacetime, causing a slight displacement in the two "arms" and altering the mirror separation by a small, random amount. This temporary disruption of perfect destructive interference enables the detector to receive photons and record them, constituting a gravitational wave signal [4]. What could be noticed is that the structure of LGIO is very similar to that of a Michelson interferometer, which is another famous apparatus that gave a strong proof of the inexistence of aether and led to the building up of special relativity theory.

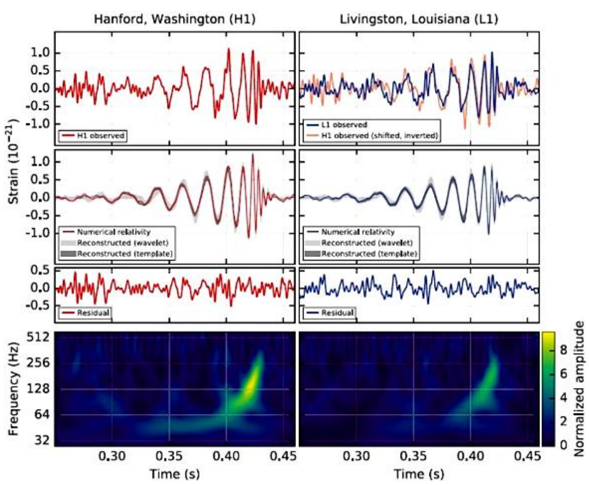

Figure 3. GW150914 signal observed by the twin LIGO observatories at Livingston, Louisiana, and Hanford, Washington.

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2.3. Classification

Based on all the signals that were already detected by LIGO, especially several important and characteristic detections, scientists were allowed to classify different types of gravitational waves and the objects that may be their sources.

Continuous Gravitational Waves. The possible source of this kind of gravitational wave that is shown in a continuous graph is a single massive spinning interstellar object like a neutron star. The continuity of this kind of gravitational wave is caused by the imperfection and asymmetry of the spherical shape of this star. If the rate of spin remains constant, the "mass flux", to be more specific, the rate of change of a pass passing through a certain space, is none-zero and constant, leading to gravitational waves that continuously have the same frequency and amplitude, much like a singer holding a single note [5].

Compact Binary Inspiral Gravitational Waves. Almost all of the signals that have been identified as being created by pairs of objects like black holes or other massive objects have this kind of gravitational wave form. Each of these types of binary pairings creates its own unique pattern of gravitational waves because they have different mass distributions, different Lagrange points, or different angular momentum, but the overall mechanism of wave generation and inspiral generation is the same. This process with gravitational waves continuously takes energy away from this system and causes the objects to spirally close to each other; at the end, they will contact and collide with each other. This also results in an acceleration of the two objects, so the rate of change of mass is non-zero and increasing, thus creating gravitational waves of increasing strength [5].

2.4. Stochastic gravitational waves(random gravitational waves)

Every day and every time, there are small gravitational waves that LIGO is unable to precisely analyze or even detect passing through the earth. These are known as stochastic gravitational waves since they have almost no noticeable features. At least part of this stochastic signal has its origins in the Big Bang [5]. This is the most mysterious kind of gravitational wave; we can ‘see’ the history of our universe from them. At 9 a.m. UTC on September 14, 2015, both LIGO Hanford and LIGO Livingston independently observed an identical signal known as the GW150914 signal. This monumental event marked the first-ever detection of a gravitational wave, affirming the validity of Einstein's theory of general relativity. Moreover, it provided compelling evidence for the merger of a binary black hole system. Prior to this observation, the behaviors of massive objects like neutron stars or black holes were merely theoretical predictions, as traditional electromagnetic wave telescopes could only detect them through their radiation pulses within a limited spatial range. Remarkably, the GW150914 signal can be converted into sound due to its inherent vibrational nature, a transformation achieved by LIGO. The resulting audio resembles a drop of water falling onto a water surface or the bursting of a large bubble. This auditory representation, referred to as a "chirp" by scientists, evokes the cry of a black hole or the whisper of the universe [6].

3. Conclusion

Overall, Gravitational wave detection, while remarkable, remains an imperfect technology. One persistent challenge that plagues all detectors, including LIGO, is the signal attenuation. Once the signal intensity diminishes below the background noise level, detection becomes unfeasible. Although LIGO excels in its ability to capture vibrations and has the world's most advanced external vibration absorption structure, the issue of background noise remains a significant concern due to its location on Earth. Another limitation is that LIGO lacks a circular "shell," preventing it from pinpointing a specific direction or area. Consequently, the positional accuracy provided by LIGO is inferior to that of traditional astronomical telescopes [7]. Nonetheless, gravitational wave detection represents a monumental milestone in the field of astronomy. In the foreseeable future, there is hope that we may have the opportunity to listen to the universe's inaugural cries at its birth.

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