# Analysis Of the Principe, Facility and Applications for Gravitation Wave Searching

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**Abstract.** Gravitational wave detection has become a crucial tool in understanding the universe, with applications in the origin of the universe, black hole physics, galaxy evolution, and more. Researchers have used gravitational wave research to explore dark matter, dark energy, and other enigmatic phenomena, offering new insights into the evolution of the universe. This study will systematically analyze the principle as well as the state-of-art facilities and applications for gravitational wave searching. The similarities between gravitational waves and electromagnetic waves suggest that detecting gravitational waves is feasible through methods akin to those used for electromagnetic waves. This has prompted extensive studies on theoretical and experimental observations of gravitational waves, with researchers delving into cutting-edge research on the topic. The properties of gravitational waves resemble electromagnetic waves, providing a new means of observing astronomical processes and potentially unveiling novel information about the universe. Collaboration among global detectors has significantly enhanced the understanding of celestial events and phenomena, paving the way for groundbreaking discoveries in astrophysics and cosmology. Continued research on gravitational waves promises to deepen the comprehension of the universe's fundamental forces and structures, offering opportunities for revolutionary discoveries in the future.

**Keywords:** Gravitational wave searching; LIGO; detection schemes.

## 1. Introduction

In the study of electromagnetic fields, one can find the form of source-producing field in electromagnetism named Coulomb’s law. In addition, according to the Newton’s work, one can find the formula of gravitational fields produced by mass points. As one can see, these two formulae are basically the same. So just as the changes of charge distribution will produce electromagnetic waves, will the changes of matter distribution have the same effect called gravitational wave. With the interest to this effect, the author has studied a series of problems of theoretical or experimental research and observation of gravitational waves, and studied and sorted out the work done by many physicists on the cutting-edge topic of gravitational waves. Under the current theoretical framework, gravitational waves have many properties similar to electromagnetic waves, and the information carried on gravitational waves also provides with a new way to observe astronomical processes.

Albert Einstein published the theory of general relativity in 1915 as a new theory to describe gravity. The theory of general relativity predicted the existence of gravitational waves which are distortions of geometry that propagate at the speed of light. The existence of gravitational waves in the next period of the twentieth century has been widely speculated by many scientists. Among them, Robert H. Dicke and James Peebles developed a method in the 1960s to verify the existence of gravitational waves by using cosmic microwave background radiation. After this result, Joseph Taylor and Russell Hulse discovered a pair of pulsar systems in 1974. Their orbital period will change due to the influence of gravitational wave radiation. This discovery of the two scientists provides indirect evidence for the existence of gravitational waves [1, 2].

Gravitational waves are an important celestial phenomenon predicted by Einstein’s theory of general relativity. They are spacetime ripples caused by the changes in the distribution of matter, like movement or collision of massive objects. As they are highly related to the spacetime and matter distribution and they are fast enough to bring some information to us, they can reveal some of the most mysterious phenomena in the universe. The detection of gravitational waves opens up a new means of astronomical observation and provides an important window for human beings to explore the universe in depth [3, 4]. Gravitational wave research has undergone a long historical development process until September 2015, when LIGO (Laser Interferometer Gravitational-Wave Observatory) successfully detected the merger of two black holes for the first time [5]. The gravitational wave signal marks the arrival of a new era in gravitational wave physics. Since then, gravitational wave research has become a hot topic in the fields of astrophysics, relativity and cosmology [6, 7].

The literature on gravitational waves covers the history, theoretical basis and practical application of gravitational wave research. Since Einstein published the theory of general relativity, gravitational waves have been the research focus of astrophysics, and its first successful direct detection marks a revolutionary breakthrough in gravitational wave physics. The literature review of gravitational waves discusses the generation mechanism, propagation characteristics and the development of detection technology of gravitational waves. The construction and operation of gravitational wave detection facilities such as LIGO, Virgo and KAGRA have also received extensive attention [8, 9]. The literature review of gravitational waves provides researchers with important information for in-depth understanding of the frontiers of gravitational wave physics and astrophysics, and promotes the development and progress of gravitational wave research.

In the progress of gravitational wave research, in addition to LIGO, Virgo detectors, KAGRA detectors, etc. have also joined the ranks of gravitational wave detection one after another, forming a global network. The cooperation and complementarity of these probes make the positioning and characteristic analyses of gravitational wave events more accurate, providing astronomers with more information about various celestial events in the universe.

At the same time, gravitational wave detection is also increasingly involved in the origin of the universe, black hole physics, galaxy evolution and other fields. With the help of the results of gravitational wave research, researchers have explored dark matter, dark energy and other mysterious problems in the universe, providing new clues to solve the mystery of the evolution of the universe.

## 2. Basic Descriptions

Gravitational waves are fluctuations caused by the changes of the gravitational field, which are predicted by Einstein's theory of general relativity. The propagation speed of gravitational waves is equal to the speed of light, which has characteristics similar to electromagnetic waves. These waves can propagate without any medium, or one can say that the propagation medium is spacetime itself. Gravitational wave sources are commonly large-mass objects in the universe that accelerate their motion, such as stars, black holes, neutron stars, etc. However, when these objects move, they will cause the vibration of the surrounding spacetime structure, thus generating gravitational waves. Gravitational waves can carry energy and propagate in the form of waves in the universe. In the case of the first order approximation, the equation satisfied by the gravitational waves without any source is the d’Alembert equation, just the same as the electromagnetic waves. This result shows that the gravitational waves can be radiated and propagated in the same way as the electromagnetic waves with the propagation speed at the speed of light [6].

In the theory of general relativity, the matter and the spacetime will affect each other, cause the changes in matter distribution and spacetime structure. One use metric as a one of the markers to quantify the curvature of spacetime. So, the gravitational wave is actually metric wave. Although any change of the matter distribution would cause the radiation of some gravitational waves, one can still hardly observe any gravitational waves. Because their amplitude is most likely to be very small, so one just cannot distinguish the signal of gravitational waves from the noises, such as the heat noise. However, in the process of moving large-mass objects such as black holes, due to their significant mass changes, it is possible for to observe the gravitational wave signal. For example, in the LIGO experiment, after the merger of the two black holes, they lost part of their mass and radiated this part of energy outward in the form of gravitational waves, which was observed by us. This experiment detected the gravitational waves released by the combination of black holes for the first time, opening the era of gravitational wave observation [9].

## 3. Principle

Due to the special properties of gravitational waves, the passage of gravitational waves will cause small distortions in space. One can detect the existence and propagation of gravitational waves by detecting the distortion of space. When gravitational waves pass through the earth, it will lead to the distortion and vibration of the space, cause structural changes of the interferometer, produce a tiny optical path difference and eventually make the light output of the interferometer changes. One can detect the gravitational waves by analyzing these changes. Moreover, one can use these data to estimate some properties of the gravitational waves like the frequency and the amplitude, then one can get some information of the source of these waves, such as the position.

LIGO (Laser Interferometry Gravitational Wave Observatory) is a device used to detect gravitational waves. LIGO consists of two optical arms perpendicular to each other and 4 kilometers in length. The laser beam is emitted from the laser, propagates along the two optical arms, and meets in the interferometer. The experimenter can judge and calculate the properties of the gravitational waves by observing the interference fringes in the interferometer [8].

VIRGO (European Laser Interference Gravitational Wave Observatory) is a device used to detect gravitational waves. Its working principle is also based on the principle of laser interferometer. Similar to LIGO, VIRGO also consists of two laser interferometers, which have optical arms of about 3 kilometers perpendicular to each other. Scholars analyze the data detected by the LIGO detector and the VIRGO detector together. It improves the overall sensitivity and coverage of the gravitational wave detector. At the same time, it can verify the measurement and calculation results with each other, reduce the experimental error, better confirm the position and properties of gravitational wave signals and gravitational wave events, and promote the development of gravitational wave research. In 2015, the LIGO/Virgo cooperative experiment about the combination of black holes was released for the first time. The gravitational wave event GW150914 marked that the direct detection of gravitational waves has entered a new era. Subsequent research not only verified general relativity, but also revealed the phenomenon of celestial bodies such as black holes and neutron stars. Gravity Wave research has become a new frontier field of astrophysics [8].

KAGRA (Japan Gravity Wave Observatory) is an underground gravitational wave detector using suspension interferometer technology. Unlike the ground interferometer, the main part of the suspension interferometer is suspended in the underground tunnel. This design helps to reduce the interference of ground vibration and ground noise on the interferometer detector, reduce the observation error, and improve the detection sensitivity. Like the first two observers, it consists of two optical arms that are perpendicular to each other, which indirectly detects the phenomenon of gravitational waves by laser interference and analyses of relevant information [9]. Comparisons for different detectors sensitivity are shown in Fig. 1 [8].s

The LISA detector (Japan Gravity Wave Observatory) consists of three space detectors, each of which is millions of kilometers apart. This configuration can reduce the interference caused by ground vibration and other noises, and improve the sensitivity of detecting low-frequency gravitational waves. Each detector has lasers and optical equipment, and also includes multiple free fall test qualities, which can move freely in a microgravity environment. When the gravitational wave passes, it will lead to small deformation and vibration in space, which will affect the relative position of the test quality. LISA will extract gravitational wave signals by comparing the optical difference between the three detectors. Through the cross-validation of multiple detector data, the error can be reduced and the theory can be verified to better determine the source and properties of the gravitational waves.

Others introduces China's research progress in the field of gravitational waves, which mentions LISA and Taiji cooperation between two gravitational wave detection projects. Taiji is China's gravitational wave detection project, and is also committed to detecting medium and low frequency gravitational waves. It is a gravitational wave research project of the China National Space Science Centre (NSSC), which plans to launch an equilateral triangle composed of three satellites outside the solar system for low-frequency gravitational wave detection. The cooperation between these two projects will help to comprehensively utilize their respective advantages and improve the coverage and accuracy of gravitational wave detection [10].

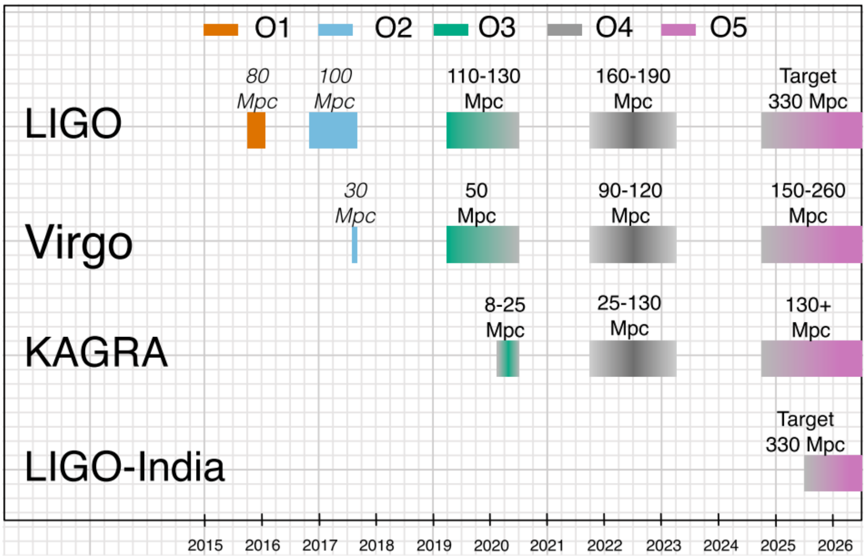


**Fig. 1** The sensitive of detectors [1].

## 4. Applications

Gravitational waves are ripples in spacetime caused by changes of mass distribution. The discovery of gravitational waves has far-reaching significance for astronomy, which has opened up a new way of observing the universe, also has important scientific significance and application prospects. The application of gravitational waves is mainly reflected in the field of astronomical observation, which provides with a new means to explore the mysteries of the universe. Compared with traditional observation methods such as electromagnetic waves, gravitational waves have stronger penetration and unique information delivery capabilities. This makes gravitational waves a brand-new window in astronomy, which can bring information about the universe that cannot be obtained by other means.

The application principle is that when celestial bodies (such as black holes, neutron stars, etc.) move or collide, they will produce gravitational waves, which propagate through space. By monitoring gravitational waves, one can understand the properties, movements and evolutions of celestial bodies in the universe, explore the large-scale structure and cosmological parameters of the universe, verify the evolution theory of the universe, and help understand the origin and future of the universe more deeply, reveal the mysteries of the universe. The Fig. 2 shows some of the scanning parameter range [5].

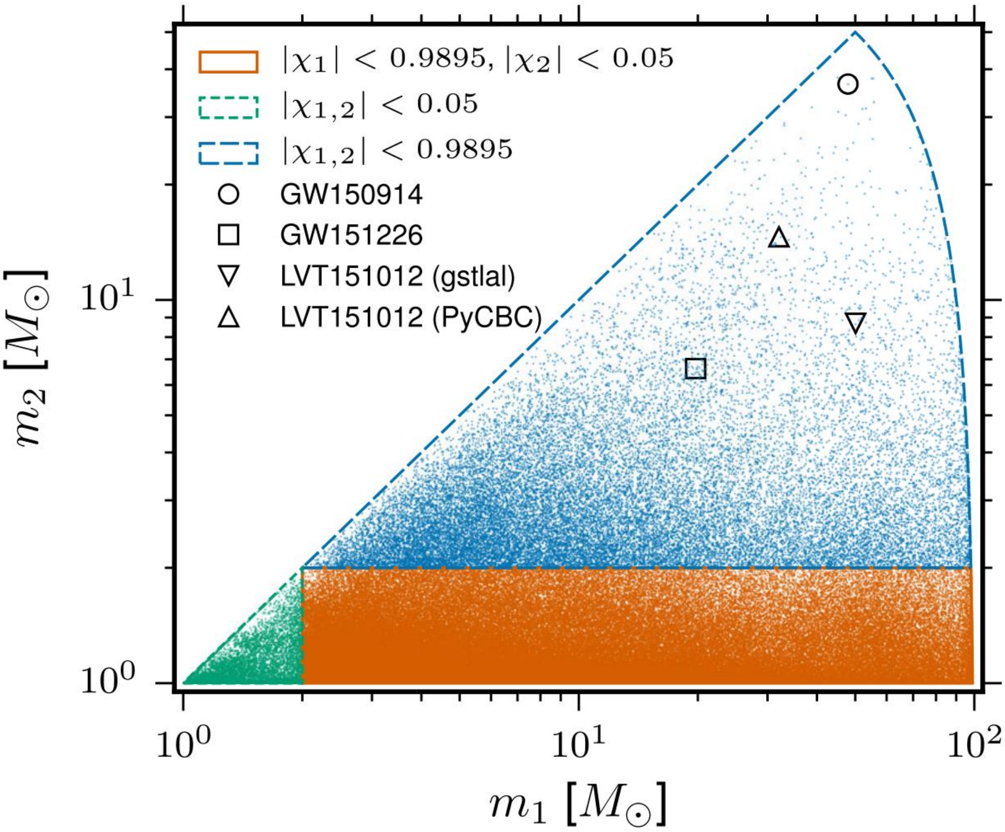


**Fig. 2** Searching parameter for gravitational wave [5].

The detection of gravitational waves requires extremely sophisticated instruments, such as LIGO and Virgo detectors. The study of gravitational waves can promote the development of laser interference technology, precision measurement technology and other fields, and promote the progress of engineering technology. Gravitational waves can pass through space, so they can be used as the basis of a new navigation system. Using gravitational wave measurement and positioning technology, a more accurate and globally applicable navigation system may be developed in the future, which has important military and civilian value.

## 5. Limitations and Prospects

The sensitivity of the current gravitational wave detector is still not enough, resulting in only detecting gravitational waves of specific types and mass ranges. The high cost of gravitational wave detectors limits their deployment and construction worldwide. Gravitational wave signals are affected by interference and background noise, which reduces the accuracy and reliability of data. The current gravitational wave detector has a weak ability to detect low-frequency gravitational waves, which limits the study of some celestial phenomena. Gravitational wave detectors have limited ability to detect ultra-high-energy gravitational wave events, which limits the study of extreme physical phenomena in the universe.

With the development of technology, the sensitivity of gravitational wave detectors will continue to improve, and it is expected to detect more types and weaker signals of gravitational wave events. In the future, there may be more new gravitational wave detectors, such as space detectors, which will provide a wider range of observation and more accurate data. The combination of gravitational waves and other observation methods will become an important trend in future research, so as to understand the evolution and structure of the universe more comprehensively. Gravitational wave research will promote the exploration of unsolved mysteries of the universe such as dark matter and dark energy, and is expected to provide new clues to solve these problems. Gravitational wave research will deepen the understanding of the origin, structure and evolution of the universe, and bring new breakthroughs and developments in the field of cosmology and astrophysics.

## 6. Conclusion

In conclusion, the discovery of gravitational waves has transformed the fields of astrophysics and cosmology and given researchers a powerful new instrument for cosmos exploration. Understanding of celestial events and phenomena, including the universe's formation, the mechanics of black holes, and the evolution of galaxies, has significantly advanced as a result of research on gravitational waves. Gravitational wave research has been utilized to explore mysterious subjects like as dark matter and dark energy, providing new perspectives on the formation of the universe. Scientists have created techniques for detecting gravitational waves that are comparable to those used for electromagnetic waves because of the similarities between the two types of waves. This has prompted a great deal of theoretical and practical study on gravitational wave observations, expanding the understanding of the subject. Gravitational waves are similar to electromagnetic waves in that they can be used to examine celestial activities and possibly reveal information about the universe that has never been known before. International cooperation amongst detectors has been essential to improving the knowledge of astronomical occurrences and phenomena. Through collaboration, scientists have been able to integrate information from multiple detectors across the globe, resulting in a more thorough examination of gravitational wave signals. Through this partnership, new directions for investigation and study in the realm of astrophysics and cosmology have been made possible, leading to ground-breaking findings in these fields. Further investigation into gravitational waves has enormous potential to advance the knowledge of the underlying structures and forces that control the universe. Scientists can solve cosmic riddles and even make ground-breaking findings that could fundamentally alter the view of the world and the role in it by researching gravitational waves. Finally, gravitational wave research offers unmatched chances for scientific growth and discovery, marking a new chapter in astrophysics and cosmology.

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