# Black Hole Formation and Gravitational Waves Generation

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**Abstract.** In the present day, black holes have recently attracted a variety of attention. Black holes and gravitational waves were studied more than 100 years ago. From theoretical reasoning and formula derivation to detector observation, people never stop to explore these curious things. This paper mainly describes the essential information and principle of black holes, and gravitational waves, as well as the basic operation principle of LIGO detectors. The basic definition of gravitational wave and several sources of the gravitational wave is discussed in this paper. According to the analysis, the properties of waves can be used in detecting gravitational waves, as well as more hidden matter. In 1915, Einstein proposed the general theory of relativity, which foresaw the existence of black holes but did not believe that black holes were real. In the 1960s, American scientist John Wheeler first named this incredible celestial body black hole. The search for gravitational waves has had a profound impact on people. With gravitational waves, people can discover an unknown matter which can be studied and benefit humankind. These results shed light on guiding further exploration of dark energy, matters, and more black hole observations.

**Keywords:** Gravitational waves; black holes; LIGO interferometer; new energies.

## 1. Introduction

Black holes and gravitational waves are the hottest topics in astronomy these days. According to Einstein's field equations, the existence of black holes and gravitational waves was eliminated. They are two things, but they are very closely related. A black hole was first photographed in 2019. The black hole is about 6.5 billion solar masses at the center of M87. Gravitational waves are not very old, just a little over a hundred years old. However, many scientists have been studying gravitational waves since they were predicted [1]. In 2015, the first detection of gravitational wave GW150914 was made, which is a two black-holes merger [2]. To inform people that science is less popular knowledge to the general public, this paper discusses. The basic information and some classification of black holes, the history and properties of gravitational waves, and the famous LIGO introduction and analysis.

A black hole is a dense mass of matter that not only has a strong gravitational force but also escapes from its event horizon faster than the speed of light. Black holes are formed more like neutron stars when a star is about to die when it explodes [3]. A black hole is a massive, dense mass of matter that generates forces that can pull anything close to it in. The black hole is a very dense matter and is a natural formation of the universe’s celestial bodies, it not only has a strong gravitational force, and the event horizon escape velocity is greater than the speed of light. It is a kind of celestial body where the curvature of spacetime makes it impossible for light to escape. Therefore, it is black as it absorbs light. When a star is ready to die, its core will rapidly shrink, collapse, or even explode. Astronomers can still see these remnants of the early universe when they look at quasars. Quasars are so big and bright that scientists think they're powered by old black holes billions of times larger than Earth's Sun. These theoretical objects are known to scientists as directly collapsing black hole [4]. As a matter of fact, black holes are made up of mass, angular momentum, and the fundamental quantity of charge. The mass can judge the energy contained in the black hole, the angular momentum can determine the speed of rotation of black holes, and the charge of a black hole can be determined by the charge. By

the above method, we divide black holes into four categories: Schwarzschild black holes, Reisner Nordstrom, Kerr black holes, and Kerr-Newman black holes.

The remainder of the paper is organized as follows. Sec. 2 will introduces the different types of black holes respectively, i.e., the Schwarzchild black hole, Reisner Nordstrom black hole, Kerr's black hole and Kerr-Newman's black hole. Subsequently, we discover the general concept of gravitational waves, which contains several categories in Sec. 3. Besides, this study simply explains the LIGO detector, where it locates, and how it operates in the same section. Afterward, the Sec. 4 will conclude some limits and future possibilities of black holes and gravitational waves. Finally, an overall conclusion as well as summary of this study will be demonstrated and clarified in Sec. 5.

## 2. Blackholes

### 2.1. Schwarzschild black hole

For Schwarzschild black hole, which has no charge and no rotation, is also called a "static black hole" or "ideal black hole." In the middle of it is a singularity (as shown in Fig. 1), and then a weird point, far out in the radius of Schwarzenegger, therefore, the mouse hole density is very low, and the bigger the black hole density, the lower the density.

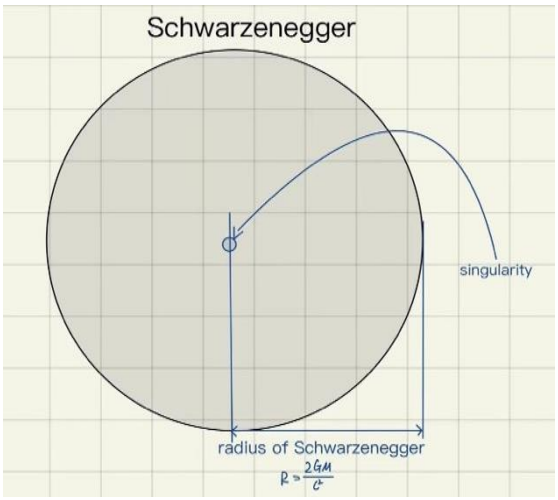



**Fig. 1** Caption of the view of Schwarzenegger 's black hole.

### 2.2. Reisner Nordstrom black hole

A black hole that is charged but not rotating is the Reisner Nordstrom black hole. Because it has an electric charge, it is also called a "charged black hole" and it has a big difference from the Schwarzschild black hole in that it has two event horizons. If the charge of a Reisner Nordstrom black hole increases, the interface between the two is made one, and the black hole is called an extreme Reisner Nordstrom hole. In the case of gravity collapse, the case crossing does not usually need to be considered. As the walls of galaxies surrounding the hole begin to form, many models of real holes will exhibit shell crossing singularities.

### 2.3. Kerr black hole

Next up is the Kerr black hole, the uncharged but spinning black hole. It is a black hole of axial symmetry that is invariant to time and rotates on its axis. Kerr black holes are closer to physical black holes than static Schwarzschild black holes. Because most stars spin, the spin will still exist when they collapse into black holes. The Kerr black hole belongs to the axial symmetry black hole, this kind of black hole's center is not a singularity, but has stretched the point into a line, and twisted into a ring, so it is called a singular torus. The center of this type of black hole is a singular torus, with inner and outer two event horizons. The inner horizon is the limit of the singularity of a black hole, and the outer horizon is a limit that cannot escape. Because this part of the region between the

boundary of rest and the visual interface will be dragged along by the spinning black hole, the drag effect is so large that it can even tear space-time apart.

### 2.4. Kerr-Newman's black hole

Kerr-Newman's black hole, which is both charged and rotating, basically doesn't emit any more X-rays and has consumed the gas around them (seen in Fig. 2) [5].

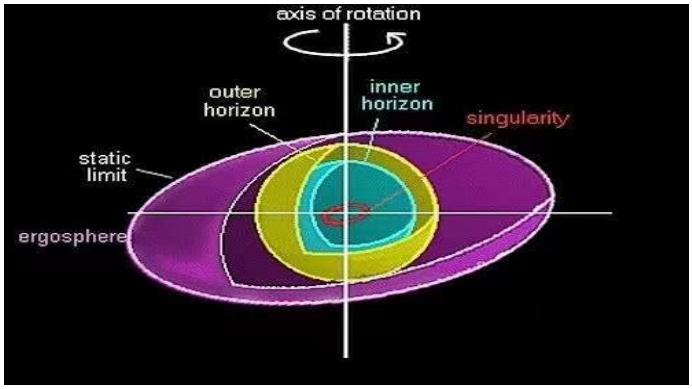



**Fig. 2** Caption the Kerr-Newman's black hole, which is both charged and rotating, basically doesn't emit any more X-rays and has consumed the gas around them.

## 3. General concept of gravitational waves

### 3.1. Basic definition of gravitational waves

Gravitational waves (GWs) usually refer to the ripples in the universe that travel as waves to other places. Matter waves are produced by changes in matter and energy in violent motion. When gravitational waves travel through space, they create a strain effect: as they pass, the distance between objects changes, and the frequency of the waves is found by this change. Gravitational waves have several unique properties: First, no matter is required to be around the source of the wave. There would be no electromagnetic radiation. Second, it does not need any medium to travel and can pass through anything that blocks gravitational waves. Light like normal light may not be able to travel if some celestial object blocks it. Moreover, gravitational waves are very closely related to black holes. Because a black hole is so massive and its singularity is so tiny, its mass bends space so much. So, if two black holes merge or collide and the black holes change the dynamics of space, and because the two black holes are accelerating as they merge, it creates ripples that are powerful enough to be called gravitational waves.

### 3.2. History

Shortly after proposing his general theory of relativity [1], the existence of GWs is predicted follwing the assumptions. In the early days, the nature of gravitational waves is uncertain, and it is not clear whether GW carries energy. The mathematical theory of general relativity was established in the 1960s. There were also significant developments in the field of experimentation during this period. Theories of stellar evolution suggest that massive stars end up as neutron stars or black holes. Neutron stars were first discovered in the Crab Nebula in 1969. In 1971, Cygnus X-1 provided that a massive dense matter could be the first evidence of a black hole. Furthermore, these findings suggest that black holes merge and emit potent energies.

### 3.3. LIGO detections

The most famous LIGO (Laser Interferometer Gravitational-Wave Observatory) was built at Livingston and Hanford in the United States. Scientific research began in 2002 [6]. It was also around this time that the smaller probe GEO600(600 million arms) became operational, and in 2007 Italy's

Virgo probe, with its 3km arm, a project of the European Consortium of Gravitational-Wave Observatories, made its first scientific run. The equipment was upgraded several times to improve its sensitivity, and LIGO Hanford and Livingstone conducted the first GWs on September 14, 2015.

Fig. 3 gives a schematically designs of the LIGO. The basic principle of LIGO involves the properties of waves. First, we know that waves can add up. The case of in-phase interference occurs when two waves overlap, and the amplitude of the resultant wave is more significant than that of the constituent wave [7]. If, at some point in time, the crest of one train of waves meets the crest of another train of waves in the same place, at this point, the vibrations caused by the two trains are constantly mutually reinforcing, and the particle has the largest amplitude. This kind of intervention is called full constructive intervention. Because light has the property of a wave, optical LIGO detection is based on the principle of laser interference. When two rays of light reach the mirror at equal distances, they bounce back on their way, causing interference. If the beams travel the same distance, their light waves will be completely staggered, resulting in full destructive interference, and the detector will not detect the laser signal. Nevertheless, if a gravitational wave interferes with a beam of light, the distance it travels will be distorted, resulting in long interference. At this point, the detector will find the laser signal called gravitational waves. The snap shots of the real facility is pesented in Fig. 4.

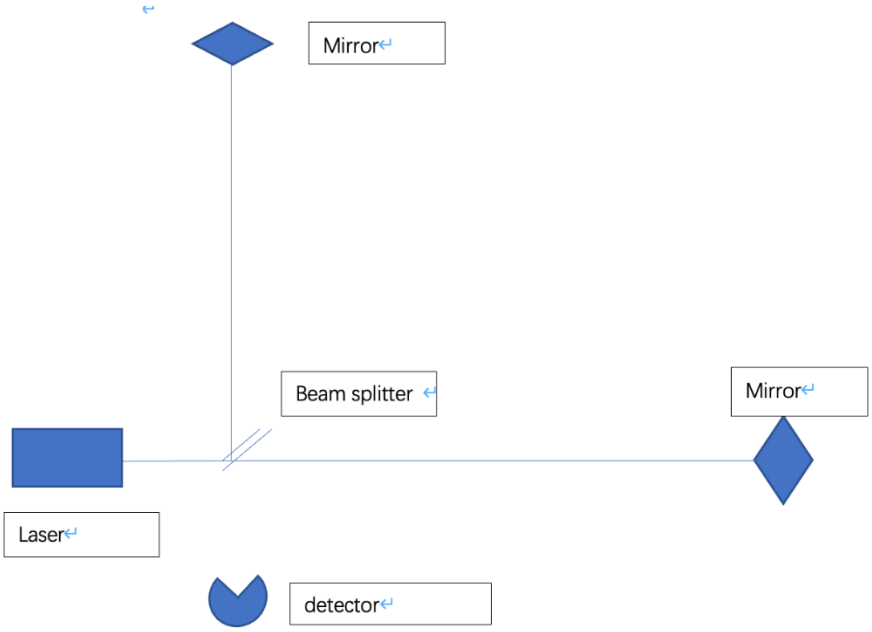



**Fig. 3** Caption of the structure of the interferometer.



**Fig. 4**. Snap shots of the LIGO (left panel) and VIRGO (right panel).

The first detected gravitational wave, GW150914, was two black holes merging, and each mass was about 36M⊙ and 29M⊙ (1⊙ is one solar mass) to create a black hole with a mass of 62m⊙. Before the detection of gravitational waves, the giant black holes ever found were only 25M⊙.

GW190814 is an exciting gravitational wave because it involves the merger of a 23M⊙ black hole with a 2.6M⊙ dense object, which may be the most massive neutron star and possibly the smallest black hole ever observed. Thus, we can see that detecting gravitational waves allows people to find more strange objects and study them (seen from the results presented in Fig. 5) [8]. Though with seveal defects, based on the researchers' detections and discussions, the sources of gravitational waves found so far have been classified as follows:

- Interacting compact binary (or many-body) systems, e.g., those of neutron stars or black holes. There are usually three phases: inspiral (gravitational radiation carries away energy and the orbit of a compact object gradually changes from elliptical to circular); merging (the dynamic merging of two stars) and ring-down (the signal and energy of gravitational waves gradually fade and eventually end after merging).
- self-rotating compact celestial bodies. This kind of celestial body does not need another celestial body to accelerate. Its periodic motion will cause gravitational wave radiation to lose angular momentum and generate gravitational waves. Neutron stars are a good example.
- Gravitational wave background. These gravitational waves are similar to the remnants left over from the universe's beginning.
- Supernovae or gamma-ray bursts. The asymmetrically moving energy of an exploding star also produces gravitational waves.

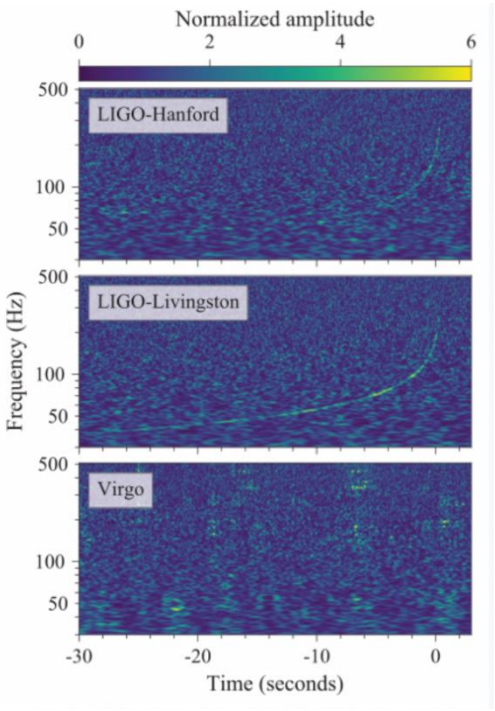



**Fig. 5** The gravitational wave signal of GW170817.

## 4. Limitations on and prospects

All gravitational wave signals detected so far agree with Einstein's theory of general relativity, but general relativity is incompatible with quantum mechanics, so some argue that general relativity needs to be modified. Events such as GW170817 are a few ways to test general relativity in the gravitational limit [6]. In addition, the path forwards do not appear to be a quick one, at least not for gravitational-wave astronomy.

There is an impossible phenomenon in black holes, that is, the mass will be concentrated to an infinitesimal point, the density will be infinite, and general relativity does not play any role at this point. To measure infinity in science but not, in reality, uses quantum mechanics, but the Schrodinger

equation of quantum mechanics has no meaning at singularities and cannot be used in general relativity, so there is no way for humans to define the existence of gravity in black holes.

However, the search for gravitational waves has considerably impacted astronomy, physics, and more as the search for new events becomes more frequent. This impact will increase as detector sensitivity improves and new facilities are invented to detect more different types of events. Soon, when people master the technology of gravitational waves, they can observe the entire universe at once, watching a merger or explosion happen in real-time eagerly listening [9, 10]. Moreover, humans will also find much new matter, as well as dark matter and dark energy, which have been bothering people for a long time.

At the same time, soon, if one can understand all the information about black holes and the energy they bring, then superluminal travel might be theoretically possible. As mentioned earlier, black holes have a tremendous gravitational pull. If humanity can overturn the current theory, then it can have a very good future.

## 5. Conclusion

In summary, this article describes the detection of gravitational waves, their history, some of their properties, and the LIGO detection. With the black hole discovery, this article discusses the basic properties and concepts of black holes, and the different categories of black holes. According to the analysis, Gravitational waves can cause detector distance changes as small as 10 to the -20th power, so LIGO is usually very large. There is also the possibility of noise, such as earthquakes or traffic on nearby roads, which must be excluded. We are now just seven years away from the first discovery of gravitational waves. Hence, there are still many limitations. From the study of the weak nature of gravitational waves, the way to observe the signal of gravitational waves in real-time is the main problem that people need to solve. Studying gravitational waves could lead further into the future, and the study of dark matter and dark energy may one day be revealed by gravitational wave technology. These results offer a guideline for More real-time observations and the discovery of hidden energy.

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