Comparison of Different Detection Approaches of Black Hole

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Abstract. The black hole has been investigated by the scholars for many years since the proposal of the concepts. Contemporarily, with the help of the state-of-art detection facilities, plausible observation results with more detail and diagnostic information have been achieved. This study investigates the two widely utilized detection methods and demonstrates a comprehensive conclusion about the method that researchers used to detect or discover the black hole. To be specific, this study mainly focuses on how the gravitational lens and gravitational wave method used to investigate the black hole, and it compares the cons and pros of the two specific method. In addition, the current limitations regarding to the nowadays detection scenarios have been discussed and the future prospects for the improvements have been clarified accordingly. This research can give people a fundamental understanding about the technique that used to discover the black hole. These results shed light on guiding further exploration of black holes as well as the proposals of the detection paradigms with better performance.

Keywords: Black Hole; gravitational lens; gravitational wave.

1. Introduction

Black hole is an object that has a lot of gravitational pulls, and it can trap everything, even light will be trapped by the gravitational pulls produced by the black hole. The black hole is massive because the mass of a star is squeezed in to a little space [1-3]. Because the light is also be trapped by the gravity of the black hole, people cannot observe the black hole by their eyes. According to STScI there will be a black hole in one out of a thousand stars, which means that our galaxy contains 100 million small or huge black hole since there are almost 100 billion stars in our galaxy [4]. Until now, scholars have defined three types of black hole, i.e., stellar black holes (small but deadly), supermassive black holes (the birth of giants) and Intermediate black hole [5-7].

If a star has enormous mass, which means 10 or 20 times bigger than our star(sun) in our solar system, they are two way it will form. One of the ways is that it will turn to the neutron star, and the second way which it will turn is the black hole. The internal fuel of the star will collapse because its own gravity when the star on its way of forming the black hole [8-10]. Then, the collapse will cause the supernova explosion, and when that happens, because no other force stops the process, star's core will begin to shrink in to itself. Black hole will be created if the core shrinks in to an infinite small point. The beginning of the super-massive black hole is barely known by human, however, one understands that it exist in the early period of galaxy. The first prediction of black hole was first given by the famous scientist Albert Einstein in 1916, using his famous theory, i.e., the general theory of relativity. The special term black hole was first claimed by John Wheeler, the astronomer in 1967 after 51 years when Einstein first hypothetically discover this phenomenon [2].

Cygnus X-1 which locate in the milk way was the first black human ever discovered. The researcher first finds the sign of the black hole was in 1964, when researcher received a celestial X ray was detected by a sounding rocket, according to NASA. In 1971, the researcher discover that the strange sign was coming from a blue star which was orbiting a weird black object. The researcher than deemed the dark object was the object that predicted by Einstein, i.e., the black hole. The first image of the black hole was taken in 2019, April, 10, by the scientist in Event Horizon Telescope Collaboration. Using the Event Horizon Telescope, Scientist got photo of black hole in the center of M87 galaxy [11]. Fig. 1 proved that the scientist's assumption about the black hole was correct.

Black hole contains three layers: the singularity, the outer and inner event horizon. The event horizon is the boundary of the black hole, and once the light or other particle enter this region, because of the constant gravity in this region, they cannot escape from it. The inner part of the black hole which the scientist called the singularity is the place where all the mass locate. This is this the point where the mass of the black hole concentrate. Since the light cannot escape from the black hole, scientist cannot directly see the black hole, instead scientist must depend on the detection of the radiation from the black hole when the gas and dust are pulled in to the creature.

This study will compare the different approaches for detection in order to provide a routine for further development. The rest of paper will mainly focus on discussing the method that be used to discover the black hole and comparing them. Also, at the end of this paper, this study will gives an envision about the future.

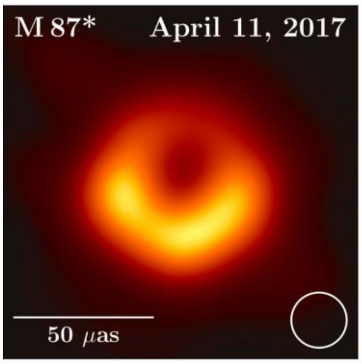

Fig. 1 The observation of M87*.

2. Gravitational lens

The gravitational lens effect is a phenomenon predicted by Einstein's theory of general relativity. Normally, the light will pass a straight line in an empty space, however, Things change when the light pass near a massive object. Due to the distortion of space-time near massive objects, the light rays will bend. If there is a massive object on the line from the observer to the light source, the observer will see one or more images formed due to the bending of the light, this phenomenon called gravitational lens [12]. Gravitational lens is one of the most important research tools and means in astrophysics, playing a huge role in cosmology dark matter, dark energy, gravity on large scales and exoplanet detection. In 1916, Einstein published the famous theory of general relativity. People realize that light, even when traveling in a vacuum, can be deflected because space itself may be curved and uneven. In the public imagination, space is like a large box, and celestial bodies occupy different positions in this large box. The celestial body will move with the passage of time, but it will not change the state of the big box. However, in Einstein's theory of relativity, cosmic space-time is more like a rubber film, and the objects on the film change the shape of the rubber film itself. Einstein's theory tells us that space-time is not always flat, and that as light travels through curved space-time, its travels will also bend with it.

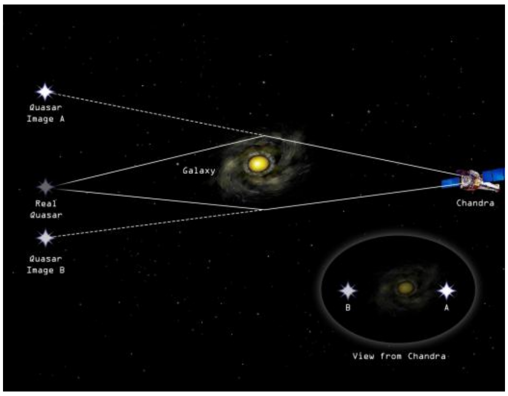

Fig. 2 A sketch of Gravitational lens detection methods.

The gravitational lensing effect is related to the relative position of the observer, the lens object, and the source object. As illustrated in Fig. 2, the three objects are completely connected in a straight line, and the light can enter the observer's eye from two paths up and down the figure. To the observer, the distant object appears to split into two image. Considering that real space is actually three-dimensional, light does not have more than just two paths to reach the observer's eyes. In fact, if the mass distribution of the lens object is spherically symmetrical, the observer will observe the light emitted by the source object in a circle around the lens object. In this case, the observer will see a halo that surrounds the lens object. This halo is called the Einstein Ring. It should be noted here that the image of the source object is not always a ring, sometimes more like a long arc, and sometimes a multiple image. This is because galaxies that are lentic objects are not all spherical, but closer to ellipsoids. The lens and source objects also do not fit into a strict straight line with the observer.

A recent study published on the preprint web confirms that a gravitational microlensing event observed in 2011 was caused by a black hole that drifts freely in interstellar space. This is the first free-drifting black hole ever discovered by researchers [13]. Black holes swallow up all light and are difficult to observe in the darkness of space. However, one can spot them through circumstantial evidence. Scientists believe that stars reach the end of their lives, many of which end in the form of supernova explosions, after which they collapse into a black hole. Scholars have observed many supernova events, and the number of black holes speculated is not in the minority. Passing through the lensing effect is an effective way to discover black holes. The black hole, located between the star and the Earth, has a bending effect on the starlight arriving at the Earth, also known as the gravitational lensing effect. Nevertheless, since these objects are so far from Earth, most of these lens effects are very subtle, and most of them cannot be detected even with the most advanced telescopes.

However, both groups were fortunate enough to notice a lens effect in 2011. They found a sudden increase in the brightness of a star, but could not find an obvious reason. So the researchers analyzed Hubble observations of the star for six consecutive years and guessed that the changes in starlight were caused by a moving black hole. Then, the researchers found other clues. The star's location also changed. It is believed this is due to the motion of the unknown celestial bodies that make up gravitational lensing [13]. After further analysis of the data, the researchers confirmed that the rays did not come from the object itself that produced the lens effect, and found that the delay effect of this gravitational lens was significant. These two factors are enough to show that the object that produces this lens effect is a black hole that does not emit light on its own. Combined with the change in the brightness of the starlight, all the evidence suggests that this is the effect of a black hole, and it is a black hole in a state of free drift. Calculations speculate that the black hole has about 7 times the mass of the Sun and is moving at a speed of about 45 kilometers per second.

3. Gravitational Wave

Gravitational Wave, in Physics, means the ripples in the curvature of the space-time that propagate in waves form from the radiation source. In other words, gravitational wave is the type of material wave produced by intense movement and change of matter and energy. Imagine a large, heavy shotput ball suddenly falling from an elastic mesh bed. Not only will the lead ball greatly change the shape of the grid, but it will also cause a large oscillation of the elastic bed, just as a stone thrown on the surface of calm water causes ripples, and the shock caused by the lead ball will spread in all directions of the elastic bed. This is the brief concept about the gravitational wave [14].

The theoretical prediction of the existence of gravitational waves was given by Einstein as early as 100 years ago. Because the energy carried by gravitational waves is very small, the intensity is very weak, and the absorption efficiency of gravitational waves by matter is extremely low, and the gravitational waves produced by ordinary objects cannot be directly detected in the laboratory. For example, the gravitational wave radiation generated by the system of the Earth rotating around the Sun is only about 200 watts in power, and the power of the Sun's electromagnetic radiation is 1022 times that of it. It is conceivable that the power of the light bulb that illuminates a room will be emitted into such a large space as the sun-Earth system. As a result, the tiny gravitational waves emitted by the Earth-Solar system have been completely undetectable. In 2014, it was rumored that Harvard's South Pole BICEP2 probe detected gravitational waves, referring to the "primordial gravitational waves" emitted during the initial surge of the Big Bang that marked the microwave background radiation map. However, it was later confirmed that this was misleading, an illusion caused by dust matter. It wasn't until 2016 that LIGO have really detected gravitational waves directly. Wheeler's "fast" took at least 30 years to realize, not to mention Einstein, who has been waiting for a hundred years. In 2016/02/11, LIGO and Virgo claim that they have detected the gravitational wave from the merge of two black holes by using the LIHO equipment. Its basic principle is to use a laser interferometer, as shown in Fig. 3. Two vertical laser beams are emitted from one point, using the phase difference between the two laser beams to detect gravitational waves. Each beam of light returns after the propagation distance L, and if it is affected by gravitational waves during its round-trip process, the travel time will change and affect the relative phase of the two beams. If gravitational waves are detected, the result is several ellipses. The LIGO Observatory has two sets of interferometers, one in Livingston, Louisiana, and the other in Hanford, Washington. Both interferometers yielded similar results [15].

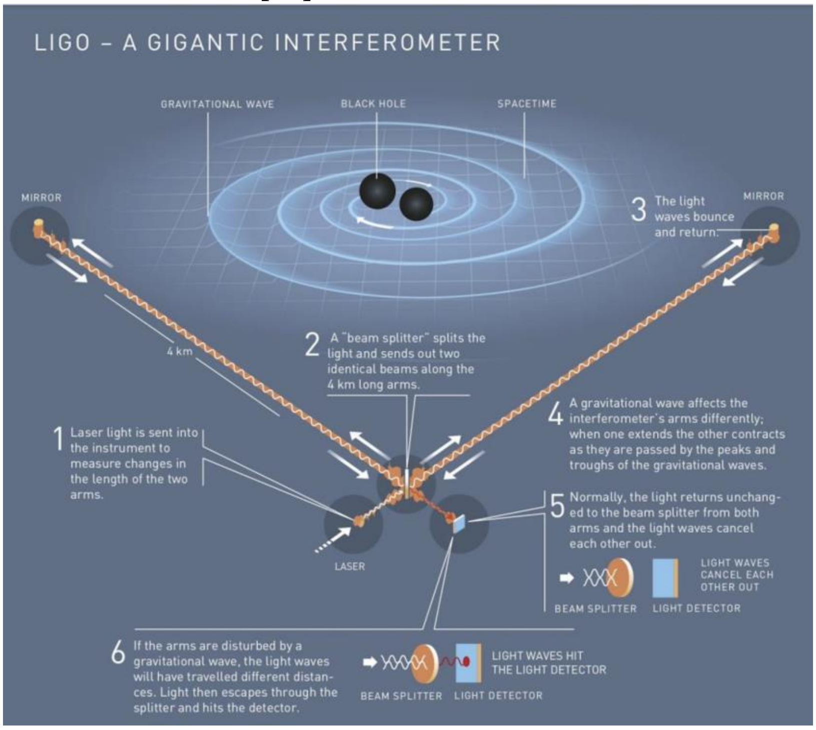

Fig. 3 A sketch of the principle for LIGO.

One of the "four discoveries" in the astronomical community in the 1960s was the discovery of quasars. Why is it called a quasar? Because if you observe their appearance with an optical telescope, they don't seem to be any different from stars (stars). However, the " redshift " values observed from them are so large that they cannot be stars, hence the term " quasar. From the redshift values of quasars, they are more like galaxies, however, their size can also be determined by observing the luminosity change period of quasars, and it turns out that their size is much smaller than the scale of ordinary galaxies. The scale of the quasar is small but the radiation capacity is quite large. There are also some difficult to explain features, and the large amount of observational data that later led to associating them with black holes. Later, after the discovery of the host galaxy of the quasar, the mainstream view of astronomy basically believes that the quasar is a young and active galactic nucleus, a process in the early stage of galaxy development called the "active galactic nucleus" (AGN) stage. At the center of the galactic nucleus is a huge superheavy black hole, and under the strong gravitational pull of the black hole, some dust or stellar material surrounds the black hole, forming an accretion disk that rotates at high speed. The external matter is sucked into the accretion disk, while the matter caught up in the black hole's event horizon is constantly falling into the black hole and being swallowed up by the black hole, and a huge jet of matter erupts at high speed from a direction perpendicular to the plane of the accretion disk, accompanied by a large amount of energy radiation.

The quasar merge with each other during evolution, so in the middle of some galaxies, there will be two black holes. Much like the binary stellar black holes detected by LIGO, the two binary black holes also produce strong gravitational waves as they orbit and eventually merge. Such gravitational waves can be detected using space detectors. One of the achievements of this method is that the scientist uses this gravitational wave detected a most strong and confusing black hole collision. This two black holes merge will at least produce a black hole that is 150 times of the mass of the sun, anticipated by the scientist, and this kind of black hole have never been discovered before.

4. Comparison

Both gravitational lensing and gravitational waves are effective ways to observe, detect, and discover black holes, which are products of Einstein's general theory of relativity, which have been confirmed in modern times. Compared to gravitational waves, gravitational lenses are more easily observed, i.e., confirmed earlier. On account of the easy-to-observe properties of gravitational lensing, although the gravitational lensing effect has only developed for a few decades, it has now become an important measurement method in cosmology. For objects of different scales, distances, and masses, the three gravitational lenses alternately play a role and provide a large amount of information, which also makes a significant contribution to the development of cosmology. It is foreseeable that the study of the gravitational lensing effect and its application has great prospects in the future

Compared with gravitational lensing, gravitational waves are much more difficult to observe, and require extremely sophisticated equipment to be observed, so gravitational waves have been testify by scientists until recent years. In the field of black hole detection, gravitational waves also have strong limitations, and only when two black holes are synthesized will they release gravitational waves and will be observed. Although gravitational waves have strong limitations, gravitational waves can find black holes that cannot be discovered by other methods, and the black hole in the above article is one of them. Although the gravitational waves seem to have only a little use, every opening of the electromagnetic spectrum will bring us unprecedented discoveries. It is believed that with the development of science and technology, gravitational waves will also set off a new chapter

5. Conclusion

In conclusion, this paper discusses Black hole from the perspective of detection technique. To be specifically, Gravitational lens and Gravitational Wave. According to the analysis of past research, both two methods are the main maneuver to find the black hole. Compare to the Gravitational lens, the Gravitational wave method has more limitation and less applicable. However, as both methods develop, both methods be the mainstay of finding the black hole. Overall, these results offer a guideline for black holes detection and further improvements of the detection paradigms.

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