Analysis of Category and the State-of-art Observations of Black Holes

Padi Xu *

Beijing No.8 high school, Beijing, China

* Corresponding author: jiashan@ldy.edu.rs

Abstract. As a matter of fact, black holes observation and investigation is one of the most mysterious part of astrophysics and cosmology. With the rapid development of techniques, high accuracy observation and detection are available based on the state-of-art facilities and detectors. With this in mind, this research paper aims to delves into all aspects of black holes, including their formation, properties, singularities, gravitational effects, and effects on the universe and matter. The mysterious and captivating nature of black holes has sparked an immense amount of interest in theoretical physics and astronomy. Through the examination of general relativity, the kinds of black holes, and the most recent astronomical observations, one can gain a deeper comprehension of these enigmatic entities and unlock their mysteries. According to the analysis, the current limitations and prospects will be demonstrated at the same time. Overall, these results offer a guideline for further exploration of black holes.

Keywords: Black holes, Types of black holes, black hole observation, EHT.

1. Introduction

Dating back to the first comprehension of gravity, the investigation of black holes has been a long-standing pursuit [1-8]. Newton's profound musings on gravitation, which dates back to the 17th century when he observed an apple tree fall and was inspired by it, were of utmost importance to him. He realized that this occurrence could not be accidental and thus composed the formula for gravitation, which he then used to explore the later renowned escape velocity formula [9].

After this, more scientists have further applied and explored Newton's theory, in the 18th century in France, the famous mathematician Laplace imagined that there might be a celestial body in the universe, which is so dense that nothing can escape from its surroundings, even from its own light. From the modern point of view this object is the most simple and simple idea of the celestial body [1]. In the 19th century, there were more observations by scientists, and the observations of more scientists also raised some challenges to Newton's theory, resulting in heated academic discussions. Albert Einstein, a renowned physicist scientist, first proposed the special theory of relativity at the dawn of the 20th century. Ten years later, he presented the ultimate form of the gravitational field equation, thus officially inaugurating general relativity and revolutionizing the study of gravitational theory. The gravitational field is not caused by mass, but rather by the bending of space-time by mass, objects with mass [2].

In 1915, Einstein's theory of general relativity was proposed; shortly thereafter, Schwarzschild - a physicist provided the precise answer to Einstein's field equations, thus establishing the first definitive solution of general relativity. the Schwarzschild solution without rotating black holes, which describes the simplest kind of celestial body (stationary, uncharged, Schwarzschild discovered that all stars have a radius, which is later called the Schwarzschild radius, and if a star's actual radius under its own gravity is smaller than its Schwarzschild radius, then it will become a black hole

As a gifted astronomer, Schwarzschild was well aware of what the nascent gravitational field equations of general relativity meant to astronomers, and he completed these works with great enthusiasm and great admiration from Einstein, which marked the beginning of modern black hole theory. However, just when one thought Schwarzschild would continue to work in this field and contribute to black hole research, Schwarzschild suddenly died in 1916, and when Schwarzschild died, black hole research was temporarily suspended. On the one hand, the revolution of quantum

mechanics was in full swing at that time, and many physicists' attention was attracted by quantum mechanics. Neither Einstein, the authority in theoretical physics, nor Eddington, the authority in astronomy, held faith in black holes as an infinitely dense monster in the field of general relativity.

In the late 1930s, Oppenheimer, the father of the atomic bomb in the United States, proved according to general relativity that when a sphere without pressure collapses under its own gravity to the Schwarzschild radius, if the mass of the sphere is greater than the critical mass, then it is impossible to reach any stable state after gravitational collapse, and only a black hole can be formed. Oppenheimer and his students also developed a theory that stars may collapse into a dense singularity when they die, and derived a lower limit for this mass, about 3.2 solar masses [1, 10].

In the 1960s, two groundbreaking advances were made in the exploration of black holes: in 1963, Roy Kel, a New Zealander mathematician, achieved the precise resolution of the Einstein field equation with rotating black holes through mathematical means for the first time. The discovery of the first stellar black hole in 1964, a breakthrough in both theory and observation, marked the start of a golden age of black hole research. Over the following two or three decades, astronomers and physicists flooded into the field. Almost everything one knows about black holes came about during this relativistic physics, Professor John Wheeler of Princeton University, who not only excelled in academic research, but also did a lot of work in science communication. The name black hole was popularized by him before it was known to all. In addition, the term wormhole was also proposed by him, and after Wheeler, Hawking further discovered the so-called Hawking radiation, which changed the previous understanding of black holes in classical general relativity.

This research paper aims to delves into all aspects of black holes, including their formation, properties, singularities, gravitational effects, and effects on the universe and matter. The mysterious and captivating nature of black holes has caused a great deal of curiosity and exploration in theoretical physics and astronomy. By studying general relativity, the kinds of black holes, and the most recent astronomical observations, one can gain a deeper comprehension of these enigmatic entities and unlock their secrets.

2. Basic Descriptions of Black Hole

The event horizon of a black hole, a celestial body whose gravitational forces are so powerful that nothing, not even light, can escape, is the boundary of its surface - a virtual surface through which, to an outside observer, matter will never return (seen from Fig. 1) [3]. Formation of black holes is typically the result of massive stars' collapse when they have exhausted their fuel. When the core of a star cannot withstand gravitational forces, it collapses and creates an incredibly condensed area that culminates in the formation of a black hole [10-12]. Black holes can also form through mergers of stars, such as neutron star mergers or black hole mergers.

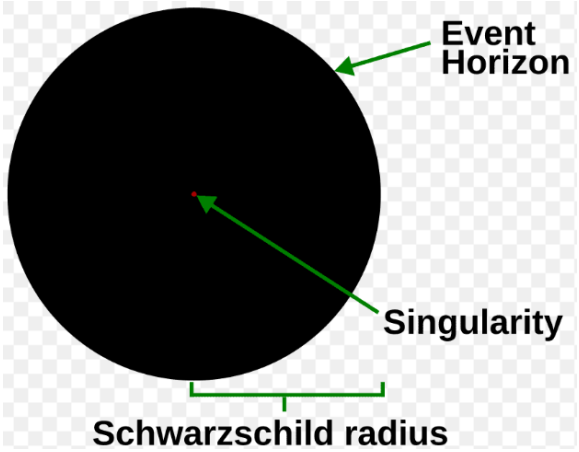


Figure 1. A sketch of the black hole.

Black holes have several important properties. Black holes are usually very massive and can be equivalent to tens of solar masses or more. The black hole's boundary, the event horizon, prevents anything beyond it from escaping its confines. A black hole can spin on its axis, causing space-time around it to bend. An electric charge can be carried by black holes, though most of them are electrically neutral.

The most conspicuous characteristic of a black hole is its gravitational force. They bend the space-time around them, bending the paths of light and objects. The gravitational lensing effect, enabling us to view multiple images of far-off entities, is also a result. A singularity, a point of infinite density and gravity, is typically located at the core of a black hole. This phenomenon is a major issue in general relativity as it appears to contravene the laws of physics.

Distinguishing between different kinds of black holes is often done through properties such as mass, angular momentum rotation, and electric charge; moreover, their space-time geometry varies. Here are some of the most frequent types and their respective space-time geometries:

- Schwarzschild Black Hole. When a star of any mass collapses, a black hole is formed. The angular momentum of the black hole is zero, meaning it does not rotate. The charge is zero, meaning the black hole has no charge. Schwarzschild metric characterizes the spherically symmetric space-time geometry of Schwarzschild black holes. It has a single event horizon and no spin effects.
- Kerr Black hole. When a star of any mass collapses, a black hole is formed. The rotation (angular momentum) is non-zero, i.e., black hole spin. The charge is usually zero, but can also have charge. The Kerr metric describes the rotationally symmetric space-time geometry of a Kerr black hole, which has two event horizons: an external one and an internal one that encircles it. Spin causes some special effects, such as the fact that a spinning black hole can spin above its limit (the Kerr limit), forming a "naked singularity".
- Reissner-Nordstrom Black hole. The mass (M) can be any mass. The angular momentum of the black hole is zero, meaning it does not rotate. An electric charge is carried by black holes, which are non-zero. The Reissner-Nordstrom metric delineates the space-time geometry of a Reissner-Nordstrom black hole, which has an event horizon but, unlike Schwarzschild black holes, is endowed with an electrical charge that influences its gravitational properties.
- Kerr-Newman Black hole: The mass (M) can be any mass. The rotation (angular momentum) is non-zero, black hole spin. An electric charge is carried by black holes, which are non-zero. The Kerr-Newman metric delineates the space-time geometry of a Kerr-Newman black hole. It has rotational symmetry and carries an electric charge. Spin and charge effects are combined in these black holes.

The geometry of space-time for these various black holes is distinct, with rotation and electric charge being a major factor in their characteristics. Investigating these properties aids us in comprehending the behavior and consequences of black holes and how they influence the fabric of space-time around them.

3. Principle of Black Hole Observation

The observation of black holes relies on several key principles and techniques. The observation of black holes necessitates the following fundamental principles [4-6]. Einstein's general relativity theory postulates that, through gravitational lensing, the path of light can be distorted by colossal entities such as black holes. It passes near them. This phenomenon is known as gravitational lensing. The presence of a black hole can be detected by observing and utilizing the gravitational lensing effect, which is produced when it passes in front of a background light source, distorting and magnifying the light [7, 12]. The emission of X-rays from black holes is often detected in the electromagnetic spectrum due to their accretion of matter from its environment. As material falls into a black hole's gravitational well, it heats up and emits these beams. To detect and study this phenomenon, Chandra and XMM-Newton are two space telescopes that have been used [7, 9, 13].

The powerful radio emissions produced by some black holes, particularly those at the core of galaxies, are often caused by a nearby accretion disk or relativistic jets of particles. To observe these emissions, radio telescopes are employed [7]. The Event Horizon Telescope (EHT)is a worldwide system of radio telescopes that collaborate to construct an Earth-sized telescope, able to observe the event horizon of supermassive black holes. This technique is known as Very Long Baseline Interferometry (VLBI) and is employed by the EHT (seen from Fig. 2) [8, 13]. By observing the movement of nearby stars, astronomers can in certain situations indirectly detect a black hole's existence. If a massive but unseen object is in a binary system with a visible star, the visible star's motion can reveal the presence of the black hole. The detection of gravitational waves has revolutionized the method of viewing black holes. When black holes merge, they send ripples through spacetime known as gravitational waves. Designed to detect these waves, instruments such as LIGO and Virgo have observed multiple black hole mergers [13]. The accretion disk, formed by matter falling into a black hole, emits electromagnetic radiation of various kinds - visible light included. Optical and infrared telescopes are used to observe and study these accretion disks. The capacity to detect and investigate black holes in the cosmos has been significantly augmented by these principles, techniques, and advances in observational technology and data analysis. They have led to groundbreaking discoveries and a deeper understanding of the nature of these enigmatic objects [9].

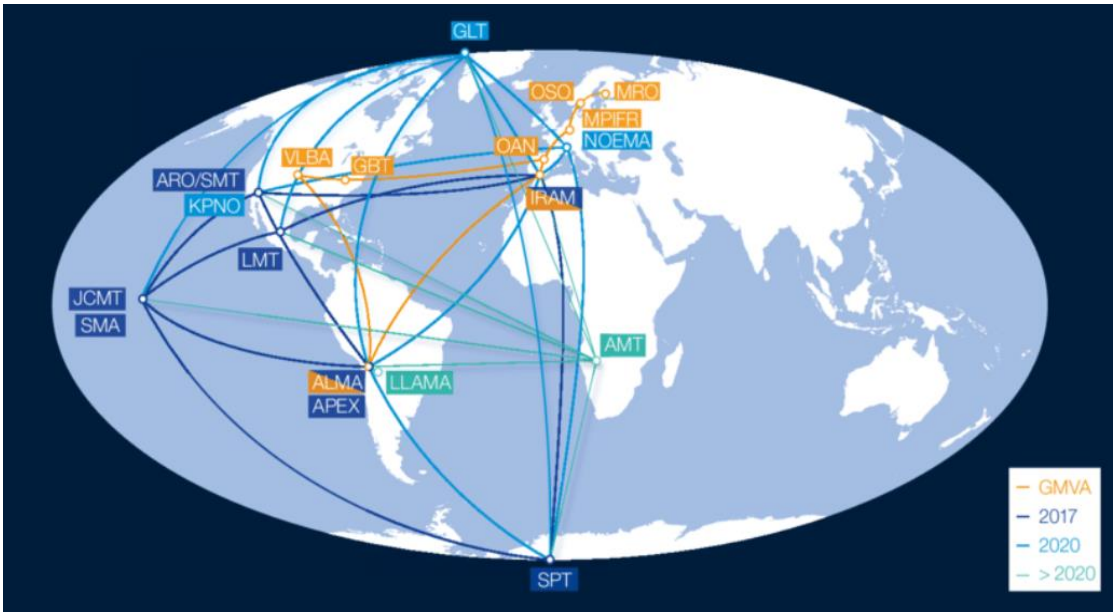


Figure 2. A sketch of VLBI.

4. Observation and Application

Black holes have long been predicted, and various observational facts continue to prove their existence. However, this is the first-time humans have directly photographed a black hole. Verification of Einstein's general theory of relativity through simulated observations was achieved by direct imaging, in addition to aiding individuals in verifying the presence of black holes. During the work of the Event Horizon Telescope and later in the process of data analysis, scientists found that the observed black hole shadow and relativity predicted almost exactly, which cannot help but sigh again Einstein's greatness [14].

The size of the shadow of a black hole can be used to restrict its mass, allowing for an independent measurement of the mass at M87's center. Until now, though, measuring the mass of a black hole has been a complex task due to the lack of observation resolution and sensitivity, making the current detailed analysis of black holes far from perfect. Anticipating the augmentation of telescopes, one anticipates a greater and more detailed view of the black hole in the future, thus enabling us to

comprehend the gas's motion around it, differentiate jet production and bunching processes, and augment the comprehension of galaxy development. To sum up:

To study a substance an object requires a model, a sample to observe and experiment. For objects that are visible from Earth, one can see them, one can touch them, one can experiment with them, so one can study them in depth for stars, one can't see and touch, only through the spectrum, observe the orbit and so on to study, many theories have been overturned back and forth. For black holes, one can not only see and touch, only by observing the trajectory of other nearby stars and some indirect radiation can infer where the black hole is Mysteries and unsolved mysteries remain, as strange objects in the universe, black holes. By delving deeper into the formation, properties, gravitational effects and observations of black holes, one can better understand these gravitational giants and further advance physics and astronomy. Unlocking the mysteries of the universe, black hole study is expected to bring us further scientific discoveries in the future, providing a breakthrough.

5. Conclusion

To sum up, by probing the presence of black holes, one can infer not only when and how the universe was created, but also how the Earth came into being after it. Alongside this, living things and humans are included. Grasping black holes can be seen as a realistic means of determining whether the universe was created by the Big Bang, if galaxy evolution is impacted by remarkable jets in galaxies, and, most significantly, if black hole presence has an effect on the survival of humans and organisms on Earth, as well as the planet's ecology and biodiversity.

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