Comparison of Different Types of Black Holes

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Abstract. With the deeper exploration on black hole, more and more categories of black holes are defined by astronomers and physicists. The article will discuss the differences in detection and process of accretion between the binary black holes and isolated black holes through analysing previous researches on black holes. To search for binary black holes, whose companion may be luminous, classical methods include spectrum test and calculation of the operation of binary star system are applied. On the other hand, the state-or-art facilities HST are used to detect them based on gravitational lens effect. These two different sorts of black holes also have their unique process of accretion. The binary black holes absorb particles from the stellar wind which is given out by their companion, forming two "minidisk". The process is accompanied with strong emission of X-ray. Meanwhile, the accretion of isolated black hole forms only one ring of gas. The accretion flow is mostly weak and radioactively inefficient. The reason for these differences can be their separate optical features and relationships with environment. It is aimed at distinguishing the two kinds of black holes with different framework, making them easier to identify only with optical evidence or data on radioactive emission. Therefore, it's easy to tell the infer structure from evidence that astronomers can comparatively easier obtain about black holes, which is beneficial for further studies about black holes internal structure details. These results shed light on guiding further exploration of black holes.

Keywords: black hole, spectral test, Double-star system operation, accretion

1. Introduction

The conception of black hole was first proposed in 18th century by John Mitchell and Pierre-Simon Laplace. Following that, in 1910s, Karl Schwarzchild proposed black holes as the first modern solution of general relativity. At the very beginning, black holes were only considered mathematically exist. However, as the researches on black holes developed wider and deeper, much more facts about black holes have been found. For instances, more and more evidence recently found suggest that the core of some galaxy may be supermassive black holes, making black holes a significant figure that participates in the formation of galaxy. Thus, to learn more about galaxies, more studies on black holes must be carried out. To distinguish different sorts of black holes and know their separate characters can be crucial, whereas there are still blanks left for it.

Most generally, black holes are divided based on their different mass and angular momentum. The article will mainly focus on the comparison between the binary black holes and isolated black holes, which are black holes under another classification. Based on retrieving previous studies on black holes, several differences between these two kinds of black holes are found. Compared to isolated black holes, the detection of binary black holes appears to be more complicated. To confirm a black hole in binary star system, a series of prerequisites such as that the black hole companion must be visible in optical or infrared, the matter of black hole companion is absorbed by the black hole, the process of accretion is with strong X-ray emission, and the apparent velocity of black hole companion and the inclined angle of the two orbits of the two stars can be measured by spectrum test must be met [1]. On the contrary, using gravitational lens effect, isolated black holes can be found without such cumbersome process. The state-of-art families (e.g., HST) that can detect the relativistic deflection of light from background stars brought by isolated black holes, are also put into use [2]. Besides, binary black holes and isolated black holes also differ from each other in the process of accretion. Since binary black holes are accompanied by their companions, usually, these black holes absorb the matter form stellar wind. In some binary stars systems, the companion of binary black holes are a comparatively smaller black hole, thus "minidisk", the accretion disc, i.e., forms around both of the black holes.

On the other hand, isolated black holes can accrete from interstellar medium. They usually form a accretion disc that is mostly consisted of gas around them. However, since the accretion flow is weak and ineffective in radiating, the process of accretion is usually accompanied with remarkable material outflow. [3] The accretion of supermassive black holes is predicted to be influential and may break the balance of the formation and evolution of their host galaxies, however, the black holes appear to have an adjustment system that help to keep the balance still. Although theories about the accretion and detection of binary black holes and isolated black holes are comparatively mature, the observation of them is at a primary stage. The number of stellar black holes in galactic system is predicted to be over hundreds of millions, however, the black holes that acquire identification from dynamical method are only around 20. Fig.1 shows the distribution of dynamically confirmed black holes and black holes candidates [4].

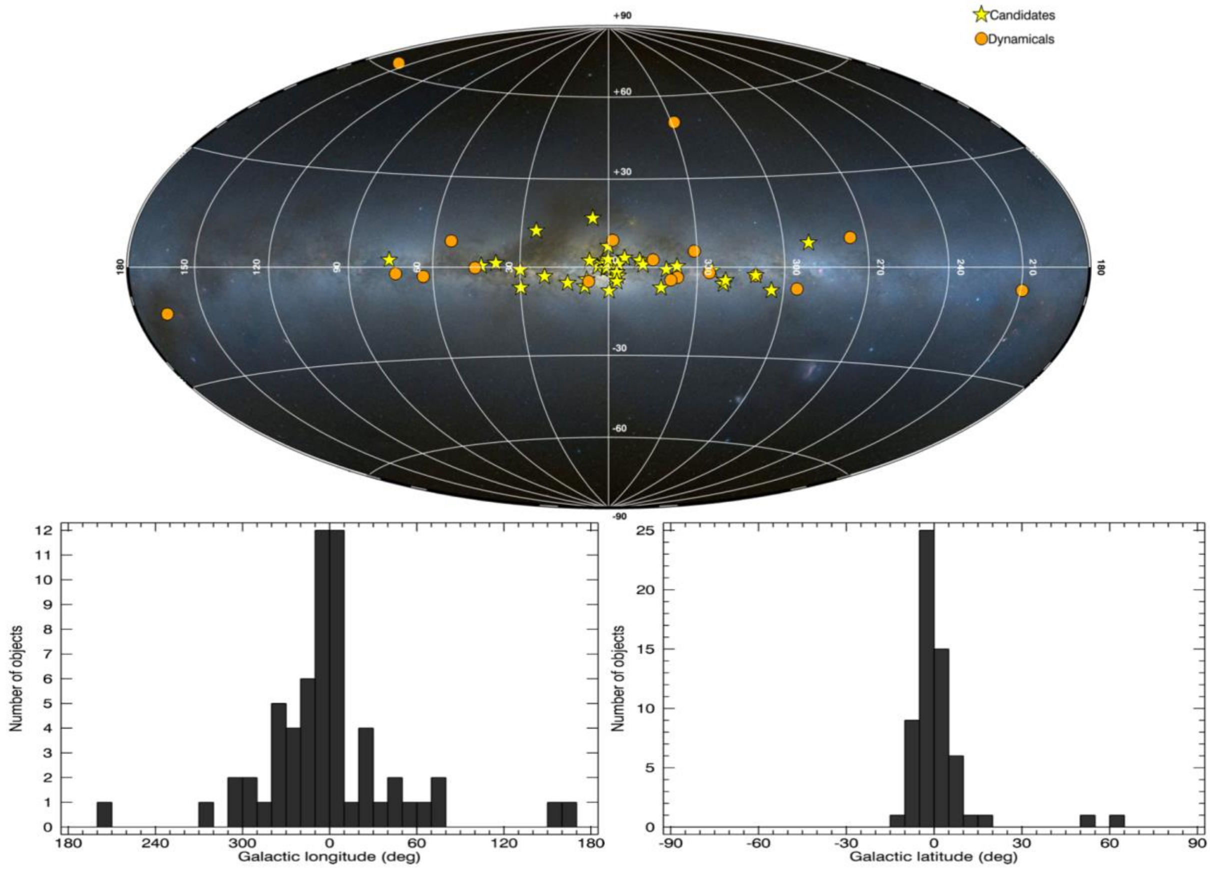

Figure. 1 the distribution of dynamically confirmed BHs (circles) and BH candidates (stars) in the Galactic plane, using the Hammer projection. (Background image credit: Mellinger 2009). The figure is taken from reference [4].

In order to better detect and research on black holes, it's essential to distinguish different kinds of black holes, better understand the characteristics of each kind of black holes and develop more mature methods to deal with them. This article hopes to achieve the goal that helps researchers who aim on further observation and researches on black holes to clarify the differences between binary black holes and isolated black holes, so that they can discuss these black holes with ease. The rest part of the paper is organized as follows. In section II, the basic descriptions of black holes will be given to enable the reading of later parts. Section III will give the category of black holes and introduce the category that will use in this article. Comparison of binary black holes and isolated black holes, mostly about their differences in detection methods and accretion process and the analysis of the differences according to previous studies, will be included in Section IV. Section V will be the conclusion part of the article.

2. Basic Description of Black Holes

Black hole is a space region where the spatiotemporal curvature is too large to allow any matter to escape from its event horizon. Even light cannot escape the black holes inside the event horizon. The mass of a black hole usually outweighs 3M⊙ (solar mass), making the black hole a supermassive celestial body. In this way, the gravitational force of a single black hole can be so enormous that its ability to distort the space and time increases drastically. The distorted space and time further change the geodesic line, which is the path that light travels by. Therefore, when passing by supermassive celestial bodies such as black holes, light defects inward into it. The gravitational force of black holes is so great, that the path of light defects so much and it cannot escape from the event horizon of black holes.

Outside the event horizon, the light can still bypass the black holes and reach the Earth. However, inside the event horizon, no light can escape. Thus, it's impossible to get direct optical images about black holes, making the ways of detect black holes extremely limited. Two methods for black holes detection are using classical dynamical methods and applying gravitational lens effect. Most of the black holes are isolated black holes that doesn't give out light, thus, astronomers observe the gravitational lens effect caused by them to detect them. Gravitational lens effect is to calculate the distribution of celestial bodies in the space due to the deviation of light their enormous mass brought. This method is used to detect many invisible celestial bodies such as isolated black holes and nonbaryonic dark matter. On the other hand, there are a small number of black holes that is giving out light. Binary black holes belong to this category. Through the light emission of their companion stars or the strong X-ray produced by their accretion process, binary black holes can be detected using optical astronomical telescopes. However, this classical dynamical method requires a long process of confirmation. The observed celestial bodies must meet many prerequires to be a black hole.

Black holes' process of accretion is to attract interstellar matter to it, enlarging its size and mass. The process also allows black holes to devour other black holes, which will interact with the formation of their host galaxies. Black holes grow almost the same way their host galaxies do, such as collide and merge with their neighbours. However, merging disrupts galaxies and leads to drastically enhanced star formation, and sends a flow of cold gas towards the merged black holes. The process, which should disrupt the simple relationship between the black holes' growth and the evolution of galaxies, however, does not function as predicted. By contrast, the black holes give feedback and regulate the evolution of the galaxy.

Three simple factors can describe a black hole. They are mass, angular momentum and charging capacity. Although the mass of black hole can be any positive number, the angular momentum and charging capacity is limited to certain amount. The total electric charge Q and the total angular momentum J are expected to satisfy the following inequality [5]. The formula is given as follows;

$$\frac{Q^2}{4\pi\epsilon_0}+\frac{c^2J^2}{GM^2}\leq \mathrm{GM}^2 \tag{1}$$

3. Category of Black Holes

Previous paragraph has mentioned that according to the no-hair theorem, a black hole can be simply defined with three factors known as the three hairs of black holes: mass, angular momentum and charging capacity. Partially depends on this, classical classification divides black holes into four types. First, the Schwarzchild black hole that has no angular momentum and charge. Then, is the Reissner-Nordström black hole, which has no angular momentum but is charged. Besides, Kerr black hole has angular momentum but is not charged. The last type of black hole is Kerr-Newman black hole that has angular momentum and is charged. According to the Birkhoff's theorem, the Schwarzchild black hole is the only spherically symmetric vacuum solution [6].

However, though a black hole can have a large amount of charge theoretically, the charge of a real black hole is usually considered to be nearly zero. It's because of the plasma around the black holes is an effective conductor [7]. Black holes are generally divided depends on their mass despite their angular momentum. A supermassive black hole has a mass of 10^5-10^{10} M⊙ and a radius of 0.001-400 AU. An intermediate-mass black hole has a mass of around 10^3 M⊙and a radius of around 10^3 kilometres, almost the size of the Earth. A stellar black hole has a mass of about 10 M⊙and a radius of 30 kilometres. The smallest type of black hole is called micro black hole, with a mass of above 3 M⊙and a radius of up to 0.1mm.

Besides, black hole can also be divided into binary black hole and isolated black hole. The binary black holes are black holes that exist in a binary star system. The system is usually consisted of a host star and its companion. A black hole's companion can be a comparatively smaller black holes or a star. In mathematical model, when two black holes reach closer and closer to each other, a protuberance is produced from one of the event horizons and starts to expand to the other event horizon. The protuberance continues to grow longer and longer until it meets its peer from the other black hole. Then, a narrow X-shaped pattern forms at the junction of the two protuberances, and finally develops to be a cylindrical connection called "bridge" [6]. Moreover, most of the black holes in the space are isolated black holes.

4. Comparison of Binary Black Holes and Isolated Black Holes

The binary black holes and isolated black holes have several characters that are different from each other, making them able to be distinguish. In this article, the differences in detection methods and the process of accretion will mainly be discussed.

For the binary black holes, classical dynamical method is used to detect them. In a binary star system, the companion star of its host black hole will have a spectral shifting, which can be observed and measured. However, the host celestial bodies can be other celestial bodies besides black holes, so after observing the light given out by the companion star, several steps must be taken to confirm it. The deciding factor is the mass of the celestial body. If the mass of it is over 3M⊙, then it can be confirmed that the host celestial bodies are black holes. To get the data of mass, researchers must go through a spectral analysis first. The data obtained from spectral analysis can be used to calculate the apparent velocity of the companion star due to the Doppler effect.
The redshift z can be defined as:

$$1 + \mathrm{z} = \frac{\lambda(\text{observed})}{\lambda(\text{emitted})} \tag{2}$$

In this case, if the line moves in wavelength about 1% to the red, then it can be calculated using the previous formula that z=0.01. The apparent velocity of the companion star can be then obtained through the formula that $v(rad) = cz$, where c is the speed of light in the vacuum.

With the apparent velocity of the companion star, astronomers can calculate the track linear speed and the radius of the orbit path. Then, using Kepler's third law of planetary movement, the mass of the host celestial body can be confirmed. During this process, the spectrum of companion star will be observed for over ten times. Through fitting the apparent velocity changing curve, the amplitude of apparent velocity and the orbital period of binary stars can be obtained. These data, combined with the temperature, metal abundance and surface gravity, can further lead to the radius and mass of companion star. This guarantees that the invisible host star has a mass that can be limited to certain range. A typical spectrum is illustrated in Fig. 2 [8].

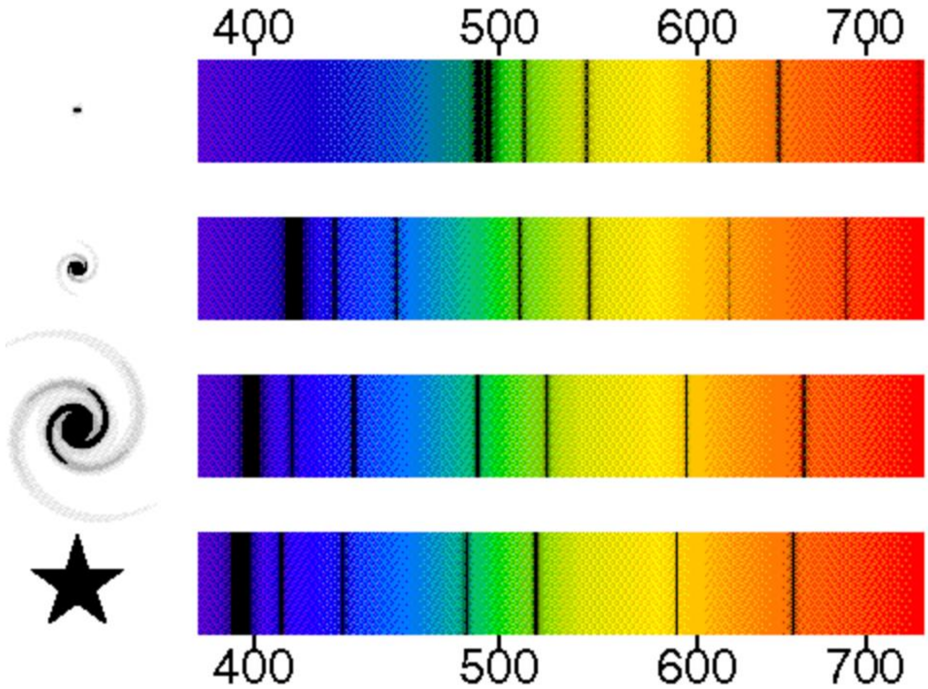

Figure. 2. The spectrum of a galactic star. Sources from reference [8].

On the other hand, the isolated black holes don't give out light. Therefore, the only way to detect them is to use gravitational lens effect. By the degree of the deviation of light paths, the space distribution of the isolated black holes can be clarified. Astronomical equipment's such as HST are used to observe the spectrum shift, which is highly demanding in its accuracy [9].

Besides, binary black holes and isolated black holes differ from each other in the process of accretion. Binary black holes usually accrete in the forms of stellar wind, a continuous flow of particles from a star. Some binary star system that consisted of a big black hole and a small black hole forms "minidisk" [10]. On the contrary, isolated black holes accrete from interstellar medium, mostly of it is gas flow. An accretion disc that is mostly consisted of gas usually forms around an isolated black hole. Since the accretion flow is weak and ineffective in radiating, the process of accretion is usually accompanied with remarkable material outflow.

5. Conclusion

In conclusion, the difference of isolated black holes and binary black holes are discussed in details. The isolated black holes don't emit out light, thus the detection of isolated black holes mostly relies on gravitational lens effect similar to many other invisible celestial bodies in the space. Detection of binary black holes, owing to the light given out by their companion stars or the process of accretion, can be conducted with the observation from optical astronomical telescope and spectrum test. For the process of accretion, the binary black holes accrete matter from the stellar wind sent out by its companion stars or devour the small black holes in binary stars systems while the isolated black holes accrete interstellar medium. Though the article has provided distinguishable characters for these black holes, the discussion only shows parts of the difference between the two kinds of black holes, and the data for it is very limited. Researchers even rely on acoustic black holes to conduct experiment and get more valid data. With the development of the state-of-art facilities and detectors, which will be greatly improved in accuracy and horizon, the research of black holes can go on more smoothly. Overall, these results offer a guideline for black holes searching and investigation.

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