Two of the Binary Stellar Evolution Formation Channels

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Abstract. More and more exo-stellar systems are being discovered step-by-step, including a type of system that is made up of two stellar, which is the binary stellar system, and the evolution of the binary stellar systems is also a field in the spotlight. Furthermore, there were gradually increasingly gravitational waves being detected in recent years, which led to more developed models of outer space objects. Following the topic of Binary Stellar Evolution Formation Channels, this article majorly discusses the models of binary stellar evolution formation channels as the results of the analysis of the data of gravitational wave detections. Accompanying, this study also included the analysis of gravitational wave detecting methods and results. Not surprisingly, there are still many remaining problems, thus the relevant currently remaining problems and the related future directions are also presented in the article. To sum up, this paper aims to give more specific explanations of the binary stellar evolution and sheds light on guiding further exploration for this topic.

Keywords: Gravitational wave; Binary Stellar; Evolution Channel; Black hole.

1. Introduction

In this universe, many stars of a mass similar to or greater than the sun have companion stars. Among them, a star system composed of two stars around a common center of mass is what is called a binary stellar system. In addition, the formation channels of these binary stellar systems' evolution are one of the most controversial issues in astronomy, and they are gradually being discovered in recent years. One of the discovered ways is through the detection of gravitational waves. Contemporarily, astrophysicists have detected a number of gravitational waves that are emitted during the eventual inhalation and merger of binary black holes and neutron stars [1].

Based on the Laser Interferometer Gravitational-Wave Observatory (LIGO) and the Virgo interferometer, there were several Gravitational waves have been detected in the past years [2, 3]. The former is a physical experiment and observatory that detects gravitational waves through laser interferometry and uses gravitational wave observations as an astronomical tool and the latter is a large interferometer aim to detect gravitational waves predicted by general relativity.

As an example, the first discovered gravitational wave GW150914 simultaneously through Virgo and Advanced LIGO, and originated from the merger of two black holes [4]. This is also the first direct demonstration that black holes are capable of merging from binary black hole systems in Hubble time (the universe to expand to its current size, about 14 billion years) [1]. In addition, the data of GW150914 are highly consistent with the second law of black hole mechanics and also provide evidence for general relativity [5]. Therefore, indisputably the observation of these gravitational waves has undoubtedly provided much data for studying the relevant models of how the binary stellar system evolved, or even as some of the channels, that are finally forming a black hole.

In order to give more specific explanations of the binary stellar evolution, this paper will discuss the resulting discoveries obtained by the detections. The rest part of the paper is organized as follows. The Sec. 2 will explain the detection of gravitational waves and. The Sec. 3 will explore the models for predicting the formation channels.

2. Detection Facilities

2.1. The principle of detection equipment

Interferometers are investigative tools, they superimpose light beams to produce interference patterns that can be measured and analyzed, the interference patterns contain information about the object or phenomenon, moreover, interferometers are often used to make very small measurements [2]. The Michelson-Morley interferometer, invented by American physicists Albert Michelson and Edward Morley, is the core of all gravitational-wave interferometric detectors today, a Michelson laser interferometer consists of a laser, a beam splitter, a series of mirrors, and a photodetector that records the interference pattern [2]. The beam splitter is a semi-transparent mirror tilted at 45 degrees that splits the incoming laser beam into two equal beams and then sent the beams into the two arms of the interferometer, as the mirrors' Fabry-Perot resonant cavity, which is a kind of optical resonator, extends the effective optical length, after which in each arm there are multiple reflections between the two mirrors, amplifying the tiny changes in arms' length caused by passing gravitational waves, and finally, the two laser beams that return from the two arms are then recombined on the photodetector [3]. The sketch of the interferometer is shown in Fig. 1 and Fig. 2.

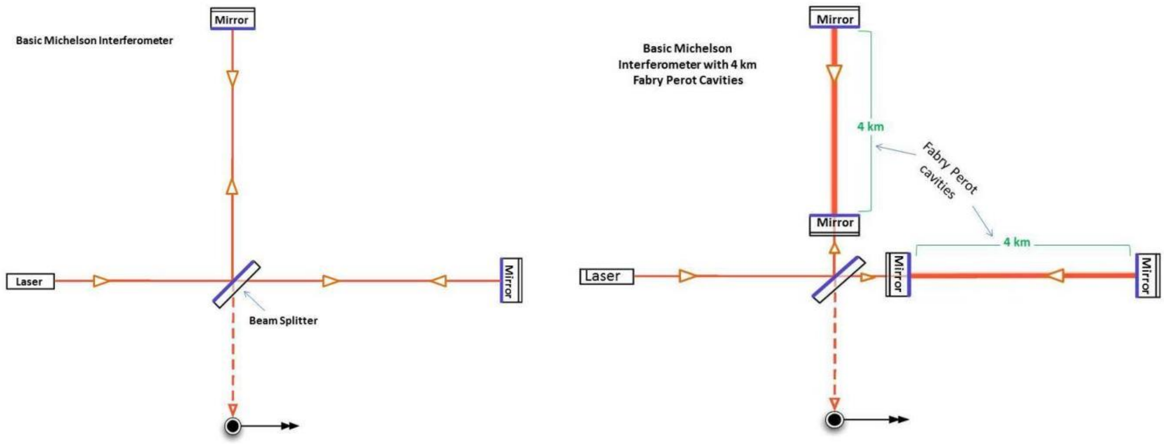

Fig. 1 A sketch of a basic interferometer without (left) and with (right) FP.

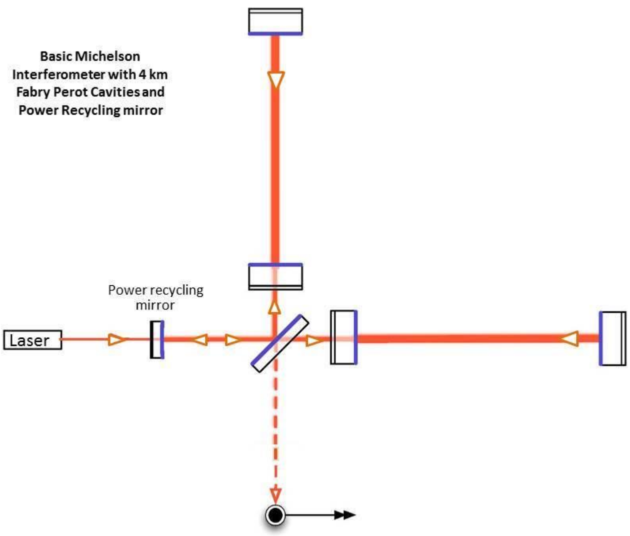

Fig. 2 A sketch of a basic interferometer with FP and PR labeled.

The distance they travel before combining can be used to determine what happens when beams combine. To be specific, if the beams travel the exact same distance, they will perform destructive interference, which means there will be no light in the interferometer. Gravitational waves stretch space itself in one direction while compressing it vertically. Therefore, this causes one arm of the interferometer to become longer while shorter for the other in LIGO. As the length of the arm changes, so does the distance traveled by each laser beam, resulting in the flickering light from the interferometer [2]. Therefore, finding the expected gravitational wave signal. Nevertheless, in real detections, interferometers need to filter out the flickering light produced by most other factors in order to detect the flickering of light caused by gravitational waves. In addition, the LIGO interferometer is 4 kilometers long and is currently the largest interferometer [2], while the two orthogonal arms of the Virgo interferometer are each 3 kilometers long [3].

2.2. Identifying the source of gravitational waves

Firstly, A binary system of stars or black holes orbiting each other long before the merger, or a star with a large irregularity rapidly spinning around its axis, produces continuous gravitational waves that are relatively weak and have a nearly constant frequency, an example of this kind of gravitational waves (GWs) is shown below in Fig. 3 [6].

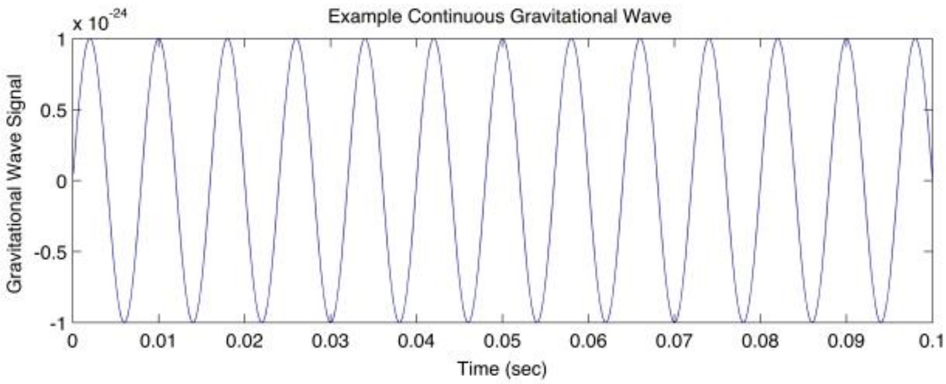

Fig. 3 Example of GW strain signal from a continuous GW source.

Secondly, binary stellar systems made up of two neutron stars, two black holes, or a neutron star and a black hole, produce inspiral gravitational waves when they merge into one at the end of their lifetime, and as their orbital distance decreases, their speed increases, causing the frequency of gravitational waves to increase, an example of this kind of gravitational waves (GWs) is shown below in Fig. 4 [6]. The first direct detection, GW150914, it's exactly the inspiral gravitational wave, released from a merging of two black holes of masses ~35$M_{\odot}$ and ~30$M_{\odot}$ at a distance of ~440Mpc from the Earth, and this merge results in a ~62$M_{\odot}$ black hole, which means ~3$M_{\odot}$ rest-mass energy was released in the form of GWs [7, 8].

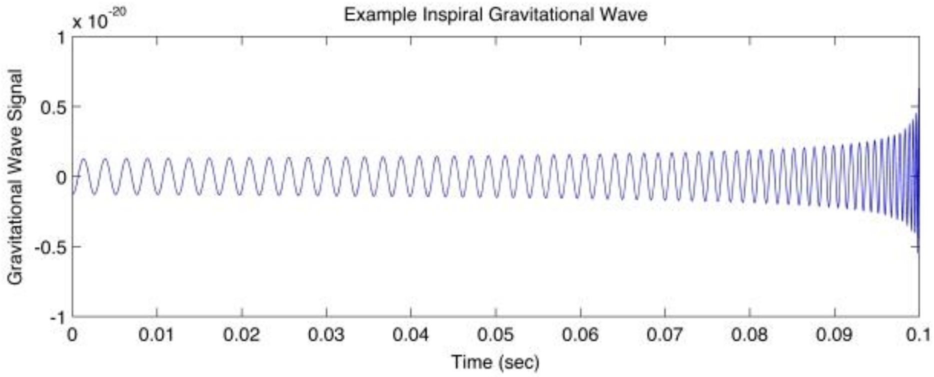

Fig. 4 Example of GW strain signal from an inspiral GW source.

Moreover, it is hypothesized that some supernova or gamma-ray burst systems may produce burst gravitational waves, but the form these waves will have been currently unpredictable. Finally, there is a kind of GW called stochastic gravitational waves, which may be the remnant light from the Big Bang. It this case, it might from many random independent events that combine to form the cosmic gravitational wave background, and the sound produced by these gravitational waves is a continuous noise. The example of these two kinds of gravitational waves (GWs) is respectively shown below in Fig. 5 and Fig. 6 [6].

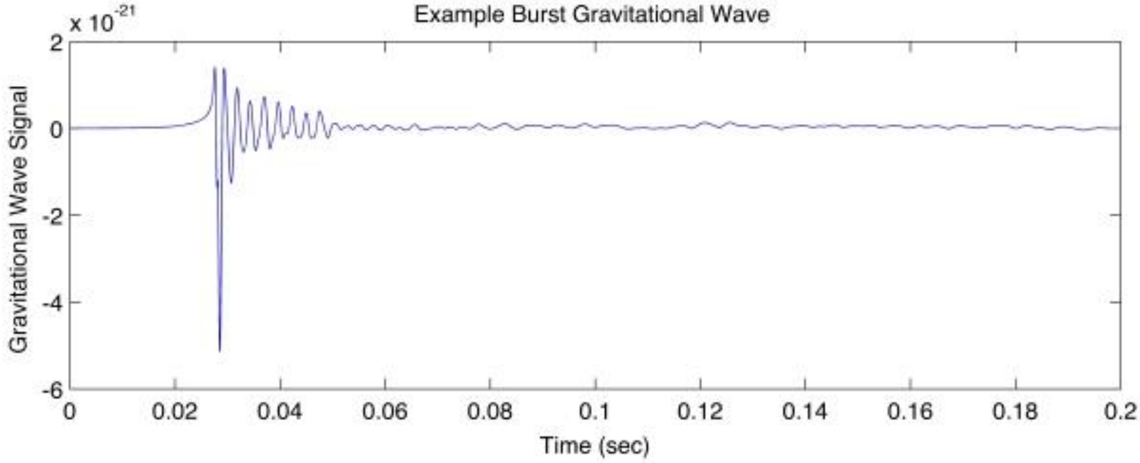

Fig. 5 Example of GW strain signal from a burst GW source

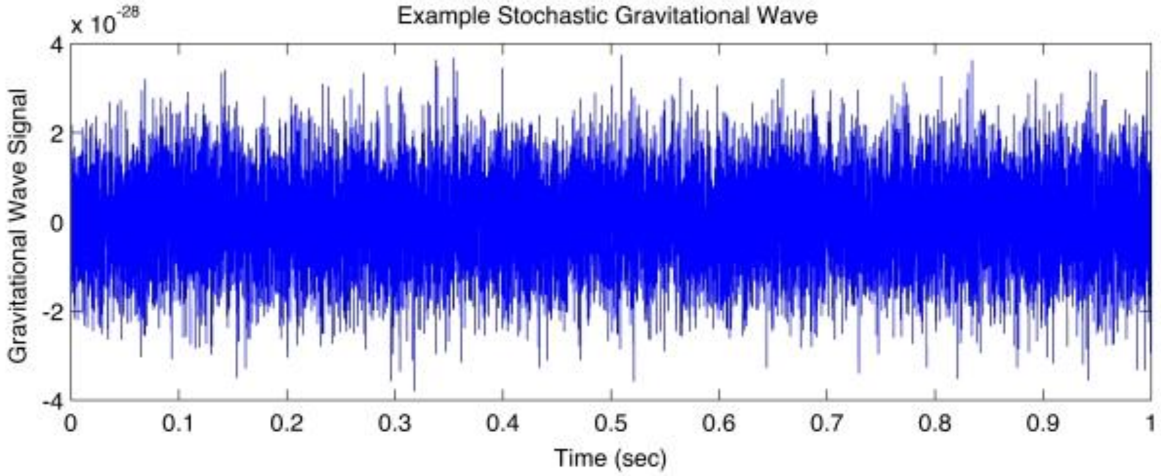

Fig. 6 Example of GW strain signal from a stochastic GW source.

3. Results

Recently, a model for predicting the formation channels of merging black holes through the evolution of isolated binary stars was brought forward. Two of the channels that start the same way can be described as the following, and the schematic diagram of them is shown in Fig. 7. Starting with two stars that are main sequence stars, they are gravitationally bound to each other. Subsequently, since the nucleation of the larger star is more intense, the hydrogen will be consumed faster. In this case, it will leave the main sequence stage earlier. At that time, its radius began to expand, even hundreds of times, becoming a giant star with a helium core and a large hydrogen envelope [9].

If the giant star had the same radius as the Roche lobe, it would start to lose mass (i.e., to the other star or just lose to space), and then collapse into a black hole. Here, the Roche lobe is an approximate teardrop-shaped region around a star in a binary system. Subsequently, when the other star in the binary system also begins to leave the main sequence star, the black hole and the helium core (which is formed by the second star) of the binary system begin to spiral in [9]. Here, the two channels start to appear different, and the system is in a phase called the common envelope, where the two objects are contained in the gas.

If their energy is not strong enough to unravel the envelope, the hydrogen core of the second star will merge with the now existing black hole, resulting in one black hole. Otherwise, a new binary stellar system that is made up of one black hole and one stripped naked helium star is formed. If the bare helium star is big enough to collapse into a black hole, then the system becomes a binary black hole system, which may merge within Hubble time if their orbital separation is very close [9].

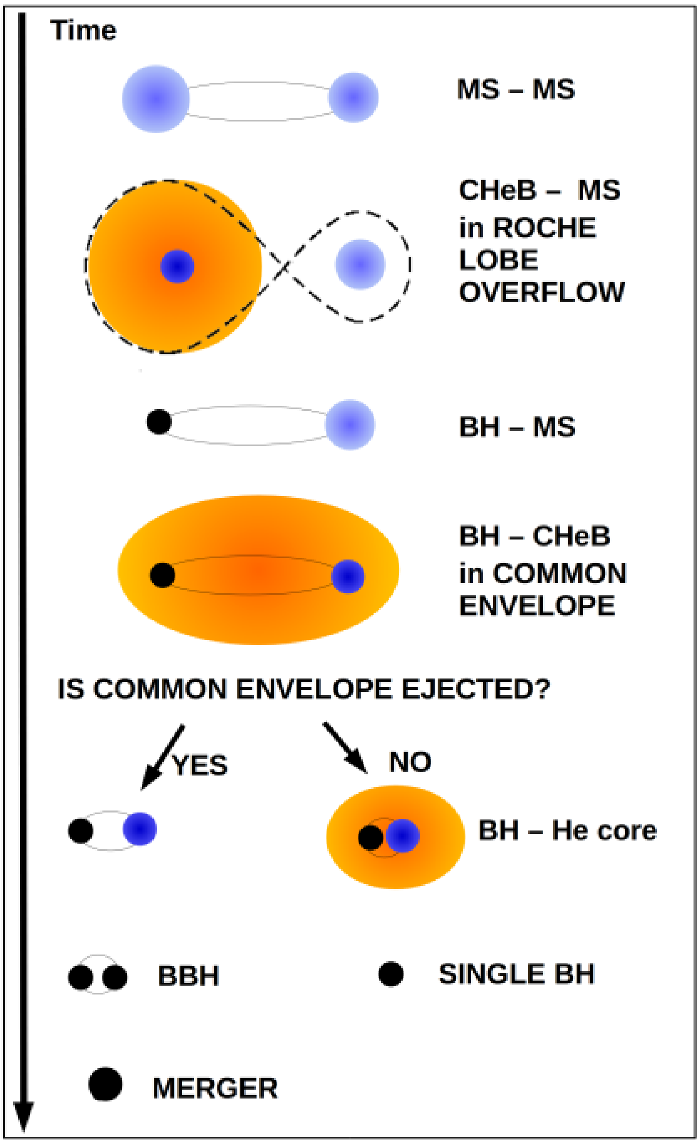

Fig. 7 Schematic evolution of an isolated binary star that can give birth to a black hole.

4. Remaining questions

Nevertheless, there are still some unsolved problems that remain. Firstly, the dynamics of the binary black hole cannot be simulated correctly as the mass and spin of the black hole from stellar evolution are not known. In fact, there is currently no way to perform dynamic simulation calculations at an appropriate cost [9]. These factors both hinder the understanding of the dynamics associated with binary black holes. Furthermore, though there are several possible channels of evolution been modeled, there is currently no way to predict the fate of massive binary stars due to the associated physical uncertainty of stars and binary stars being too large [10].

5. Future directions

In the future, it seems that potential development directions can be as follows. First, more Gravitational waves are expected to be observed via the LIGO and the Virgo. Therefore, there will be more data for scholars to investigate and speculate on the relevant models of the mass and spin of black holes produced by stellar evolution. In order to better carry out the simulation of the dynamics of binary black holes. Furthermore, more observational data may also help reduce the physical uncertainty associated with binaries, thus leading to the possibility of predicting the fate of massive binaries. In addition, improvements in computational methods and techniques can also be expected to enable better dynamic simulation calculations for these binary stellar evolution channels.

6. Conclusion

In summary, this paper discusses models of binary stellar evolution channels from the perspective of the results of gravitational wave observations. Specifically, two channels of binary stellar evolution formation that finally resulting the black hole. According to the analysis, through the observations of gravitational waves in recent years, the binary stellar system models have been better refined. Moreover, these also brought straight demonstrations of binary black holes can merge within Hubble time. Besides, these results further verified Einstein's general theory of relativity. Nevertheless, the future behavior of massive binary stellar systems still cannot be predicted currently. Therefore, it may be expected that there will be enough data and technology to enable these predictions in the future. Overall, these results offer a guideline for the models of binary stellar evolution formation channels based on analysis of gravitational wave detections.

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