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Analysis of black hole merger in AGNs

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Abstract. In recent years, the phenomenon of black hole fusion in AGNs is a direction that cosmologists focus on at present. On this basis, this study will present an overall analysis of black holes mergers in AGNs. To be specific, this paper will first introduce some basic rules observed during black hole fusion. Secondly, a brief overview of black hole fusion in AGNs is given. Subsequently, the gravitational wave device (LIGO) used to detect BHs fusion is introduced in more illustration, and some relevant data on its measurement accuracy, its structure and related uses are given. After that, the authors will review several cases of BHs fusions in AGNs. At the same time, there are still several areas such as the role that gases and stars play in BH Merger and the attributes of the merged Black Hole require further exploration. Overall, these results shed light on guiding further exploration of black holes merging.

Keywords: black hole, merger, detection, AGNs.

1. Introduction

Black holes (and their homologs) are crucial topics of observational work in much of astronomy, as well as theoretical objects of study in many fields, including optical science, solid-state Physics, superfluid mechanics, high-energy particle Physics, astrophysical science cosmic science, conventional, quasi-classical, and quantum mechanics [1]. In past several year astrophysicists have changed their perspective towards massive Black Holes (MBHs), which are now regarded as an essential part in initial galaxy formation. This change was driven by a series of observation achievements that show the presence of MBHs and the phenomenon that these BHs are always at the heart of most galaxies [2].

Through the detection astrophysicists perceive massive Black Holes must have originated from the same substance that gave rise to galaxies and the rest of the cosmos. The baryonic component of galaxies is represented by stars and gas, as opposed to nonbaryonic dark matter, which only communicates with its surroundings gravitationally and not electromagnetically [2].

In observations, astrophysicists spot a special phenomenon called Black Hole merger. LIGO-Virgo has detected gravitational waves from five BH mergers, which greatly promoted the development of high-energy physics [3, 4]. One of the most perplexing unanswered mysteries of our day concerns the astrophysical origin of these mergers. Triple systems, gas-assisted mergers, isolated binary evolution through a common envelope phase, chemically homogeneous development in short period star binaries, and dynamically constructed binaries in dense stellar systems like globular clusters (GCs) or galactic nuclei are all possibilities [5]. In this paper, the author will illustrate the basic principle of BH mergers

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in AGNs, how astrophysicist detect this phenomenon by gravitational wave and provide one instance of investigation of BH mergers (GW170104).

2. Basic description

Firstly, this study will mention about the basic principles of BH mergers and then have a further illustration of the BH mergers in AGNs. General relativity explains how gravity works in the universe and predicts the behaviour of massive objects like BHs. According to general relativity, the existence of matter and energy results in the curvature of spacetime. Schwarzschild metric describes the spacetime around a non-rotating BHs. It predicts that the BH has a singularity at its centre and an event horizon, which is the boundary beyond which nothing, not even light, can escape.

$$g = -c^2 d\tau^2 = -(1-\frac{r_s}{r})c^2 dt^2 + (1-\frac{r_s}{r})^{-1} dr^2 + r^2 g_\Omega \tag{1}$$

where g_Ω is the metric on the two spheres, i.e., $g_\Omega = (d\theta^2 + \sin^2\theta d\phi^2)$. Kerr metric equation describes the spacetime around a rotating BH. It predicts that the BH has an ergosphere, which is the region outside the event horizon where the spacetime is dragged along with the rotation of the BH. The spacetime geometry around a mass M revolving with angular momentum is described by the Kerr metric. The metric in Boyer-Lindquist coordinates is,

$$\begin{gathered} ds^2 = -c^2 d\tau^2 \\ = -\left(1-\frac{r_s r}{\Sigma}\right)c^2 dt^2 + \frac{\Sigma}{\Delta}dr^2 + \Sigma d\theta^2 + \\ \left(r^2 + a^2 + \frac{r_s r a^2}{\Sigma}\sin^2\theta\right)\sin^2\theta d\phi^2 - \frac{2r_s r a \sin^2\theta}{\Sigma} c dt d\phi \end{gathered} \tag{2}$$

where the coordinates r, θ, ϕ are standard oblate spheroidal coordinates, which are equivalent to the cartesian coordinates

$$x = \sqrt{r^2 + a^2}\sin\theta\cos\phi \tag{3}$$

$$y = \sqrt{r^2 + a^2}\sin\theta\sin\phi \tag{4}$$

$$z = \mathrm{r}\cos\theta \tag{5}$$

where r_s is the Schwarzschild radius

$$r_s = \frac{2GM}{c^2} \tag{6}$$

Binary black hole system describes the movement of two BHs orbiting each other before they merge. It considers the BHs' masses and spins and predicts the emission of gravitational waves as the BHs spiral towards each other.

3. Black hole mergers in AGNs

AGNs are special circumstance that can help or alter how BH mergers develop. It is anticipated that the nuclei of active galaxies could contain Numerous stellar-masses BHs that have relocated into the nearest parsec as a result of mass segregation [6-10]. The reciprocity between the BHs and the AGN disk can make these BHs' orbits coincide with the disk [11-16]. Additionally, certain BHs can be generated within the disk directly [17, 18]. Once within the disks, contact with the revolving gas may cause the BHs to migrate to spots 300 Schwarzschild radii away from the supermassive BH in the center [14]. Migration traps may be the cause of the binary BH creation within the AGN disk [19]. Around these traps, BHs can build up and create binary BH systems [19]. If there are more than one BHs enter the disk, they will ultimately collide and combine in the migration trap. As a result of dynamical friction within the disk, this merger will happen rapidly [16]. Furthermore, before the binary BHs falling into the migration trap, they may be able to coincide their orbits with AGN disk and integrate fast [16]. In addition, when many BHs travel to the migration trap and line their routes around the AGN disk, they combine and stay close to the migration trap, allowing the remnant to merge with other BHs [14]. Gravitational wave measurements will be able to distinguish these hierarchical mergers due to their distinctive, high BH masses and distinctive spin characteristics [20-22]. A sketch is shown in Fig. 1. AGN-assisted BH mergers have unique characteristics that may set them apart from other paths for development. One of these is their mass distribution, where it is projected that heavier BHs will be disproportionately represented by a percentage roughly proportionate to their mass. Center-of-mass

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acceleration, probable electromagnetic fingerprints created by the BHs accreting from the surrounding dense gas, or their placement in AGNs, which can identify binaries generated in other types of galaxies [16, 23].

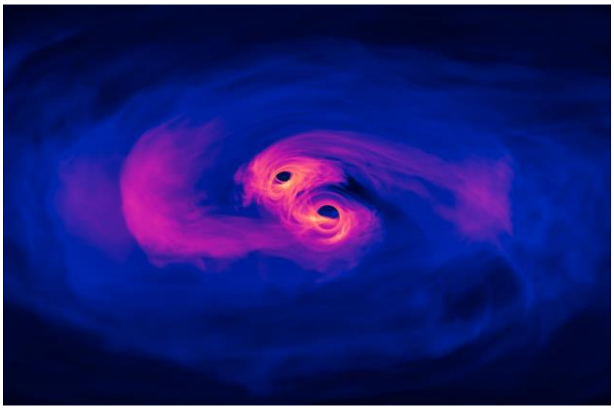

Figure 1. A sketch of black hole merging.

4. Detector LIGO

Then, this study will refer the supermassive BH detector, cosmologists usually detect BH mergers through gravitational wave equipment. Localizing the source sky, quantifying wave polarizations, and separating gravity waves from nearby instruments and environmental noise are all necessary, gravitational-wave astronomy makes use of numerous, widely separated detectors [24]. At each of the LIGO stations, the Advanced LIGO detection device, an improved Michelson interferometer, is utilized to monitor the gravitational-wave [25]. Two mirrors construct each arm, spaced Lx=Ly=L=4km apart. The arm lengths are effectively changed by a passing gravitational wave, resulting in a measurement variance of $\Delta L(t)=\delta L_x-\delta L_y=h(t)L$ [25]. The detectors incorporate many upgrades to the fundamental Michelson interferometer in order to attain the necessary sensitivity to detect gravitational waves. First, the mirrors on its arms create a resonant optical cavity that doubles the impact of a affecting the light phase by a factor of 300 gravitational waves [26]. Second, a mirror that recycles signals in part of the output that increases the arm cavities' bandwidth enhances the extraction of gravitational-wave signals. An Nd: YAG laser 1064 nm in wavelength that illumines the interferometer and has been regulated in terms of frequency, sensitivity, and beam shape. A homodyne printout is employed at the conclusion of the channel to extract the gravitational wave signal (seen from Fig. 2) [25].

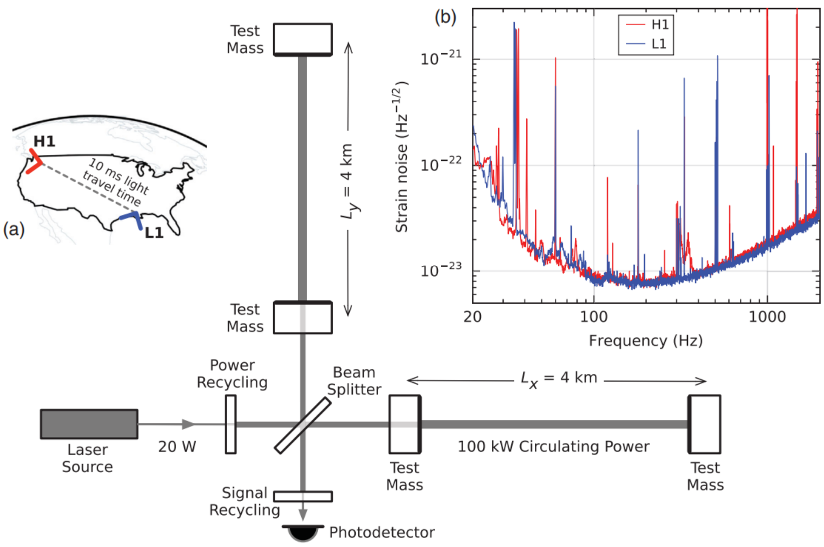

Figure 2. Upgraded LIGO detector simplified schematic.

By maximizing the conversion of strain to optical signal, these interferometry techniques seek to mitigate the impacts of photonic discharge vibration, which is the primary high-frequency disturbances. The test masses must also be designed to have low thermal noise and low displacement noise in order to obtain high strain sensitivity. This is done by isolating the test masses from geological vibration which has low frequencies and reducing their displacement noise (intermediate frequencies) [25]. At quadruple-pendulum system's final phase, each test mass is suspended and an active seismic isolation platform served as the system's support [25]. For frequencies above 10 Hz, these technologies work together to offer greater than 10 units of scale in separation from movement in the ground. Low-mechanical-loss materials are utilized in the test masses and their suspensions to reduce thermal noise [25]. The test masses are made of 40 kg of fused silica substrate with low-loss dielectric optical coatings, and they are hung from the stage above using fused silica fibers. Rayleigh scattering results in optical phase fluctuations, which are reduced by keeping the volume of the 1.2-m-diameter pipes under pressure housing the arm cavity beams below 1μPa [25].

The arm chambers are kept on resonance using servo controls [27] and keep the ocular components properly aligned [28]. By observing how the detector responds to evaluate movement of mass brought on by light stress from a calibrating laser stream that is modulated, the output is strain-calibrated [25]. The measurement of accuracy is monitored continuously for variation of no more than ten percent in magnitude and ten DEG stage using calibration laser stimulation at certain frequencies [25]. The calibration laser is also used to inject simulated waveforms into the detector to evaluate its sensitivity to gravitational waves [25]. Each observatory location is outfitted with a variety of sensors, including seismometers, accelerometers, microphones, magnetometers, radio receivers, weather sensors, ac-power line monitors, and a cosmic-ray detector, to keep track of environmental disturbances and their impact on the detectors [25]. The functioning position of the interferometer and the state of regulation mechanisms are both recorded on additional 10^5 channels. The gathering of data is linked to satellite time to an accuracy of greater than 10μs [25]. At each observatory location, an atomic clock and a backup GPS device are used to confirm timing accuracy [25].

5. GW170104

Two very statistically significant double BH merger signals, GW150914 and GW151226, as well as a less significant contender signal, LVT151012 have been discovered in the first-ever observations by the Advanced Laser Interferometer Gravitational-Wave Observatory (LIGO) [29]. With the help of these findings, a new age of astronomy observation has begun, enabling cosmologists to explore the astrophysics of twin BHs and investigate GR in ways that were previously inaccessible [29]. Cosmologists now know that populations of binary BH of mass$\gtrsim 25M_\odot$ exist, and that the merger rate is high enough that they can expect more detections [29]. On November 30, 2016, the second observation run of sophisticated LIGO started. A very statistically noteworthy gravitational wave signal was discovered on January 4, 2017 [29]. The signal GW170104, which can be recognized as the distinctive chir of binary merger, may be seen in the Fig. 3 [29]. A thorough investigation reveals that GW170104, which came formed as a result of two stellar-mass black holes coalescing, arrived at Hanford 3 milliseconds earlier than Livingston [29].

A double binary BH system with a total mass of roughly 50 $M_\odot$ is the source of GW170104, indicating that it developed in a metal-rich environment beneath the solar system [30]. BH spin measurements indicate a predisposition towards being (positively) oriented with the circular angular momentum, but they are not ruled out 0 spinning. GW151226, however, displayed a high predilection for spins that had positive distributions along the circular angular momentum, which is different from the present situation [31].

The properties of the BH that merged to produce GW170104 are also what cosmologists focus on. The larger of the two BHs had a mass of approximately 31 times the mass of the sun, while the smaller BH had a mass of approximately 19 times the mass of the sun. The resulting BH after the merger had a mass of approximately 49 times the mass of the sun. These masses are among the largest detected in

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binary BH systems, and they are located in a "mass gap" that was previously thought to be empty, between the maximum mass of a neutron star and the minimum mass of a BH.

The spins of the black holes were also determined by analyzing the signal of gravitational wave. The spin of a BH is a measure of how much it is rotating on its axis, and it can be lined or misaligned with the axis of the orbit in a binary system. The LIGO data revealed that the two BHs that produced GW170104 had spins that were misaligned with the axis of their orbit. This was the first time that such a misalignment had been observed in a binary black hole system, and it has important implications for our understanding of how black holes form and evolve in binary systems. The distance to the source of the gravitational waves is estimated to be about 3 billion light-years away from Earth. This means that the signal detected by LIGO traveled for 3 billion years before reaching the Earth. The energy released during the merger of the two BHs was enormous, equivalent to the mass of about three suns being converted into gravitational waves in a fraction of a second. This energy was emitted as gravitational waves, which traveled across space and were detected by the LIGO detectors on Earth.

Astrophysical implications: The observations of GW170104 have important implications for our understanding of how BHs form and evolve in binary systems. The misaligned spins of the BHs suggest that they may have formed in separate star systems before being brought together in a binary system. The large masses of the BHs suggest that they may have formed from massive stars that collapsed under their own gravity. The detection also provides new challenges for future research in gravitational wave astronomy, as it pushes the limits of our current models and raises new questions about the behavior of BHs in extreme environments.

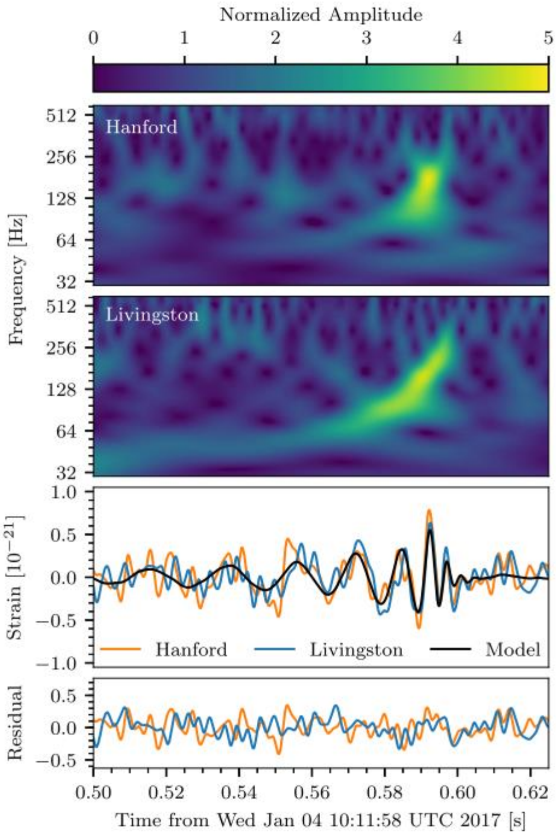

Figure 3 The top two panels at GW170104 show a representation of time and frequency of strain statistics from the detectors in Hanford and Livingston.

6. Conclusion

In summary, this study briefly introduces some basic principles of BH fusion, and the structure and working principle of the gravitational wave detector (LIGO), and then analyses a special case

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(GW170104) to briefly clarify the observation of the GW170104 phenomenon has an important impact on the field of astrophysics. But while reviewing this article, the author also found that some areas of black hole fusion need further research by astrophysicists and cosmologists. For instance, the observational signatures of BH mergers. When two BHs merge, they produce gravitational waves that can be detected by ground-based observatories, e.g., LIGO and Virgo. However, the electromagnetic counterparts of these mergers (e.g., flares of radiation from the AGN) are still largely unknown, and understanding them could provide valuable insights into the physics of BH mergers. Moreover, the role of gas and stars. When two BHs merge, they release a tremendous amount of energy in the form of gravitational waves, which can drive gas out of the AGN and affect star formation in the host galaxy. However, it is not yet clear how important these effects are in different types of AGN and how they might depend on the properties of the merging BHs (e.g., their masses and spins). These are areas of research waiting to be explored in depth.

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