Analysis of Galaxy, Black hole and BH-BH mergers based on IllustrisTNG

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Abstract. Contemporarily, one of the most significant current trends in the studies of black holes is the black hole mergers. In this paper, we would present prescriptions for star formation and stellar evolution of black hole, and make comparisons in features of the black holes before and after the merger. Based on Illustris TNG, we collect our data to investigate Galaxy and black hole mergers and utilize the corresponding programming API function on it to visualize the results. Specifically, the relationship between galaxy mass and gas size will be demonstrated with the help of diagrams in part one. Besides, the general relationship between the characteristics of the black holes before the merger and the characteristics of the black hole after the merger will be discussed. The variance and standard division of the data will be calculated to confirm the relationship. These results explore the basic relationship between galaxies and the similarity between black holes before and after the merger, which shed light on further understanding of the corresponding processes.

Keywords: Galaxy, Black hole, IllustrisTNG, The Merger

1. Introduction

Human being's inherent curiosity has motivated us to discover where the origination and future of universe. By analyzing the evolution of the universe itself and its ingredients, we could predict the future and make a more and more explicit plan for ourselves. With great interest in the morphology of black holes and the enthusiasm to investigate the process of mergers, the galaxy and black hole mergers are selected as the research target of this paper. Specifically, we mainly focus on the investigation of relationship between number of mergers and mass and gas richness and comparison in the features of the progenitors and the merged black hole. To obtain the data, the IllustrisTNG is utilized, which successfully builds the model of galaxy formation including prescriptions for star formation, stellar evolution, as well as the formation, growth and multi-mode feedback of black hole [1]. The rate of galaxy merger is one of the basic measures of galaxy evolution, and it provides clues about how galaxies expand over time through encounters with other galaxies. However, there has been a huge difference in the frequency of galaxy mergers previously. NASA's Hubble Space Telescope's measurements of galaxies in the deep-field survey have produced broad results: between 5% and 25% of galaxies are merging [2]. Generally, researchers normally classify cosmology merger into three categories in terms of size, numbers and gas richness by using N-body simulations to construct merging history trees of dark halo [3]. Based on the graphs and the process of investigation, we discovered that the number of galaxy merger is positively correlated to galaxy mass. In addition, the general relationship between some features of the two progenitors and their merged black holes are also discussed. Some part of the black hole will scatter in the universe, possibly leading to a decrease in the mass of the merged black hole compared to the total mass of two black holes before the merger [4]. According to the analysis, the general trend is also obtained that their accretion rate will be larger for the larger black holes [5]. Besides, different black holes may acquire different mass loss rate, which is a result of factors (e.g., stellar winds) that led to the decrease in the mass of the merged black hole [6].

The rest of the paper is organized as follow. The Sec. 2 will introduce the data origination and evaluation method. Afterward, the Sec. 3 will conduct the analysis with the help of excel plotting functions and the obtained data is automatically synthesized by IllustrisTNG. The Sec. 3 will utilize data from IllustrisTNG to find and visualize the correlation between mass and merger rate (as well as cumulative energy injection). Subsequently, the Sec. 4 will discuss the relationship between different characteristics of the black holes before the merger and the merged black hole. Eventually, a brief summary is given in Sec. 6.

2. Data & Method

This paper focuses on the merger of black holes based on the data from Illustris TNG50-1, TNG100-1 and TNG200-1. Primarily, our ideal method was to find the exact data correlated to each point on the plotted graph. However, due to the truth that the total data volume is as huge as 265 TB, including 800 full volume snapshots and 30,000 subbox snapshot, it is too complicated to extract our helpful data [7]. On the basis, we abandoned this unfeasible solution and made a new attempt. In fact, the optimal approach found was that according to the graphs provided by IllustrisTNG both y axis and x axis are divided to infinite squares, which makes points coordinates on a curve roughly measurable. The data given by IllustrisTNG enables us to put emphasis on the relationship between number of mergers and mass and gas richness. Based on the acquired statistics, we discovered the general relationship between the mass, mdot, rho, cs values of the two progenitors and the four values of their merged black hole. Afterward, we would calculate the difference between the estimated value acquired from the progenitors' values and that value of the merged black hole. At last, we calculate the standard deviation and the variance of the differences to prove the reliability of the relationship.

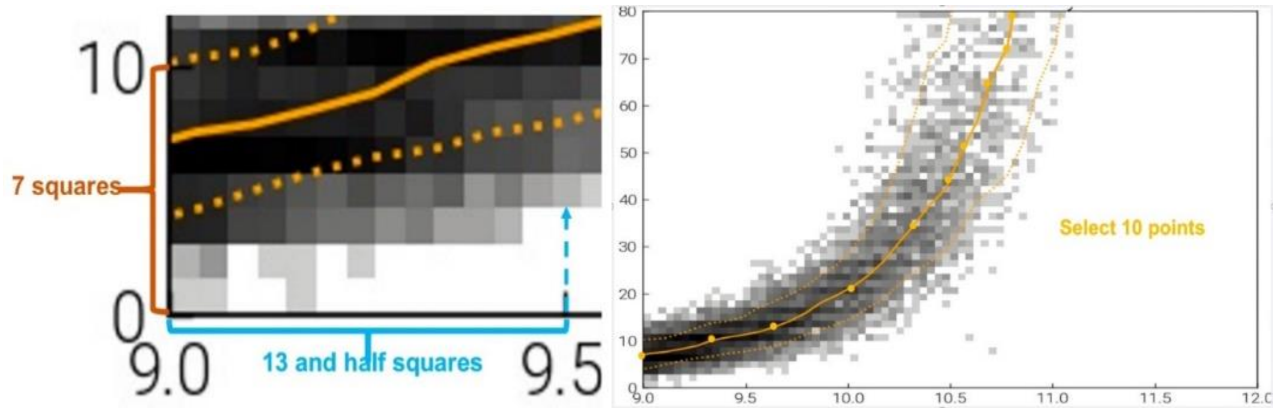

Figure 1. A sketch of the data selection criteria.

3. Cosmology merger category

Based on this background information, Single Square is regarded as a unit length on each axis and select ten points on the curve to find out the corresponding data. After rough data is founded, a data list is made in excel and plot a graph to see whether the trend is in agreement with the result from tng. As shown in Fig. 1, all the graphs plot by tng show a clear positively increasing trend. The excel trend line gives us hints about the probability of functions behind those graphs. We make comparison between different functions to decide which one fits the tng plot most closely.

First, we analyse the graph with respect to number of mergers and mass. The tng graphs enables us to associate the curve with an exponential function. Therefore, we fit an exponential function that is nearest to our data. The exponential trendline does fit well at the beginning, but as the mass increases, the difference between the theoretical value and actual value is unneglectable (as shown in Fig. 2). We try several other models to find out the best fits line such as the logarithm and polynomial. Finally, we discover that when the order of a polynomial goes to six, the trendline is extremely close to the tng plot (see Fig. 3). This surprising result indicates that our assumption is valid. The greater the mass of a cosmology is, more likely the galaxy mergers will appear and their relationship can be described by polynomial functions.

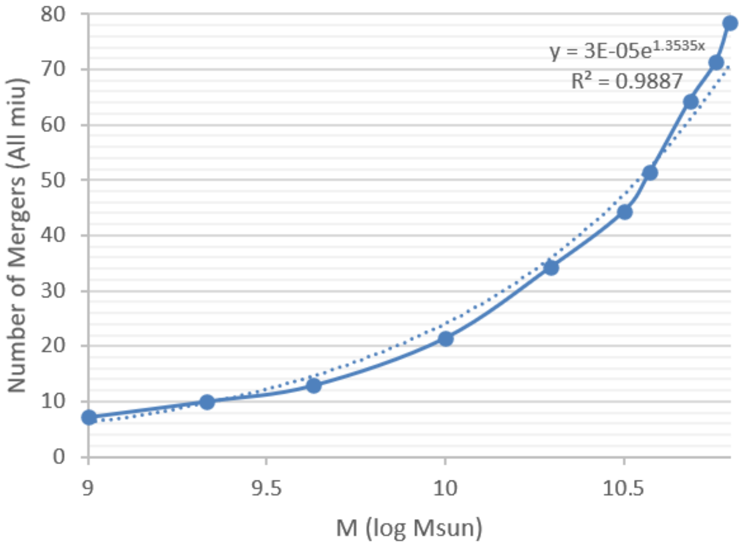

Figure 2. The number of Mergers as a function of Msun with exponetional fitting.

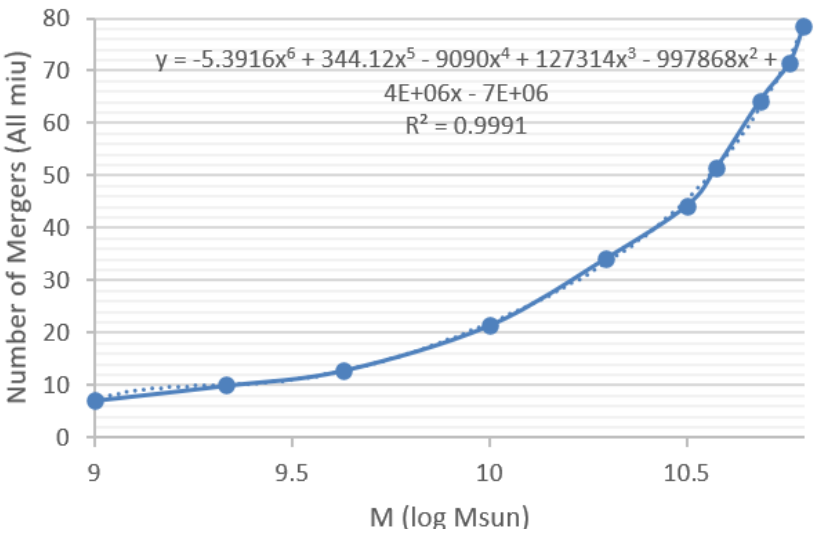

Figure 3. The number of Mergers as a function of Msun with 6 order polynomial fitting.

Second, we apply the same method to a graph whose x axis is gas size. The common point between this graph and a previous one is that both of them has a clearly exponential growth trend at first glance as illustrated in Fig. 4. However, if look at it more deeply, one will find that the six polynomial function is actually the one fits best with the original data.

Finally, when it comes to analyzing the number of merges vs gas mass graph, using six polynomial function becomes our first choice. To our surprise, this time, this function does not work as well as before. It is in reasonable agreement with our data only when gas mass is very big. As depicted in Fig. 5, when the gas mass is small, six polynomial trend line shows a wave curve which does not live up to our expectation. We also try the exponential curve as our trend line function. Nevertheless, the fact is that exponential trend line merely fits the data at the beginning and has a vast difference at large gas mass (see Fig. 6). As a result, one can assume that mathematical relationship between those two parameters is much more complicated which is out of the range that excel function can fit.

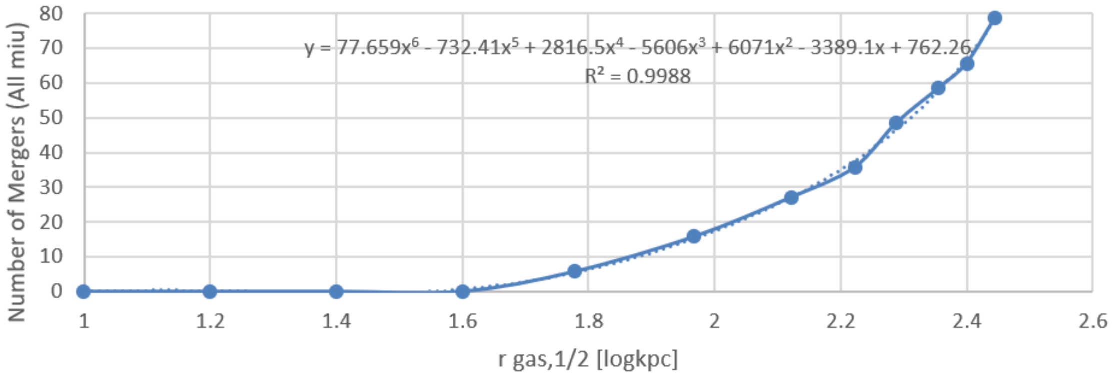

Figure 4. The number of megers as a function of gas size with 6 order polynomial fitting.

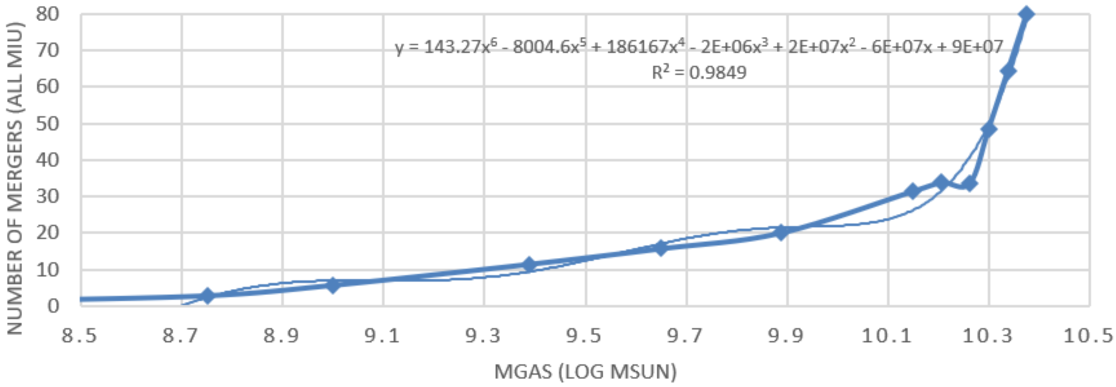

Figure 5. The number of megers as a function of gas mass with 6 order polynomial fitting.

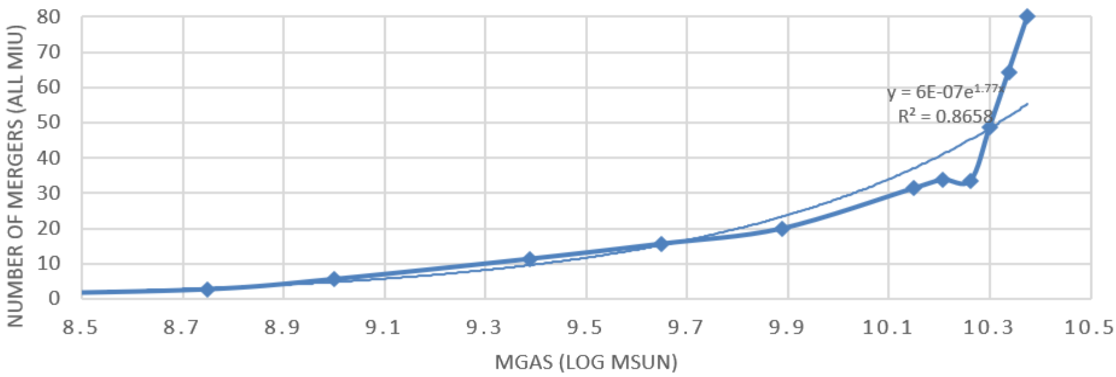

Figure 6. The number of megers as a function of gas mass with exponetional fitting.

4. Black Hole Merger: mass and energy injection

Fig. 7 determines the relationship between state of black hole and it's mass. Conclusion: 6.0-8.0~high state/quasar mode8.5-9.0~low state/kinetic mode. When IllustrisTNG group have employed model for supermassive black hole (SMBH) growth and feedback in two-mode scenario in which the feedback from active galactic nuclei occurs through a kinetic, comparatively efficient mode at low accretion rates relative to the Eddington limit, and in the form of a thermal, less efficient mode at high accretion rates [8] with a self-consistent accounting of spin-dependent radiative efficiencies and thus feedback strength [9].

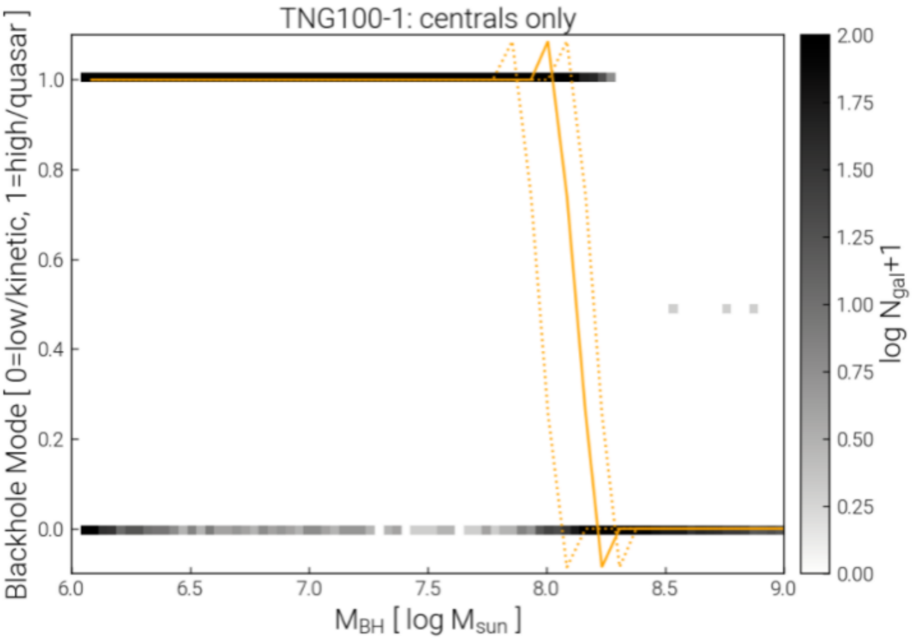

Figure 7. The relationship between state of black hole and its mass.

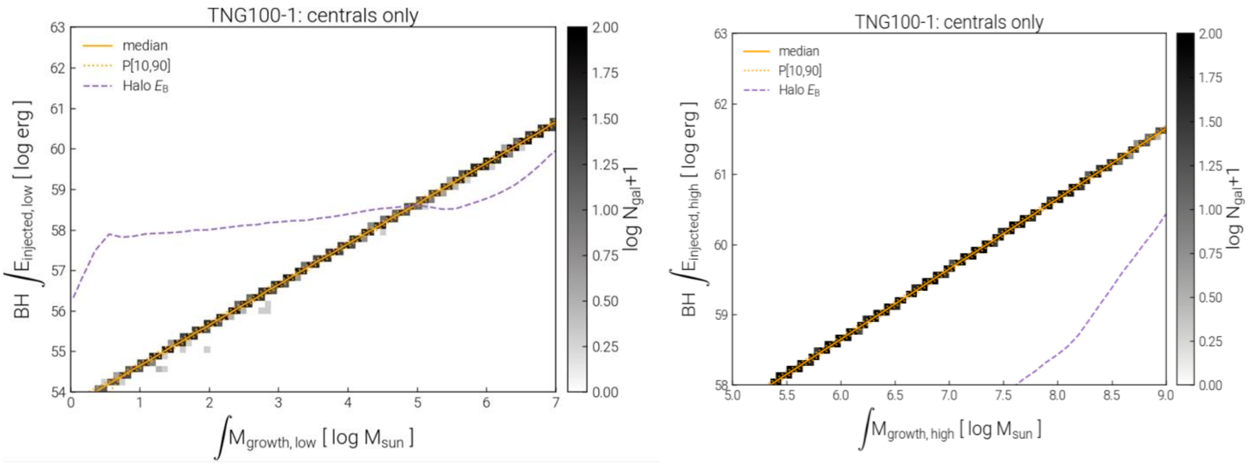

Figure 8. Black hole mass growth as a function of energy released (by mergers).

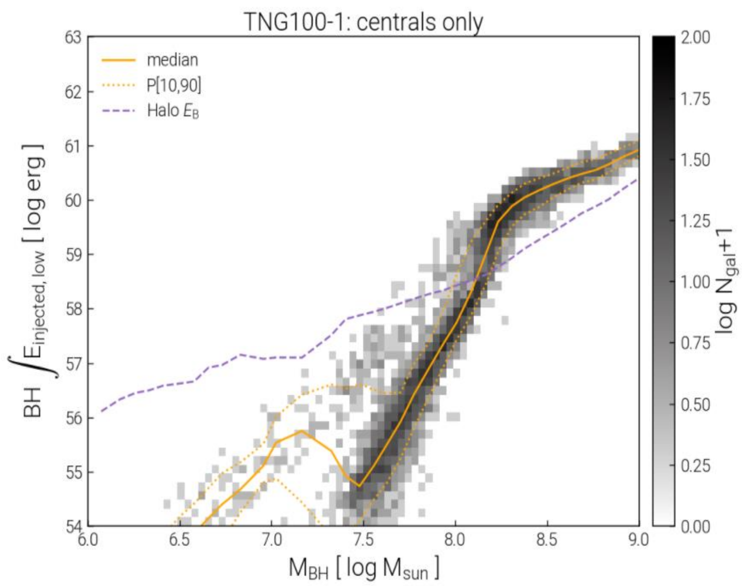

Figure 9. The growth rate as a function of the mass of black holes.

According to Fig. 8, black hole mass growth proportional to energy released (by mergers). It is clear among 8.5-9.0, merger rate increases from 6.5-7 steadily. Conclusion is for low state, greater the mass is, more likely the merger happens. Deduction is same trend for injection & mass. As exhibited in Fig. 9, it is clear that among 8.5-9.0, cumulative energy injected increases from 60.5-61 steadily. Even the whole trend is the same. Conclusion is that for low state greater the mass is, more energy is released. Deduction is more dramatic growth for high state. As shown in Fig.10, it is apparently that merger rate increases from 6.0-8.0 faster among 6.3-8.0, while cumulative energy released increases from 58-60.7 faster among 6.2-8.0. These works can be extended and found the similar results in TNG 50-1 and TNG 200 -1.

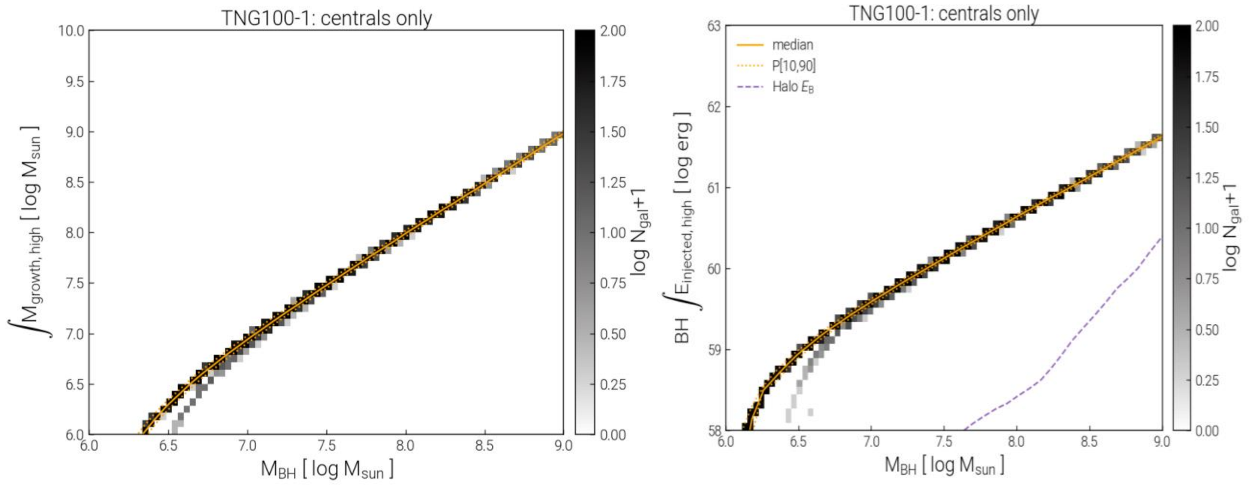

Figure 10. The merger rate as a function of the mass of black holes.

5. Black Hole Merger- comparison in mass, mdot, rho, and cs

Table 1. The comparison between the mass of two progenitors and the merged black hole.

the mass of the first black hole	the mass of the second black hole	the total mass of two black holes	the mass of the merged black hole	the difference between the merged black hole and the total mass of two separate black holes
0.000112671	0.0000855	0.000198171	0.000198162	-9E-09
0.000592582	0.000139481	0.000732063	0.000732138	7.5E-08
0.000121969	0.0000864	0.000208369	0.000208411	4.2E-08
0.000152355	0.0000923	0.000244655	0.000244727	7.2E-08
0.0000973	0.000109722	0.000207022	0.000207035	1.3E-08

Table. 1 demonstrates the trend of each sum mass of two progenitors and the mass of their merged black holes. Based on the results, one can assure whether the relationship between these two groups of data is generally correct. The standard division in the loss of mass equal to 0.008821454 and a variance of 0.00007818. Table. 2 lists the trend of twice the sum mdot values of two progenitors and the mdot of their merged black hole. The standard division in the difference between those two values equal to 0.101212127 and a variance of 0.010243895. Table. 3 summarizes the trend of the average rho value of two progenitors and the rho of their merged black hole. The standard division in the difference between those two values equal to 0.195420846 and a variance of 0.038189307. Table. 4 shows the trend of the average cs value of two progenitors and the cs value of their merged black holes. The standard division in the difference between those two values equal to 124.466328 and a variance of 15491.8668.

Table 2. The comparison between the mdot of two progenitors and the merged black hole.

the mdot of the first black hole	the mdot of the second black hole	twice the total mdot of two black holes	the mdot of the merged black hole	the difference between twice the total mdot of two separate black holes and mdot of the merged black hole
0.000328509	0.000191914	0.001040846	0.0010257	-0.000015146
0.173225	0.000985335	0.34842067	0.267423	-0.08099767
0.000632519	0.000314765	0.001894568	0.00182495	-6.9618E-05
0.000145442	0.000535238	0.00136136	0.00376701	0.00240565
0.000223181	0.000283751	0.001013864	0.00100897	-4.894E-06

Table 3. The comparison between the rho of two progenitors and the merged black hole.

the rho of the first black hole	the rho of the second black hole	the average rho of the two separate black holes	the rho of the merged black hole	the difference between the average tho of two separate black holes and the merged black hole
0.260748	0.266015	0.2633815	0.266391	-0.0030095
8.21153	8.37068	8.291105	8.35298	-0.061875
0.546285	0.530094	0.5381895	0.527791	0.0103985
0.965927	0.967891	0.966909	0.97022	-0.003311
0.207971	0.207731	0.207851	0.207204	0.000647

Table 4. The comparison between the cs of two progenitors and the merged black hole.

the cs of the first black hole	the cs of the second black hole	the average cs of two separate black holes	the cs of the merged black hole	the difference between the average cs of two separate black holes and the cs of the merged black hole
61.6511	61.7567	61.7039	61.8895	0.1856
72.8805	72.7072	72.79385	73.0216	0.22775
66.8532	66.3794	66.6163	66.3528	-0.2635
71.0391	71.0456	71.04235	71.0539	0.01155
58.975	58.9608	58.9679	58.9355	-0.0324

However, this paper has some limitations and drawbacks needed to be addressed. For example, the function between gas masks and galaxy mergers cannot be founded easily (Sec. 3). The general conclusion can be drawn is that the bigger the galaxy mass and the richer the gas are, the higher the probability that galaxy mergers will occur? According to the results of Sec. 4, the merger rate is intuitive while the growth in mass may come out of other interactions. In this section, we cannot acquire a persuasive relationship of the four characters between progenitors and the merged black holes. The formula to calculate the accretion rate of black holes is [10]:

$$\dot{M} = 2.2\times10^{-9}[1-(rout/rin)-(3\beta-1)/2]^{-2/3}\left(\frac{M_{BH}}{6.6\times10^{9}M}\right)^{4/3}\left(\frac{2}{3\beta-1}\right)^{-2/3} r_{in}^{7/6} RM^{2/3} rad^{-2} \quad (1)$$

In which the value of r_{in} and r_{out} are unknown for the black holes that we are studying. It is impossible for us to acquire such statistics as the data did not illustrate the name of these black holes, which impedes the further proof of the relationship we acquired.

6. Conclusion

In summary, we investigate the relationship between gas masks and galaxy mergers, the relationship between the values of the progenitors and those values of the merged black holes can reflect some aspects of the merger in galaxies and black holes as well as discover some features during the merger. Based on the analysis, there is a general conclusion that mass is proportional to the merger rate and cumulative energy released as well as high state has a greater rate than low state. We are looking forward to witness more articles revealing the relationship between the mass of galaxies and their possibility to merge with others and studies explaining the difference between the expected mass, rho, mdot and cs of the merged black hole and the real value. This research offers a general insight into the basic characteristics of the galaxies and give a comprehensive comparison of black holes before and after the merger.

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