Searching origin of binary black hole with gravitational wave observation

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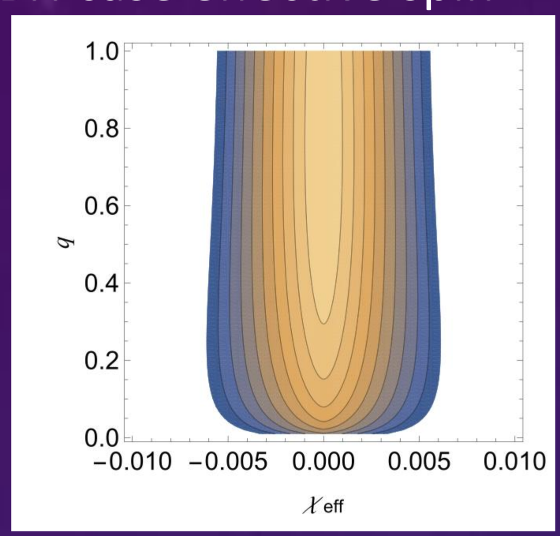
1. Introduction

In 2015, gravitational wave was first detected by LIGO. The gravitational wave came from binary black hole(BBH) mass are $36M_\odot$ and $29M_\odot$. From this event, BBH events are observed mass is from $10M_\odot$ to $30M_\odot$. Also, it is observed mass is over $100M_\odot$ after coalescence but origin of these binary black holes are not solved. So, my research theme is to solve origin of binary black hole using three physical quantities black hole's mass, effective spin's value and cosmological merger rate and we will compare simulated these three results to gravitational wave observation results to estimate binary black hole origin.
To solve this problem using three physical quantities, first, we made mass distribution obeys initial mass function and made primordial black hole's mass distribution.

2.Binary black hole's effective spin

Black hole has effective spin. It leads from black hole's mass and orbit angular momentum.
There are researched about binary black hole's effective spin distribution using three models which their origin are low metal environment, primordial black hole and dynamical formation in dense star cluster.
For example, Kushnir et al. 2016 state that if black hole origin is low metal environment, effective spin is almost 1 ($\chi_{eff} \sim 1$) but Koga et al. 2022 state that if black hole origin is primordial black hole, effective spin is near 0.00.
In addition, according to Rodriguez et al. 2018, if black hole origin is dynamical formation channel, effective spin distribution is upper and lower symmetry. So, origin of binary black hole is different, effective spin's value is like to be different.

Origin of binary black hole is PBH case effective spin



Koga et al.2022

3. Origin of binary black hole's research and my research purpose

There are many researches heavy binary black hole's formation channel about observed by gravitational wave observation.
For example, Sasaki et al. 2016 argue that first gravitational wave event "GW150914" whose first detected binary black hole is like to be from primordial black holes. They researched using black hole mass and effective spin value and value 0.1% which is probability if primordial black hole is dark matter from cosmic microwave background observation.
While Rodriguez et al. 2016 argue that "GW150914" 's black hole formation is like to be dynamical formation. They research using black hole's mass and merger rate.
Therefore, formation channel of "GW150914" is not solved.
From above, there are many researches about origin of binary black hole observed by gravitational wave.
However, almost all researches about it, it use two physical quantities black hole mass and effective spin or black hole mass and cosmological merger rate to research origin of binary black hole. Therefore, using three physical quantities simultaneously to research origin of binary black hole has not performed yet.
So, my research purpose to research about it is using three physical quantities simultaneously and compare it which is three physical quantities simulated to gravitational observation data.

4. Method

Generating black hole mass obeys Initial Mass Function(IMF) using monte carlo method which is same way as Kinugawa et al. 2014.
In particular, we decided BBH's primary and secondary mass using below formula.

$$X = \frac{\int_{M_{min}}^{M_1} \Phi(M_1')dM_1'}{\int_{M_{min}}^{M_{max}} \Phi(M_1')dM_1'}$$

$$X = \frac{\int_{M_{min}}^{M_2} \Phi(M_2')dM_2'}{\int_{M_{min}}^{M_{max}} \Phi(M_2')dM_2'}$$

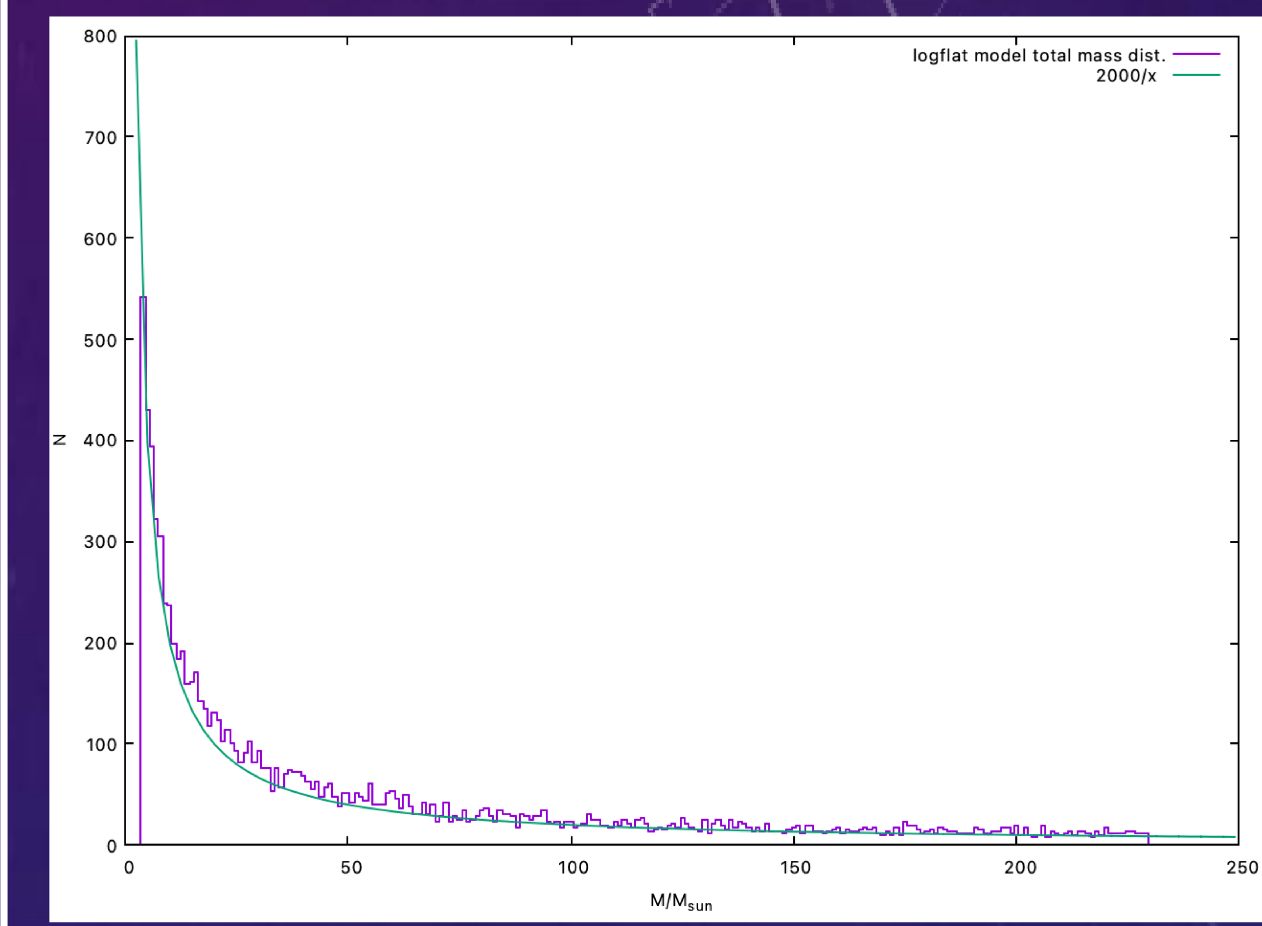
Where $\Phi(M_1')$ and $\Phi(M_2')$ are IMF, X is uniform random number from 0 to 1 and M_1 , M_2 are primary black hole mass and secondary black hole mass.
Next, we assumed IMF three models: Flat model, Log Flat model and Salpeter model and we set below three formulae:

- Flat $\Phi(M_1') = M^0 M^{-1}$
- Log Flat $\Phi(M_1') = M_1^{-1}$
- Salpeter $\Phi(M_1') = (M_1^{-2.35})^{\frac{1}{2.35}}$

Also, we assumed $\Phi(M_2')$ is same IMF function of $\Phi(M_1')$.
Next, we assumed BBH number is 10000 and we set BBH's primary black hole mass is from $2M_\odot$ to $120M_\odot$ and secondary black hole mass is from $2M_\odot$ to $110M_\odot$.

5. Result

BBH total mass log flat distribution



From above figure, we set black hole mass range are $2M_\odot$ to $120M_\odot$ and $2M_\odot$ to $110M_\odot$ and we set 10000 black holes obeys log flat IMF model.
We found 541 black holes whose total mass is $4M_\odot$ and there are around 20 over $100M_\odot$ black holes.

6. Conclusion

To solve origin of binary black hole which is observed by gravitational wave, first we made BBH total mass distribution obeys log flat IMF model.
As a result, in log flat model, We found 541 black holes whose total mass is $4M_\odot$ and there are around 20 over $100M_\odot$ black holes.
However, this mass distribution is before calculating signal noise to ratio(SNR). Therefore, after calculating SNR, this mass distribution will change.

7. Future Work

we made mass distribution obey initial mass function model. However, this mass distribution is before calculating SNR. So, we need calculating SNR and making mass distribution after calculating it and we need evaluate whether these mass black holes can detect using LIGO-Virgo-KAGRA detector or not.
Also, we need making effective spin distribution three black hole formation channel and calculate cosmological merger rate.
Therefore, future work are making effective spin distribution three black hole formation channel calculate cosmological merger rate and we will evaluate these quantities comparing to gravitational wave data.

8. Reference

1. Kinugawa et al. 2014
2. Sasaki et al. 2016
3. Rodriguez et al. 2016
4. Rodriguez et al. 2018
5. Kushnir et al. 2016
6. R. Abbott et al. 2021
7. Koga et al.2022