Calculation of Mass and Spin of Remnant Black Holes (RBH) from Compact Binary Mergers

Abstract

When Gravitational waves were detected in 2017 by Laser Interferometer Gravitational wave Observatory(LIGO) and Variability of solar IR radiance and Gravity Oscillations(VIRGO) collaboration they gained immense popularity. In this project, we expect to find the final mass and spin of the remnant black hole(RBH) using a mathematical model. After analysing the data from GW190521 we find that the final spin is 0.71 and mass of the RBH is 141.17M. It is also found that mass and spin of the RBH are inversely proportional. Our data sets fit the model with the accuracy of more than 90 %, which proves that the model which we chose is sufficiently accurate to find the spin and mass of RBH and to study other properties of RBH also

Introduction

1.1 Motivation

This project is inspired by the gravitational waves. When they were first observed and reported in the year 2015 proving Einstein's theory of general relativity. This subject has been gaining popularity ever since the gravitational waves were detected and further research is going especially in the field of observational astronomy. We expect to learn how can we study remnant black holes by the gravitational waves signals. What is the relation between the mass and spin of RBH?, How we can determine the final mass and spin of RBH?, How does the mass of a black hole gets converted into gravitational radiation?. Therefore, our work will revolve around analysing the data of gravitational wave signals and reporting our findings.

1.2 Aims and Objective

In this project, we aim to find the final mass and final spin of the remnant black hole. We use the mathematical model to calculate mass and spin of binary black hole mergers. With the help of the model, we try to fit the data and compare analytical results with predicted results to check whether the model is feasible to calculate the mass and spin of the remnant black hole. We consider a binary system having a total mass of 150M.

1.3 Proposed Solution

Expected results are that final spin of the RBH must be in the range of 0.70 to 0.75 and expected final mass should be in the range of 140M to 145 M. The relation between the final mass and spin of RBH.[2] As we expect that the final mass must increase linearly with the χ(chi). The final spin must vary with η (eta) linearly

Methodology

Considering the binary system where ,

m1 = the mass of the first black hole.

m2 = the mass of the second black hole.

a1 = the spin of the first black hole.

a2 = the spin of the second black hole.

The mass ratio q = m_2/m_1

- The dimensionless orbital angular momentum of the binary at the ISCO is given by:

$$\hat{L}_{ISCO} = A_a \frac{m_1 m_2}{M} = A_a \eta \qquad (1)$$

Where, $\eta = \frac{q}{(1+q)^2}$

- The net initial dimensionless spin angular momentum is given by:

$$\chi = \frac{a_1 m_1^2 + a_2 m_2^2}{(m_1+m_2)^2} \qquad (2)$$

- Total mass of the system is given by

$$M = m_1 + m_2 \qquad (3)$$

- For spin

$$a_f = A_n \eta + B_a \chi - C_a (1 - m_f) \qquad (4)$$

- For mass

$$m_f = A_m + B_m \eta^2 + C_m \chi \qquad (5)$$

Where,

a_f = final spin of RBH

m_f = final mass of RBH

χ = effective spin

q = mass ratio

$\eta = \frac{q}{(1+q)^2}$

$m_f = M - \frac{dm}{M}$

$dm = M - m_f$

and, A_m, B_m and C_m are unknown constants to be determined.

Data Selection and Analysis

.Boundary Conditions For Data Analysis

- q(mass ratio) ≤ 4
- $-0.85 \leq a_1$(Primary spin) ≤ 0.85
- $-0.85 \leq a_2$(Secondary spin) ≤ 0.85
- a_f(Final Spin) ≥ 0.1

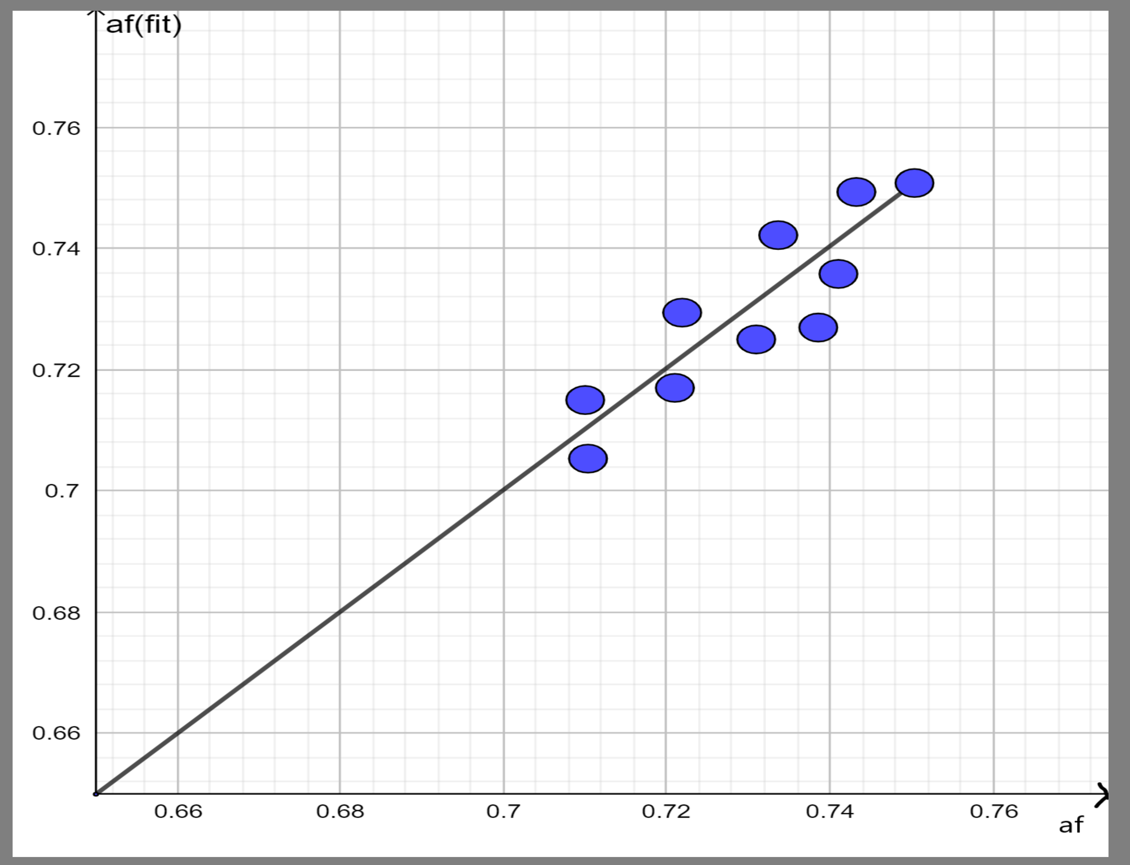
Results

FINAL SPIN:= 0.71

FINAL MASS=141.17 M$_\odot$

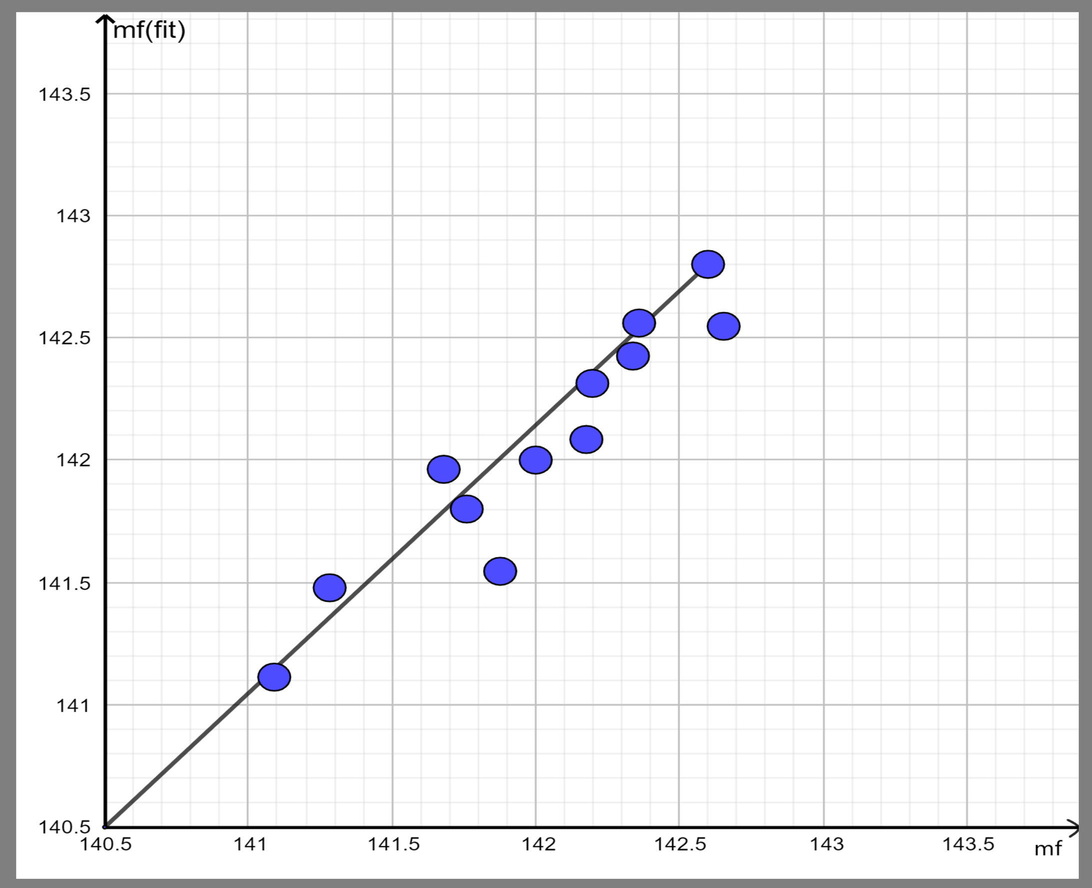
GRAVITATIONAL RADIATION =8.83C^2

FINAL SPIN ON REFERENCE SPIN



Results

FINAL MASS ON REFERENCE MASS



Conclusion

THIS MODEL FITS WELL FOR THE BINARY SYSTEM OF BIGGER MASSES .

THIS MODEL IS HIGHLY ACCURATE AND SIMPLE TO USE FOR CALCULATING FINAL MASS AND SPIN OF RBH.

THE MASS AND SPIN OF BLACK HOLES ARE INVERSELY PROPORTIONAL.

IF THE MASSES OF BOTH SYSTEM ARE ALMOST SAME (M1 ≈ M2) THEN THE VALUE OF SPIN CAN BE GREATER THAN 1 BUT ONLY FOR SYSTEMS HAVING TOTAL MASS OF MORE THAN 180 M$_\odot$.

Acknowledgements

- TEAM WOULD LIKE TO PRESENT OUR SPECIAL GRATITUDE TO THE WHOLE SSERD TEAM FOR GIVING US THE OPPORTUNITY.
  MENTOR - MR. SUNDAR M. N.
  TEAM COORDINATORS - MR. PRATEEK B. AND MS. ANISHA
  TRAINING SESSIONS BY MR. PAVAN KUMAR AND MR VISHNUVARDHAN SHAKTIBALA
  TEAM LEADERS - GAURAV AND PURNIMA
  TEAM MEMBERS