Analysis of Gravitational Wave from GWOSC and parameter estimation by Bayesian Inference

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The Gravitational Wave Open Science Center (GWOSC) [1] has released data set for general public which they observed in LIGO and VIRGO. This document shows how anyone can utilize the data set to find different parameter analytically and by bilby modules. We have estimated the Chirp mass, velocity of the Binary Black Hole before merging and other parameters.

INTRODUCTION

Einstein's general theory of relativity predicts gravitational wave(GW) in space-time but with a caveat.The amplitude of GW is so small which is almost impossible to detect. After almost 100 years of General Relativity scientists have been able to detect Gravitational Wave by extremely precise interferometer which is a

DATA ANALYSIS

The primary data from GWOSC is strain data. Strain means the fractional difference of the two arms of the detectors. This difference tells us that space-time can contract and it is the evidence of gravitational wave.Our job is to find the data which is buried inside noise, in general the noise amplitude is higher than the data. Here we have carefully eliminated the noise and find the instance when Signal to noise ratio (SNR) is the highest.This is the primary step for data selection and there are various steps involved in that.
Let's start with the "GW150914" merger event which is a binary black hole merger and the data is from Hanford detector. The strain data looks is given in Figure 1.

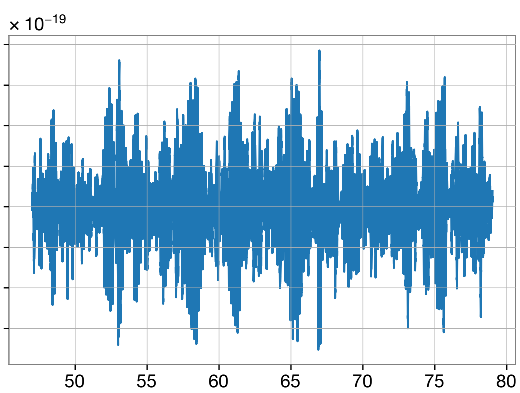

Figure 1. Strain for merger 'GW150914' from Hanford detector.Strain is the difference of length between two arms of the detectors.UTS time is given in In the x axis.

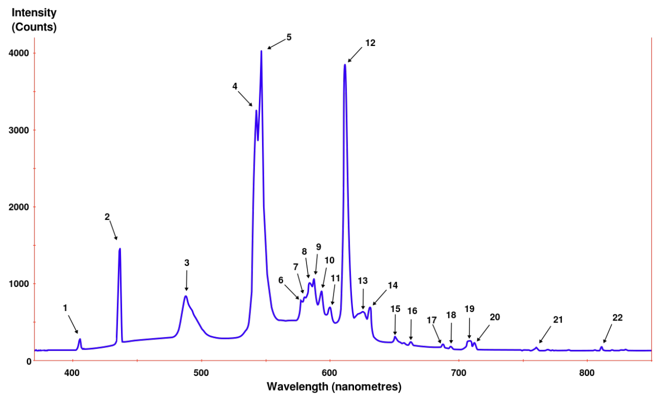

Figure 2. Illustration of Spectral Density.

To find the actual data hidden inside the noise the very first step we have taken is the process of matched filtering. But what matched filtering is? When we have an unknown signal and we want to find our known signal within that unknown signal then this process is called matched filtering. If we know what signal we are looking for in the data then matched filtering is known to be the optimal method in Gaussian noise to extract the signal. We assume that our noise is of Gaussian type.Now we remove the content which frequency is below 15 Hz and also down sample the data to 2048Hz.This modification gives us spikes at the boundary due to the discontinuity of the data itself. To avoid this we just trim 2 seconds of data from the beginning and the end.

The next tool we use is Power Spectral Density (PSD). Power Spectral Density is the measure of signal's power w.r.t frequency.Figure 2 shows us what it really represents. For optimal matched filtering the frequency components is weighed by $1/PSD$. As the signal lived only for a few seconds we used a 4 seconds of sample time series data. Here $1/PSD$ works like a filter for the signal.

In matched filtering we lay our signal over the data after weighing by frequency. To create our known signal we have used an aproximant "SEOBNRv4_opt" which assume the binary black hole having equal masses. After creating the signal we lay this over the data and look for the instance of time where we have highest signal to

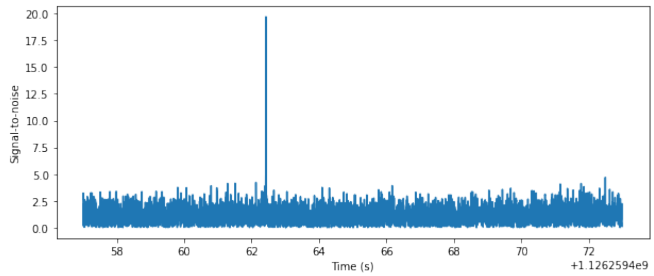

Figure 3. Signal to Noise Ratio (SNR).The signal is at 1126259462.4228516s with SNR 18.334442605451233

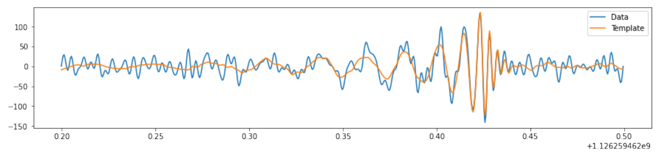

Figure 4. Overlap of Data and Signal.

noise ratio (SNR).For our data the signal to noise ratio looks like Figure 3. Now we know what is the time range where the signal lies. Here we modify the template to have SNR equals to 1 and scale the template amplitude and phase to the peak value. To visualize the overlap of signal and the data we have whiten both the data and template and pass them through a bandwidth of 30-300 Hz. This transforms the data in the way template has been transformed.If we zoom onto the overlap we get Figure 4. From this figure we can see at maximum amplitude the data is completely overlapped on the data which means that we have detected gravitational wave successfully.

PARAMETER ESTIMATION

This will primarily done by using Bayesian Inference Library (bilby) which is a software package designed to enable parameter estimation for compact binary coalescence.[reference] But before moving to that we will find the chirp mass from the fit we have already managed to do.The chirp mass is given by

$$\mathcal{M} = \frac{(m_1 m_2)^{3/5}}{(m_1+m_2)^{1/5}} = \frac{c^3}{G}\left[\frac{5}{96}\pi^{-8/3} f^{-11/3}\dot{f}\right]^{3/5} \quad (1)$$

From Eq. (1) we can calculate the chirp mass if we know the average frequency f and the time derivative of the frequency $\dot{f}$.G is the gravitational Constant and c is the speed of light. From the plot we have $f = 70Hz$ and $\dot{f} = 575Hz/s$. From these values we get $\mathcal{M} \approx 30M_\odot$

The rest of the analysis is still to be done .

ERROR ANALYSIS

Yet to be done

RESULT

Will be completed later.

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[1] GWOSC.