Gravitational Wave Analysis
(I will improve this title later!)

Landon Buell*
University of New Hampshire, Durham, NH, 03824, USA
(Dated: September 22, 2020)

In this work, we explore a system of analysing LIGO Gravitational Wave data to predict properties of the event that produced the detected disturbance. Based on multi-parameter best-fit estimations, and currently known procedures on processing gravitational waves, we show how to derive similar results as LIGO derived. We show the process of using cleaning, filtering, and fitting raw data to extract a series of parameters that best represent each signal. From these parameters, and additional known information we also show key properties about the event that generated the waveform.

INTRODUCTION

Before 1920, the formulation of the Theory of General Relativity (GR) was well-developed and consequently lead to the prediction of *gravitational waves*. Einstein found that linearized weak-field equations had solutions that indicated a wave-like behavior of space time. Particularly when large masses accelerate, they cause a strain effect which produces radial transverse waves that move at the speed of light through space [1]. It was not until 2016, almost 100 years after their conception, that experimental evidence of this phenomenon was detected for the first time. Two Laser Interferometer Gravitational Wave Observatory (LIGO) detectors measured an oscillating pattern in space-time that matched with the predicted in-spiral, and merger event of a binary black hole system [1].

Since then, much of the data from the detected event has been made publicly available for educational or personal use. For this experiment, we use this raw waveform data and subject it to a series of preprocessing steps. From the resulting data, we are able to derive various key features of the merger event that enable a better comprehension of the behavior of gravitational waves and binary black hole systems. These features are includes, but not limited to (i) chirp mass, (ii) signal-to-noise ratio, (iii) total mass, (iv) relative velocities, and (v) physical quantities related to the event's ring-down.

This introduction is very not finished!

EXPERIMENTAL METHODOLOGY

In order to ensure the validity of all computational results, we must complete a series of preprocessing steps that allow for minimal error and uncertainty. This preconditioning also reduces numerical error and removes redundant, or non-useful information. We detail these preprocessing steps below. These steps are derived from Dr. Long's lab write-up and Tutorial notebook 2.2 - How do I cite these?

1. **Time-Series Cleaning**
   We subject the signal to a high-pass filter to reduce the presence of low-frequency oscillation terms which introduce numerical error in the time-domain representation of the signal. We additionally down sample the signal from starting frequency? 16 kHz? to 2048 Hz. These modification introduce large amplitude spikes at both the starting and ending of the signal. We remove 2 seconds of time (4096) data samples from either end of the array.

Image of Time-Series Signal Before and After this section of pre-processing goes here

Figure 1. Time series signal before and after initial cleaning step

2. **Power Spectral Density**
   We window the time-series waveform into 4 second, (8192 samples) analysis frames and estimate the power spectral density in the frame. We use the reciprocal of the power spectral density as a filter in the signal.

3. **Signal-to-Noise Ratio**
   We compute the signal-to-noise (SNR) ratio of the time-series waveform. This is the ratio of the signal's power to the noise's power at any given sample. A large SNR is indicative of a sample that contains a large amplitude, with little background noise to offset the ampltiude.

Once the preprocessing has been completed, we begin the formal analysis and interpretation of the information contained within the time-series representation of the signal. To start, we isolate a section of the signal that represents the "in-spiral near merger time" which occurs right before the largest amplitude of the waveform Citation needed. Based on the visible behavior of the waveform in the time frame, and the known oscillatory properties of gravitational waves, we tailor a function to best fit the waveform accordingly. We choose out hypothesis-space to be a subset of an expoentially decaying sinusoidal waveform.

$$f(t) = Ae^{-\gamma t} \cos\left(\frac{\omega t}{t - t_m} - \delta\right) \tag{1}$$

Where $f(t)$ is out approximation of the waveform amplitude, A gives an initial amplitude condition, γ provides an estimate for the exponential decay factor, ω is the angular frequency in the subset of the waveform, t_m is the known time of merging and δ is a phase shift.

With this hypothesis, we pass an initial set of predicted parameters into a curve fitting function. For this, we implement the *scipy.optimize.curve_fit()* function in python 3 Cite scipy???. This function then uses the hypothesis space in eqn. (1) and the provided initial conditions to produce a function-of-best-fit to the waveform.

RESULTS

I currently do not have formal experimental results to display here

CONCLUSION

I currently do not have a formal conclusion to display here

* Corresponding author: lhb1007@wildcats.unh.edu

[1] Abbott, B.P. et al. 2016, "Observation of Gravitational Waves from a Binary Black Hole Merger". *Physical Review Letters*, Vol. 116, 061102