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VISUALIZING THE POSTMERGER RANGE OF GW170817 USING LIGO OPEN DATA

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Abstract

GW170817 is the first gravitational wave signal of a binary neutron star inspiral recorded by the advanced LIGO and Virgo detectors.The waves produced depend on the masses of the two neutron stars and how much they deform due to tides from the other star. After the stars collide, the system may have also produced higher-frequency 'post-merger' waves that were too weak for the detectors to measure. With data from LIGO and the use of python packages, we take the distribution of masses and tidal parameters inferred from GW170817 to generate and model post-merger waveforms. The model tells us that the post-merger lasted tens of milliseconds at frequencies of between 3 and 4 kHz. Similar sets of post-merger waveforms can be used to train machine learning algorithms.

Introduction

On August 17, 2017, the Laser Interferometer Gravitational-wave Observatory (LIGO) and Advanced Virgo gravitational-wave detectors observed a binary neutron star inspiral for the first time. The gravitational-wave was identified by match filtering the data against post-Newtonian waveform models. Through bayesian parameter estimation, it is inferred that the total mass of the system is between 2.73 and 3.29 solar mass with individual masses having a range of 0.86 and 2.26 solar mass. Additionally, the bayesian inference also recovers dimensionless tidal deformity values under 750 [1]. We use parameter estimations samples publicly available online from the Gravitational Wave Open Science Center (http://gw-openscience.org). We then use the numerical-simulation based NRPM model to generate analytic post-merger waveforms compatible with GW170817.

Methods

We use Jupyter notebook hosted on Google Colaboratory to execute this project [2]. The waveforms are generated using bajes, a python software for Bayesian inference developed at Friedrich-Schiller-Universtät Jena and specialized in the analysis of gravitational-wave and multi-messenger transients [3, 4] publically available on github. Each posterior sample from the Open Science Center data of GW170817 was used to set the mass and tidal parameters for a NRPM waveform approximant using bajes. We generate And downsample to 10 and 100 parameter samples and overplot the post-merger waveforms in the time-domain as well as the frequency domain to show the range of predicted post-merger signals compatible with GW170817 observations. The full code written used to generate the post-merger waveforms can be found on my github (https://github.com/sherelene).

Results

With the NRPM model, we find a range of post-merger signals compatible with GW170817. Creating post-merger waveforms reveals a h plus strain within -1.5e-22 to 1.5e22 at ~0.0015 seconds as shown in figure 1, 2, and 3. Thus, showing consistency that supports these waveforms of GW170817 as post-mergers without the prompt formation of a black hole. Graph 2 from figure 1 and figure 2 shows the post-merger amplitude vs frequency past the amplitude of ~10e-28. As of now, the advanced gravitational-wave detectors can only detect at an amplitude of ~10e-22.

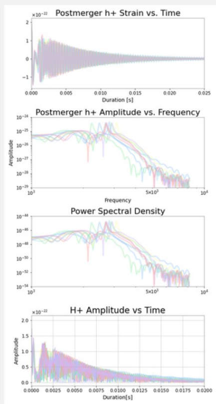


Figure 1: Analytical waveforms of 10 post-mergers selected from the posterior samples.

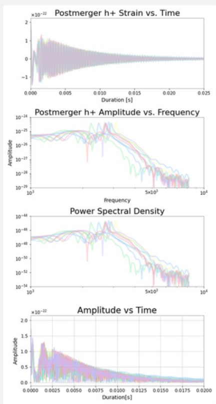


Figure 2: Analytical waveforms of 100 post-mergers selected from the posterior samples.

Results

In addition, we outputted a waveform to show only the positive values of h plus. A comparison of figure 3 with figure 2 shows a beautiful wave oscillation.

Figure 3: Analytical waveform of a single post-merger randomly selected from the posterior samples

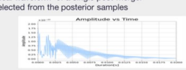
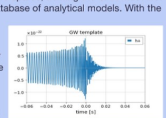


Figure 4: Amplitude vs Time analytical waveform with the same posterior samples from figure 1 selected

Future Work

Typical analytical models use classical physics to create gravitational-waveform simulations. Relativistic effects become dominant near the point of merger, though, making classic analytic models lose accuracy near the time of merger. Numerical simulations, on the other hand, take these relativistic effects into account. Even so, due to the computational complexity of numerical simulations, not many exist. Graduate student Derek White (CSUF) has collected numerical simulations around the world in hopes of expanding the numerical models database by using machine learning. By creating a generative adversarial network (GAN), one may take a small dataset and generate new data that emulates data from the original set. However, since numerical simulations are sparse, training the GAN must first be done with a large database of analytical models. With the code produced from this project to create waveforms with both inspiral and postmerger data (pictured, right), we are able to create the required amount of simulations needed to train the GAN (~20,000 simulations).



References:

[1] B. P. Abbott et al. (2017). GW170817: Observation of Gravitational Waves from a Binary Neutron Star Inspiral. Phys. Rev. Lett. 119,161101

[2] Google, https://colab.research.google.com/notebooks/basic_features_overview.ipynb

[3] Breschi, Matteo and Gamba, Rossella and Bernuzzi, Sebastiano (2021), bajes, GitHub Repository, https://github.com/matteobreschi/bajes

[4] Matteo Breschi, Rossella Gamba, and Sebastiano Bernuzzi (2021), bajes: Bayesian inference of multimessenger astrophysical data Methods and application to gravitational-waves. https://arxiv.org/pdf/2102.00017.pdf

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I integrated gravitational-wave specific and Bayesian inference python packages to produce data from analytical waveforms structured with numerical simulations in the form of a time-domain and frequency-domain.

Alternate Text:

Sherelene De Belene

Quote: "I integrated gravitational-wave specific and Bayesian inference python packages to produce data from analytical waveforms structured with numerical simulations in the form of a time-domain and frequency-domain."

Image of Sherelene De Belene

Image of text and graphic laden project presentation entitled "Visualizing the Postmerger Range of GW170817 Using Ligo Open Data. Sherelene De Belene, Dr. Jocelyn Read"