Characterization of Transient Noise in LIGO Data

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Abstract

The Laser Interferometer Gravitational-Wave Observatory (LIGO) is one of the most sensitive experiments ever developed, it can detect distance changes to about a width of a proton. The first detection of a gravitational wave signal was from a binary black hole merger on September 14, 2015. First predicted by Albert Einstein's Theory of General Relativity in 1916, gravitational waves carry energy through space due to collisions of compact objects, usually black holes or neutron stars. However, noise transients, also known as glitches, mimic astronomical gravitational wave signals decreasing the sensitivity of the detectors. Glitches occur due to a variety of reasons, including environmental noise or instrumental artifacts. In this research, I work to improve the quality of the collected data and eliminate as much noise as possible in the interferometers. I participate in detector characterization that uses tools and methods to identify, characterize, and remove noisy data in the analysis time. Performing data quality shifts enhances the ability of the instruments to probe some of the most exotic objects in the universe, including black holes and neutron star mergers. The search for gravitational waves opens a new era in astrophysics enabling us to observe events that an ordinary telescope can't.

First Coherent GW Signal

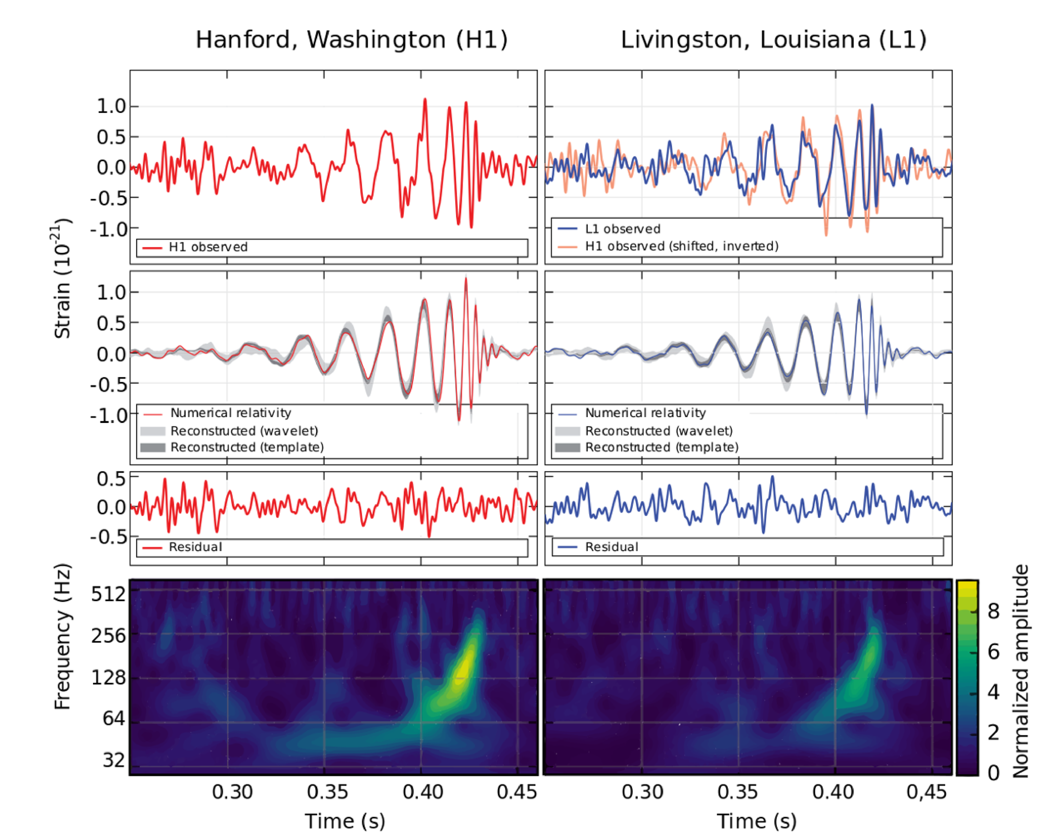

Figure 1: a numerical relativity waveform of a gravitational wave signal in comparison to the measured and observed waveform of GW150914, detected by both LIGO observatories. Credits: https://losc.ligo.org/events/GW150914/

Glitch Table

Class	Total	Livingston	Hanford	Class	Total	Livingston	Hanford
Air Compressor	54 (0.7%)	0 (0.0%)	54 (1.1%)	No Glitch	84 (1.1%)	64 (2.2%)	20 (0.4%)
Blip	1869 (24.2%)	374 (12.7%)	1495 (31.4%)	Paired Doves	30 (0.4%)	0 (0.0%)	30 (0.6%)
Chirp	65 (0.8%)	32 (1.1%)	33 (0.7%)	Power Line	454 (5.9%)	180 (12.6%)	274 (1.7%)
Extremely Loud	453 (5.9%)	187 (6.3%)	266 (5.6%)	Repeating Blips	285 (3.7%)	36 (1.2%)	249 (5.2%)
Helix	279 (3.6%)	276 (9.4%)	3 (0.1%)	Scattered Light	453 (5.9%)	59 (2.0%)	394 (8.3%)
Koi Fish	829 (10.7%)	250 (8.5%)	579 (12.1%)	Scratchy	354 (4.6%)	259 (8.8%)	95 (2.0%)
Light Modulation	573 (7.4%)	5 (0.2%)	568 (11.9%)	Tomte	116 (1.5%)	46 (1.6%)	70 (1.5%)
Low Frequency Burst	652 (8.4%)	473 (16.0%)	179 (3.8%)	Violin Mode Harmonic	178 (2.3%)	0 (0.0%)	178 (3.7%)
Low Frequency Line	452 (5.9%)	371 (12.6%)	81 (1.7%)	Wandering Line	44 (0.6%)	0 (0.0%)	44 (0.9%)
None of the Above	189 (2.4%)	36 (1.2%)	153 (3.2%)	Whistle	305 (4.0%)	303 (10.3%)	2 (0.0%)

Figure 2: Above is a list of morphological categories of O1 from both LIGO observatories.
Credits: https://arxiv.org/pdf/1611.04596.pdf

Graviational Wave Detections from the Second Observing Run (O2)

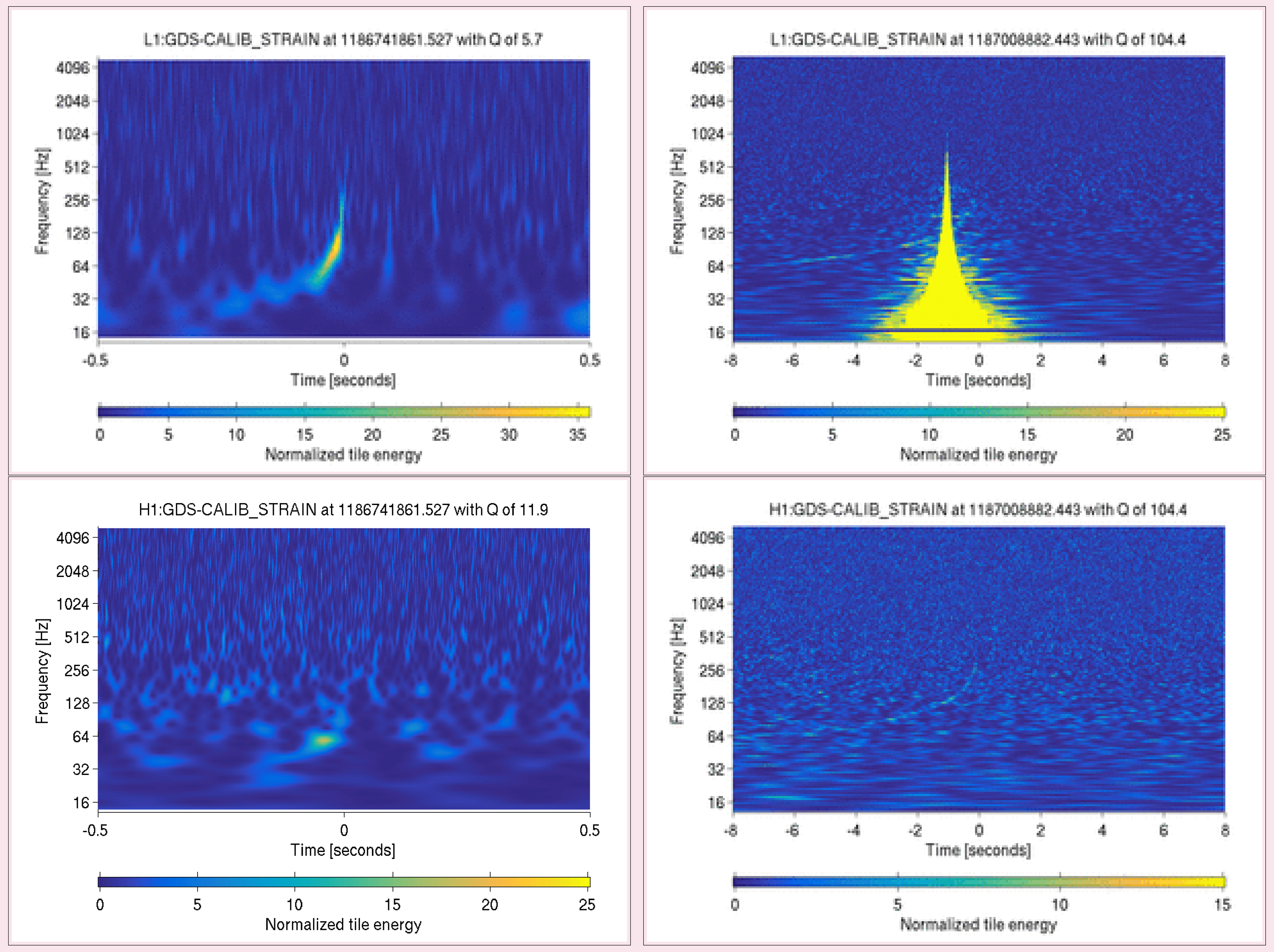

Figure 3: Gravitational wave detections that I've worked on from the O2 Checklist. The two images on the left are from the binary black hole event known as GW 170814. The two images on the right are from the binary neutron in-spiral detection, known as GW170817. Where the top two images are Livingston's data and the bottom images are from Hanford's.

Experimental Methodology

With the detectors currently off, LIGO has detected and gathered an abundance of data from the second observing run (O2). Some of which, captures the most recent triggers that are potential candidates for future gravitational waves, are analyzed more thoroughly. My responsibility as a student researcher is to perform independent checks on three of the most recent Compact Binary Coalescence (CBC) triggers. In order to do so, I compare the $h(t)$ Omega scans of these events to the Gravity Spy classes. Omega scans are a detector characterization tool to help measure the Signal-to-Noise-Ratio (SNR) of transient noises during detections. This helps scientists distinguish the difference between a gravitational wave signal, which looks like a 'chirp' versus a glitch in the data. Gravity Spy is a citizen science program that helps LIGO in classifying glitches to improve machine learning for gravitational wave signals. For each event I determine if it looks like one of the known categories of solved or unsolved glitches seen in the Advanced LIGO detectors? My results are then recorded in the O2 event detection checklist. Omega scans are a 'burst-type' search pipeline that detect glitches efficiently. The Omega scan is labeled using time measured in seconds on the x-axis, frequency measured in Hz on the y-axis and the signal measured is normalized to demonstrate how 'loud' the noise is. Many of these omega scans are stored in Gravity Spy where these glitches are then classified.

Single Inspiral Table

Subject	GW150914	GW170814	GW170817
IFO	H1, L1	H1, L1, V1	H1, L1, V1
Source	BBH	BBH	BNS
Dist(l.y.)	1.4b	2.2b	160m
Merger	09:50:45	10:30:43	12:41:04
Duration	200ms	.28s	60s
1st Mass	41M	36M	2.26M
2nd Mass	33M	28M	1.36M
Total Mass	70M	59M	3.29M
SNR	24	18	32.4

Table 1: Gravitational wave detection fact table sheet that compares the most recent CBC triggers to the first gravitational wave detection.

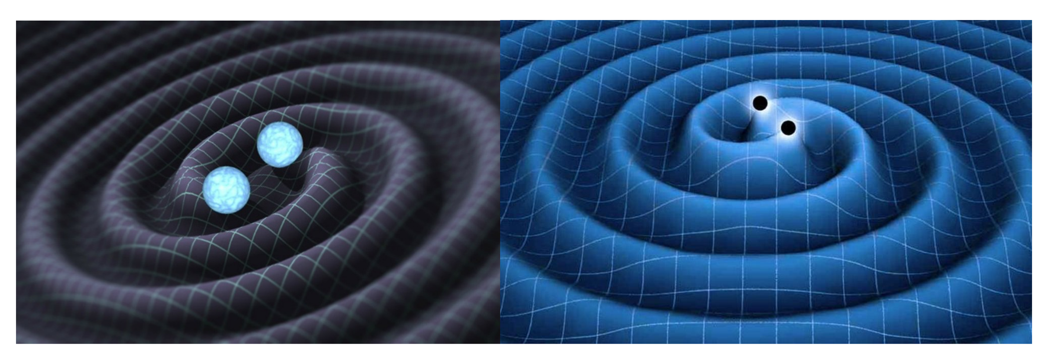

Figure 4: Artist sketch of a binary neutron star (BNS) merger (left) and a binary black hole (BBH) merger (right).

Discussion

Throughout my research, three of the four CBC triggers have been classified as confirmed Gravitational wave candidates. By comparing each data set of normalized Omega scans with the Gravity Spy classes, it enabled me to determine whether each CBC trigger is either classified as a transient noise seen in Advanced LIGO or a similar GW150914. Transient noise can be correlated or uncorrelated in the two Advanced LIGO detectors. Uncorrelated noise sources produce short bursts and can have significant impact in the data when searching for gravitational wave signals. Some of these potential noise sources occur within the frequency range for unexpected gravitational wave signals. Some anthropogenic noise sources are caused by human activity near the detectors, such as a passing truck. Earthquakes are also uncorrelated noise that produce a lot of ground motion at the detectors with frequencies from .03Hz to .1Hz or even higher when near by. Radio frequency (RF) modulations are also detected with sporadic periods of loud noise between 9 and 45 Hz. Lastly, a common uncorrelated glitch that scientists are unable to weed out from the data are Blip transients which are short noise bursts that constantly appear in the gravitational wave strain channel $h(t)$ as a shape of a 'teardrop'. Some correlated noise sources that may affect both detectors due to the fact that they could potentially imitate a gravitational wave event would be some potential electromagnetic noise sources and Cosmic ray showers.

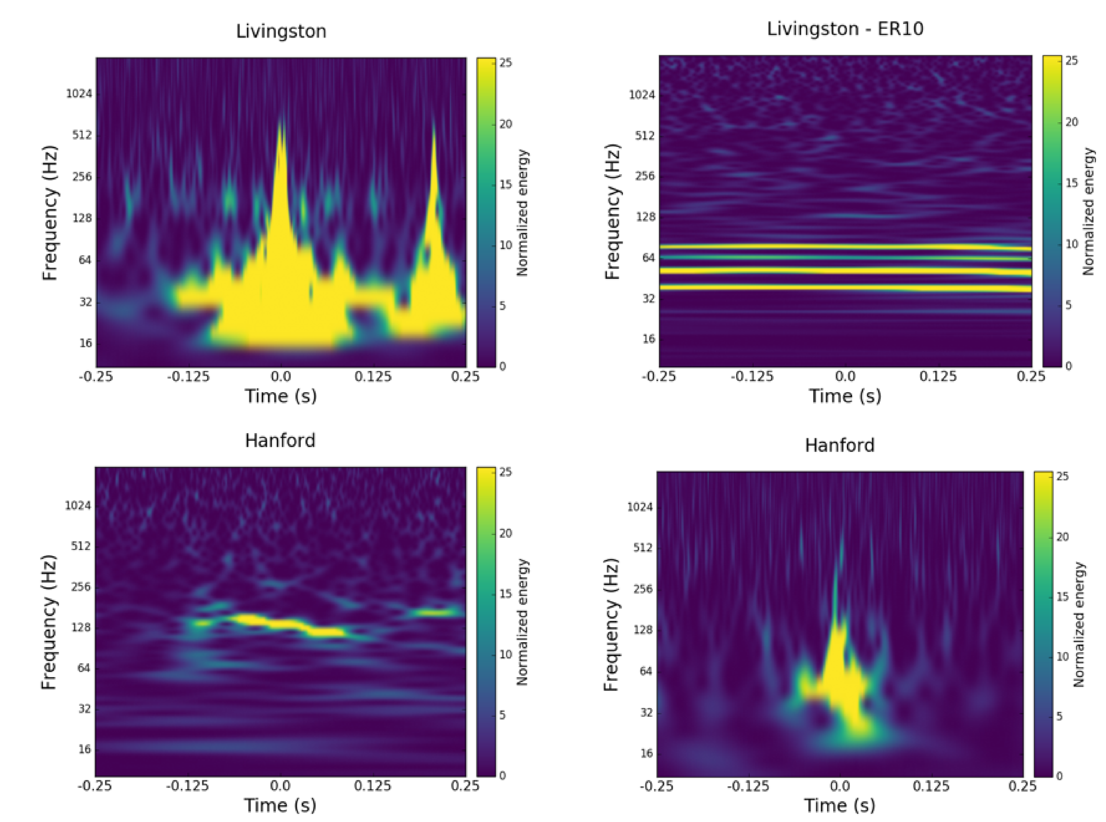

Figure 5: Spectrograms of some of the most common glitches seen in the Advanced LIGO observatories throughout all observing and engineering runs. Credits: Zooniverse, Gravity Spy

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