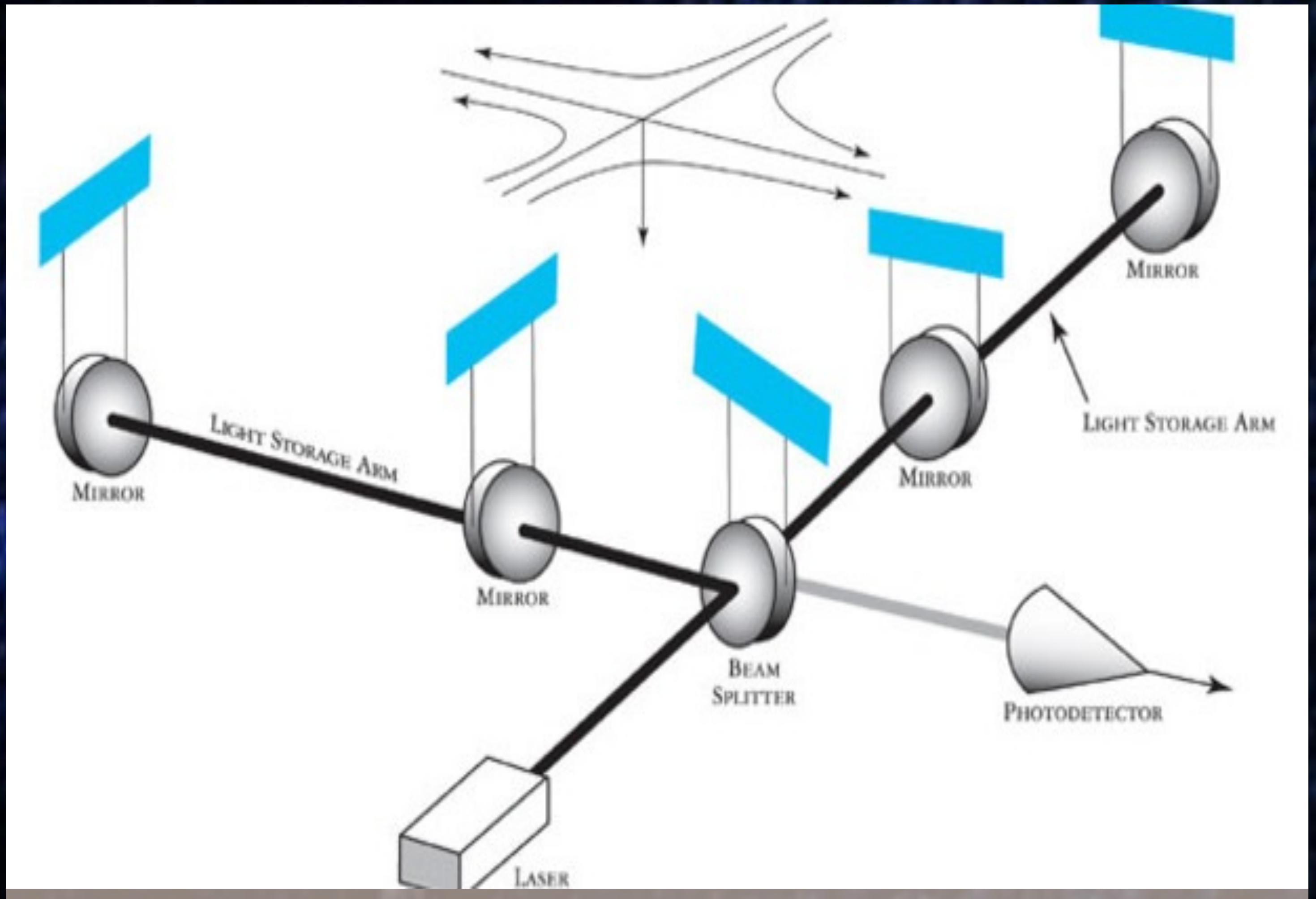
Potential of Gravity Spy Glitches to be used as Vetoes, and Improve the Gravitational Wave Background of LIGO's Hanford Observatory

Ray A. Dean, Amber Stuver (advisor)

The objective of this research is to ascertain the benefit (or lack there of) of using Gravity Spy glitch classifications as vetoes to improve the gravitational wave background of LIGO's interferometer data, by using the Veto Evaluation Tool (VET) to analyze these glitch classifications from the Second Observation Run ("O2", November 5, 2016-August 26, 2017) in the LIGO Hanford data. Improving the gravitational wave background (GWB) would increase the confidence in any potential gravitational wave detection by the LIGO Collaboration, as the GWB is a build up of glitches and other noise sources that interfere with data analysis methods. Gravitational wave detections provide invaluable information concerning the cosmic source of the wave, Einstein's theory of general relativity, and the gravitational force itself.

What is LIGO?

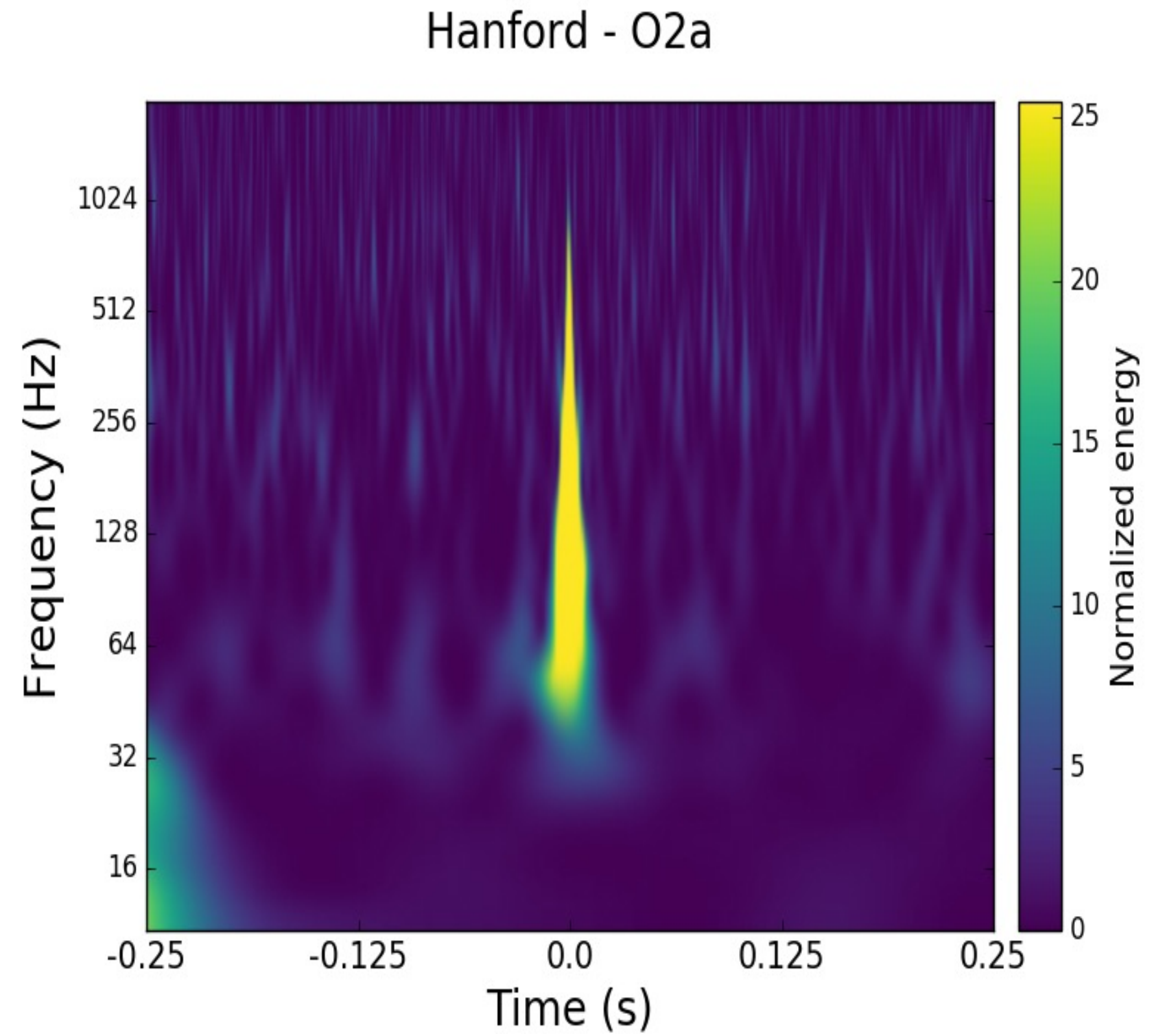
Albert Einstein predicted the existence of Gravitational waves in his general relativity theory in 1916. He predicted that the acceleration of cosmic masses, like spiraling binary black holes, or colliding binary neutron stars, would cause ripples in space-time that would travel across the universe at the speed of light. These ripples would eventually reach Earth, many light-years from the event itself. He also predicted that encoded within these waves is information about both the event itself and the nature of gravity. The objective of the LIGO (Laser Interferometer Gravitational-Wave Observatory) collaboration is to detect and analyze gravitational waves using their two interferometers based in Hanford, Washington and Livingston, Louisiana. Only signals seen by both detector are considered candidate detections.



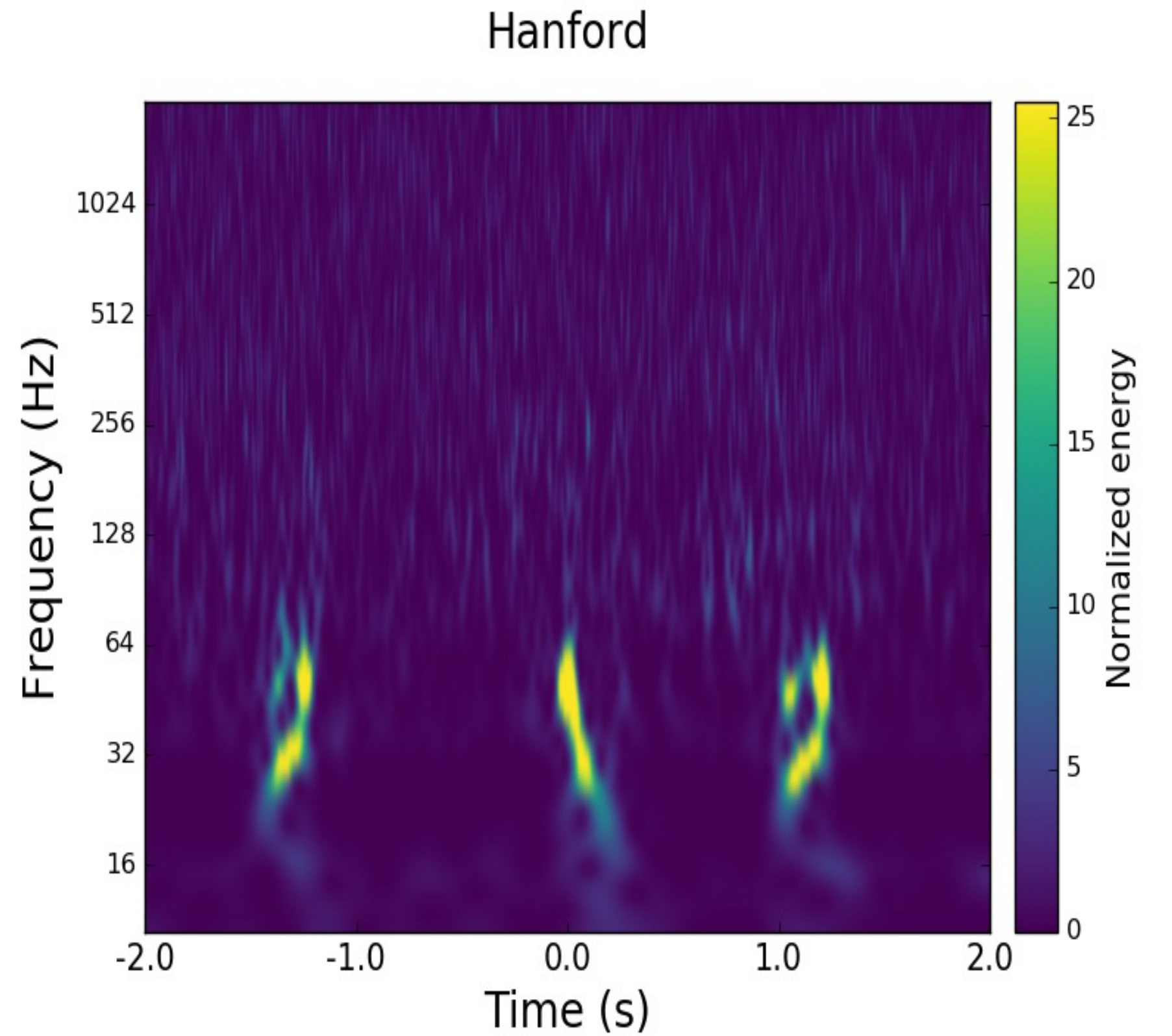
[2]This image depicts a basic interferometer design, where a laser is split between two arms, reflected back through these arms, and the resulting signal is received by the photodetector. Take note of the vector field depicted at the top of the image. This shows the distortions of a gravitational wave incident perpendicular to the detector will produce in the interferometer. That is, the gravitational wave will alternatingly stretch the length of one arm, and contract the length of the other.

How do LIGO's interferometer's work?

LIGO's interferometers utilize basic interferometer design, except on a massive scale, a laser is emitted, and then split between two resonance chambers 4 km long. These lasers are then reflected off of mirrors at the ends of these resonance chambers, and returned to a photo sensor, at the same location of the splitter. If the arms of the interferometer remain equal throughout the lasers journey, the phases of each laser will add constructively, essentially recreating the original signal. However, if the arms of the interferometer change length with respect to reach other, the returning waves will add destructively, returning a much dimmer signal. In addition to measuring the output light, LIGO monitors different phenomenon occurring in or around the detectors. For example some channels monitor the length of the resonance chambers while others monitor seismic vibrations, or sound vibrations. Analyzing the data in these separate channels allows LIGO to make the smallest length measurements ever recorded, about 1/10,000 the width of a proton.



[3]The Blip Glitch example used by Gravity Spy to identify other Blip Glitches.



[3]The Paired Doves Glitch example used by Gravity Spy to identify other Paired Dove Glitches.

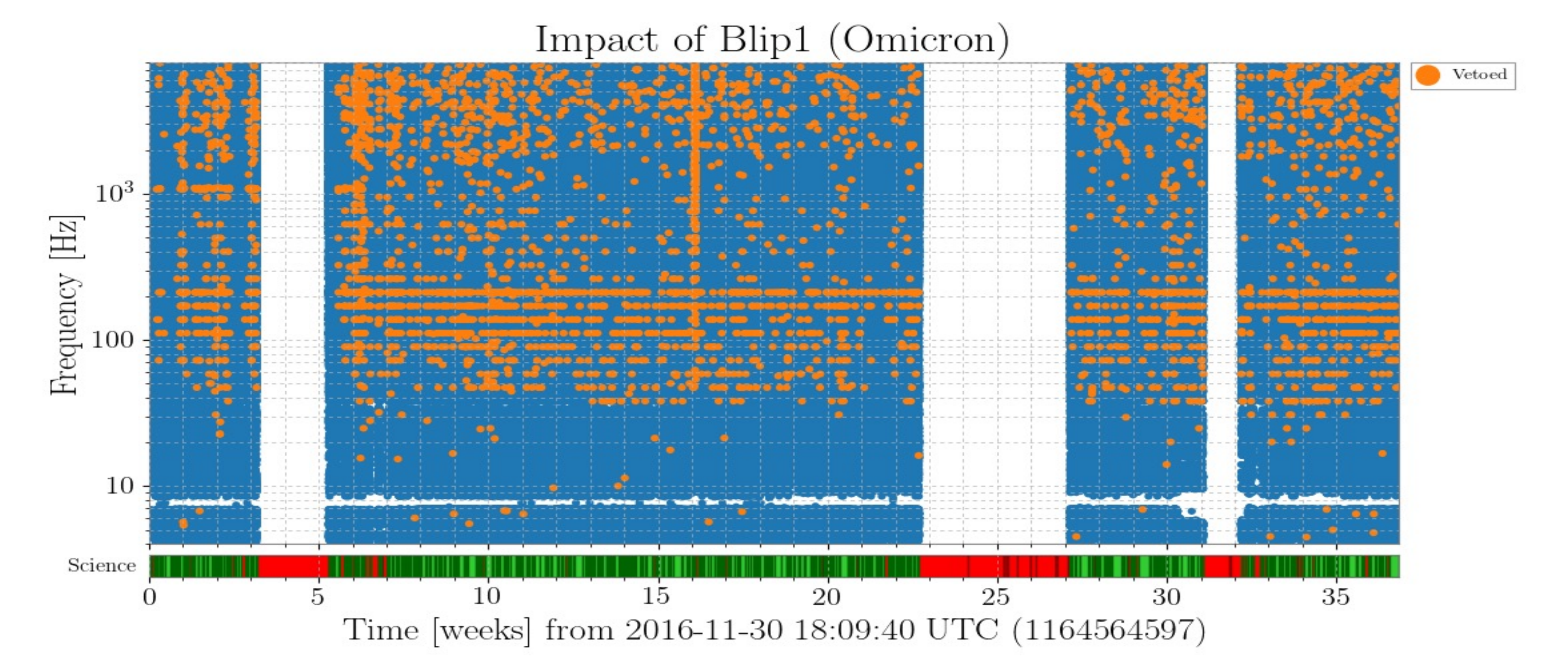
What is a Glitch?

With LIGO's high length sensitivity comes an increased sensitivity to environmental noise. LIGO determines if a noise transient is a glitch by multiple different methods. For example, if a signal appears in both the gravitational wave channel and a sound channel (recorded using a microphone), it is likely a glitch, as gravitational waves travel through space-time and make no sound. The most likely scenario is that the arm length channel has coupled to the microphone channel and is being corrupted by this sound noise. We can remove this data only when we can associate it with an environmental disturbance: this is called a veto. Strong, "loud" glitches create more accidental detections between the 2 LIGO detectors and have a greater impact on the GWB. More frequent, low amplitude glitches are much more numerous but produce low significance candidate detections that are easily discounted. This will impact much of our analysis later on.

What is Gravity Spy?

This is where Gravity Spy comes in. Gravity Spy is a citizen science effort to visually verify computer classifications of glitches by inspecting individual spectrograms. The verifications are then used to better train the machine learning algorithms to improve future classifications. Any person can assist in the identification of these glitches so that LIGO can better adjust their data analysis methods to accommodate for these sources of noise. To be a part of the future of gravitational experimental physics go to:

https://gravityspy.org



Above is a VET plot for all Gravity Spy classified Blip Glitches across the entirety of the O2 run (approx. 37 weeks), with Omicron trigger generation.

What is a Veto?

A veto is a specific time that is removed from the data, as a result of the presence of some kind of glitch that invalidates the data. A glitch is a data artifact caused by an environmental or instrumental disturbance. Data cannot be simply removed just because it doesn't look the way we'd like. Therefore, a glitch must be seen in the gravitational wave data and a channel that is insensitive to gravitational waves, like a microphone or hygrometer. We also want to minimize the amount of vetoed data to minimize the possibility of rejecting data that may contain a gravitational wave.

What is VET?

VET correlates the Gravity Spy glitches with triggers automatically generated by one of two LIGO trigger generators, Omicron and Coherent Wave Burst (CWB). Omicron creates triggers by specifically searching for glitches while CWB creates triggers by searching for short duration gravitational waves. Running VET on Omicron triggers gives us the measure of a vetoes impact on the glitch population while CWB provides the impact on a specific gravitational wave search. The results of VET are presented as a scatter plot of glitches where those being removed are highlighted gold, as well as other important metrics pertaining to the quality of the veto. Using the VET we can determine how efficient the veto of Gravity Spy classification would be, in lowering the gravitational wave background. However, this does **not** mean we can actually remove the glitch from our data set. Only that it would be profitable to direct resources towards finding a "safe" environmental channel that we can veto this glitch against.

Analysis

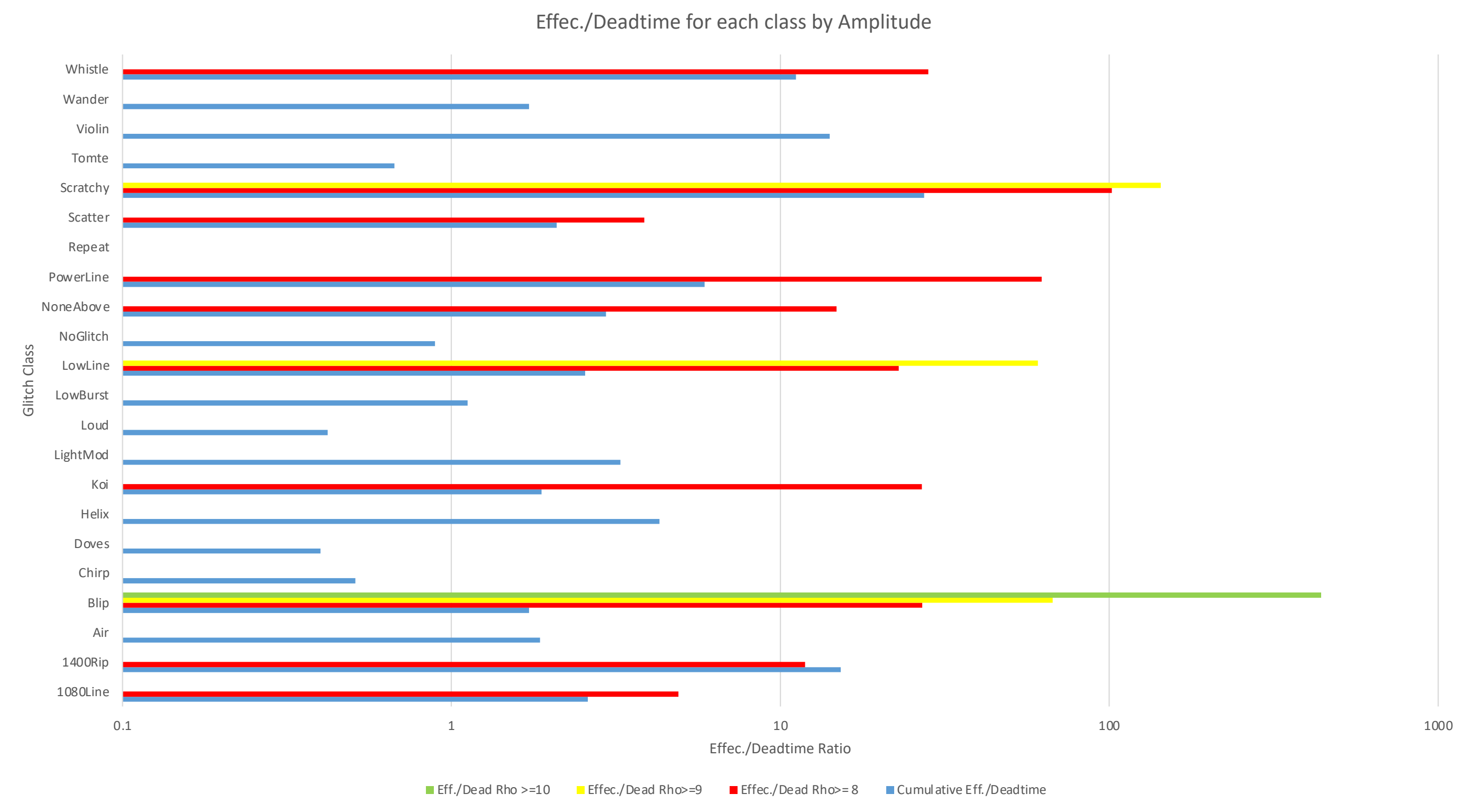
The determining factor of whether a glitch classification has high or low veto potential lies in the VET metrics, specifically its Efficiency/Deadtime (Effec/Deadtime). For each glitch class, the ratio of glitches vetoed out of the total number of glitches present (efficiency) to the amount of observation time being removed from the data (deadtime) is calculated. Special attention is given to this ratio for "loud" glitches because of their impact on the GWB. A veto would have to efficiently remove many, many more glitches with lower amplitude to cause the same positive effect on the GWB as removing only a few, louder glitches. The gold plated, high potential indicator, is a ratio of 10+ at the highest amplitude possible. A ratio of 10+ cumulatively would also be a high potential indicator. A ratio of 10+ at lower amplitudes would not necessarily indicate more than low or medium potential for a good veto. The results of each VET scan are condensed in the bar graphs to the right.

High Potential:

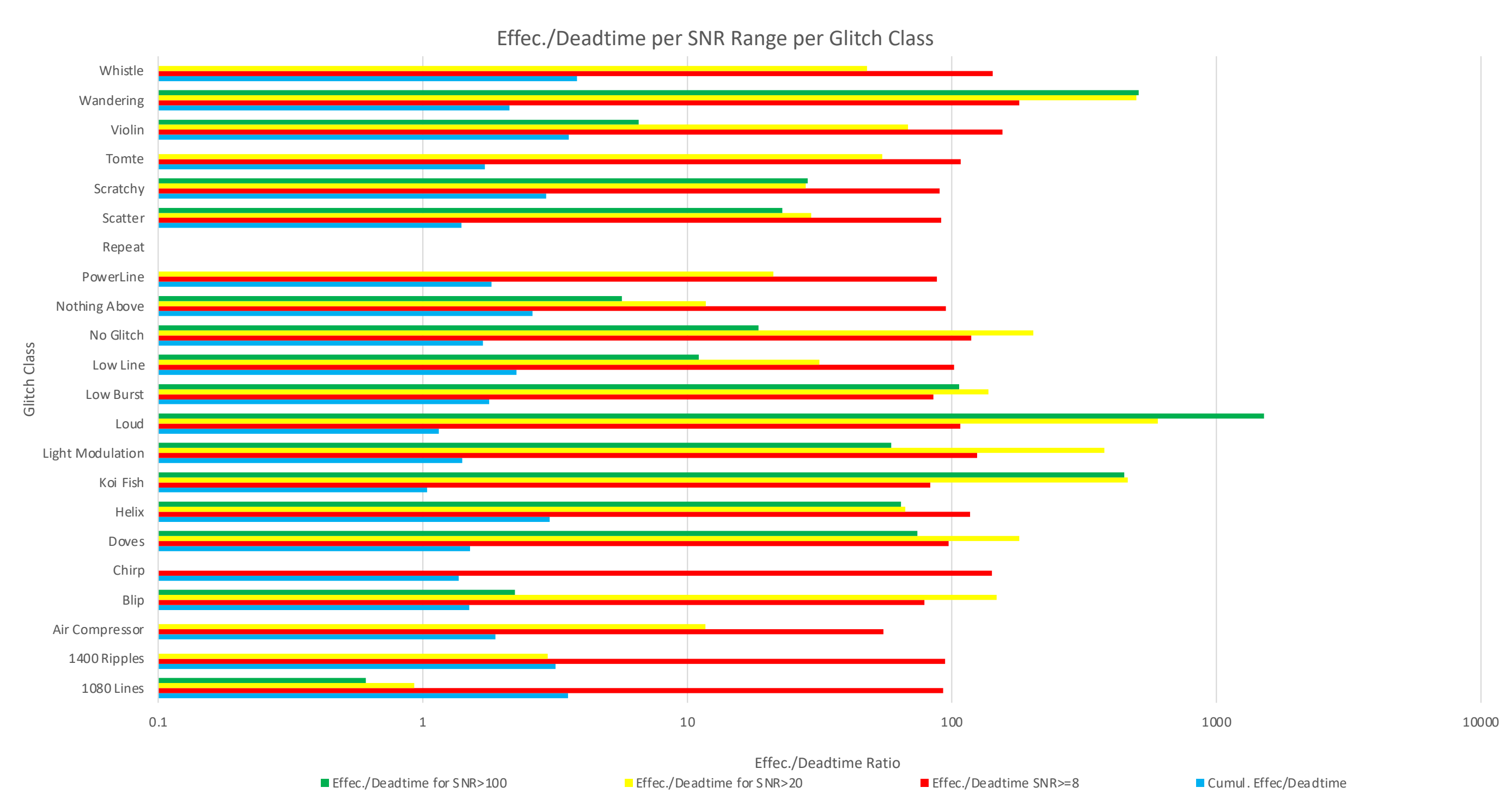
Effec./Deadtime >10 at Rho>=10, SNR>=100, Cumulative

Medium-Low Potential:

Effec/Deadtime >10 at any other Rho or SNR



The above table represents the individual metrics of each Gravity Spy glitch class, when a VET scan is performed using the the Cohesive Wave Burst (CWB) trigger generator across the entire O2 run for the Hanford Interferometer. The important statistics to note (in order of importance) are: Effec. /Deadtime Rho>=10, Effec./Deadtime Rho>=9, Effec./Deadtime Rho>=8, Cumulative Effec./Deadtime.



This table represents the individual metrics of each Gravity Spy glitch class, when a VET scan is performed using the Omicron trigger generator, across the entire O2 run for the Hanford Interferometer. The important statistics to note (in order of importance) are: Effec. /Deadtime SNR>=100, Effec./Deadtime SNR>=20, Effec./Deadtime SNR>=8, Cumulative Effec./Deadtime.

Conclusions

The following are the determine potentials for each glitch class to be used as veto, and should be investigated further (low potential classes are not noted).

High Potential (Omicron):

Doves, Helix, Koi Fish, Light Modulation, Loud, Low Burst, Low Line, No Glitch, Scatter, Scratchy, Wandering

High Potential (CWB):

Blip, 1400 Ripples, Scratchy, Violin, Whistle

Medium Potential (Omicron):

Blip, Air Compressor, Power Line, Tomte, Violin

Medium Potential (CWB):

Low Line, Power Line, 1080 Lines

Keep in mind these glitches can not be removed yet. This only directs our search for a safe channel in which to veto. If we were to perform this analysis again, we would more critically take into account the confidence level of each Gravity Spy glitch. That is to say, we would consider if some of the Gravity Spy glitches were identified incorrectly.

Further Work

- This analysis should be performed for these glitch classes using the Livingston Observatory data. Having this knowledge for both interferometers has the potential to most benefit the GWB.
  - Note: CWB triggers are only those coincident between both LIGO detectors.
- Search for auxiliary channels that can be safely veto the highest potential glitch classes.

References and Acknowledgements

1. Penn State University. "Astronomy Talk Will Trace Gravitational Waves from Crashing Black Holes." *Astronomy Talk Will Trace Gravitational Waves from Black Holes*, 21 Sept. 2016, news.psu.edu/story/427047/2016/09/21/astronomy-talk-will-trace-gravitational-waves-crashing-black-holes.
2. LIGO. "What Is an Interferometer?" *LIGO Lab | Caltech*, 2018, www.ligo.caltech.edu/page/what-is-interferometer.
3. LIGO. "Gravity Spy." Gravity Spy, blog.gravityspy.org/.

This work is supported by the Villanova Center for Research and Fellowship through the Niedbala Family Summer Research Fellowship. The authors also wish to thank the LIGO Scientific Collaboration for providing access to data, computational resources, and collaboration opportunities.