Automating Veto Algorithms for Application to the Search for Burst Gravitational Waves with LIGO

Michael Davis and Amber Stuver

Department of Physics, Villanova University, Villanova, PA 19085

Abstract

The Laser Interferometer Gravitational-Wave Observatory (LIGO) measures astrophysical gravitational waves. During the process of data acquisition, transient noise from environmental and instrumental sources creates glitches in the data. The impact of these glitches on the search for gravitational waves can be mitigated by removing (vetoing) them from the data. Omicron is an algorithm that is currently used to automatically identify data segments likely to be glitches. Two different statistical algorithms evaluate data quality when Omicron glitches originating from different auxiliary channels are vetoed: hierarchical veto (Hveto) and Used Percentage Veto (UPV).

This research applies these automated veto tools to evaluate their potential to improve the search for burst (unmodelled) gravitational waves. We have developed software to collect the daily results of Hveto and UPV and apply those candidate vetoes to the burst search algorithm, Coherent WaveBurst (cWB). The results are evaluated by the Veto Evaluation Tool (VET) to measure a veto's efficiency in removing cWB triggers, deadtime (amount of time removed by the veto), and the ratio of efficiency to deadtime. The higher this ratio, the more effective the veto. This work will be integrated onto the LIGO summary webpages, a data quality utility that is available to the entire LIGO collaboration.

Results of this research show that Hveto and UPV provide vetoes that identify unique glitch features, and both have the potential to improve data quality for burst gravitational wave search.

Introduction

A gravitational wave is a propagating transverse wave of changing gravitational field resulting from the acceleration of mass. As the wave passes through space, it compresses and stretches space in orthogonal directions. Only large amounts of mass experiencing large accelerations can produce gravitational waves with a strength that is detectable at Earth.

Transient noise (**glitches**) in the data can negatively impact the search for gravitational waves (see fig. 2 below). To mitigate theses glitches, LIGO must determine a terrestrial source of the noise and perform appropriate instrumental improvements and/or develop a list of times of known data contamination (**vetoes**) to exclude from the search. Many glitches are identified by Omicron, a program that was originally designed for the identification of burst gravitational waves but has been found useful for detecting glitches.

Fig. 1: The LIGO Livingston Observatory (left) in Louisiana and the LIGO Hanford Observatory (top) in Washington State. The arms of each site are 4 km (2.5 mi) long.

Statistical Vetoes

Vetoes can only be generated when a glitch is also observed in an instrumental or environmental data stream (auxiliary channel) which is unable to detect gravitational waves. These "safe" channels minimize the chance that a glitch may be a true gravitational wave.

There are several existing tools that generate statistical vetoes, including:

- **Hierarchical Veto (Hveto)** [1] uses Poisson statistics to determine the significance of the rate of observed coincidences between Omicron glitches produced from the gravitational wave data and the safe auxiliary channels. For every safe auxiliary channel used, the number of coincidences with the gravitational wave data and the significance are calculated for several time windows. The channel with the most significance, the "round winner" channel, has its coincident triggers vetoed. This process is repeated for more rounds until the method no longer finds any channels above a set significance threshold.
- **Used Percentage Veto (UPV)** [2] uses the same round mechanism as Hveto but ranks channels based on the greatest use percentage (which vetoes are used the most against a set of triggers).

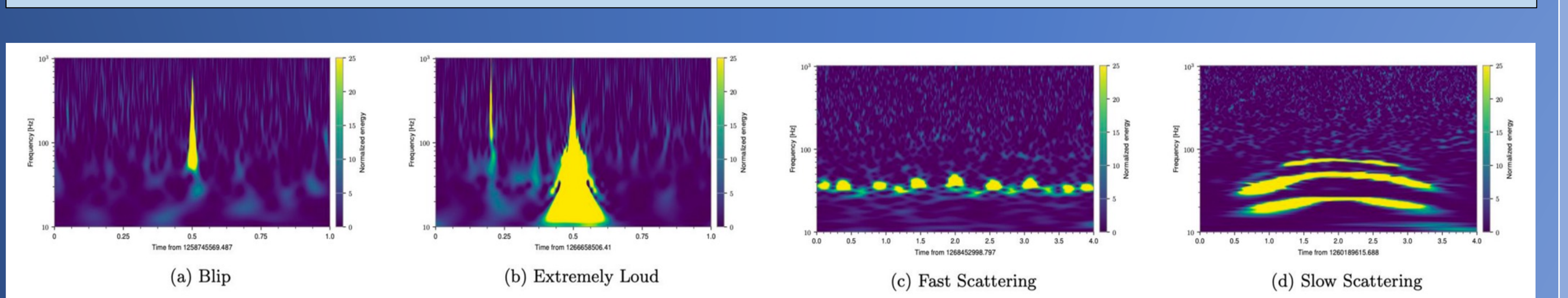


Fig. 2 (above): Example time-frequency representation of four known glitch classes. On the horizontal axis, the time scales are shown around each glitch and the vertical axis shows frequency range. The color bar on the far right shows the normalized energy contained in each time-frequency area. Not all known glitch classes have a known cause or reliable auxiliary channel on which to base a veto. Figure taken from [3].

Burst Gravitational Waves

Burst gravitational waves are a class of short duration signals that are difficult or impossible to model because the initial conditions of the source are unknown, the dynamics in the extreme environment are not understood, or the system is unanticipated. Sources could include core collapse supernova or neutron star instabilities. By performing a search that makes minimal assumptions about a signal, there is a possibility for detections in this class of gravitational waves from unexpected sources.

The primary search algorithm for burst gravitational waves is **Coherent WaveBurst (cWB)** [4]. This method identifies excess power in the time-frequency representations of the detector strain data that is coherent (similar) between multiple detectors. cWB reconstructs the source sky location and signal waveforms by using a constrained maximum likelihood method. The background of cWB (how likely it is for noise in the detectors to create a false positive) uses glitches from both LIGO detectors that have been time shifted more than the light travel time between the detectors (> 10 ms). Any coincident glitches are accidental and can be used to determine the confidence of candidate gravitational waves.

Veto Evaluation Tool

The **Veto Evaluation Tool (VET)** [5] evaluates the effectiveness of the proposed veto segments in terms of the efficiency (fraction of the background events that were vetoed), deadtime (fraction of the analysis time removed), and use percentage (fraction of auxiliary channel glitches used to veto). The ratio of efficiency over deadtime indicates the quality of the data versus how much time was removed. It is better to have as little time as possible removed from vetoes, so a useful veto results in a higher ratio of efficiency to deadtime (around eight to ten).

Other than providing data statistics, VET also creates graphical representations of the results, as shown in figures 3 to 7.

This research ties the existing statistical veto tools, Hveto and UPV, and automates the evaluation of their effectiveness on the results of the burst search, cWB, using the VET tool.

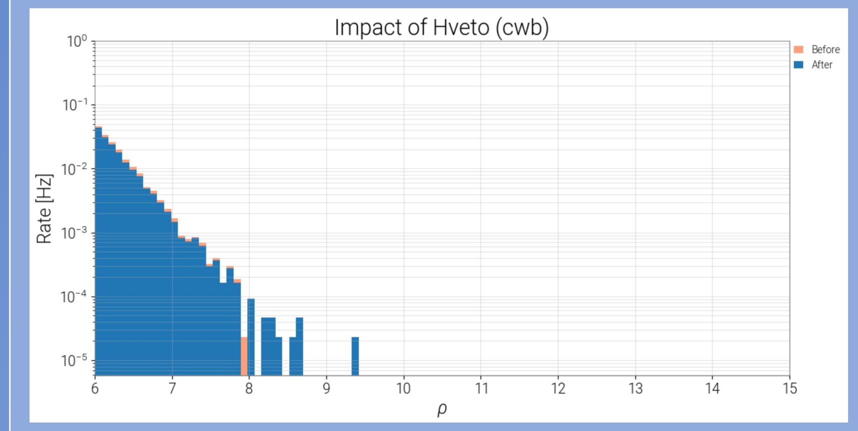
The software **automates** collecting the daily Hveto and UPV vetoes and uses VET to measure their efficiency on the cWB background. This will be used by LIGO data analysts to identify problematic glitch classes and determine which safe auxiliary channel is best used to remove them and improve the burst search. This is the *first time* that statistical vetoes will be tested against burst data analysis results on a near real-time basis.

Hveto

Flag performance summary

Metric	Result	Description
Deadtime	1.06%	The active duration of a given set of segments
Efficiency	7.96%	The decimal fraction of events vetoed by the given segments
Efficiency/Deadtime	7.51	The ratio of efficiency to deadtime
Efficiency | effective correlated amplitude rho>=6.5	9.21%	The decimal fraction of events vetoed by the given segments (effective correlated amplitude rho >= 6.5)
Efficiency/Deadtime | effective correlated amplitude rho>=6.5	8.70	The ratio of efficiency to deadtime (effective correlated amplitude rho >= 6.5)
Efficiency | effective correlated amplitude rho>=7	8.73%	The decimal fraction of events vetoed by the given segments (effective correlated amplitude rho >= 7.0)
Efficiency/Deadtime | effective correlated amplitude rho>=7	8.24	The ratio of efficiency to deadtime (effective correlated amplitude rho >= 7.0)
Efficiency | effective correlated amplitude rho>=8	0%	The decimal fraction of events vetoed by the given segments (effective correlated amplitude rho >= 8.0)
Efficiency/Deadtime | effective correlated amplitude rho>=8	0	The ratio of efficiency to deadtime (effective correlated amplitude rho >= 8.0)
Use percentage	8.91%	The decimal fraction of segments that are used to veto triggers
Loudest event by effective correlated amplitude rho	0%	Percentage reduction in the amplitude of the loudest event by effective correlated amplitude rho

Fig. 3 (above): The data on efficiency and deadtime produced by VET for Hveto. The efficiency/deadtime indicates the quality of data and the usefulness of a veto. An efficiency/deadtime >8-10 is a good veto.



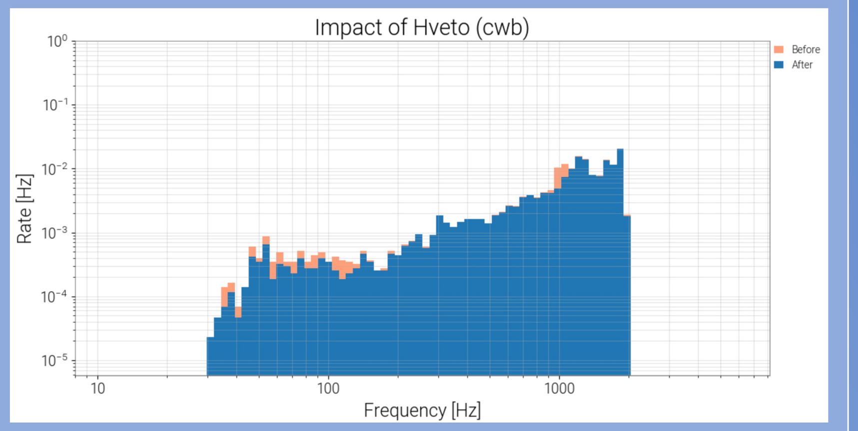


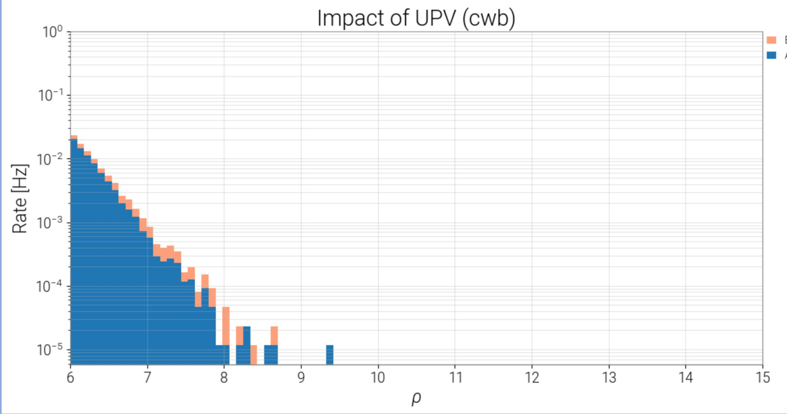
Fig. 4a (above, left) and Fig. 4b (above, right): The impact that Hveto had on the day's data. In Fig. 4a, the vertical axis displays the rate of the glitches, and the horizontal axis displays their strength (ρ) In Fig. 4b, the vertical axis displays the rate of the glitches, and the horizontal axis displays the frequency of the glitches.

UPV

Flag performance summary

Metric	Result	Description
Deadtime	0.17%	The active duration of a given set of segments
Efficiency	15.91%	The decimal fraction of events vetoed by the given segments
Efficiency/Deadtime	93.97	The ratio of efficiency to deadtime
Efficiency | effective correlated amplitude rho>=6.5	27.24%	The decimal fraction of events vetoed by the given segments (effective correlated amplitude rho >= 6.5)
Efficiency/Deadtime | effective correlated amplitude rho>=6.5	160.86	The ratio of efficiency to deadtime (effective correlated amplitude rho >= 6.5)
Efficiency | effective correlated amplitude rho>=7	35.64%	The decimal fraction of events vetoed by the given segments (effective correlated amplitude rho >= 7.0)
Efficiency/Deadtime | effective correlated amplitude rho>=7	210.47	The ratio of efficiency to deadtime (effective correlated amplitude rho >= 7.0)
Efficiency | effective correlated amplitude rho>=8	46.15%	The decimal fraction of events vetoed by the given segments (effective correlated amplitude rho >= 8.0)
Efficiency/Deadtime | effective correlated amplitude rho>=8	272.59	The ratio of efficiency to deadtime (effective correlated amplitude rho >= 8.0)
Use percentage	21.35%	The decimal fraction of segments that are used to veto triggers
Loudest event by effective correlated amplitude rho	0%	Percentage reduction in the amplitude of the loudest event by effective correlated amplitude rho

Fig. 5 (above): The data on efficiency and deadtime produced by VET for UPV. The efficiency/deadtime indicates the quality of data and the usefulness of a veto. An efficiency/deadtime >8-10 is a good veto.



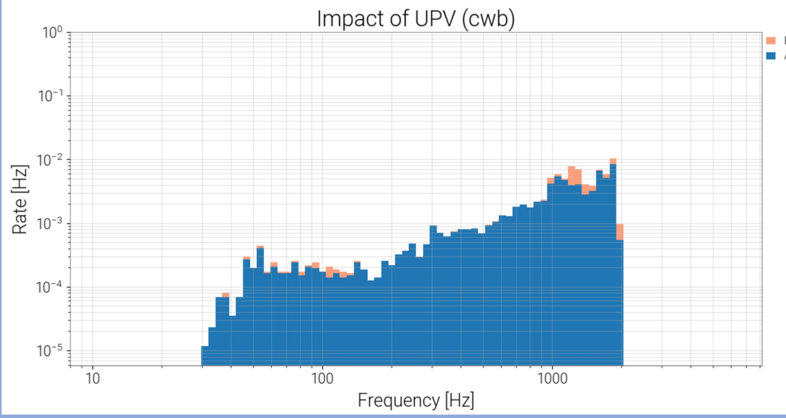


Fig. 6a (above, left) and Fig. 6b (above, right): The impact that UPV had on the day's data. In Fig. 6a, the vertical axis displays the rate of the glitches, and the horizontal axis displays the In Fig. 6b, the vertical axis displays the rate of the glitches, and the horizontal axis displays the frequency of the glitches.

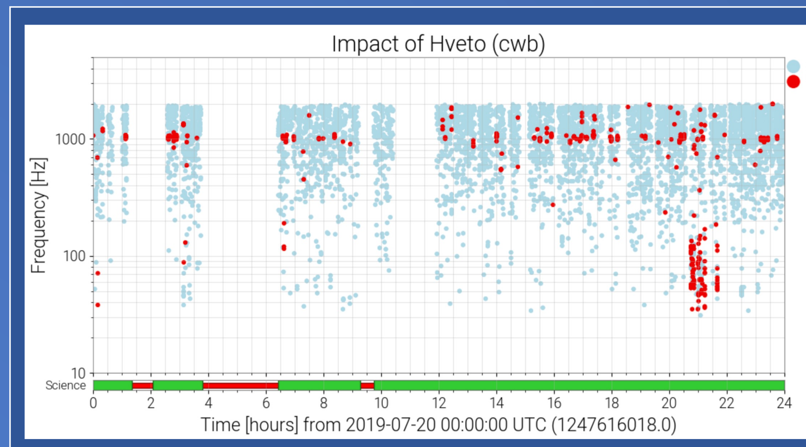


Fig. 7a (above): The effect that Hveto had on the day's data. The red points indicate the glitches that were vetoed by VET. Hveto had a focus on the lower frequencies of glitches, with a slight dependence on the time of day, and a light spread on the high frequencies of glitches.

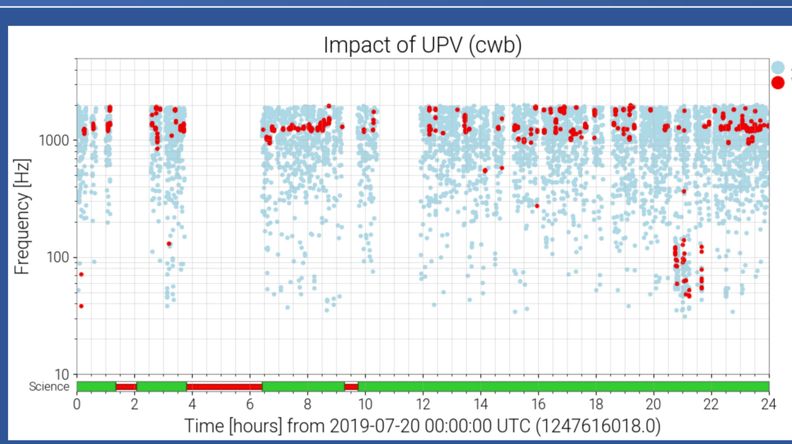


Fig. 7b (above): The effect that UPV had on the day's data. The red points indicate the glitches that were vetoed by VET. UPV had a focus on the higher frequencies of glitches.

Results and Future Work

- This research provided a tool that automatically evaluates the usefulness of statistical vetoes for the purposes of the burst search.
- **Both Hveto and UPV provide different and complementary vetoes.** Hveto tends to veto glitches in lower frequencies while UPV tends to veto glitches in higher frequencies. This comparison shows that it is essential to analyze both vetoes.
- The differences in performance with respect to the burst search continue to be investigated.
- This software will be integrated into the LIGO summary webpages, where *every member of the LIGO collaboration* will be able observe and analyze the daily glitch data.

Acknowledgments

This material is based upon work supported by the Villanova Center for Research & Fellowship and NSF Grant no. 2110157. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of Villanova University or the National Science Foundation. The authors also wish to thank the LIGO Scientific Collaboration for providing access to data, computational resources, and collaboration opportunities.

Sources

[1] J. R. Smith, T. Abbott, E. Hirose, N. Leroy, D. Macleod, J. McIver, P. Saulson and P. Shawhan, "A hierarchical method for vetoing noise transients in gravitational-wave detectors," Class. Quant. Grav., vol. 28, p. 235005, 2011.

[2] T. Isogai, LIGO Scientific Collaboration and Virgo Collaboration, "Used percentage veto for LIGO and Virgo binary inspiral searches," J. Phys. Conf. Ser., vol. 243, p. 012005, 2010.

[3] D. Davis et al., "LIGO detector characterization in the second and third observing runs," Class. Quant. Grav., vol. 38, no. 13, p. 135 014, 2021.

[4] S. Kilmenko, G. Vedovato, M. Drago, F. Salemi, V. Tiwari, G. Prodi, C. Lazzaro, K. Ackley, S. Tiwari, C. Da Silva and G. Mitselmakher, "Method for detection and reconstruction of gravitational wave transients with networks of advanced detectors," PRD, vol. 93, no. 4, p. 042004, 2016.

[5] "GWpy VET," [Online]. Available: https://ldas-jobs.ligo.caltech.edu/~duncan.macleod/vet/latest/.