LIGO-GEO S4 analysis with the Waveburst-CorrPower pipeline

LIGO-T070279-00-Z

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Abstract

This document is a status report of the LIGO-GEO S4 untriggered burst analysis using the Waveburst-CorrPower pipeline as of the 3rd of October, 2006. No zero-lag coincidences have been observed for a threshold corresponding to an $h_{rss}^{50\%}$ efficiency of $6.6 \times 10^{-21} Hz^{-1/2}$ with one accidental coincidence remaining. Details of the analysis and follow-up investigations are reported.

Contents

1 Introduction

The LIGO-GEO S4 untriggered burst analysis aims to compare the performance of the "standard" Waveburst-CorrPower pipeline with that of the coherent Waveburst pipeline. A comparison of the efficiency and accidental coincidence rate for the two pipelines will be compared. This analysis will not set an upper limit should there be no zero-lag coincidences. In this document, we will only report on the details of the Waveburst-CorrPower pipeline. We begin with a brief overview of the detector performance in S4, followed by a summary of the data quality work in LIGO and

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GEO. We then describe the production of triggers by Waveburst and post-processing by CorrPower before presenting our observations on the time-shifted, accidental coincidences as well as the zero-lag coincidences.

This report is based on results and decisions summarised in a S4 e-notebook page which can be found at the following link:

`http://www.lsc-group.phys.uwm.edu/cgi-bin/bag-enote.pl?nb=burs4ligo-geo-untriggeredsearch&act`

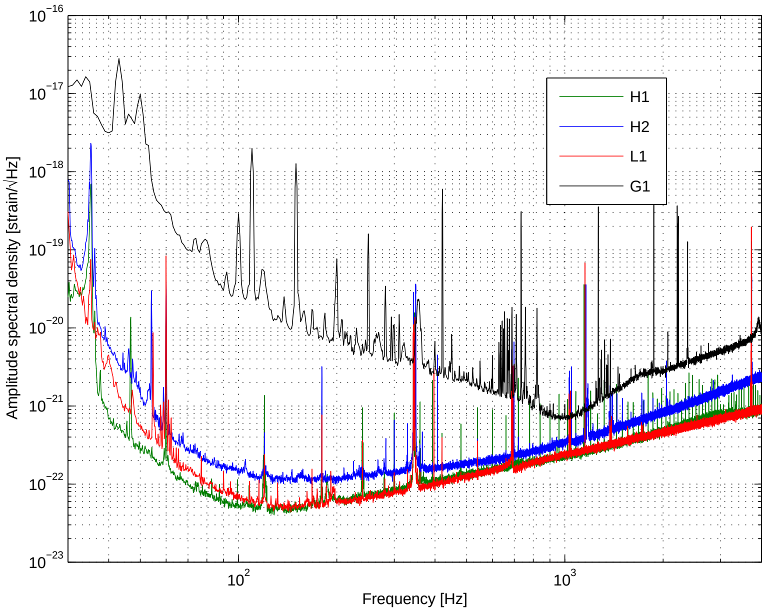

Figure 1: RMS sensitivity of all detectors in the LIGO-GEO network

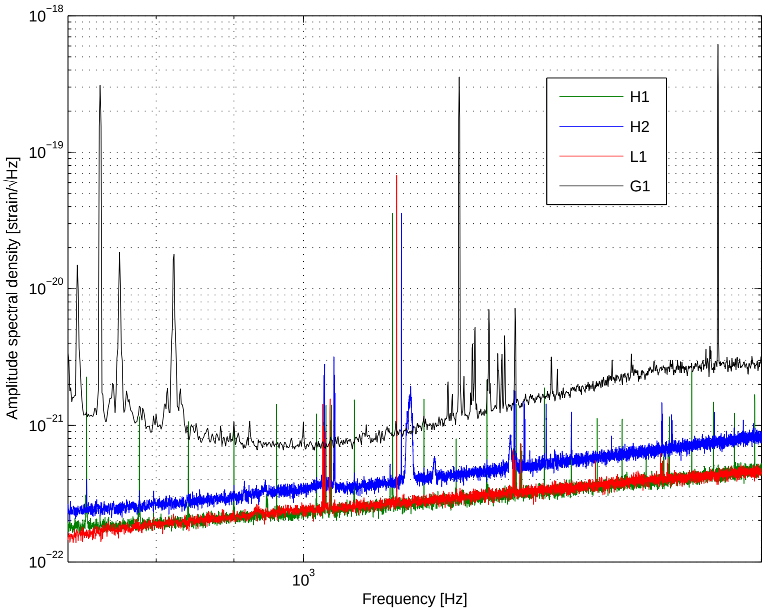

Figure 2: Sensitivity of detectors between 700 and 2000 Hz

The noise curves for the LIGO and GEO 600 detectors are shown in figure 1 with figure 2 showing the same but only for frequencies between 700 and 2000 Hz. The signal recycling detuning frequency for GEO 600 was set at 1000 Hz (but not exactly, will check) and this corresponds to the frequency where the detector's sensitivity is the greatest. Away from this frequency, we see that the noise level rises rapidly. If we look at the noise for all detectors between 700 and 2000 Hz (figure 2), GEO's sensitivity is, for the most part, about a factor of 5 away from the LIGO detectors. We, therefore, choose to analyse data in this frequency band.

The Waveburst-CorrPower pipeline processed LIGO-GEO data between 768 and 2048 Hz using Waveburst to produce quadruple coincidence triggers. Then, using the parameters of these coincident triggers, the r-statistic was calculated by the CorrPower code using LIGO data only. The r-statistic was not calculated using GEO data because of the significantly different orientation of GEO 600 with respect to the LIGO detectors. The sensitivity of this analysis pipeline was evaluted using sine-Gaussians. Conceptually, the LIGO-GEO analysis described above is very similar to that of the LIGO-only S4 analysis but with GEO 600 as an additional detector to reduce the Waveburst quadruple accidental coincidence (background) rate. The performance of this analysis pipeline will be compared to that of the coherent network analyses.

2 Data Quality

2.1 Data quality flags

The data quality flags used are the ones proposed by Alessandra di Credico for H1,H2 and L1. (table of flags)

For GEO data, the CALIB_CHISQR_V1 flag was applied. This removed 153947 seconds of GEO's livetime. Also, P and Q saturation flags were added at a later stage. They flag periods when the analogue-to-digital converters were saturated in the P or Q channels. This is most often caused by strong winds at the site. The flagged periods for the P channel accounted for a total of 11111 seconds. For the Q channel, a total of 5561 seconds.

This analysis began before there were data quality cuts available for the GEO segment list. The segment lists were obtained by performing the following steps:

1. find intersection of LIGO preETG segment list (with minimum DQ cuts) and GEO list without data quality flags;
2. get rid of segments that are shorter than 300 seconds;
3. divide the resulting segment list into segments suitable for a single condor job (between 300 and 1200 second long);
4. run waveburst with the segments from 3;
5. find intersection of LIGO postETG segment list (which takes into account more DQ cuts and vetoes) with GEO list with data quality;
6. use the list obtained in 5 to select triggers obtained in 4.

Note that the data quality flags chosen for the LIGO-only analysis since June 2005 have not been applied. (a posterior, veto-like cuts)

`http://www.ligo-la.caltech.edu/~igor/S4/p3/OUTPUT_LIGO-GEO.quadruple.2/segment.lst`

2.2 GEO data characterisation and quality studies

2.2.1 KleineWelle

Erik Katsavounidis and Lindy Blackburn ran the KleineWelle pipeline on GEO S4 data. A series of plots summarising their observations for significance thresholds of 20 and 50 can be respectively found at:

`http://lancelot.mit.edu/~kats/geo/s4_geo_thr020.html` `http://lancelot.mit.edu/~kats/geo/s4_geo_`

These triggers were used to compliment GEO data quality investigations for S4 which we will describe in the following sections.

2.2.2 Mounting Unit 3 glitches

For about the first 10 days of S4, there were long periods when the data was extremely glitchy. This problem was eventually tracked down to the suspended optical component Mounting Unit 3 (MU3) being stuck to a nearby support structures. On the 10th day, MU3 was moved to a new position and the glitch was greatly reduced.

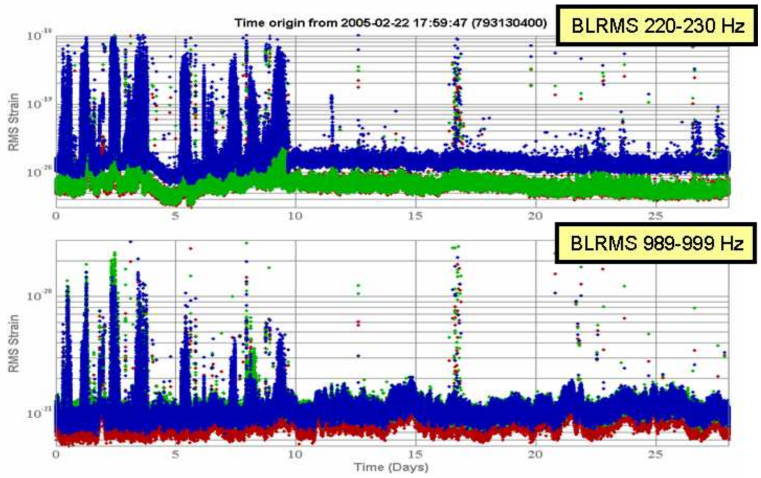

Figure 3: Bandlimited RMS noise for the entire S4. Problems with MU3 were observed on the first 10 days of the run.

The GEO data quality flag CALIB_CHISQR_V1 can flag some of these when the detector was malfunctioning. An investigation into the effectiveness of CALIB_CHISQR_V1 found that this flag was not very effective at reducing the glitch rate. Figure 4 shows the GEO glitch rate before and after the application of the CALIB_CHISQR_V1 flag for triggers with frequency between 768 and 2000 Hz. Though the glitch rate has been reduced for many periods, many periods of high glitch rate remain.

The GEO's duty cycle during this malfunctioning period was much lower than for the rest of the S4 run (76% as opposed to 98%). Given the large glitch rate and the lower duty cycle, we chose not to include the first 10 days of the S4 run into the LIGO-GEO S4 analysis.

2.2.3 One-pulse-per-second glitches

Investigations into the Waveburst time-shifted, accidental coincidence triggers (described in the next section in figures 7 and 8) found an excess number of triggers with the nanosecond field close to 0 and 0.999 seconds. Further investigations showed a periodic one-pulse-per-second glitch when the GEO data was very quiet and stationary (see figure 5). We tracked the source of the glitches to the calibration process and give an explanation below.

We have observed for some time that the spectral content of the calibration parameters is dominated by measurement noise from about 0.05 to 0.5 Hz. This means we can average these parameter estimates to reduce the measurement noise without losing information. The suspect for the 1Hz glitches was the updating of the optical response correction filters. The coefficients of these IIR filters are updated once per second based on the new estimates of the optical parameters. Now I implemented some low-pass filtering on the measurements of the calibration lines in P and Q. These measurements feed into the optical parameter estimations. The result is less measurement noise on the optical parameter estimations and less 'noise' on the filter coefficients. This has probably been the major effect in reducing the 1Hz glitches. This is equivalent to doing an averaged fft to measure the calibration lines.

The excess at the one-second boundary correspond to about 3% of the total number of accidental coincidences. This is a small effect and, after some discussion with the team, we decided not to apply this veto.

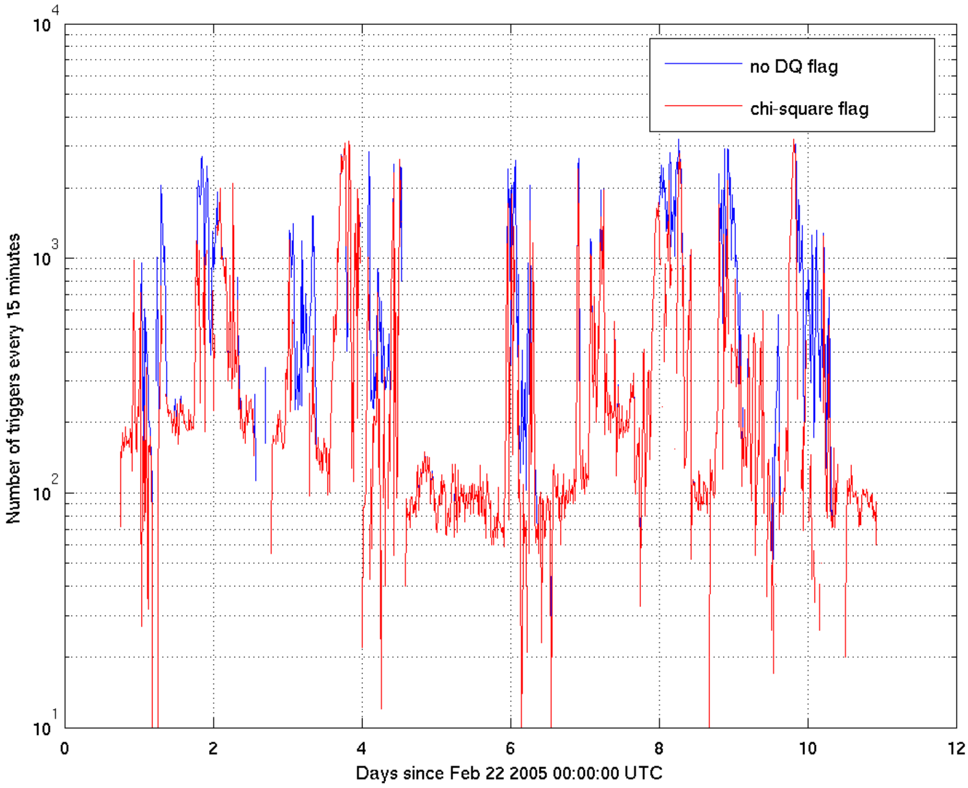

Figure 4: KleineWelle trigger rate for GEO data before and after the application of the CALIB_CHISQR_V1 for triggers with frequencies above 768 Hz

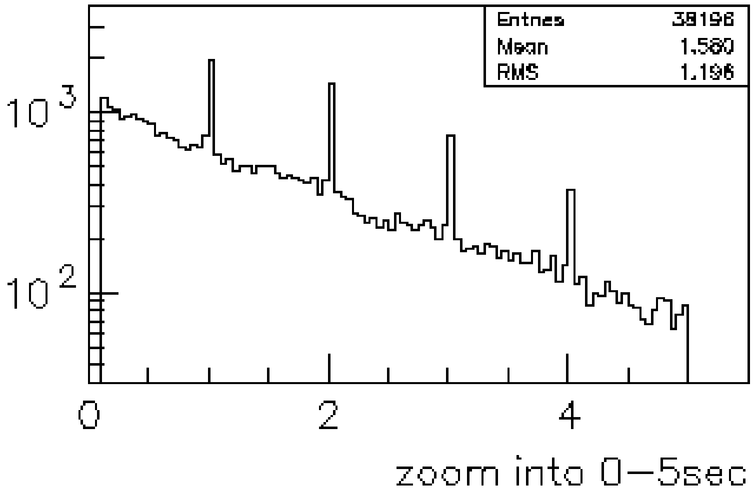

Figure 5: Time difference between successive triggers, show an excess in periodic, one-second glitches

3 Waveburst trigger production

The data from the three LIGO detectors and GEO 600 was processed using Waveburst algorithm. It processed LIGO data from DARM_ERR and GEO h(t) data. The accidental coincidence (background) rate was obtained by apply 100 time-shifts, in steps of 3.125 seconds, between -156.25 to 156.25 seconds. The zero-lag bin was excluded.

`http://www.ligo-la.caltech.edu/~igor/S4/TRIGGERS/17/index.html`

Below is a plot of the quadruple coincidence trigger rate versus Geometric Significance threshold (Geomectric Confidence, GC = exp(GS)/log(10) and Zg = exp(GS)) shown at the August 2005 LSC Meeting. The recommended threshold was GS=1.62 (GC=2.2, Z_g=5.0). This would correspond to a quadruple coincidence rate of about 10^{-5} Hz.

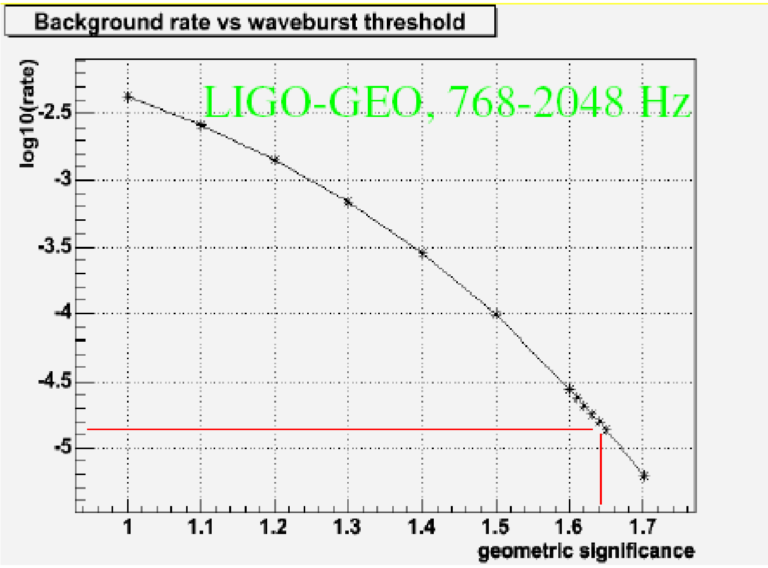

Figure 6: Waveburst Geometric Significance vs R-statistic Gamma

The GPS nanosecond field of the quadruple coincidence triggers from Waveburst was binned and plotted below. This tells us how often a trigger is observed at each point of a GPS second. For Gaussian, stationary noise, one would expect a uniform distribution. However, we can clearly see the effects of the 1 PPS if we zoom in around the 1 second border.

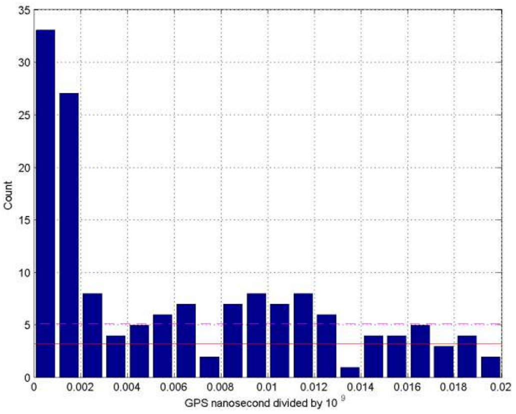

Figure 7: GPS nanosecond count near 0 second boundary

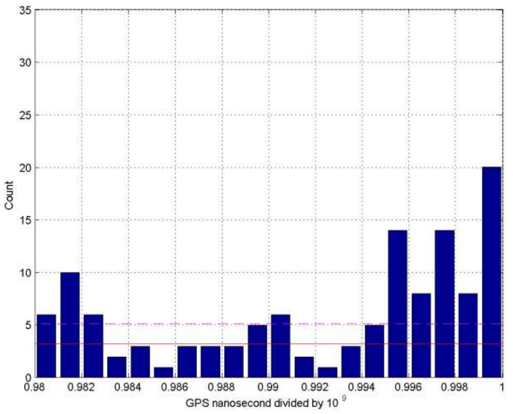

Figure 8: GPS nanosecond count near 1 second boundary

The excess triggers in the first 2 ms and last 1 ms of each GPS second and 3% of the total number of accidental coincidence.

4 MDC

The MDC data set SG21 (sine-gaussians with Q9) were injected into the LIGO-GEO data to evaluate the efficiency of the network.

For a WaveBurst Geometric Significance threshold of 1.62 (Geometric Confidence threshold of $\exp(1.62)/\log(10) = 2.19$), the $h_{rss}^{50\%}$ level for the LIGO-GEO S4 for sine-gaussians with Q=9 centered at 1053 Hz is about $6.6 \times 10^{-21} Hz^{-1/2}$

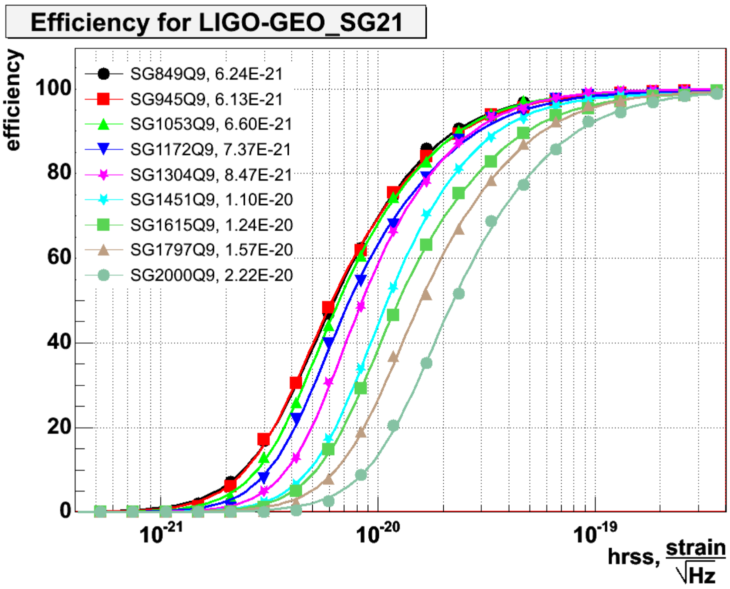

Figure 9: Efficiency as for SG21 sine gaussian injections

5 R-statistic

The R-statistic is usually applied to data acquired by the LIGO detectors only. This is because we tend to assume that these detectors are aligned and would, therefore, see the same waveform in all three LIGO detectors.

If a threshold of Gamma=3 is used, the accidental coincidence rate is 2×10^{-8} Hz. This corresponds to a probabilty of 4×10^{-2} of observing a coincidence in the zero lag bin. Thresholds of Gamma=4 or greater would yield no accidental coincidences. For Gamma=3, the $h_{rss}^{50\%}$ for 1053Hz sine guassians is at $6.6 \times 10^{-21} Hz^{-1/2}$. For Gamma=4, the corresponding $h_{rss}^{50\%}$ is $6.7 \times 10^{-21} Hz^{-1/2}$. A plot of of how $h_{rss}^{50\%}$ varies with sine gaussian frequency for a Gamma threshold of 4 can be found in figure 11.

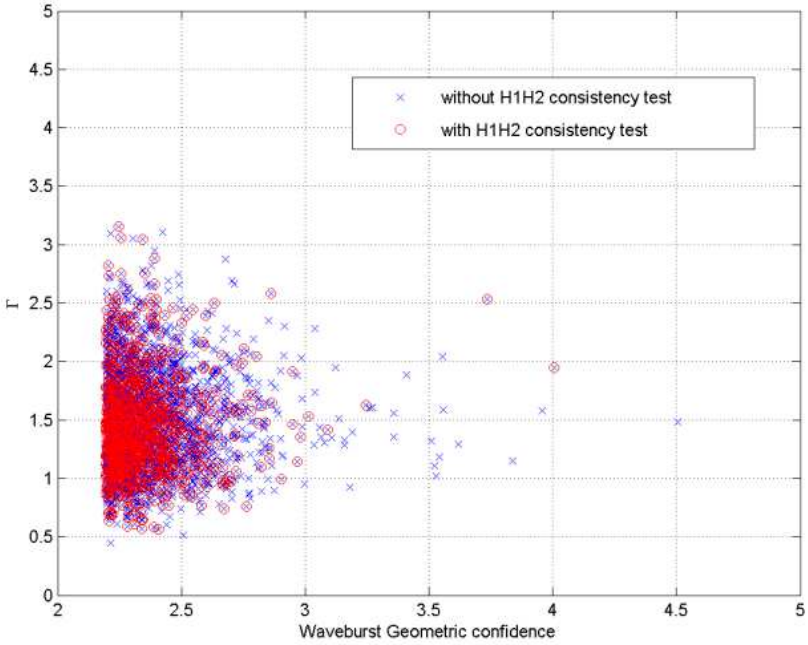

Figure 10: Waveburst GC vs R-statistic Gamma

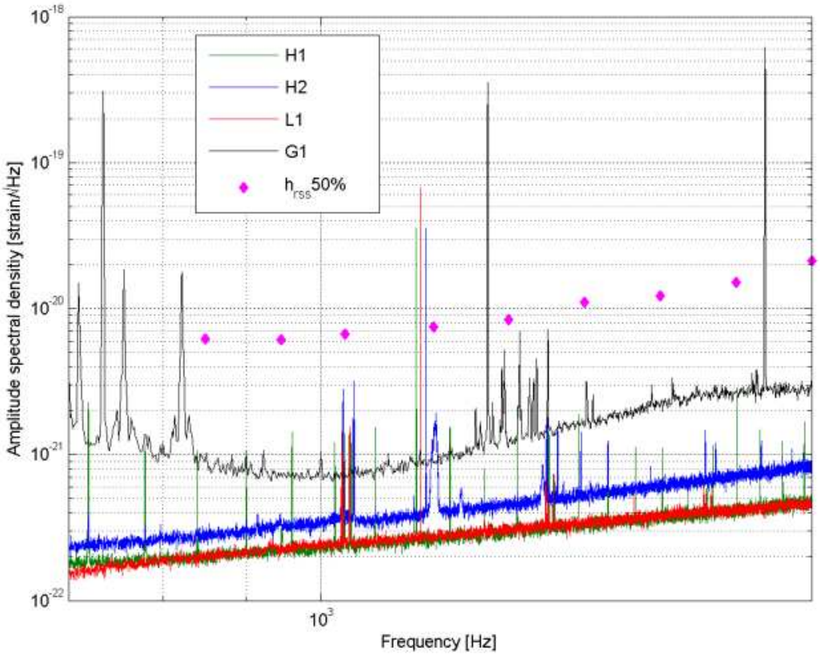

Figure 11: $h_{rss}^{50\%}$ as a function of sine gaussian frequency for a Gamma threshold of 4

6 Zero-lag observations

Given the observations on time-shifted accidental coincidences, we chose the a threshold of $Z_g > 5$ and $\Gamma > 4$. This corresponds to an efficiency of $h_{rss}^{50\%}$ of $6.7 \times 10^{-21} Hz^{-1/2}$.

The Waveburst triggers corresponding to $Z_g > 5$ which included the zero-lag bin can be found as entry 17z here:

`http://touro.ligo-la.caltech.edu/~igor/S4/TRIGGERS/index.html`

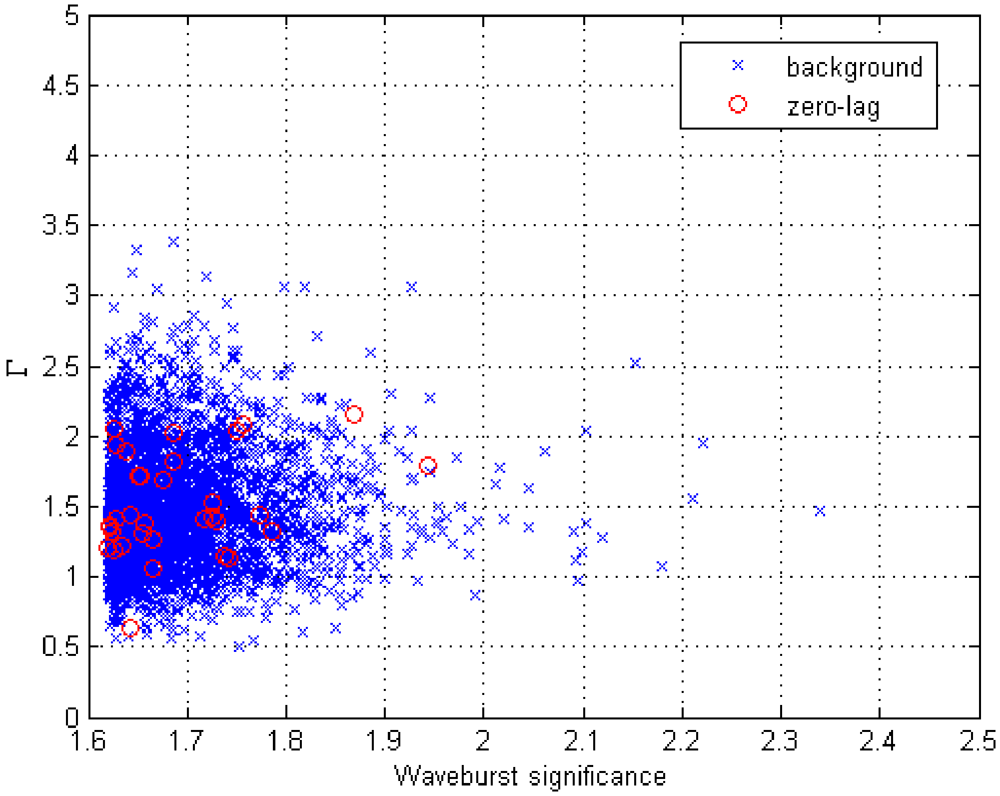

Figure 12: Waveburst GC vs R-statistic Gamma including the zero-lag triggers

Note that they include accidental coincidences with the same time-shift used for tuning the Waveburst and CorrPower thresholds. After processing the data around these triggers using CorrPower with the selected threshold, we found that no quadruple coincidence triggers in the zero-lag time bin. However, we did find that one of the accidental coincidences remained, despite having observed none before (see figure 13). This led us to perform the investigation detailed in the next section.

6.1 Last trigger standing

While the thresholds for this pipeline were being tuned, CorrPower was modified. This trigger was previously vetoed only by the R0:H1H2 cut (requiring a signal in H1 and H2 to have a positive correlation). However, with the newer version of CorrPower, this trigger now passed this cut.

We noticed that the majority of the contribution to Gamma for this particular trigger came from H2 and L1 which initially was a bit puzzling. However, this meant that the R0:H1H2 was not a good "handle" for this trigger.

Q-scans were generated for DARM_ERR data for H1, H2 and L1 as well as h(t) data for G1 around the trigger times. Nothing significant could be seen. One should note that Z_g for this particular trigger is rather small, so there is not a lot of excess power in this trigger. We eventually found that the strong correlation between H2 and L1 originated from a line at about 3700 Hz which

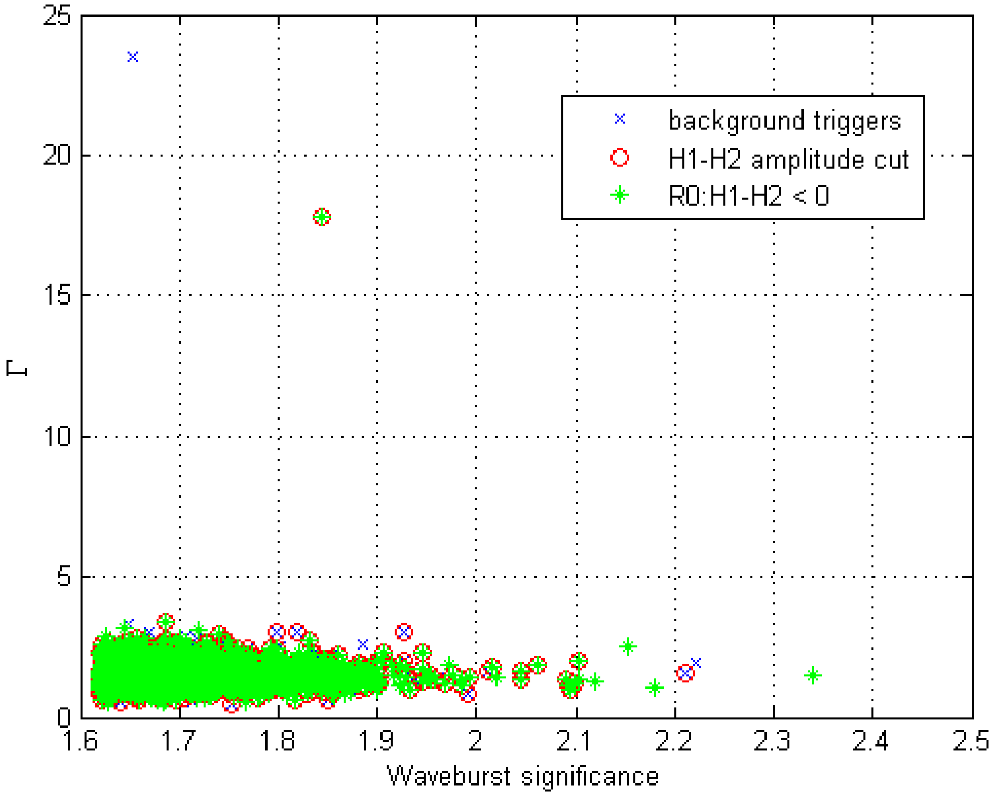

Figure 13: H1-H2 consistency cuts that veto accidental coincidence triggers

was not properly whitened by the data conditioning filters. Figure 14 plots the spectra of the H1, H2 and L1 data around the time of this trigger. It clearly shows a large peak at 3700 Hz.

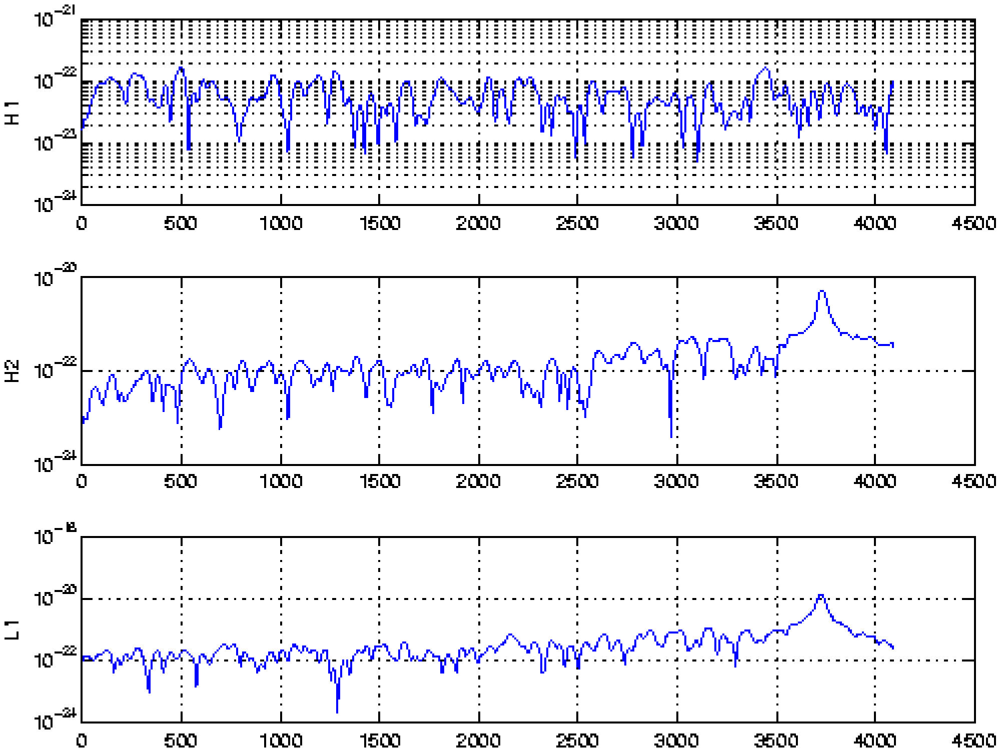

Figure 14: Whitened spectra of H1, H2 and L1 data around trigger