Data quality and detector characterization for Burst Search in Virgo data

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The Gravitational Wave (GW) burst search carried out in a single interferometer requires thorough understanding of the quality of the data. Indeed many sources of glitch events can mimic GW burst events. The C7 commissioning data taking 2005 period during which Virgo run in its final recycled configuration and the latest data acquired during WSR have been especially used for an all-sky GW burst search. A procedure to systematically identify the periods of poor quality data has been set up and the origin of the highest Signal to Noise Ratio (SNR) events have been understood.

1 Introduction

Virgo [1] is a 3-km long arm power-recycled Michelson interferometer located in Pisa, Italy. Its scientific goal is to directly detect gravitational waves emitted by cataclysmic astrophysical events such as supernovae or coalescence of binary systems. One of the difficulties of the burst search is the high false alarm rate when looking for low Signal to Noise Ratio (SNR) events and the numerous sources of transient events which are detected by the GW burst pipelines. In an individual detector search we cannot eliminate the fake events performing coincidence analysis with another detector's output. It is then mandatory to identify fake event sources, due to the interferometer poor performance or environmental disturbance.

2 The Data Set

The study is focused on four data sets. The first one is the C7 run, 5 days of data taking in September 2005 before the long shutdown which took place for the Input Bench replacement. Since September 2006, regular (typically every month) data taking named Week-end Science Run (WSR) have been organized, lasting 56 hours from Friday evening to Monday morning. Nine WSR took place and in depth investigations have been performed only on three of them: WSR 1 (September 2006), 7 (January 2007), 8 (February 2007) and 9 (February 2007). Figure 1 presents the various sensitivities obtained during these runs. The best achieved sensitivity is about few $10^{-22}/\sqrt{Hz}$ in the 100 Hz-1kHz region.

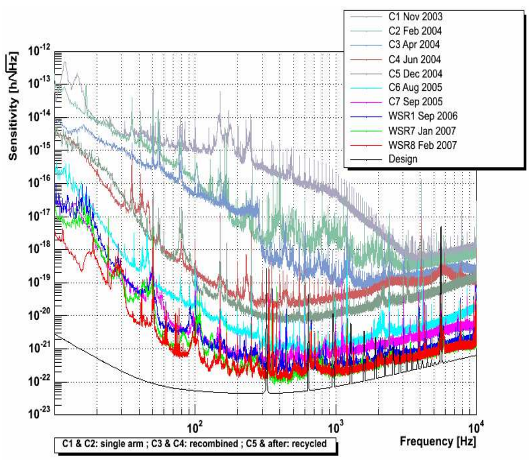

Figure 1: The Virgo sensitivity for the various data sets

3 The Data Quality Flags

Interferometer data like any other detector data exhibits unforeseen noise events which can spoil any analysis. In particular, for burst searches, as there is no strong theoretical predictions for the waveforms, lots of noise sources can mimic the effect of a gravitational wave. Anyway, all noise sources do not have the same impact on the analysis pipeline. Two main categories can be defined. For DQ Category 1, the period must be remove before running the pipeline as it can spoil all the results even far from this period. This category redefines the data segment which are independently analyzed. For the second category, the period can be excluded after the analysis. Most of the time, it corresponds to periods of "obvious" malfunctioning of the detector or presence of "obvious" external noise sources. By now, for the first category, only three DQ1 flags have been defined:

1. End Of Lock: last seconds of data before the loss of mirror control. This period is characterized by strong oscillations leading the loss of lock. The last 10 seconds are flagged.

2. Calibration: for calibration purposes, some white noise is injected on the mirror leading to a dramatic increase of the dark fringe noise. The 5 minutes following the noise injection are also removed as the injection excites some resonances.

3. Lines: after a relock, it appears that the violin mode of the mirror suspension wires are excited. The height of the 338 Hz (main resonance) line is monitored with a band RMS and the period is flagged till the value is greater than 10% of the maximal value

Three subclasses of DQ2 flags can be defined:

1. Technical problem in the gravitational wave channel (h) reconstruction: it appears when the permanent calibration lines are too weak to insure a good computation of h. The flag is provided by the reconstruction itself.

2. Events which can be flagged by an external channel such as a seismometer for example. Airplanes are a typical example of such kind of events as shown on Figure 2.

3. Events which involves the optical behavior of the interferometer such as control signals: saturation of coil drivers or photodiodes, problem of the laser frequency stabilization (signal in the control loop above a given threshold)

While DQ flags lead to a significant reduction of the duty cycle for the C7 run (from 64.5 % to 57.4 %), their impact becomes negligible in the WSR runs.

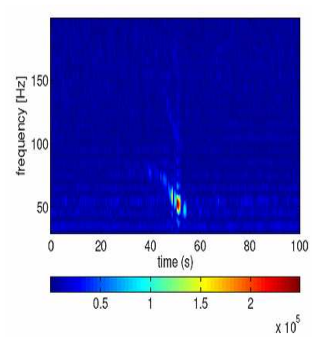

Figure 2: Airplane seen by a seismometer. The plot shows the time-frequency map of a seismometer output.

4 Event-by-Event vetoes

Once the DQ flags are applied, we try to understand the cause of the loudest events and when possible define a veto. Three main sub classes of vetoes can be defined:

- external source (seismic activity, acoustic noise) clearly related to the dark fringe event
- control loop signals (not involved in the dark fringe control) exhibits strange behavior leading to dark fringe events. The propagation mechanism is supposed to be understood.
- the dark fringe event appears in correlation with events in the other optical signals (DC or other AC signals) but the fundamental origin is not clearly understood. In this case, the hardware injections are very important in order to evaluate the safety of the vetoes.

In all cases, the efficiency (fraction of dark fringe events suppressed by the veto), the dead time (fraction of science time suppressed by the veto), the use percentage (fraction of veto events in coincidence with a dark fringe event) have to be evaluated. Of course, as first check, the coincidence rate has to be compared to the accidental rate (fraction of false associations) and should be significantly higher. A "good" veto should have a high use percentage and a low dead time. A high efficiency for the highest SNR is very interesting.

WSR1 event distribution is dominated by similar events characterized by a strong oscillation of the control signals (see Figure 3). This kind of events is easily vetoed using any optical channel. It appears that these events are present at a smaller rate in C7. Some correlations with extreme values of the angular degrees of freedom have been observed. The analysis of the height of the sidebands seems to indicate that the events are related to the disappearance of one sideband, leading to spikes in the control loops. The problem seems to have disappeared since a tighter alignment has been implemented and a better balance between sidebands has been achieved.

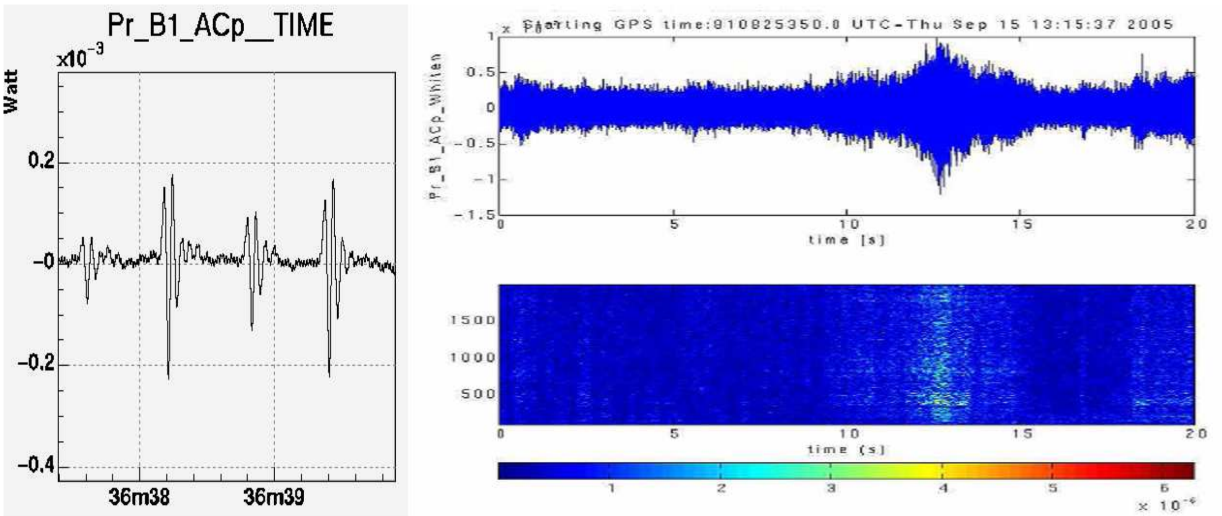

Figure 3: The left plot shows an example of control problems. The right plots present a typical " BoB" event (top: whiten h time series, bottom: time-frequency map)) .

During C7, the events are not uniformly distributed in time but appear by bunch lasting few seconds (see Figure 3). The spectrogram shows that the events are broadband contrary to most of events caused by external disturbance. This broadband spectral signature gave hints to identify the BoBs as local increases of the noise level due to an increase of the coupling factor between the frequency noise (which is dominant at high frequency for C7 and the dark fringe. Two possible vetoes have been set up. The first one is based on a quadratic combination of all angles while the second one directly uses the height in the dark fringe channel of a line injected at the laser level. Both vetoes gives similar results. It should be noticed that this kind of events are present at all SNR values and cannot be isolated.

5 Conclusion

The 4 best sets of Virgo data has been deeply investigated in order to identify the noise sources which can mimic the effect of a gravitational wave. Several categories have been defined accordingly to their impact on the analysis and data quality flags are now routinely produced for each new run. At the level of event-by-event vetoes, several noise sources have been identified and most of the time, the physical mechanism has been understood. This detector characterization effort allows a better understanding of the detector and provides to the Burst group the means for performing upper limit estimations [2].

References

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2. M.-A.Bizouard (for the Virgo Collaboration), these proceedings