# Tools for noise characterization in Virgo



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**Abstract.** Several software tools were used to perform on-line and off-line noise analysis as a support to commissioning activities, to monitor the rate of glitches, the occurrence of non stationary noise, the presence of environmental contamination, the behavior of narrow spectral features and the coherence with auxiliary channels. We report about the use of these tools to study the main sources of identified noise: broadband, spectral lines and glitches. Plans for the upgrade of the tools will be presented, for example for lines identification purpose to let the scientists in control room do noise characterization in an easier way.

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## 1. Introduction

Several software tools were set up for the understanding and following up of the noise behavior for the Virgo gravitational-waves detector [?] and the results are reported on web pages. The goal is to have user-friendly tools to let the commissioning and data analysts easily characterize the data.

We want to have information on stationarity and gaussianity of the data, identify the spectral lines and characterize the transient noises. The idea was to have tools which, looking either at on-line or off-line data, produce results and plots which could be archived in files or MySQL database. We monitor

- the presence of transient noise in the data using different transient signal detection algorithms;
- the stationarity estimating the rms in frequency bands and spectrograms;
- the coherence of the gravitational wave channels and auxiliary channels to understand the source of spectral lines;
- the presence of continuous signals which appear as spectral peaks or lines in the frequency domain, trying to follow the temporal behavior of wandering lines.

## 2. Transient noise signals

Signals which last for a very short period of time are referred to as transient signals. The monitoring of transient noise signals is fundamental for the characterization of the data, since the gravitational waves signal produced by a supernovae explosion or a coalescing binaries event is a transient signal and we need to disentangle noise events by genuine Gravitational Waves (GW) signals. We need to understand how the transient noise can spoil the data and the path it follows to enter in the GW channel. For this reason we monitored these events in the GW channel and in a large set of auxiliary and environmental channels.

Event Trigger Generator (ETG) tools were used to produce lists of triggers for noise events. Two of them, WDF (Wavelet Detection Filter) [?] and VirgoHACR [?], produce triggers which are sent to a MySQL database, while Omega-pipeline [?] and OutlierMoni [?] write triggers in ASCII files on disk. We report in figure ?? an example of the plots which could be seen on the web. Moreover we produced summary pages for the last 1 hour, 8 hours and 24 hours, where we report frequency-time plots for the triggers and glitch rate values. The most energetic events are followed up in the GW channel and auxiliary channel in order to understand the origin of the event. The Omega-Scan [?] tool scans in the time-frequency domain a set of auxiliary and environmental channels and a report is automatically produced on the web.

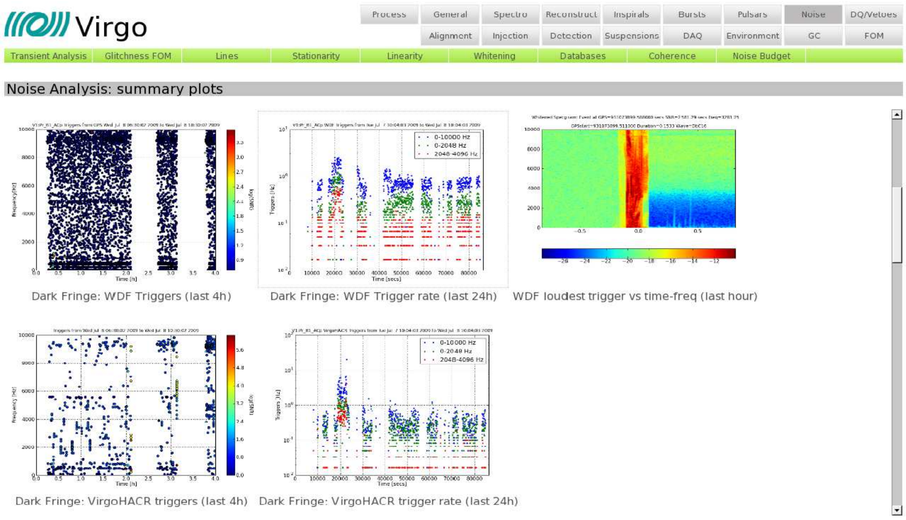


**Figure 1.** Example of monitor web pages: transient events detection, glitch rates and follow up of most energetic events

## 3. Slow non stationary noise

A tool was developed to run on-line in the Virgo environment (NonStatMoni) [?] to monitor how the noise is modulated in time. It can compute the root mean square (RMS) in several frequency bands, with different spectral resolutions for different channels.

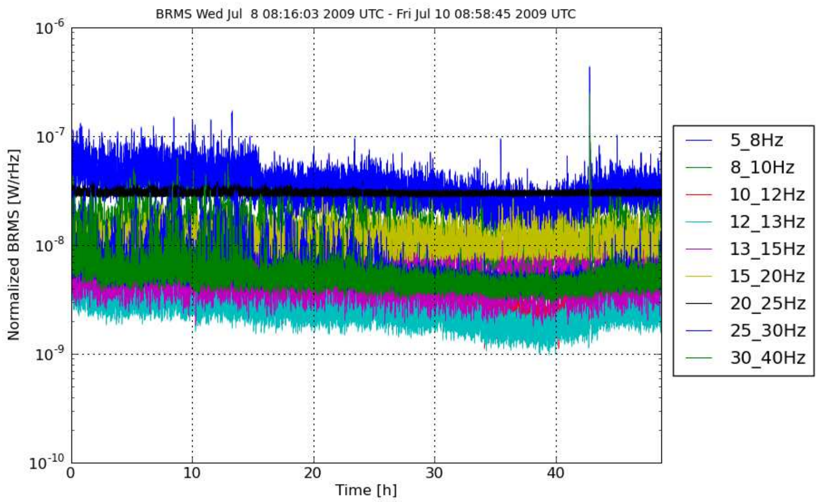


**Figure 2.** Example of monitors: Band-limited RMS in different frequency bands. Here is plotted the BMRS for uncalibrated GW channel. The low frequency part of the detector sensitivity band is limited by seismic noise. In this plot it is evident that in the first 10 hours there is higher noise in the low frequency band. This is due to excess of seismic noise.

Figure ?? shows an example of the plots produced for the low frequency band [?].

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In the plot reported, there was an excess of seismic noise in the first 10 hours; this was evident as higher values of Bandlimided Root Mean Square (BMRS) in the low frequency bands. The excess of seismic noise causes up-conversion via scattering of diffused light on the optical benches [**?**].

## 4. Lines identification

We refer to continuous wave signal as the signals which have constant frequency and infinite time duration. To identify continuous wave signals in the GW channel, an algorithm has been developed to separate the contribution due to the broad band noise from the one due to narrow lines (LineMonitor) [**?**]. The algorithm works in two main steps: first it estimates the noise floor and afterward it searches for lines and estimates their parameters. Therefore it allows one to track separately the evolution in time of the power in lines and in the bulk of the noise spectrum. It is used in the on-line LineMonitor process for high resolution search for lines in the dark fringe spectrum.

In addition, we are developing a framework for the identification of the lines which makes use of some of the tools developed and used by the Continuous Waves (CW) search group [**?**]. The CW code (written in C) has been adapted in order to run as an "event finder" in either the calibrated GW channel data or uncalibrated GW channel and the set of auxiliary channels. The analysis procedure goes as follows:

- program looks for transient events in the time domain, which would affect the subsequent analysis in the frequency domain.
- time domain events are removed from the data, thus obtaining a "cleaned" data set (for the details see ref. [**?**]);
- program estimates the average spectrum, by means of an auto-regressive (AR) technique [**?**];
- From the average AR spectrum the events in the frequency domain higher than a given threshold are identified;
- Besides, the removed time and frequency domain events, together with their main parameters are archived in an ASCII file and could be analyzed for transient signal detection goals.

Some preliminary scripts have been run to read and analyze the daily data, produce time-frequency and persistency plots and publish them on a web page [**?**] or to load results in a MySQL database. Once the data are in the MySQL database, they can be retrieved by means of the APIs available for various platforms and operative systems.

Figure **??** presents two example plots obtained with the data analyzed by the event finder and retrieved from the database. The plots show the time-frequency diagrams of the calibrated GW channel data (left) and of an auxiliary channel (Em_SETODE01, right, which is a seismic sensor on the vacuum chamber containing the bench where the photo-diodes for the GW signal detections are).

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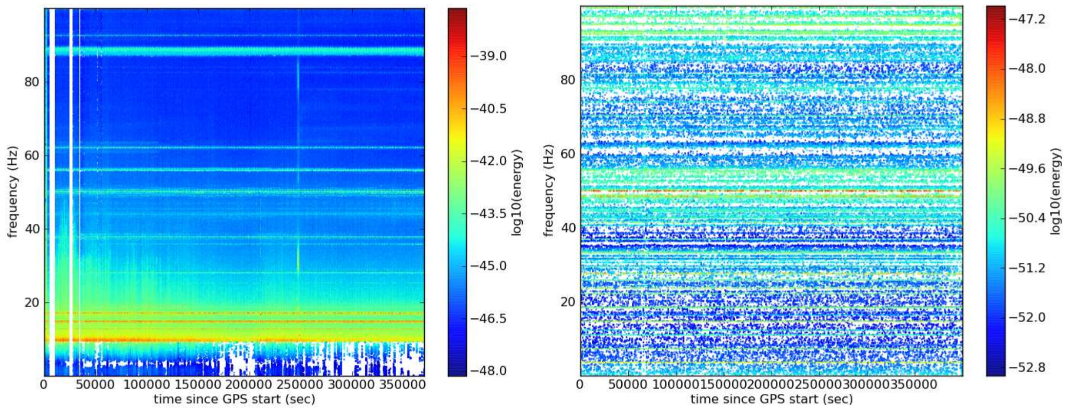


**Figure 3.** Time-frequency diagrams of the calibrated GW channel data (left) and of one seismic auxiliary channel (right). The color scale is based on the logarithm of energy of the frequency event.

## 5. Coherence

To understand the source of lines which enter in the GW channel, we automatically compute coherence between the dark fringe and all existing channels (about 1000), averaged over 15 minutes of data in about 1 h.

It run periodically (three times per hour) to always give updated results, which are summarized in a web page [?]. It produces links to coherence plots of all analyzed channels (see figure ??) and a list of the 10 most coherent channels for each frequency bin (see figure ??). We plan to archive such results in a MySQL database in order to

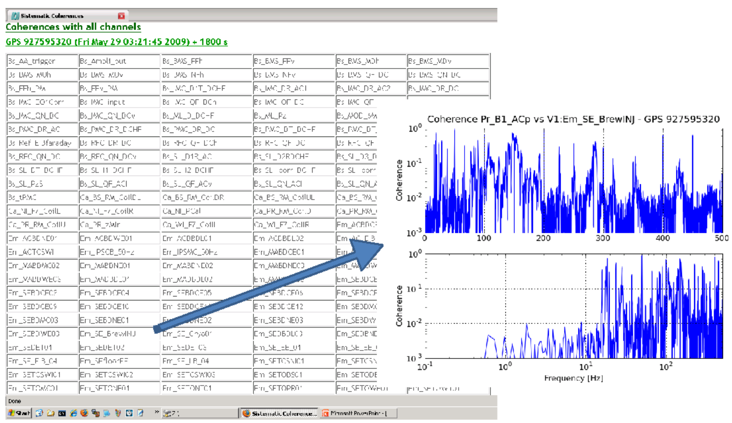


**Figure 4.** Table of coherence between GW channel and auxiliary channels

retrieve the information on user demand using simple web interfaces.

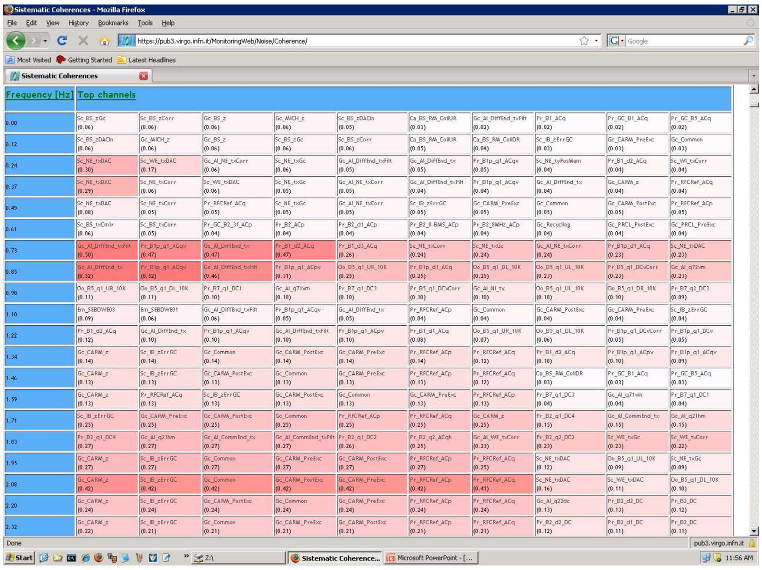


**Figure 5.** The most coherent channel organized by frequency bin.

## 6. Conclusions

We set up monitoring tools to characterize data and produce in-time results useful for data analysis and commissioning teams. The framework is still not complete. For example, we need to set up tools for the understanding and detection of non linear noise. We worked in the last months to set up of a new line monitoring tools which could work also on auxiliary channels, with the aim to have automatically the lines which are common to the calibrated GW channel and auxiliary ones. The ultimate goal is to follow the wandering lines using cross correlation between the GW channel and noise monitor channels.

Moreover we are working on a web interface for the noise data base which could let the users query easily the archived information, produce plots or launch scripts to follow up of the events or coherence.

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