Noise and signal reconstruction and characterization in the AURIGA detector

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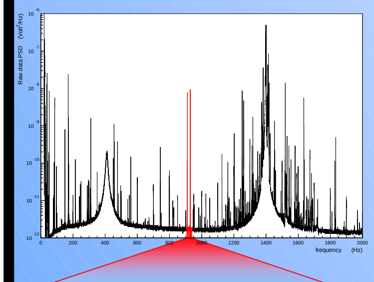
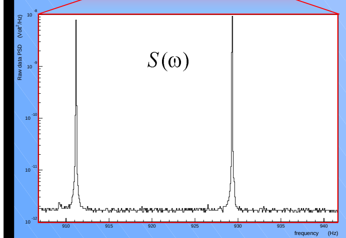
① The experimentally measured power spectrum density (PSD) of the noise is closely fitted by assuming a model of two coupled harmonic oscillators (the bar and the transducer) plus the amplifier wide band electronic noise:

$$S(\omega) = S_0 \prod_{k=1}^{2} \frac{(i\omega - q_k)(i\omega + q_k^*)(i\omega - q_k^*)(i\omega + q_k)}{(i\omega - p_k)(i\omega + p_k^*)(i\omega - p_k^*)(i\omega + p_k)}$$

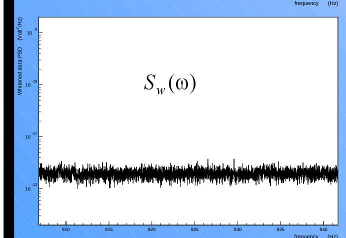




①

② We know that we have found the right parameters if we succeed in building the *whitening filter* for this model:

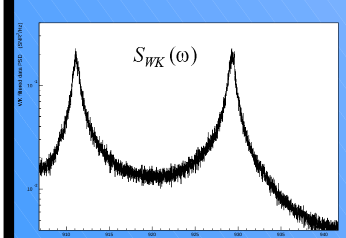
$$L(\omega) = \prod_{k=1}^{2} \frac{(i\omega - p_k)(i\omega - p_k^*)}{(i\omega - q_k)(i\omega - q_k^*)}$$



②

③ The last part of Wiener-Kolgomorov (WK) filter matched to a δ-like event –*the mask* $M(\omega)$– involves no new parameter:

$$M(\omega) = S_0^{-1} \prod_{k=1}^{2} \frac{i\omega}{(i\omega + q_k)(i\omega + q_k^*)}$$



③

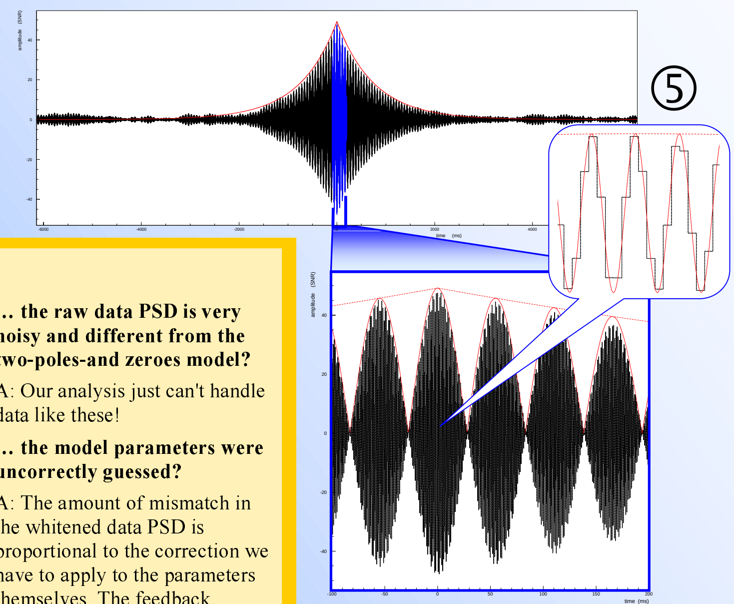
④ Effective noise temperature (T_{eff}) is adaptively estimated from the Root Mean Square (RMS) of the WK filter output, assuming the low amplitude part of the filtered data histogram follows a normal distribution.

⑤ A candidate (δ-like) event is a pattern in the WK filtered output with a specific mix of an exponential decay ($\tau \equiv -\max\{\mathrm{Re}(q_k)\}$) a beat modulation ($\omega_* \equiv \frac{1}{2}(\mathrm{Im}(q_2) - \mathrm{Im}(q_1))$) and a carreer wave ($\omega_0 \equiv \frac{1}{2}(\mathrm{Im}(q_2) + \mathrm{Im}(q_1))$):

$$f_{WK}(t) \approx A e^{-\frac{t}{\tau}} \cdot \cos(\omega_* t)\cos(\omega_0 t)$$

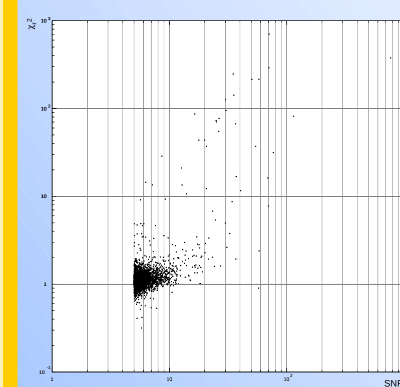
We locate precisely its maximum by interpolation, and wait at least 3 decay times before accepting a new event.

⑥ WK filtering is a maximum-likelihood fit based on models for both the noise and the signal, so passing a χ^2 test is a necessary and sufficient condition for time-of-arrival and amplitude determination to make sense. Fast electromagnetic pulses and gravitational wave burst are dramatically different when looked with χ^2-glasses. And things are getting better with higher Signal-to-Noise-Ratio (SNR).

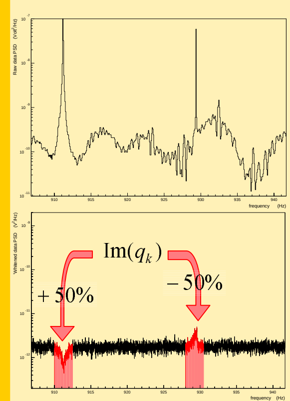


⑤

⑥



What if ...



... the raw data PSD is very noisy and different from the two-poles-and zeroes model?

A: Our analysis just can't handle data like these!

... the model parameters were uncorrectly guessed?

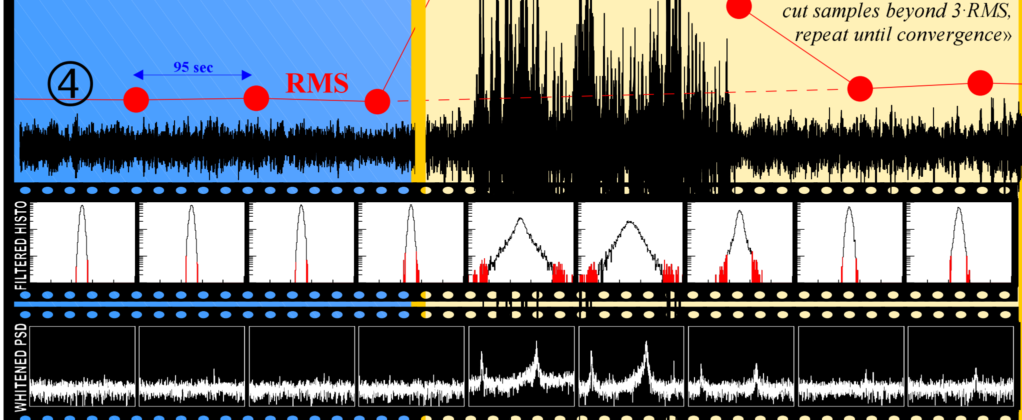
A: The amount of mismatch in the whitened data PSD is proportional to the correction we have to apply to the parameters themselves. The feedback algorithm converges in a few hours.

... a big short-lived excitation enters the system?

A: A signal whatever –either GW or spurious– spoils both the whitened noise PSD estimate and the histogram of WK filtered data. We quantify the latter effect by using a Chauvenet convergence algorithm, which is both a cleaning procedure and a validation criterion:

«compute the Root Mean Square, cut samples beyond 3·RMS, repeat until convergence»

④



NOTES: V^2/Hz units in ① and ② are relative to what measured at the ADC input. At ②, the same hour of data was filtered with the correct whitening filter (*right*) and with a mismatch of ±50% in parameters $\mathrm{Re}(q_1)$ and $\mathrm{Re}(q_2)$ (*left*). The black stream across the poster represents 1300 sec of WK filtered data drawn with a linear vertical scale. The red dots represent the sincronous RMS, but it is drawn with a smaller scale to be graphically enhanced. The dashed line point out the fact that T_{eff} is not computed from RMS if the presence of signal is detected. Each frame in the upper film-strip represent the histogram of 109 sec of the same filtered data set; the red tails exceed 3 times RMS. In the lower frames are represented the corresponding whitened data PSD, in the same scale as at ②. In ⑤ the signal is a hardware calibration pulse to the bar. In ⑥ a entire month of AURIGA events are plotted.

WHEN WE CAN MODEL THE NOISE…

…THEN WE LOOK FOR MODELLED SIGNALS