IGEC toolbox for coincidence search

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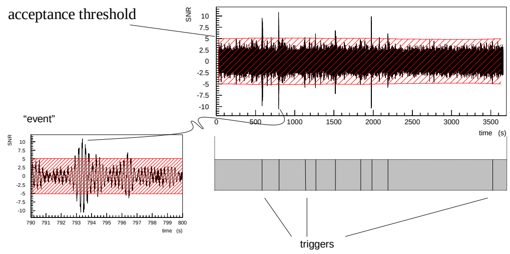
The standard IGEC approach to detection of gw with many detectors is simple time coincidence search. We issue the problems of false alarm and false dismissal assessment, particularly in the case of non-stationary background noise. The observation results are based on Maximum Likelihood Methods (MLM).

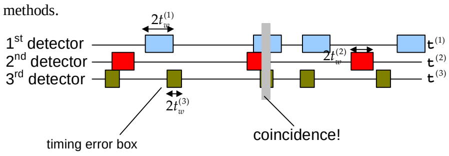
Triggers, coincidences and time windows

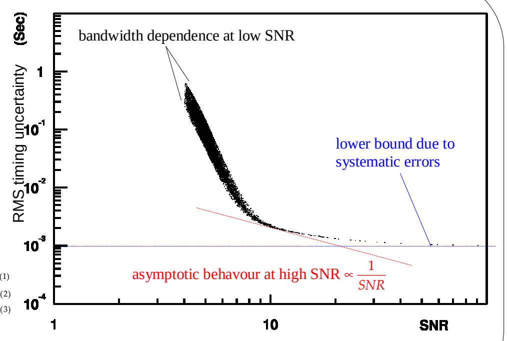
The basic ingredients of the gw search recipe of IGEC are the self-consistent "event files", which are temporally ordered records of every *trigger* (or *event*) selected by each group of the collaboration as candidate gw signals. Bundled in the same files, there are asynchronous information about the timing and amplitude precision and accuracy, and the values of the amplitude selection threshold used



The sequence of events can be described by a (possibly non-homogeneous) Poisson point series, which means *rare* and *independent* triggers. A coincidence is defined as a multiple detection on many detectors of triggers with estimated time of arrival (ETA) such that when there is a common overlap between their *time windows*.

Time windows are proportional to the timing uncertainty of the detector, and may be therefore be different for different detectors. They are obtained from the timing error distribution once a minimum confidence level (or a maximum false dismissal probability) has been fixed. This distribution is a non-analytical function depending on the implementation of trigger search, and is determined by Monte Carlo methods.





False alarms estimates

If the spurious triggers are modelled as a homogeneous Poisson point processes, and being $\lambda^{(k)}$ and $t_w^{(k)}$ respectively the background rate and (fixed) time window of the kth (over M) detectors, the expected false alarm rate is given by →

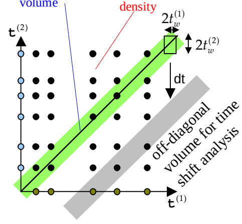
$$\lambda_b = \sum_{k=1}^{M} \prod_{h\neq k} 2t_w^{(h)} \times \prod_{i=1}^{M} \lambda^{(k)}$$

section volume of coincidence volume; M-dim n-tuple density

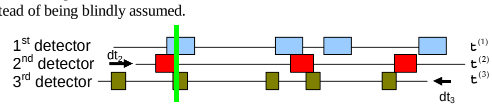
This formula holds also as *instantaneous* rate predictor, when the background is non-stationary, and as linear operations (like integrals) on Poisson RV give as a result a Poisson RV, this leads to

$$\lambda_b(t) = \sum_{k=1}^{M}\prod_{h\neq k} 2t_w^{(h)} \times \prod_{i=1}^{M} \lambda^{(k)}(t) \quad \Leftrightarrow \quad \bar{\lambda}_b = \sum_{k=1}^{M}\prod_{h\neq k} 2t_w^{(h)} \times \int_{t=0}^{T} dt \prod_{i=1}^{M} \lambda^{(k)}(t)$$

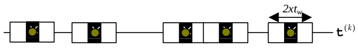
In practical use of this result, the observation time is divided in smaller time intervals where the background process can be considered stationary, but wide enough to collect statistics on the detector noise parameters.



A time-shift search strategy to estimate false alarms allows for the definition of a variable coincidence window from trigger to trigger. It happens to be a function of the signal-to-noise-ratio (SNR) of the signal and of the bandwidth of the maximum SNR filter (which influences the timing accuracy). The time shift analysis keeps care naturally of the non-homogeneous character of the trigger rate, at least up to an amount of time shift of the same order of magnitude as the smallest-scale time structure in the data. By repeated independent time shifts, the Poisson statistics of the coincidence counts can be directly tested, instead of being blindly assumed.



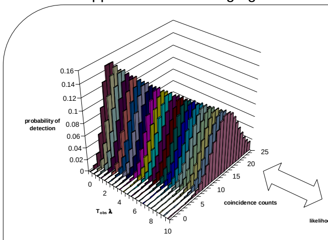
When a homogeneous blow up of all time windows of a factor x is applied, the number of false alarms is increased proportionally to its width x^{M-1}. This fact can be deployed as a complementary technique to gain statistics in the shifts method when coincidence probability is very small. It serves also as an alternative estimator by interpolating coincidence counts down to smaller time window scales. Gw signals possibly present in the data can be skipped by opening a "hole" in the coincidence interval, with aperture t_w.



$$\bar{n}_c(x) \propto \left[\frac{2t_w(1-x)}{T_{obs}}\right]^{M-1}$$

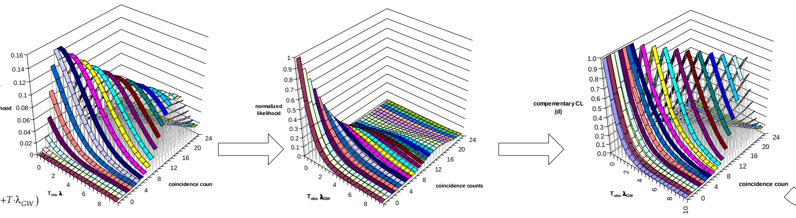
Upper limits on average gw burst rate

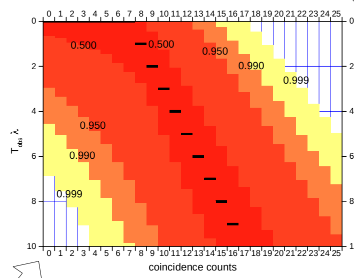
When predicted and found coincidences have been determined, a decision has to be made at last about the presence among the latter of gw signals. In the usual frequentist approach, a straightforward result in terms of confidence intervals is obtained by MLM, in the case of Poisson RV.



likelihood function:

$$\ell(T\cdot\lambda_{GW}; N_c, \bar{\mathbf{N}}_b) \propto$$
$$\propto \frac{1}{n!}\left(\mathbf{N}_b + T\cdot\lambda_{GW}\right)^n e^{-(\mathbf{N}_b + T\cdot\lambda_{GW})}$$





background false alarms
$\bar{\mathbf{N}}_b = 7.0$ in this example

Upper limits on external triggers

Instead of acting as signal alarm observatory, the IGEC can also set upper limits on the gw burst flux on earth during a particular time interval of interest (e.g. close to a Gamma Ray Burst signal). It is often the case that the exact delay between the external trigger and the gw radiation emission is unknown, and a large confidence neighbourhood is allowed. If no event is present in the trigger neighbourhood, the conservative upper limit is based on the maximum within the interval of the minimum detection threshold reached by any detector working simultaneously.

When events are present, within the range of observation of both detectors, and they are not coincident with any event in the other detector, then they are not considered. In the case they are in coincidence, or they are not in the range of the other detector, they raise locally the upper limit previously set solely by the thresholds.