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Search Method for Quasi-Monochromatic Gravitational Wave Signals in the Time-Frequency Space

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Overview

According to theoretical predictions, monochromatic and quasi-monochromatic gravitational wave (GW) signals are expected to be detectable by interferometric detectors. They can be produced by rotating non-axisymmetric massive objects, e.g. neutron-star pulsars or ringdown remnants of collapsing binaries. Some models of long gamma ray bursts [1] also predict quasi-monochromatic GW signals of limited duration emitted during the gamma ray burst event. We have developed two general methods to search for quasi-monochromatic GW signals in datastreams of GW detectors [2].

Input

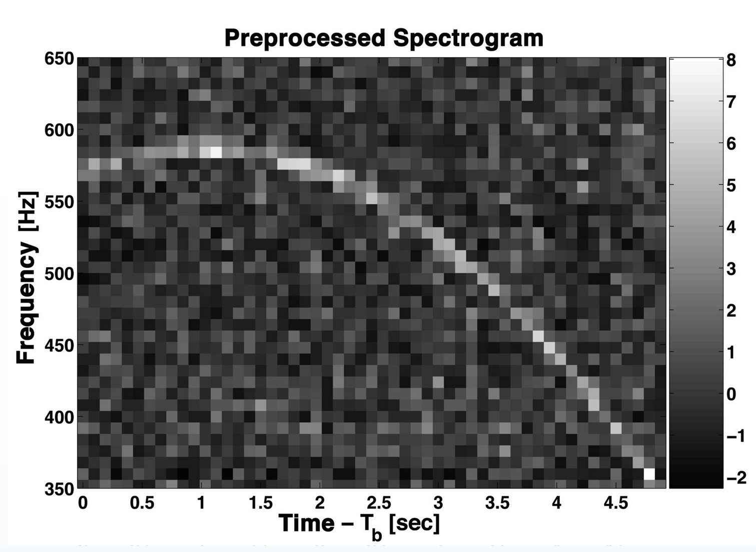
A search process is applied on finite-sized, overlapping samples of the time-amplitude datastream. Data is the result of amplitude contributions of noise and injected signal events. Tests are carried out for simulated (Gaussian) noise, as well as for modified LIGO H1 noise.

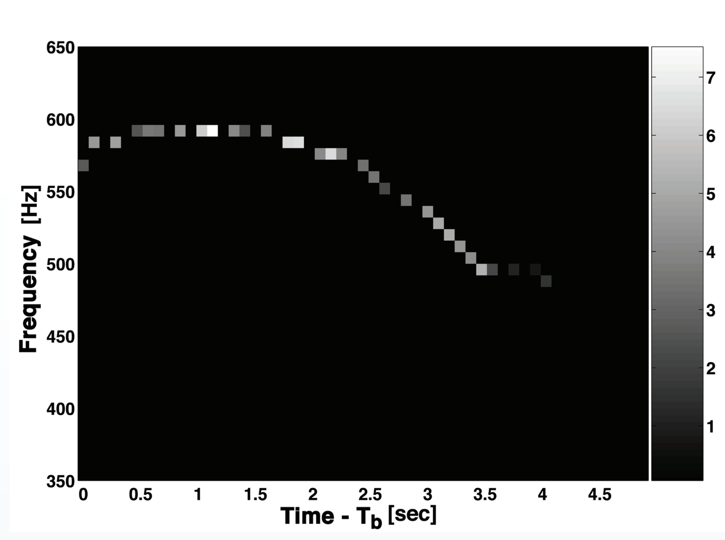
Preprocess

As a pre-process of input data, filtering in time domain (Butterworth bandpass filter), a discrete Fourier transform, and flattening of the spectrum (consisting of normalizing rows with mean and sigma of an assumed gamma distribution) are carried out.

Algorithms

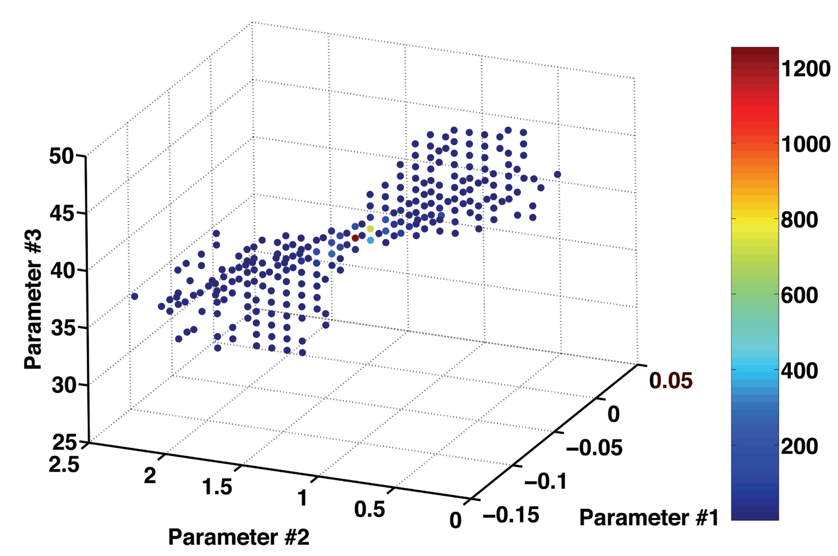
Quasi-periodic signals cause traces of local maxima to appear in the pre-processed spectrum (see below, left). Two image processing methods - "Locust" and "Hough" algorithms - were developed to identify traces of local maxima in the grayscale image of the noisy matrix.

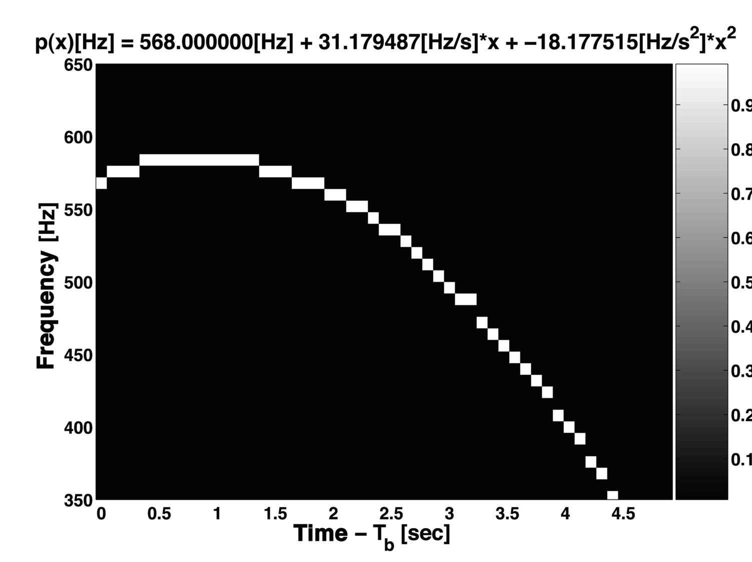




The *Locust* algorithm splits the matrix to traces of local maxima through wandering, starting with the first column. Choosing a non-zero starting point, the method looks for the local maximum in the 2D environment of an element, heading forward in time. Tracking a trace continues until a side of the matrix is reached. Output of the *Locust* process is parameterized by a threshold: our program gives an alarm if any of the traces have an (integral / element number) ratio higher than a predefined value. A trace accomplishing this criterion is visualized above right.

Alternatively, the search process can be based on a *Hough* transform of matrix data. Assuming that the frequency change with time can be described by a polynomial of order *D-1*, parameters of the fit to each combination of *D* non-zero elements of the matrix results in a point in the binned parameter space (below left). An alarm is considered if the number of points in any of the bins exceeds a given threshold. An identified trace with a high alarm signal is shown below right.

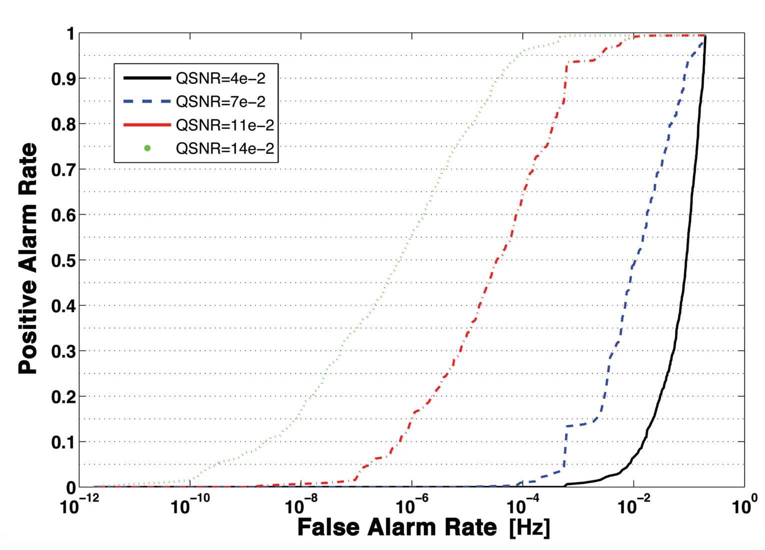


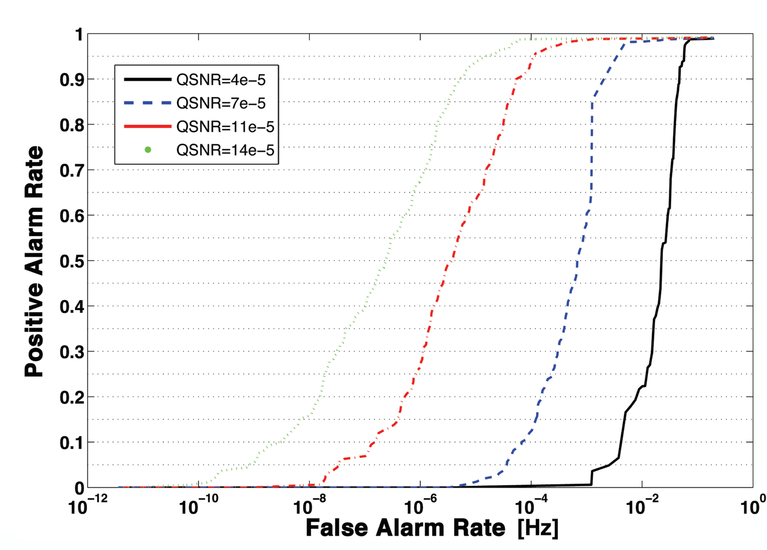


Comparison and conclusions

The *Locust* algorithm is faster. Also, the detection probability is independent of the shape of the function being fitted. However, since it is based on local wandering, the *Locust* algorithm is more sensitive to trace discontinuities.

The sensitivity of algorithms can be characterized by Receiver Operating Curves (ROCs). Below are ROC curves corresponding to one of our algorithms (*Locust*), both in the case of Gaussian noise (left) and LIGO H1 noise (right).





Combining *Locust* and *Hough* algorithms in one process highly increases search robustness and sensitivity. Correlating spectra of multiple detectors also increases search sensitivity.

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References

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