LIGO-G040568-00-Z

CorrPower: a Cross-Correlation Based Algorithm for Triggered and Untriggered Gravitational-Wave Burst Searches

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What is *CorrPower* ?

A new search code for bursts of gravitational waves, looking for excesses of coherent power in multiple detectors.

Three modes of operation:

1. continuous cross-correlation of data from multiple detectors and generation of event triggers associated with an excess of coherent power (the focus of this poster)
2. r-statistic test on burst candidate events → ref: 2004 *Class. Quantum Grav.* **21** S1695-S1703
3. external trigger search similar to GRB030329 → ref: 2004 *Class. Quantum Grav.* **21** S1831-S1837

Unification of coherent techniques implemented in the LIGO triggered and un-triggered burst analysis.

Two platforms:

A. MATLAB standalone (*status: running on LSC grid clusters; useful for pipeline development, but non-optimal computational speed*)
B. C++ LIGO Data Monitoring Tool (*status: in development; potential for online analysis*)

Search Strategy

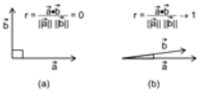
Cross-correlation of data from a pair of GW detectors.

1. The power of the sum of the two data vectors is: $(a+b)^2 = a^2 + b^2 + 2a\bullet b$

$P_{coher} = a\bullet b$ is the coherent power component for the detector pair

2. The angle between data vectors is the quantity used in the r-statistic test

2004 *Class. Quantum Grav.* **21** S1695-S1703



C_M is the r-statistic confidence for the correlation of a detector pair

For each (i,j) pair of detectors, we build a matrix of P_{coher}^{ij} and C_M^{ij} for several

A. integration windows (=dimension of the data vectors)
B. central times

NOTE: P_{coher}^{ij} and C_M^{ij} are maximized over time lags between the two data vectors, up to the light travel distance between detectors + timing resolution

Combine all detector pairs and build network detection statistics for each central-time/integration-window:

r-statistic Gamma: $\Gamma = P_c = \Sigma C_M^{ij} / N_{pairs}$

Coherent Power: $P_c = \Sigma P_{coher}^{ij} / N_{pairs}$

$hrss_c = \mathrm{sqrt}(P_c)$

Normalized Excess Power: $NEP = (P_c - \mu)/\sigma$
μ and σ computed separately for each integration length, average over all central times in the analyzed data segment after removal of outliers

Corrgram = 2D pixelization of integration-time versus central-time

- The set of integration times and the separation between central times (= overlap between consecutive integration windows) are parameters of the search

- Corrgram pixels with significant statistics are passed to the post-processing:
  - cluster by requiring a minimum separation between events;
  - assign the event the max values of NEP, Γ and $hrss_c$ over the cluster;
  - empirical minimum NEP threshold = 3;
  - empirical minimum Γ threshold = 3;
  - potential for a distributional analysis (compare the distribution of NEP or $hrss_c$ in foreground and background, for a given threshold on Γ);
- The pipeline detection efficiency is determined with MonteCarlo simulations
- The background is estimated introducing an unphysical delay between time series

Sample Performance

We show a sample performance of the method using:

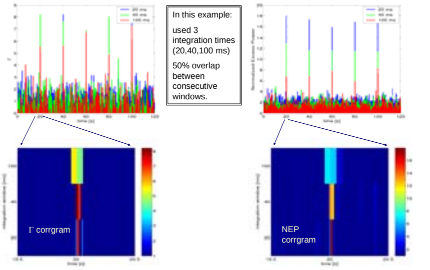
- white gaussian noise sampled at 4096 Hz
- 2 or 3 detectors
- Gaussian pulses, with τ=1.0 ms and different amplitudes

$$h(t) = h_{peak}\, e^{-(t-t_0)^2/\tau^2}$$

In the following, the amplitude of the simulated events is expressed as the optimal SNR from matched filtering, computed in the least sensitive detector:

$$\rho = \sqrt{4\int_0^\infty \frac{|\tilde{h}(f)|^2}{S_h(f)}\,df}$$

Noise: 2 detectors with white gaussian noise (4096Hz) and same sensitivity
Signal: 1 ms gaussians, ρ=10, injected every 20 sec
Analysis segment = 120sec

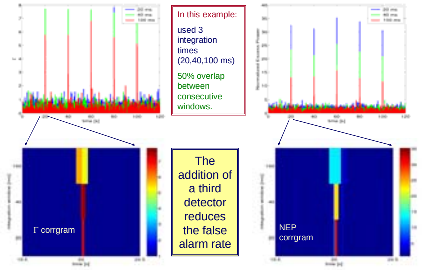


In this example:

used 3 integration times (20,40,100 ms)

50% overlap between consecutive windows.

Noise: 3 detectors with white gaussian noise (4096Hz) and same sensitivity
Signal: 1 ms gaussians, ρ=10, injected every 20 sec
Analysis segment = 120sec



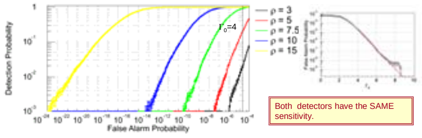
In this example:

used 3 integration times (20,40,100 ms)

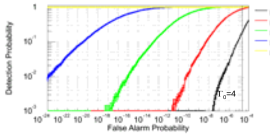
50% overlap between consecutive windows.

The addition of a third detector reduces the false alarm rate

Noise: 2 detectors with white gaussian noise (4096Hz)
Signal: 1 ms gaussians, ρ=10, injected every 20 sec. NEP> 3
Parameter on these R.O.C. curves: Γ_0 (threshold on Γ)

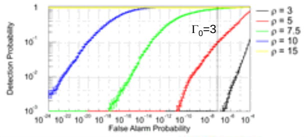


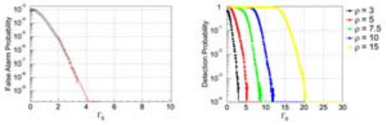
Both detectors have the SAME sensitivity.



One detector is 3 times more sensitive than the other.
ρ is computed in the least sensitive detector.

Noise: 3 detectors with white gaussian noise (4096Hz) and same RMS
Signal: 1 ms gaussians, ρ=10, injected every 20 sec. NEP> 3
Parameter on these R.O.C. curves: Γ_0 (threshold on Γ)





Challenges of Real Data

Colored spectrum

- This is not problematic with the LIGO-type spectra. A linear-predictor error filter is very effective at whitening real data.

Non-stationary lines

- Known lines can be notched out. Also, the linear-predictor error filter, applied to minute-scale data segments (as in the *CorrPower* search) reasonably removes lines, but in some instances a post-processing r-statistic test run over small time-scales (seconds) is needed as veto for highly non-stationary lines.

Broadband transients

- Broadband instrumental "glitches" in non-colocated detectors sometimes appear as correlated events and increase the false rate. A larger Γ_0 threshold (6-10) is necessary, for instance, in the S3 analysis (see Yakushin's talk). Background studies are needed to tune the value of Γ_0.

Environmental correlations affect the false rate in the two Hanford detectors

- Acoustic coupling can produce spurious correlations, but an environmental veto is possible for these instances.

Antenna patterns reduce the detection efficiency

- Simulations for the LIGO Hanford-Livingston show the effect is not worse than in incoherent searches. Studies are in progress to evaluate the effect when more detectors are added to the network.

Outlook

Current status

» A MATLAB standalone code is currently running on the LSC grid clusters.
» With 3 integration windows, data at 4 kHz and 50% overlap between windows, the code runs at 4 x real time on the cluster at LIGO-Caltech.
» A C++ Data Monitoring Tool (DMT) implementation is in progress.

Short-term goals

» Finalize tuning strategies for the *CorrPower* pipeline.
» Analyze S3 and E11 data with *CorrPower* and the triggers are used for detector characterization (*in progress*).
» Use *CorrPower* in the AURIGA-LIGO (AU1/S3) joint analysis (cross-correlation limited to the LIGO interferometers).
» Adopt *CorrPower* in the externally triggered burst search.

Long-term goals

» Promote the DMT version of the code to an online analysis pipeline for LIGO's S5 run.
» Explore use of *CorrPower* in joint analysis with other detectors.