Black Holes, Lasers and Data Analysis:
Contributions to Gravitational Wave Searches with the ExcessPower Pipeline

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Introduction

Gravitational waves (GWs) are tiny perturbations to the spacetime structure of the universe that propagate freely as wavelike solutions to the Einstein equations. The direct detection of GWs is currently a major goal in experimental physics, and a number of large scale efforts to detect them are currently underway.

Designed to detect GWs in the 10 Hz – 10^3 Hz frequency band, the Advanced Laser Interferometer Gravitational-wave Observatory (aLIGO) is network of kilometer scale ground-based laser interferometers that will recover signals generated by astrophysical sources such as supernovae, rotating neutron stars and the coalescence and eventual inspiral of compact binary objects [1].

Gravitational wave *bursts* are transient GW signals and differ from other types of GW signals in the sense that they 1) have durations much shorter than the observational timescale, and 2) they are identifiable by a distinct arrival time. One of the most important sources of GW bursts is compact binary coalescence (CBC).

If the anticipated waveform from a CBC event can be well-modeled with post-Newtonian techniques or numerical relativity, matched filtering techniques can be employed to search for GW bursts in detector data: a template bank containing some large number of possible waveforms is constructed, and the GW signal is extracted from the data by correlating the template to the data. For some astrophysical systems, however, the dynamics underlying the gravitational field are complex enough that exact forms of the GW signal cannot be obtained. Additionally, unknown signals from unanticipated sources could exist. In this case, a technique other than matched filtering is necessary to extract the signal of unknown shape from the data. One method that has been proposed and employed for this type of *unmodeled* search is the excess power method, which involves studying time-frequency decompositions of detector data [2–5].

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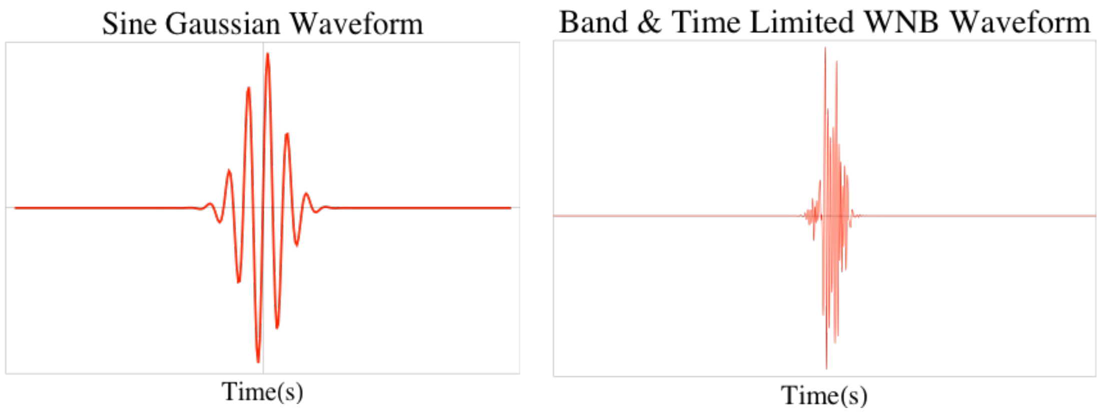

Figure 1. Sine Gaussian (left) and band and time limited white noise burst (right) waveforms serve as the basis for injections in the ExcessPower injection study.

The excess power method effectively scans detectors' outputs for transients that are statistically significant relative to back- ground noise: blocks of time and frequency (or time-frequency tiles) are constructed based on knowledge of the signal's duration and frequency, and the total power within each tile is calculated: the energy in each tile is determined, and added in quadrature. If a signal exists in the data, more power should be present than would exist from detector noise alone. The *ExcessPower pipeline* is a data analysis pipeline (or set of software tools) that employs the excess power method in unmodeled GW searches using LIGO data.

ExcessPower Pipeline Efficiency Test

Pipeline efficiency tests aim to identify how well a given pipeline can recover signals with known parameters. To do this, signals with known (desired) parameters are injected into appropriate background noise and analyzed by the pipeline. An efficient pipeline is one that recovers the injected signals within some specified level of accuracy.

The work described in this document aims to quantitatively assess the efficiency of ExcessPower for burst searches of GWs. Because the objective is to simulate any sort of signal that ExcessPower may come across in real data, two types of signal waveforms are being used in the study: Sine Guassians, which are sine signals modulated by Gaussian envelopes, and band-and-time limited white noise bursts (BTLWNBs) (see Figure 1). These two families of signals have the advantage that they can be used as templates for nearly any practical signal.

Signals were injected into simulated aLIGO data and analyzed with ExcessPower, resulting in *triggers* (or candidate GW signals).

Preliminary Results

Out 40274 injections, 33974 were recovered by ExcessPower. This is about 85% of the injections (see Figure 2). Initial results indicate that while some bulk parameters (time and frequency) are recovered well by ExcessPower, additional work needs to be done to correctly estimate the signal-to-noise ratio and amplitude of injected signals. This work is ongoing.

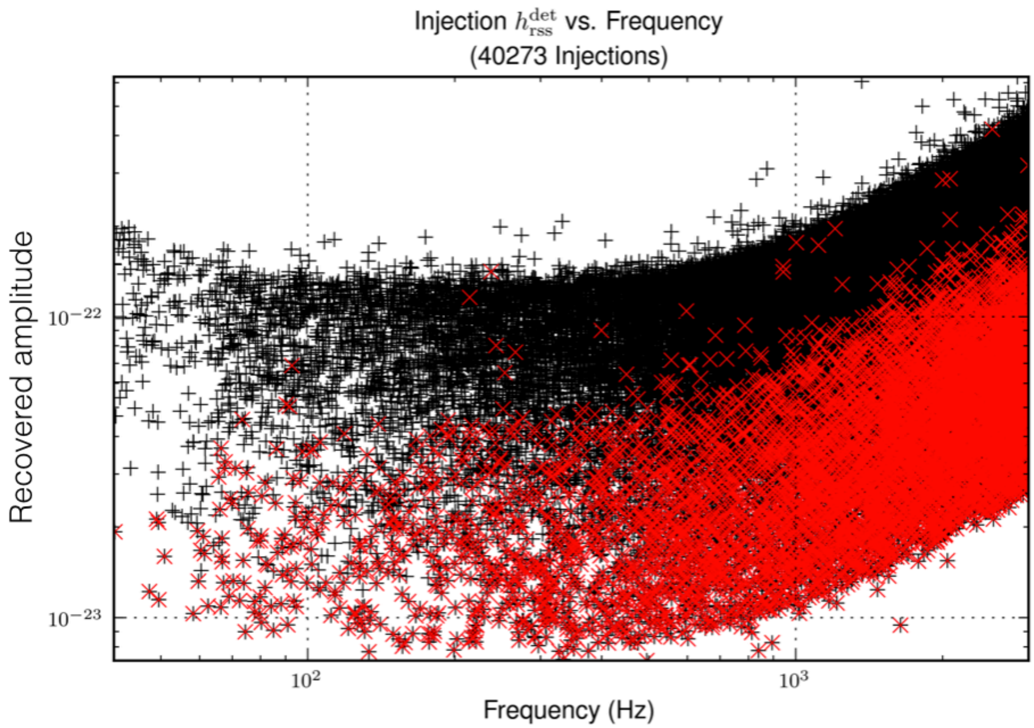

Figure 2. Recovered injections (black cross-hairs) are shown along with missed injections (black cross-hairs superimposed with red xs). Note that many recovered injections are covered by the missed injections. The total number of injections recovered was near 85%.

References

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