A High Frequency Search
for Gravitational Wave Bursts

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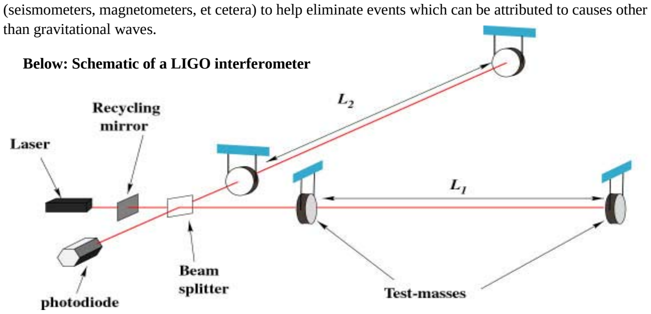
Abstract: We present a first look at an all-sky gravitational wave burst search in the frequency range 1 to 6.5 kHz, currently being conducted on data taken during the first calendar year of LIGO's 5th science run. Previous burst searches with ground-based interferometers have mostly been limited to frequencies below 2 kHz. However, various models predict gravitational wave emission in the several kHz range from astrophysical phenomena including gravitational collapse, neutron star modes and mergers of some compact binaries. This shot-noise dominated frequency regime can be analyzed with the same tools as lower frequency analyses.

1. Introduction to LIGO

LIGO consists of three power-recycled Michelson interferometers with Fabry Perot cavities, located at two sites. LIGO Hanford consists of an interferometer with 4 km-long arms and an interferometer with 2 km-long arms enclosed in the same vacuum system. LIGO Livingston consists of a single 4 km interferometer. Gravitational waves distort space itself, causing slight relative changes in the lengths of the perpendicular interferometer arms, measured through the creation of an interference pattern by the two recombining laser beams. The sites are equipped with a number of additional detectors (seismometers, magnetometers, et cetera) to help eliminate events which can be attributed to causes other than gravitational waves.

Below: Schematic of a LIGO interferometer



2. Motivation for High Frequency Search

Previous LIGO burst searches have been limited to frequencies below 2 kHz. In addition to our desire to explore the full frequency range possible in case unexpected signals are present , the search is motivated by several burst models that predict gravitational wave signals with frequency content in the few-kHz range.

Models that have resulted in predictions of burst signals with frequency higher than 1 kHz include:

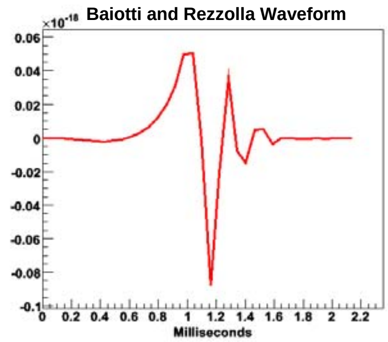
Neutron star stellar collapse as predicted by Baiotti, Rezzolla et al. (1,2,3)

Nonaxisymmetric hypermassive neutron stars as an intermediate phase during the merger of compact objects (4,5)

Neutron star torque free crust precession (6)

Neutron star vibrational f-modes (7)

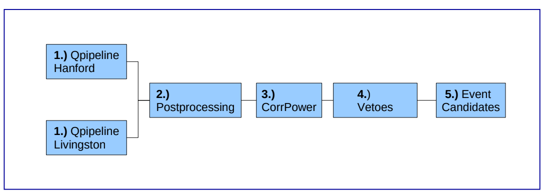
Low mass black hole mergers (8)



Above: Waveform predicted from the gravitational collapse of a 1.67 solar mass neutron star in (3) as sampled at 16 kHz.

3. Summary of Analysis Pipeline

This analysis looks for gravitational wave burst signals of duration less than 1 second in the frequency range 1 to 6.5 kHz. We are currently in the process of analyzing the first calendar year of LIGO's 5th science run. In addition to being run on normal data, the pipeline is run on data including injections, which simulate gravitational waves. These are either added after the fact via software or physically put into the system via an actuator in order to determine the efficiency of the analysis.



Steps in the Analysis

1. Triggers are generated at both sites using Qpipeline software. The Qpipeline algorithm uses a bank of generic sine-Gaussian waveforms (sine waves with a Gaussian envelope giving them finite duration) to assign central time, central frequency and Q value (the ratio of central frequency to bandwidth) to each event (9).

2. A coincidence criterion with a 20 ms window is applied between the two sites. Only triggers with a corresponding event of similar time and frequency content at the other site are kept. The remaining events are then clustered in a time window of 1 second to avoid multiple triggers from the same event.

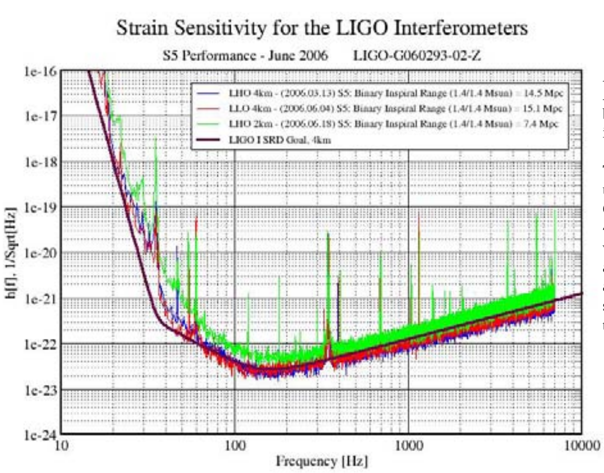
3. The resulting triggers are run through CorrPower, which measures the correlated energy between the three detectors without regard to the relative amplitude. A cut is placed on the output value, which is based on Pearson's linear correlation statistic (10). The background is measured using 100 "time slides", wherein an unphysical time lag is applied between the two sites to obtain background measurements which will be free of gravitational wave signals coincident at the two sites.

4. Auxiliary channel vetoes are applied to eliminate events that are clearly associated with disturbances other than a gravitational wave.

5. Any remaining event candidates will then be subjected to further scrutiny.

4. Characteristics of High Frequency Data Analysis

We have found that data with frequency content in the few kHz range can be analyzed with the same tools and methods as lower frequency data with only a few basic modifications, such as using a higher sampling rate and filtering out some high frequency vibrational modes in the optics. However, there are some significant differences in characteristics between the two regimes.



At higher frequencies shot noise (statistical uncertainty in the number of photons detected) is the dominant background. Although strain sensitivity is reduced and noise is higher at these frequencies, the background is also closer to Gaussian behavior. Environmental vetoes must be treated separately from low frequency analyses, since the population of glitches is different.

There are additional systematic uncertainties above 1 kHz. The overall strain calibration is less precise. Likewise, phase uncertainty between the interferometers rises to around 20 degrees near 5 kHz. Fortunately, this is dealt with by the CorrPower algorithm, which automatically searches over multiple time shifts. The current calibration is only valid up to ~7 kHz, so we limit the analysis to frequencies below 6.5 kHz. Additionally, the antenna pattern as calculated with the long wavelength approximation has uncertainties which increase as a function of frequency. The first order correction to this approximation is about 1% of the overall magnitude at 1 kHz, but this correction rises to 10% at 6 kHz. In addition to accounting for increased uncertainties in our upper limits, the primary adjustment to processing required by the increase in systematic uncertainty is that the consistency requirements in energy between the two Hanford detectors must be loosened to account for greater fluctuations.

5. Beyond the First Year S5 Analysis

Virgo, a 3 km interferometer near Cascina, Italy, has sensitivities comparable to LIGO in the range above 1 kHz. An independent effort is currently underway to analyze times wherein Virgo's first science run overlaps with the last several months of LIGO's 5th science run, using a different set of analysis tools than described here . Upon completing our current analysis, we plan to also examine this joint data period using Qpipeline with a follow-up by Xpipeline (11), software that handles detectors which are aligned differently (such as Virgo and LIGO) better than CorrPower.

In the future, Enhanced LIGO (in operation 2009) and the second generation detectors Advanced LIGO and Virgo+ (in operation around 2014) will have greatly improved sensitivities throughout their entire frequency range. At frequencies in the few-kHz range, this improvement is largely accomplished through increased power to the laser, which reduces shot noise. Thus, prospects for gravitational wave detection in this frequency band will increase dramatically in the next several years.

References:

1. Phys. Rev. Lett. **94** (2005) 131101
2. Phys. Rev. Lett. **97** (2006) 141101
3. Class. Quant. Grav. **24** (2006) S187-S206
4. astro-ph/0702228v
5. Phys. Rev. Lett. **94** (2005) 201101
6. AIP Conf. Proc. **586** (2001) 805-807
7. Class. Quant. Grav. **16** (1999) A131-A156.
8. Phys. Rev. Lett. **91** (2003) 021101
9. S. Chatterji, MIT PhD. Thesis 2005.
10. Class. Quant. Grav. **22** (2005) S1159-67
11. Phys. Rev. D **75** (2006) 082005

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