Methods of a Search for Gravitational Waves Associated with GRBs

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Abstract

The central engines of GRBs are thought to be compact, energetic, and asymmetric, and are expected to be powerful sources of gravitational waves. Using the time and sky location of the GRB observed by satellite experiments, we are able to perform targeted searches for GW emission. This allows for both improved sensitivity to real astrophysical signals and strong consistency tests to suppress background noise. We discuss the methods used to search for GWs from observed GRBs during the fifth ‘Astrowatch’ period of the LIGO–Virgo detectors, and consider the model parameters applied in the consistency cuts and in the estimation of upper limits.

GRBs & GW Detectors

GRB trigger times and sky coordinates are obtained through the Gamma-Ray Burst Coordinates Network, for both short and long bursts.

A full analysis (detection search and upper-limit calculation) is performed for all GRBs with well-defined sky positions and for which at least two interferometers have science-quality data — i.e., the instruments are in a resonant, stable configuration, and the detector environment is free of known sources of noise. Data segments which are flagged as being of poor quality are not included in the analysis.

X-pipeline

The analysis code used in triggered GRB burst searches by the LVC is called X-pipeline [1]. X-pipeline is an analysis package that exploits the known sky position of the GRB to coherently sum the data streams from each detector using a basis defined by the antenna response of the detector network. The summation is calculated for three different projections in this basis: the plus- and cross-polarizations of the gravitational waves, and the null direction, which is perpendicular to the plus and cross response vectors. In the null direction, the contributions of a real gravitational wave will cancel, and any true signal will have energy consistent with background.

Background rejection is performed by tuning data cuts based on the null stream data [2]. In each of the three projections, events are quantified by their coherent and incoherent energy. For the null projection, real gravitational waves will have significantly more incoherent energy than coherent energy. Glitches, on the other hand, are anomalous transient signals that are likely to have about equal coherent and incoherent energies in the null direction.

Right: Coherent vs. incoherent energy in the null direction for events produced by background noise and simulated gravitational wave signals. The color axis is the base-10 logarithm of the event significance. Glitches are vetoed by rejecting all events that fall below the dashed line (here, the median-tracking veto cut is used).

Astrowatch

Data collected between October 2007 to July 2009 is referred to as the A5, or fifth Astrowatch, epoch. During this time the two km LIGO interferometers were offline for planned enhancements. The 2km LIGO detector in Hanford, WA (“H2”) and the GEO and Virgo detectors (“G1” and “V1”), respectively, collected science-mode data on a best-effort basis.

During this period there were 361 GRB triggers, nearly all from the Swift and Fermi satellites. Sufficient LIGO/Virgo science data exists to analyze 53 of these triggers.

Notable GRBs during the Astrowatch epoch for which there is adequate science data include GRB080319B, the brightest gamma-ray event ever observed in the optical spectrum, and GRB080905A, which has the lowest confirmed redshift for a short GRB (z=0.12, or roughly 560 Mpc).

Search Bandwidth

During the Astrowatch epoch, there were no GRB triggers with coincident data between three or more GW detectors. In addition, there were no H2-V1 coincident events; all GRBs with sufficient science data were either H2-G1 (31 events) or V1-G1 (2 events).

Due to the spectral sensitivity of the GI detector, the Astrowatch search will focus on the upper frequency band (400-1792 Hz). In this frequency band the sensitivity of the GI interferometer is comparable to H2 and V1. In the lower-frequency regime the search would be limited by the GI sensitivity and would suffer from poor background rejection.

Source Models

To estimate the sensitivity of the search to astrophysically interesting sources, we add simulated-gravitational-wave signals of various amplitudes, from random directions in the Swift or Fermi error box, within a few minutes of the actual GRB time. In GRB searches that extend to low frequency, typical waveforms used are chirplet sine-gaussians, to mimic a binary neutron star inspiral, and low-Q sine-gussians, to measure the sensitivity to unmodeled bursts.

The A5 search band is above the typical frequency of a compact binary coalescence. To motivate our upper limits, we selected four waveforms for simulations:

- Two Q=99 sine-gaussian bursts at 500Hz and 1kHz to quantify sensitivity to unmodeled short bursts.
- A high-Q sine-gaussian (f=910Hz, Q=100) to approximate a bar-mode waveform from a core-collapse supernova [3].
- A chirping sine-gaussian (f=910Hz) with a broad frequency range (~300Hz) to approximate a neutron star with a massive (0.1-1 solar mass) accretion disk [4] and also the model of a precessing accretion disk for GRBs [5].

References: