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Limits on GRB distances from LIGO and Virgo

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Abstract

Several popular models for Gamma-Ray Burst (GRB) progenitors are also expected sources for gravitational wave emission, including core-collapse supernovae and compact binary mergers. Using information from the Gamma-ray bursts Coordinates Network and the LIGO and Virgo gravitational wave observatories, we search the data for gravitational wave events in coincidence with known GRBs between November 4, 2005 and October 1, 2007. This poster presents the latest results. The observed limits on gravitational wave energy are used to construct a minimum distance for each GRB which does not have a measured redshift.

Figure 1 - The interferometers of the LIGO/Virgo network are located in Livingston, LA; Hanford, WA; and Cascina, Italy. For each GRB considered, we look for events of excess power in 2 or more detectors at times within a small window around the GRB. In addition to looking for time coincidence with the GRB, the GRB position is used to demand a relative time delay between gravitational wave phase at the three locations.

Two Search Methods

We use two methods to search the gravitational wave data with different assumptions. The Burst method uses "X-Pipeline" to search the time around each GRB for excess power, making only loose assumptions on the waveform. This method is designed to be general enough to see nearly any short duration (< 1 s) waveform. The Burst method searches the gravitational wave data around all 137 well-localized GRBs for which two or more detectors were operating simultaneously.

The second method takes advantage of extra information available for a subset of the GRBs. The GRB population is typically divided into two groups – long bursts (> 2s) and short bursts (< 2 s). Short bursts are thought to originate with compact object mergers – systems for which the gravitational waveform is well studied. The second search, known as the inspiral search, is tailored specifically to find the predicted waveforms from in-spiraling binary compact objects. The inspiral search is used for 22 short duration gamma ray bursts (SHB) in the data set. Compared to the general excess power search, the inspiral search makes more stringent demands on the signal space, and so is generally expected to be more sensitive to weak signals.

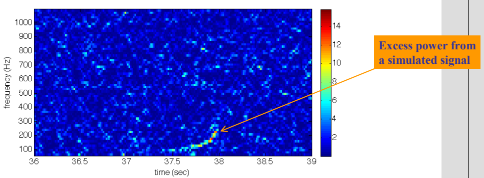

Figure 2 – Time/Frequency Map produced by X-Pipeline. A simulated inspiral signal from a 1.4 solar mass neutron star merging with a 10.0 solar mass black hole star at an effective distance of 37 Mpc, added to simulated H1-H2 noise. The color-scale represents a standard likelihood statistic for each point in the time-frequency plane. The standard likelihood takes advantage of cross-correlations between multiple detectors to best separate signal from noise without making assumptions about the waveform. In comparison, the inspiral pipeline computes a cross-correlation between each detector and a pre-determined waveform, a method known as matched template filtering.

Signal and noise

Both searches - Burst and Inspiral - need to distinguish between real signals in the gravitational wave data and bursts of noise from the detector environment (glitches). To understand the background rates of glitches, the searches assume that any real signal associated with the GRB will be in a short time window around the GRB event. This time window is labeled "on-source time", and time outside this window is labeled "off-source". Before searching the on-source time, events in the off-source time are used to characterize the statistical properties of background glitches.

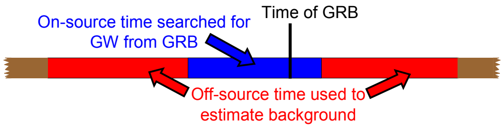

Figure 3 – Graphical timeline showing the time around a GRB is divided into "on-source" and "off-source". For the Burst search, the on-source stretches from 120 s before the event to 60 s after, and 3 hours of "off-source" time are used to estimate the background. The Inspiral search assumes a better understood source, and so uses a comparatively shorter on-source window from 5 s before the GRB to 1 s after with about 33 minutes of off-source time.

Injections

To measure the sensitivity of the search algorithm, we add simulated waveforms (injections) to off-source data. Comparison of recovered parameters for background events (glitches) and injections allows the creation of cuts which reject glitches and pass a maximal number of injections.

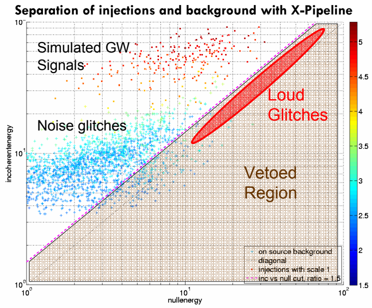

Figure 4 – Sample cut by X-pipeline can be seen as the pink line on this plot. The cut is placed to reject loud background events, which will tend towards the diagonal in this plane (shown as a dashed gray line). The red squares near the top of the plot represent simulated signals. The loudest event in the on-source data to pass the cuts is used to construct an upper-limit on gravitational wave energy for each GRB.

GRB 070201

GRB 070201 was reported to have an error box consistent with a position in the near-by Andromeda galaxy (M31), which lies a mere 780 kpc away. The analysis of this GRB was previously released in [3]. The analysis excluded a compact object merger in the Andromeda galaxy with > 99% confidence, lending support to the hypothesis that this GRB is a soft-gamma repeater.

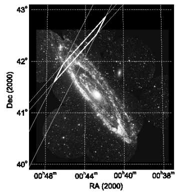

Figure 5 - The error box of GRB 070201 overlaps the Andromeda Galaxy. GW from a compact object merger in this galaxy would show up strongly in our analysis. We rule out this possibility with > 99% confidence, suggesting the event may have been a soft gamma ray repeater.
Image credit: Mazets, et al. Astrophys. J. **680**, 545 (2008)

Results: X-Pipeline

The X-Pipeline analysis finds no evidence for gravitational waves associated with any of the 137 analyzed GRBs. For each GRB, the loudest event in the on-source window is used to set an upper-limit on the gravitational wave energy associated with the event. Using a scaling law between GW energy and distance, and the assumption that each source emits $0.01Mc^2$ (M = 1 Solar Mass) in GW, we convert the GW energy limits into distance limits for each possible gravitational wave source.

$$E_{GW} \simeq \frac{\pi^2 c^3}{G} D^2 f_c^2 h_{rss}^2$$

Equation 1 – Relation between gravitational wave energy and source distance. D is the distance, f the central GW frequency, and h_{rss} a measure of the GW strain.

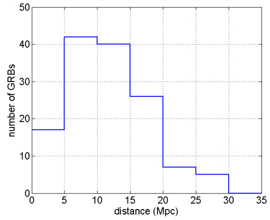

Figure 6 – Histogram of lower limits on distances to the 137 GRBs in the X-Pipeline analysis. The distances are derived from the observed GW energy limits. The majority of the GRBs lack a distance estimate based on the available electro-magnetic data. A table listing the limit placed on each GRB distance is available in [1].

Inspiral Analysis Upper Limits (Short GRBs)

The Inspiral analysis converts limits on GW energy into distances by assuming the source to be a compact object merger in the mass range appropriate for double neutron star mergers (NS-NS) or a merger of a black hole and a neutron star (NS-BH). The distance limit for each GRB is a 90% confidence limit lower Feldman-Cousins distance. These results are currently in preparation.

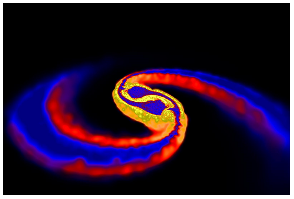

Figure 7 – Two magnetized neutron stars are shown merging in this simulation image. Credit: Daniel Price (University of Exeter) and Stephan Rosswog (International University Bremen).

More information

Details of the X-Pipeline analysis, along with tables listing the distance limits for each of the 137 GRBs analyzed, are available in [1].

Details of the Inspiral analysis, along the tables listing the distance limits for each of the 22 SHB analyzed are in preparation [2].

[1] *Search for gravitational-wave bursts associated with gamma-ray bursts using data from LIGO Science Run 5 and Virgo Science Run 1* - Preprint, arXiv:0908.3824v1

[2] *Search for gravitational-wave inspiral signals associated with short Gamma-Ray Bursts during LIGO's fifth and Virgo's first science run* - In Preparation

[3] Astrophys. J. **681**, 1419 (2008)

Acknowledgements

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