OVERVIEW

Gamma-ray bursts (GRBs) are divided into two classes, long and short, based on their characteristic duration and spectral hardness. Long GRBs (duration ≥ 2s, with soft spectra) are mostly related to the core collapse of rapidly rotating massive stars. Gravitational-wave (GW) emission is expected in this process. Short GRBs (duration < 2s, with hard spectra) are widely thought to be produced by the mergers of binary systems composed of neutron stars (NSs) or a neutron star and a stellar-mass black hole (BH). Such compact binary coalescences are the premier candidates for GW signals in the analysis band of detectors such as Laser Interferometer Gravitational Wave Observatory (LIGO) and Virgo.

SEARCH STRATEGY

Searches for gravitational waves associated with GRBs are performed for both unmodeled GW bursts and modeled coalescence signals. Targeted GW burst search is performed on the interval from 600s before to either 60s or the T90 (whichever is larger) after each GRB trigger. This conservative window (called “on-source”) is large enough to take into account most plausible time delays between a GW signal from a progenitor and the onset of the gamma-ray signal. This window is also safely larger than any uncertainty in the definition of the measured GRB trigger time. For cases when less early GW data are available, a shorter window starting 120s before the GRB trigger time is used. The input of GRB time and position improves sensitivity of the targeted search over the all-time, all-sky searches.

RESULTS FROM THE INITIAL DETECTORS

The LIGO Scientific Collaboration and the Virgo Collaboration have searched for gravitational waves associated with GRBs detected by the Gamma-ray Coordinates Network (GCN) and the InterPlanetary Network (IPN) in 2005-2010 during LIGO’s fifth and sixth science runs and Virgo’s first, second, and third science runs. No evidence of a gravitational wave signal associated with the GRBs in the sample is found, and hence exclusions on GRB populations are placed. The distance distribution is parameterized with two components: a fraction $F$ of GRBs distributed with a constant comoving density rate up to a luminosity distance $R$ and a fraction $1-F$ at effective infinite distance. The exclusion is presented in the $(F, R)$ plane (see Fig. 4).

SEARCHES WITH THE ADVANCED DETECTORS

A number of different searches will be deployed in advanced detector era for the search for gravitational wave signals associated with GRBs (see Fig. 5):

- As soon as possible after a GRB event (~minutes) provide information on which of the detectors are operational and estimate of network sensitivity in the direction of the GRB.
- Look for coincidences between events in the online blind burst, binary neutron star, neutron-star black-hole searches and the GRB (see “RAVEN” in Fig. 6). The results will be ready in minutes after the GRB and will provide additional information to potential EM followup efforts, e.g., if there is a clear association, that may inspire a stronger EM followup effort.
- Soon launch two fully coherent prompt triggered analyses around the time of the GRB: “X-pipeline” for GW burst search, and “Coherent-CBC-pipeline” for the coalescence search (see Fig. 6). First results from these analyses will be available within hours of the GRB alert and will be shared with partner astronomers. The final results will be made available within a few days whenever a better estimation of the significance is necessary. [CBC: Compact Binary Coalescence]
- An archival search with a latency of around a month will be performed. This will be run of the data with better (final) data quality, calibration, etc.

SUMMARY

The search for gravitational waves associated with GRBs plays an important role in gravitational-wave astronomy. A GW signal associated to a long GRB would give new astrophysical insight into long GRB progenitors, which in general are not expected to be efficient GW radiators, but some models do predict significant GW emission. A merger signal associated to a short GRB would confirm the compact binary merger nature of the engine and allow for measurements of the binary components masses and spins, as well as constraints on the beaming angles.

![Fig 4: (a) Cumulative redshift distribution $f(R)$ exclusion with 90% confidence level from the analysis of 508 GRBs with GW burst search (solid black). We assume a standard sirensine-Gaussian GRB burst at 150 Hz with an energy $E_{GW} = 10^{-3} M_{\odot} c^2$. The dashed blue curve is the extrapolation assuming the same standard sirens, a factor 10 improvement in sensitivity, and a factor 2 increase in number of GRB triggers analyzed (dash-dot green curve assumes standard sirens energy of $E_{GW} = 10^{-2} M_{\odot} c^2$). (b) Cumulative distance exclusion for 69 analyzed short GRBs for both a NS-NS (solid blue) and a NS-BH (solid black) progenitor model. The dashed curves represent the corresponding extrapolated (factor of two in number and ten in sensitivity) advanced detector era expectations. The red staircase curves in (a) and (b) show the cumulative distribution of measured redshifts for Swift GRBs.

![Fig 5: Flow of gamma-ray and GW data for the GRB searches. There are three main time scales, with each having an associated search: Low-latenity (minutes), prompt triggered (hours), and archival (weeks).]