Neutron Star and Black Hole Binaries in Dense Star Clusters (P7)  
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- Dense star clusters can host neutron stars and black holes
- These stars can form binaries via 3-body interactions
- Hardening occurs as a result of encounters
- Eventually binaries get kicked out since the recoil energy \( \sim \) binding energy
- Some fraction of the ejected binaries go into merger in Hubble time
- Rate is estimated to be \( \sim 10^{-6} \, \text{yr}^{-1} \)
- Giant ellipticals have more star clusters/mass \( \rightarrow \) good place to look for them
We review recent changes made to the ringdown analysis pipeline to increase sensitivity and efficiency.

We review the pipeline’s efficiency at recovering full inspiral-merger-ringdown waveforms in the mass range 25-100 $M_{\odot}$. 
Short duration gamma ray bursts
A gamma ray burst (GRB) is one of the most violent events in the Universe. These events are classified broadly into two categories. The events that are longer than a duration of two seconds are called long duration GRBs and those that are shorter are termed as short duration GRBs or SGRBs. The latter type is conjectured to have compact binary coalescences (CBCs) as progenitors. Therefore, SGRBs provide external triggers for searching signals from CBCs in gravitational-wave (GW) detectors. Whereas for many SGRBs the sky-position is determined by the electromagnetic detections with high accuracy, for some others it can be off by several degrees. Here we develop a method for coherently searching a patch of the sky, several degrees wide, for CBC signals in multiple baselines of GW detectors. We compare its performance in Gaussian noise with that of an all-sky (or “blind”) search and a targeted search and show where it can perform better than the latter two.

External trigger pipeline
The algorithm used for searching GW signals from SGRBs is called the External Trigger pipeline [2]. Prior information about the sky position and the time of arrival of the signal is assumed to be known to some accuracy. This means that instead of doing a “blind search” in time and sky position, one can concentrate on a small time window and on a particular sky position (“known sky”) or a set of sky-positions (i.e., on a “sky patch”). The external trigger pipeline focuses on a time window of six seconds around the external trigger time that one obtains from a GRB alert. The background is calculated by analysing the off-source times, away from the six-second-time-window that includes the GRB trigger time.

The sky-position of the burst is known beforehand, therefore, one can construct a mini sky-grid around that point, and including it as one of the grid points. This ensures that:

1. We have the accurate sky position not falling in the “hole” of our grid spacing.
2. Parameter covariance error will not cause too much damage since we are not searching at a single sky position. An adjacent sky position in the grid may well yield the larger SNR. The detection efficiency will be helpful.
3. The false-alarm rate will be smaller than the all-sky search.
4. If a GRB satellite provides large sky-position errors, the sky-patch of the appropriate size mimics against a fake GW signal.
5. The computational cost, though larger than that of the known-sky search, nevertheless can be significantly smaller than the all-sky one if we optimize the grid size and the grid spacing for efficiency and speed.

The time taken to run the search increases as we increase the grid size. This is maximum for an all sky search and minimum for the known-sky mode. In Fig. 2 we show the time taken to run one instance of the coherent code with different sky-patch sizes.

Comparison of the different sky mode searches
What we observe here is that the performance varies as a function of the sky position of the GRB. This is expected since the network sensitivity itself varies with the sky position. Accordingly, sky-patches with step-size and sky-coverage adapted to a network’s varying sensitivity (in sky position) are more optimal than those that have three parameters fixed for all sky positions. We plan to present that study in the future.

References

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FIG. 1: The coherent stage of the hierarchical external trigger search pipeline.

FIG. 2: Timing plots for the coherent code for different sky-patch sizes. The x-axis represents the size of the sky patch, where a value of 0 implies a sky patch with (0 × 0) points. The timing values in the y-axis are given in seconds and are averaged over 100 trial runs.

FIG. 3: Efficiency plots for coincident stage, and the coherent stage in known-sky, all-sky and sky-patch modes of different sizes. The left plot shows low-mass bin, the middle one the medium-mass bin, and the right one the high-mass bin.

FIG. 4: Efficiency plots for coherent-stage sky-patch search with varying step size. Left panel shows low-mass bin, middle panel shows medium-mass bin and right panel the high-mass bin.

FIG. 5: Efficiency plots for a coherent known-sky search for GRBs with two different sky positions occurring at the same time. Left panel shows low-mass bin, middle panel shows for medium-mass bin and right panel the high-mass bin.

We also studied how the sky-patch efficiencies vary with changing step-size. We choose three different step sizes for the sky-patch grids, namely 1 degree (default), 0.5 degree (fine), and 2 degrees (coarse). The result shown in Fig. 4 reveals no significant change in efficiency, indicating that the choice of the step size is not going to cost us in efficiency at least up to a step-size of 2 degrees. Hence, we can improve in computational cost by choosing a coarse grid.
Estimation of binary black hole coalescence event rate exclusion plots with mass and spin parameters from burst search results.

Satya Mohapatra and Laura Cadonati

UMASS Amherst

Gravitational wave burst sensitivity and event rate upper limit exclusion plots are expressed in terms of root-sum-squared strain amplitudes, $h_{rss}$:

$$h_{rss}^2 = \int_{-\infty}^{\infty} |\tilde{h}(f)|^2 \, df$$

A high mass binary black hole coalescence (> 100 $M_\odot$) waveform resembles a short duration (10 ms to < 1 s) GW burst.

In this poster we estimate the event rate upper limit in binary black hole source parameter space by relating $h_{rss}$ of coalescence waveform with burst search results.

GWPAW2011
Uncovering the Progenitors of Short GRBs through 
HST Observations of Host Galaxies

Wen-fai Fong, Edo Berger (Harvard), Derek Fox (PSU) 

Short GRB progenitor: 
Merging neutron stars?

Host galaxy studies:
• Morphologies
• Offsets
• Light distribution

Long GRBs from Bloom et al. 2002

Poster #P16
A triggered search for gravitational wave bursts from GRBs with LIGO, GEO, and Virgo. On-source window is [-600,60] seconds.

Uses the X-pipeline coherent analysis package. It’s the same method as the S5/VSR1 GRB burst search (arXiv: 0908.3824).

Astrowatch: Oct 2007 to June 2009. The LIGO 4km detectors were offline for planned enhancements. The LIGO H2, GEO, & Virgo detectors acquired science data on a best-effort basis.

→ 361 GRBs, 53 with sufficient data to analyze. Short and long.

Caveat: all 53 GRBs are doubly coincident between {H2,V1} and GEO. The G1 detector’s sensitivity is only comparable to H2 & Virgo at hi-freq. So, our search band is 400-1800Hz; have adjusted astrophysical simulations to consider likely GW signals in this band.
Search for long gravitational-wave bursts and high-energy neutrino coincidences

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- Sources for GWs and HENs
  - (GRBs, Microquasars, SGRs etc.,)
- STAMP (box search)
- HEN triggers from IceCube and ANTARES
- Spatial and Temporal triggers
Bayesian approach to multi-messenger astronomy: Population study of gamma-ray bursts
Marc Normandin & Soumya Mohanty
The University of Texas at Brownsville

Abstract
Several astrophysical models predict gravitational wave (GW) emission from gamma-ray burst (GRB) progenitors, although the GW signal to noise ratio (SNR) associated with single events ("trigger") is expected to be too low for detection in the majority of GRB triggers. It is possible, however, to combine data from several GRB triggers to look for the GW signature of the progenitor population as a whole. This involves estimating the parameters of the underlying astrophysical distribution from which an observed set of triggers is obtained.

We present an improved algorithm for population study which optimally uses information obtained from the electromagnetic counterpart of events. Existing methods do not associate suitable weight factors to the GRB triggers besides trivial ones like a hard cutoff on flux. However, the assignment of weights needs to take into account the background astrophysical distribution to be estimated. This is done using the Bayesian approach where electromagnetic data is explicitly incorporated into the likelihood functional of GW data before the parameters of a given population distribution are estimated.

We demonstrate a preliminary version of this method using simulated data corresponding to simplified models of GW and electromagnetic detectors along with quasi-realistic astrophysical population models.

Background
The basic idea behind a population study approach is that even if we do not detect the signal in conjunction with a given GRB trigger, it is still present in the GW data. Thus, by suitably combining data from multiple triggers, the SNR of the association between the set of triggers and a whole class of GWs can be increased. This idea was developed and analyzed quantitatively in the context of GWs and GRBs by Finn, Hannam and Romano in (11) (FHR).

An improved version of the FHR method was derived in (2) from first principles using a likelihood-based approach. In (3) it was shown that a population study analysis can significantly improve the reconstruction of the distribution in the associated GRB with a set of associated GW triggers. One of the key points of this method is that the prior belief in such a detection is weak at best. This study shows that population study and single-trigger searches are mutually complementary, and that both are essential.

Scientifically, a population study on the data from current and planned GW detectors is important. In an extensive review, Kajita and Yagi (4) have shown that an extragalactic origin is more likely, with the detection of a single GRB triggering, for example, one-megarayon detection per year in a collapser GRB with advanced LIGO. On the other hand, the number of GRBs occurring per year in the large (1<200) 10 GRBs) and 10 GWs are associated with GRBs, then even for a small, weak signal is present in the data. A population study can potentially uncover this association or put astrophysically interesting constraints on it. The same holds for other types of triggers, and a population study on SNR triggers, which are also collected in large numbers, has been proposed (5). It is also important to note here that there is a significant room for improvement in the sensitivity of population studies, particularly in the future of the LIGO detectors, as they are expected to be much more sensitive than the current data set.

We note that population study is listed in the LSC data analysis work paper (Sec. 3.2 and 3.3.1) as a required analysis project for SG data and beyond.

Analysis Algorithm

The basic idea behind the population study approach is that even if we do not detect the signal in conjunction with a given GRB trigger, it is still present in the GW data. Thus, by suitably combining data from multiple triggers, the SNR of the association between the set of triggers and a whole class of GWs can be increased. This idea was developed and analyzed quantitatively in the context of GWs and GRBs by Finn, Hannam and Romano in (11) (FHR).

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Implementation

The analysis algorithm was implemented in MatLab 7.11.3 (R2010b) and utilized the Parallel Computing Toolbox. We used the LIGO-T016004 and LIGO-T016006 datasets to test our algorithm. The datasets are composed of long (4096 s) and short (640 s) (16) GWs, each carrying 240-census at frequency of 1.36 Hz, supported by two QuaD Core Intel Xeon E5450 3.2 GHz two-socket processors. The analysis was run in parallel using 8 workers, which significantly reduced the computation times.

The bulk of the computation time is spent in determining the conditional probability of the GW cross-correlation. This computationally intensive step can be performed for each trigger in parallel.

In the future we plan to parallelize more of the code and run it onAsync as well as UTB's larger Future computer cluster.

Conclusions

Our main conclusions are as follows:

(1) The model calculation described here clearly demonstrates the feasibility of using the Bayesian approach for population study.
(2) The ad-hoc weight factors need to be used in selecting an optimal set of triggers. The algorithm presented here automatically allocates suitable "weights" to the triggers depending on what is being asked of the data for different classes of astrophysical distributions, the triggers should be weighted differently.
(3) Combining GW observations with electromagnetic data from other telescope arrays could result in a strong detection even if each telescope array individually fails to detect the source, thus doubling the reach of the triggers. However, further combining gamma-ray flux information leads to a significant improvement.

Future work

Work is in progress to extend the algorithm to include measured redshifts directly into the likelihood (if feasible). The method can combine triggers with or without redshift information into the same likelihood function.

Instead of using a standard cosine model, we will use different families of GW waveforms and a distribution for source-frame gamma-ray luminosity. For short GRBs we will use the output of imaging analysis pipelines as this class of GRBs is likely to arise from the merger of compact stars following an inspiral phase. For long GRBs we plan to replace the cross-correlation statistic with coherent network analysis statistic. Our proposed approach is quite general and can be used for other classes of triggers also, such as SNeIa.
Search for long gravitational-wave transients from gamma-ray bursts during LIGO S5 and S6

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- GRBs as potential source for GWs
- STAMP (locust and Hough algorithms)
- Gamma-ray bursts Coordinates Network
  - S5 - 212 triggers
  - S6 – 377 triggers
- Time window (-350 sec + 150 sec)
Radio Transients Surveys with ASKAP & the MWA

- ASKAP & MWA: new radio arrays under construction in Western Australia
- **ASKAP**: 0.7-1.8 GHz
  - 36 antennas, 12m each, 10” resolution
  - Focal plane arrays to achieve 30 deg$^2$ FOV
- **MWA**: 80-300 MHz
  - 512 tiles w/ 16 dipoles each, 5’ resolution,
  - Points through beamformers: no moving parts, can repoint in 8s, 1000 deg$^2$ FOV
- Both: real-time, sensitive surveys; good localizations; followup or discovery