

Gravitational Wave Search Using Gamma-Ray Burst Triggers

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We use LIGO data from a recent engineering run to set a statistical upper limit on gravitational-wave strain associated with Gamma-Ray Burst trigger events.

PACS numbers:

I. INTRODUCTION

Give basic information about the Engineering Run E7: dates, total data duration, lock segment duration etc. Refer to “master paper” with details about data taking, filtering, characterization, instrument status. Mention sensitivity levels and maybe include a figure with noise curve.

Describe main goal in this paper: set an upper limit on gravitational-wave strain associated with Gamma-Ray Burst (GRB) events detected during the period of the Engineering Run E7. Make brief statements about basic understanding of GRB origin, connection to compact objects and specifically black-hole formation, connection to gravitational wave emission (REF to one or two review articles).

Although ultimately a one-to-one GRB-GW association would be desirable, progress can also be made by searching for a statistical association of gravitational-wave strain with a whole sample of GRB triggers (REF to Mohanty et al.). Here we present such a statistical analysis of the recently obtained LIGO data. This method however has already been used in the past and applied on data from gravitational-wave bar detectors (right? REFS).

In the following section we discuss the current astrophysical understanding of GRB engines from the point of view of their connection to gravitational-wave emission. We then develop a number of possible criteria used to select data associated in time with GRB triggers. In Section III we describe the concept and basic analysis method we use to derive the upper limit on the gravitational-wave strain associated with any kind of external triggers, and in Section IV we discuss how this method is implemented in the specific case of the E7 data set and simultaneous GRB triggers obtained from the Inter-Planetary Network (IPN). In Section V we describe in detail the simulation calculations used to calibrate the trigger-based statistical method. In Section VI we present our results from the analysis of the complete set of selected triggers and associated E7 data using start-time and sky-location information for the GRBs (see Section VIA), as well as distance information (see Section VIB). In Section VIC we extend our analysis to include triggers with unknown sky locations, and in section VID we present results for sub-classes of GRBs with the specific characteristics. In Section VII we discuss

our results with a look into the future and the upcoming LIGO Science runs, we compare them to the current upper limits obtained with gravitational-wave bar detectors, and discuss how this method could be extended in the cases of other kinds of external triggers, i.e., supernovae and neutrino detections.

II. ASTROPHYSICAL MOTIVATION

Review current understanding of main classes GRB models for the main energy source. Discuss the implications of each model class for gravitational wave emission. What is the order in time of associated GW and EM signals? What are possible time lags between GW and EM signal? Are they different for different GRB models or are they more “universal” and derived based on simple arguments about the dynamics and energetics of the GRB engines?

Outline choices in data selection motivated by astrophysical understanding. Two ways to look for association: one-to-one and statistical for a whole sample of triggers. Acknowledge power of first, but point out astrophysical significance of second. For now concentrate on upper limits.

III. METHODOLOGY

Describe the basic concept of the statistical coincidence analysis. Go through all individual steps and explain in detail assumptions. Point out significance of the derivation of final result.

IV. ANALYSIS IMPLEMENTATION

A. SAMPLE OF GRB TRIGGERS

Give all information available for *all* GRBs detected during E7. If more than just start-time and position is known (if for example afterglows have been detected and host galaxies are debated in the literature, etc.) write short paragraphs for each of these “rich” events with the info, claims, and relevant references. Compile basic info in a Table with GRB number, start time, location, duration, basic spectral properties.

B. SELECTION OF GRAVITATIONAL-WAVE DATA STREAMS

For each of the GRB triggers, explain the condition of the relevant GW data streams. Describe all cuts imposed for a number of different reasons: one or more of the IFOs unlocked, vetoes from monitoring channels, etc.

Clearly identify GRB triggers selected for analysis and GW data segments for each trigger as well as cross-correlating channels.

Give details about time delay imposed on data from different sites based on GRB location measurements.

V. SIMULATIONS AND CALIBRATION

Explain what are the goals of the simulations and the calibration analysis: determining false rates and detection efficiencies.

Describe how the simulations were set up: types of signals (strength, duration, lags), injection method, numbers.

Give conclusions about false rates and detection efficiencies. Describe how these are used in the derivation of results.

VI. RESULTS

A. BASIC ANALYSIS

Present results for our main sample of triggers and basic analysis for different cases of assumptions (time delays etc.)

Results can include:

- confidence limits on GW strain in a certain bandwidth for a given GRB sample and time intervals
- limits on ratios of GW fluence over gamma-ray fluence

Present results in terms of Figures or Tables:

- On and Off-source distributions to show the differences
- Plot for different choices in GW cuts in time
- Show some representative cross-correlations

B. ANALYSIS WITH DISTANCE INFORMATION

Describe the modifications of the basic analysis if distances have been constrained for some of the GRB trig-

gers.

Derive results for such a sub-sample (if it exists).

C. ANALYSIS FOR NON-LOCALIZED EVENTS

Describe the modifications of the basic analysis if GRB positions are not known. Point out problems both conceptual and computational.

Derive results for such a sub-sample. Consider whether the analyses for the two samples (with and without known locations) can be combined into one coherent analysis to obtain a better constrained upper limit that takes advantage of the larger number of useful triggers.

D. ANALYSIS FOR GRB SUB-CLASSES

Discuss the motivation for such a separate analysis. It is possible that a subclass of GRBs with certain characteristics (long, short, soft, hard, long or short spectral time lags, etc.) has stronger GW emission possibly, for example, because their distances are systematically lower.

If such sub-samples exist present results and implications.

VII. DISCUSSION

Summarize main goals and results presented in this paper.

Comment on current and future status of LIGO and the implications for this kind of analysis for a statistical association. Comment on improvements to be expected not only with improved sensitivity but also with larger sample of GRB triggers.

What do the current results tell us about astrophysical models if anything ? (It's not certain whether we really want to comment on this or leave it to the astro community exclusively ...)

How could this method be applied to other kinds of triggers: SNe and neutrinos ?

Acknowledgments

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