Techniques in LSC Searches for GW Bursts Associated with GRBs

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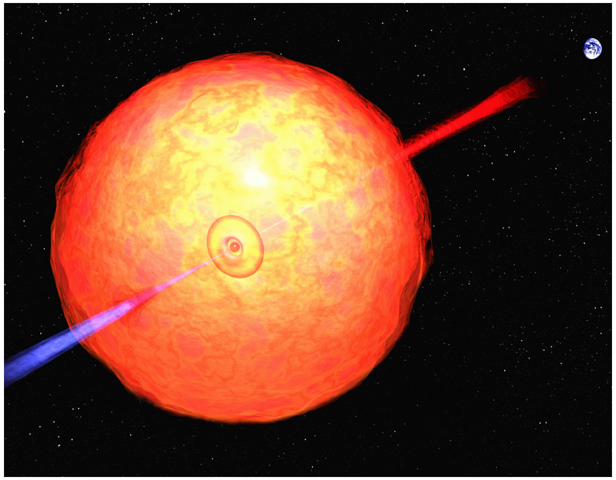
Outline

- Classes of GRB searches
- How GRB information is used in burst GW searches
- GW burst search techniques
- Search procedures
- Example: GRB070201
- Where we could use help

Why use Astrophysical Triggers?

- Ready association of detected GW signal with known astrophysical system
  - Will help extract maximum scientific information information.



- Know time of event
  - Can concentrate efforts to probe sensitively small amount of data around the event time.
- Often know sky position
  - Can account for time delay, antenna response of instrument in consistency tests
    - Better background rejection
- Sensitivity improvement:
  - Often a factor of ~2-3 in amplitude / 4-10 in energy.

GRB-based Searches for GWs

- LSC's GRB-triggered searches are motivated by the hypothesized progenitor.
- Short GRBs: widely thought to be produced by NS-NS or NS-BH coalescence.
  - GW emission well-modelled; can use matched filtering (Alex's talk)
  - See also James's talk on pulsar glitches
- Long GRBs: convincingly associated with hypernovae.
  - GW emission not well-modelled; need to use techniques for detecting generic ``bursts'' of GWs.
    - Less sensitive than matched filtering, but more robust.
  - LSC: Apply burst search techniques to both long *and* short GRBs
    - Just in case ...

How GRB Information is Used

- GRB trigger time
  - Look for GW signal within ~few minutes of the GRB
- GRB sky position
  - Search only the relevant portion of the sky, or
  - Veto candidates not consistent with the time delay between detectors.
    - Light travel time between LIGO sites = 10 ms
    - Light travel time LIGO and Virgo = 27 ms
- GRB redshift:
  - Used *a posteriori* in constraining characteristics of GRB population.

What we *don't* use

- GRB duration
  - except for classification of long/short GRB

- Temporal structure of the EM emission
  - Including, *e.g.*, late-time flares or other activity.

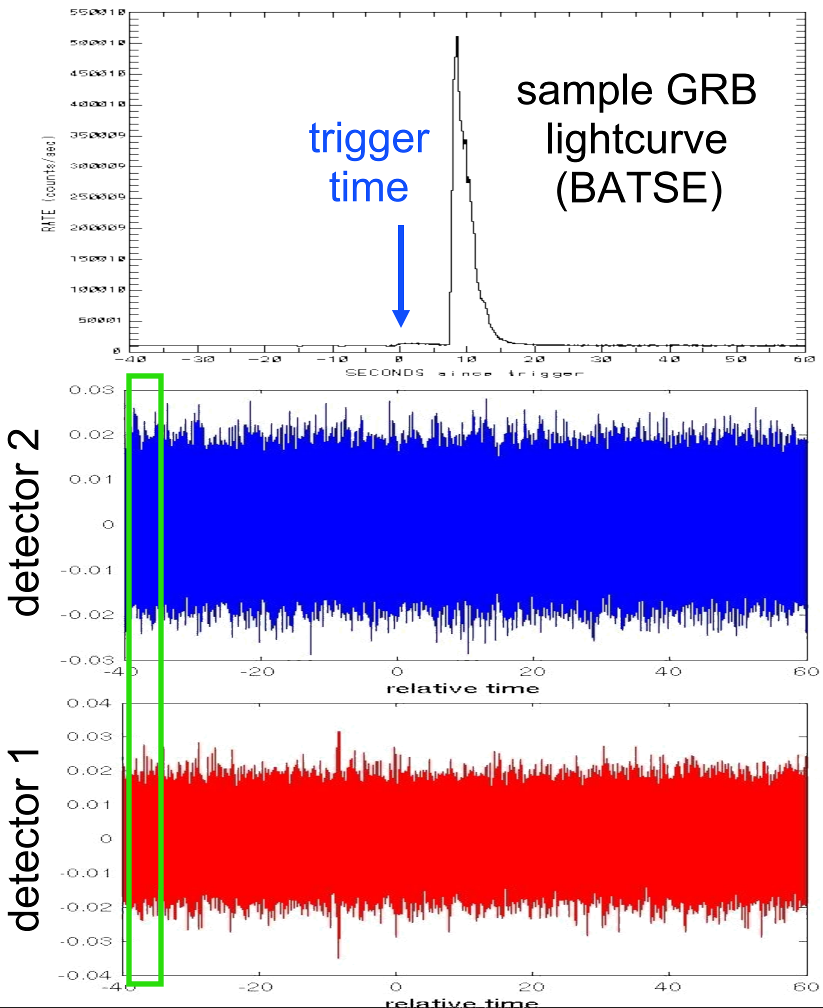
GW Burst Detection Algorithms

- Cross-correlation:
  - Measure correlation between data streams of pairs of detectors on 25 ms and 100 ms timescales.
  - Simple and robust.
  - Used in LSC science runs S2-S4 and for GRB070201 in S5.

- Coherent network methods:
  - Construct linear combinations of data from multiple detectors, weighted by relative sensitivity to the sky location of the GRB, to maximise the SNR of any GW signal present. Search time-frequency map of that data for excess energy.
  - Typically more sensitive than cross-correlation.

- Both of these types of searches are orthogonal / complementary to the Virgo WDF search procedure (Alessandra's talk).

Cross-Correlation Analysis

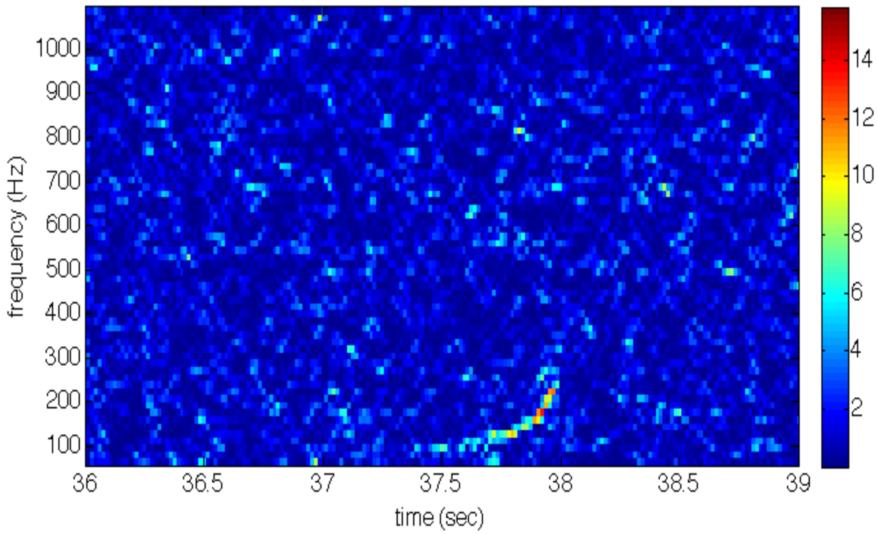


- Use triggers from satellites
  - Swift, HETE-2, etc.
  - Both short and long GRBs
- Correlate data between pairs of detectors around time of event
  - 25 – 100 ms target signal duration
  - [-2,+1] min around GRB
- Compare largest measured CC to neighbouring times with no GRB signal.
  - Compute distribution of CC values from neighbouring data.
  - Improbably large CC equals candidate GWB

Search Methods

- When the signal waveform is unknown (i.e., usually):
  - Cross-correlation of data from pairs of detectors (S2-S4 GRBs)
  - Excess power power analysis of each detector separately.
  - Coherent combinations of data from several GW detectors (aperture synthesis)
    - Next “big thing” in externally triggered searches.
  - All: look for any GW signal in the sensitive band of the detectors (~ 60 – 2000 Hz) with duration from ~1 ms to ~1 sec.

Excess power map: A simulated 1.4-10.0 M_o neutron star – black hole inspiral at an effective distance of 37 Mpc, added to simulated H1-H2 noise.



Chatterji et al., 2006 PRD 74 082005;
Klimenko et al., 2005 PRD 72 122002;
Rakhmanov M, 2006 CQG 23 S673

The Search

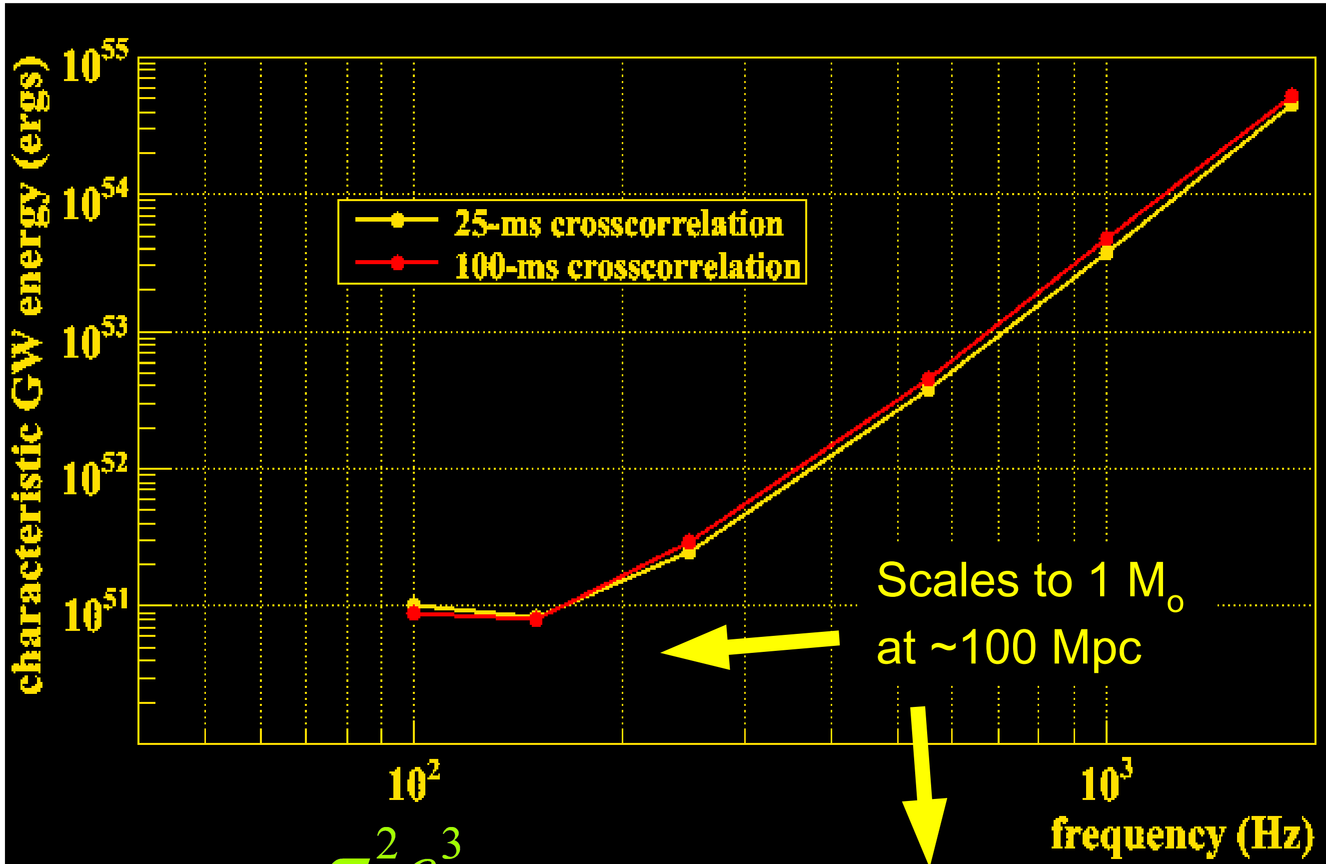
- The data is divided into two sets:
  - On-source: [-2, +1] min around the GRB trigger.
  - Off-source: all other data within +/- 1.5 hr of the GRB, divided into blocks of the same length as the on-source period.
- The on-source data is searched for large cross-correlations / excess energy events.
  - The significance of each cc / event is estimated by comparing to typical values in the off-source data.
- Assign probability to the “loudest” event
  - P := fraction of off-source blocks that produced event as loud.
  - Small P means a possible GW detection.
- Estimate minimum detectable GW signal amplitude by adding simulated GWs to the data and re-analysing.
  - Upper limit := signal amplitude/energy at which 90% of simulations are louder than the loudest on-source event.

Ex: Cross-Correlation Analysis of GRB 070201

Sky position consistent with M31 (Andromeda)

- $E_{iso} \sim 10^{45}$ erg at M31 distance (770 kpc)
- Plot: Energy limits vs. GW frequency from cross-correlation analysis
- LIGO cannot exclude SGR in M31.

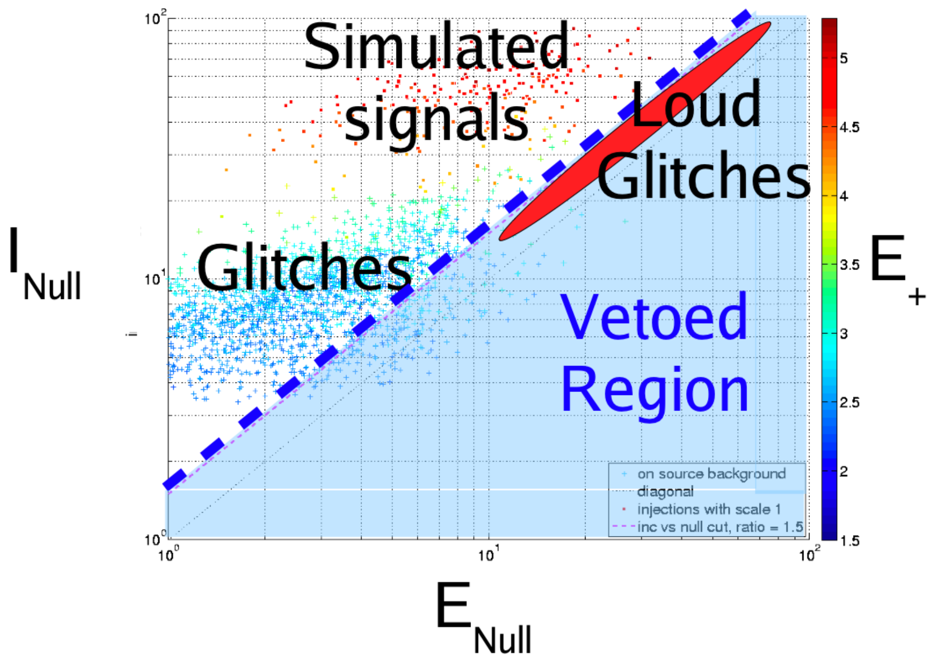
ArXiv:0711.1163; to appear in ApJ



$$E_{GW} \approx \frac{\pi^2 c^3}{G} D^2 f_0^2 h_{rss}^2 \sim 4.4 \times 10^{-4}\ M_{sun}$$

Coherent Methods & Glitches

- Coherent methods typically measure several properties of a GW candidate, such as the energy in each of the two GW polarizations.
  - Background noise glitches do not give same reconstructed polarizations as simulated GWs.
- Better information on, *e.g.*, polarization of GW emission from hypernovae would give stronger tests.

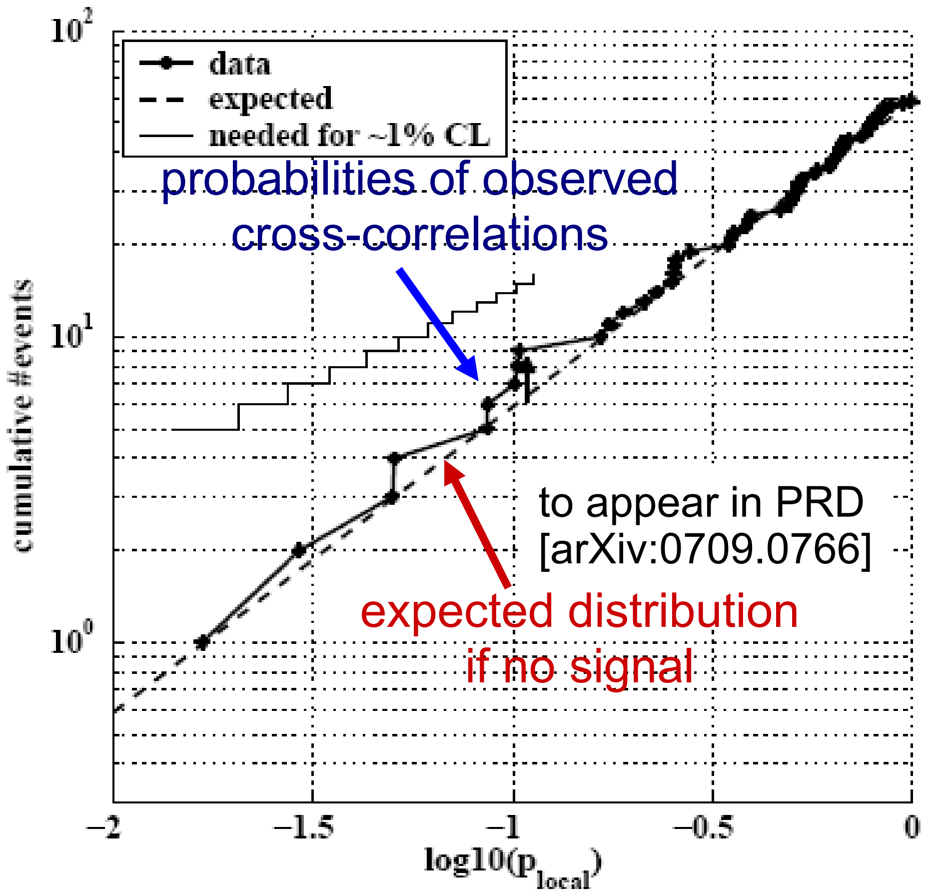


Events from analysis of simulated H1-H2 data

Statistical & Population Studies

- Statistical search for cumulative effect of many weak GWs
  - Plot: binomial test comparing distribution of probabilities of loudest events to that expected for null hypothesis.
- Constraining GRB population parameters:
  - demonstrated with toy-model standard-candle GW emission: Mohanty, CQG 23 (2006) S723-S732.
  - S5: Incorporate priors; e.g. redshift distribution model.

36 GRBs from S2-S4



Summary

- LSC has looked for GWs associated with GRBs for several years, using several different techniques.
  - S2, S3, S4 data (39 GRBs): cross-correlation algorithm.
    - Also statistical study.
  - SGR1806-20 hyperflare (Dec 2004): QPO search using single-detector excess power, looking at QPO-related frequencies.
    - Not discussed in this talk.
  - No detections yet.

- Expected for S5 (~213 GRBs):
  - Cross-correlation & coherent algorithms (in progress).
    - Network methods are expected to yield better upper limits (if no detection).
  - Large GRB (& SGR) dataset allows for more significant statistical studies.

How you can help.

- Choice of on-source interval.
  - Traditional: We look for GW signals in the window [-2, +1] min around the GRB. Can we tighten this?
  - Should we be looking at late-time flares?
- Waveforms!
  - Frequency ranges, durations, polarization, any similar info can be used to improve sensitivity.
- What ***not*** to bother looking for?