Searching for Gravitational-Wave Bursts

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Gravitational-Wave Bursts: Sources and Searches

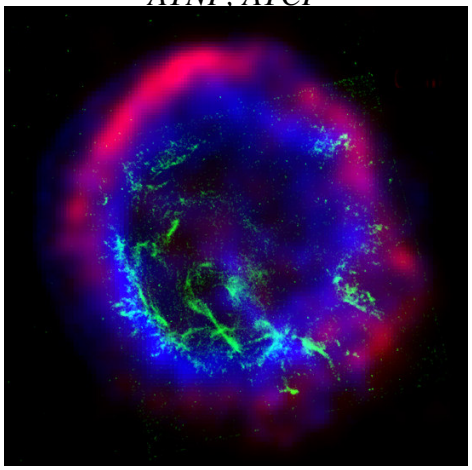
Astrophysical sources:

- possible sources are core-collapse supernovae, coalescing compact binaries, gamma-ray burst (GRB) engines, soft gamma repeaters, ???
- waveforms of gravitational-wave burst signals from these sources are unknown

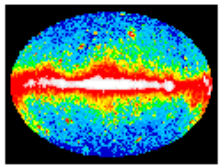
Search methods:

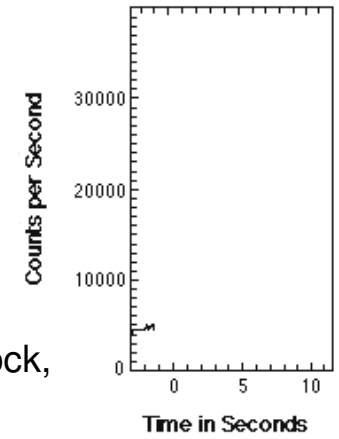
- untriggered search: perform an all-sky search using entire data set
- triggered search: analyze data which are contemporaneous with astrophysical events observed by other experiments, e.g. GRBs found by satellite experiments

SNR E0102-72
NASA, Chandra, SAO, Hubble
ATNF, ATCF



GRB





credit: Laura Whitlock, GSFC, NASA

Untriggered Search

Overview of the Most Mature Search Pipeline

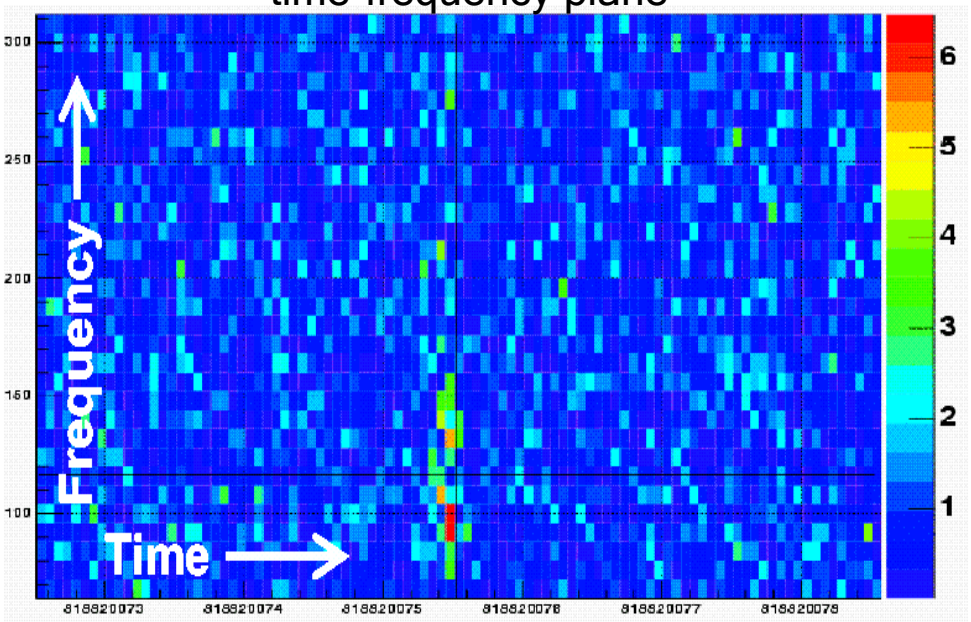
WaveBurst algorithm:

- measures signal power in time-frequency plane
  - signal time scale < 1 second
  - frequency range of 64-1600 Hz
- for each interferometer, WaveBurst searches for signals with power in excess of baseline noise

We require a candidate GW signal to:

- be seen in all three interferometers with a combined, overall significance above a pre-determined WaveBurst threshold
- be "coincident" in time at the three interferometers; have consistent amplitudes at H1 and H2; have consistent waveforms at the three interferometers

time-frequency plane



We estimate the background rate by:

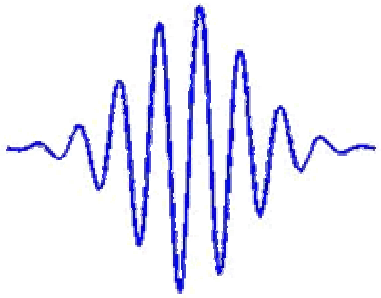
- shifting the LLO data stream relative to the LHO data streams, and then identifying events which pass the selection requirements

We analyze many auxiliary channels to decide on data quality cuts and vetoes

S4 Search Sensitivity for Sine-gaussian Waveforms

- sensitivity of search is measured by injecting burst-like waveforms, e.g. sine-gaussians, into data and performing search
- h_{rss}: root-sum-square strain amplitude of injected waveform
- efficiency curves give a measure of the sensitivity of the search at different frequencies

$$h_{\mathrm{rss}} = \sqrt{\int_{-\infty}^{+\infty} \left|h(t)\right|^2 \, dt}$$



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Results will be shown at review

We also use other types of waveforms.
Similar sensitivities expected for different waveforms with similar overall properties.

S4 Search Results

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Results will be shown at review.

Comparison of S4 Run Results to Published Results from Previous Runs

- S4 rate upper limit:

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Results will be shown at review.

- S2 rate upper limit:

published

$$R_{90} = 0.26 \text{ events per day}$$

- S1 rate upper limit:

published

$$R_{90} = 1.6 \text{ events per day}$$

published

(S3 sensitivity: ~10e-20 strain/$Hz^{1/2}$)

S5 Run Preliminary Burst Search Results

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Triggered Searches

Triggered Searches

- analyze segments of data which coincide with astrophysical events observed by other experiments to look for associated gravitational-wave bursts
- one can think of this as “pointing” the detectors at the target astrophysical source for short time intervals --- this decreases the amount of background noise significantly

We currently use the following astrophysical events as triggers:

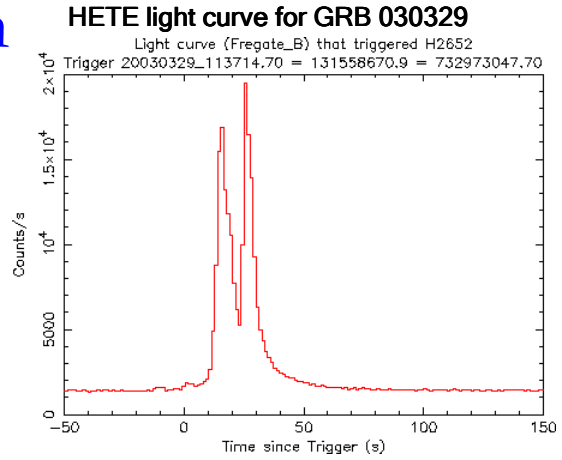
- cosmic gamma-ray bursts (GRB) detected by satellite experiments
- hyperflares from soft gamma repeaters (SGR) or magnetars detected by satellite experiments

Analysis methods:

- crosscorrelate IFO data streams in pair-wise manner to search for correlated signals
- search for excess power in data spectrum

Gamma-ray Burst 030329 / SN2003dh (S2 Run)

- bright and "nearby" GRB
- z = 0.1685, D_L = 800 Mpc



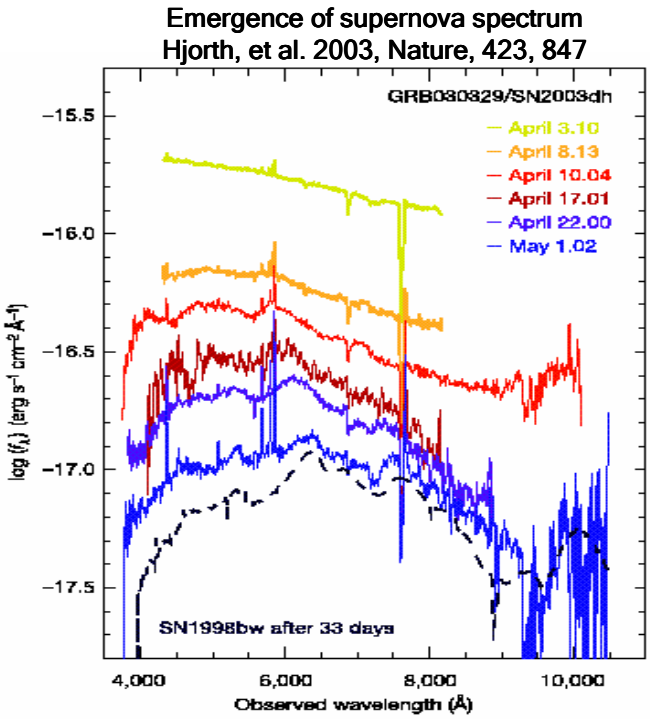
Search of S2 LIGO data showed no GW burst signal associated with this GRB. The measured hrss upper limits correspond to an energy emitted in GW waves of:

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

published

$$E_{GW} \sim 10^5 M_{sun}$$

We expect to improve on this!



39 GRB Triggers used to Search for GW Bursts in S2, S3, S4 Runs

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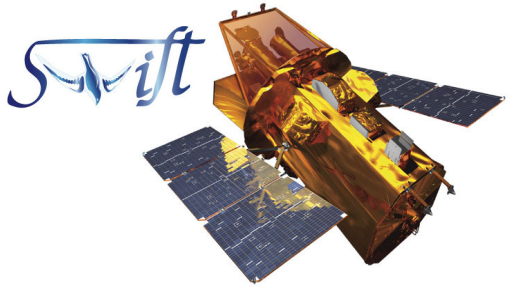
GRB Triggers for S5 Run



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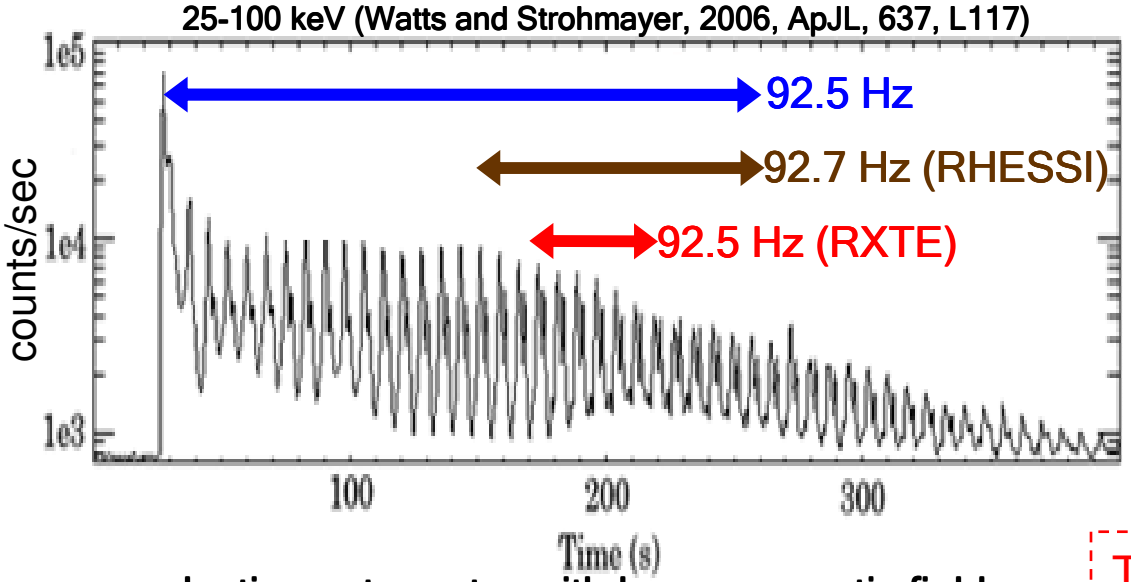
- Swift satellite experiment was launched November 2004, started detecting GRBs
- 10 GRB triggers per month
- 117 GRB triggers for S5 as of October 7, 2006

Search for GW Signal Associated with December 2004 Hyperflare from SGR 1806-20



- galactic neutron star with huge magnetic field
- at a distance of 7.5-15 kpc
- source of record gamma-ray flare on December 27, 2004
- flares thought to be caused by "starquakes" - magnetic stresses cause crust to break and release energy
- had pulsating tail lasting 6 minutes - quasi-periodic oscillations found

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Results will be shown at review.

Other Ongoing Projects Related to Burst Searches

In our zeal to dig out gravitational-wave signals from the data, we have developed several analysis projects and search algorithms, in various stages of maturity, among them:

- Joint analyses with GEO and Virgo
- Network analysis methods
- Q Pipeline
- KleineWelle
- Excess Power
- AstroBurst
- GRB population study

For triggered searches, we plan to expand the astrophysical sources used as triggers, e.g.,

- supernovae
- neutrinos
- other hyperflare events from soft gamma repeaters

Summary

- We have gained considerable experience in searching LIGO data for gravitational-wave bursts ➔ several published papers, more in the works
- We perform both an all-sky, untriggered search, and searches triggered by astrophysical events detected by other experiments
- There was about an order of magnitude improvement in sensitivity from the S2 to the S4 run

- The burst group is abuzz with activity as we continue to improve our search algorithms and develop methods to search for gravitational-wave bursts!