Search for Gravitational-Wave Bursts (GWBs) Associated with Gamma-Ray Bursts (GRBs) Using LIGO Detectors

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Outline of GRB-GWB search

- search for short-duration gravitational-wave bursts (GWBs) coincident with gamma-ray bursts (GRBs)
- use GRB triggers observed by satellite experiments
  - Swift, HETE-2, INTEGRAL, IPN, Konus-Wind
  - include both “short” and “long” GRBs
- search 180 seconds of LIGO data surrounding each GRB trigger (on-source segment)
- waveforms of GWB signals associated with GRBs are not known
- use crosscorrelation of two interferometers (IFOs) to search for associated GW signal

$$crosscorr = \frac{\sum_i x_i y_i}{\sqrt{\sum_j x_j^2}\sqrt{\sum_k y_k^2}}$$

correlated signal in two IFOs
➔ large crosscorr

- use crosscorrelation lengths of 25 ms and 100 ms to target short-duration GW bursts of durations ~1 ms to ~100 ms
- use bandwidth of 40 Hz to 2000 Hz

The GRB sample for LIGO S2/S3/S4 runs

- **S2: 28 GRBs** with at least double coincidence LIGO data
  - 24 for LHO 4km – LHO 2km
  - 9 for LHO 4km – LLO 4km
  - 9 for LHO 2km – LLO 4km
- **S3: 7 GRBs** with at least double coincidence LIGO data
  - 7 for LHO 4km – LHO 2km
  - 0 for LHO 4km – LLO 4km
  - 0 for LHO 2km – LLO 4km

IPN, HETE-2, INTEGRAL, Konus-Wind (pre-Swift)

- **S4: 4 GRBs** with at least double coincidence LIGO data
  - 4 for LHO 4km – LHO 2km
  - 3 for LHO 4km – LLO 4km
  - 3 for LHO 2km – LLO 4km

start of Swift era

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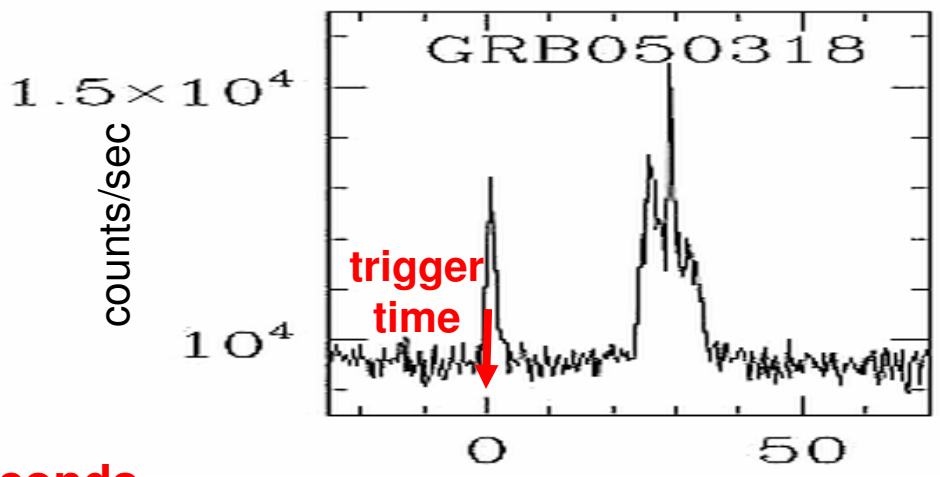
59 LIGO on-source pairs analyzed

- only well-localized GRBs considered for LHO – LLO search

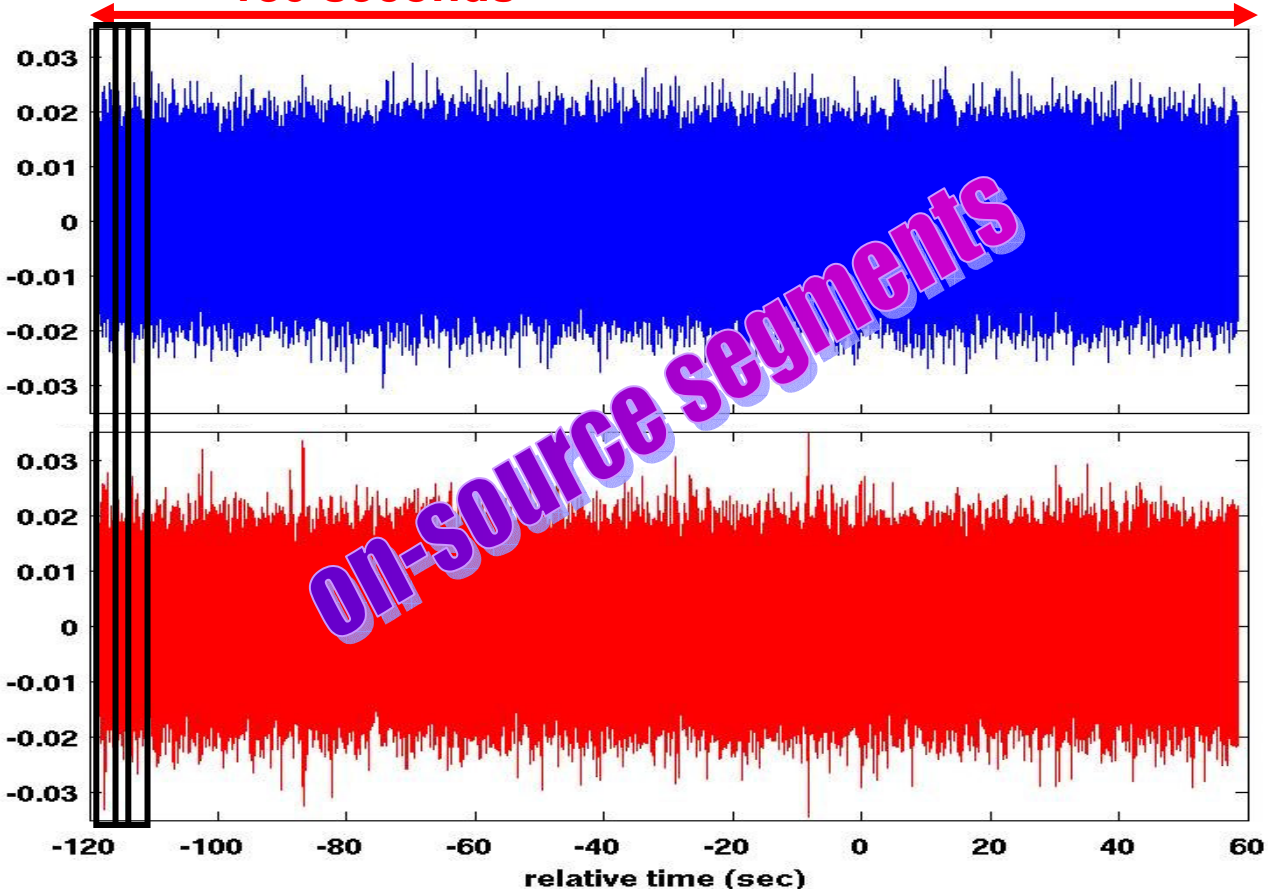
sample GRB lightcurve (Swift)



180 seconds

LIGO IFO 1

LIGO IFO 2

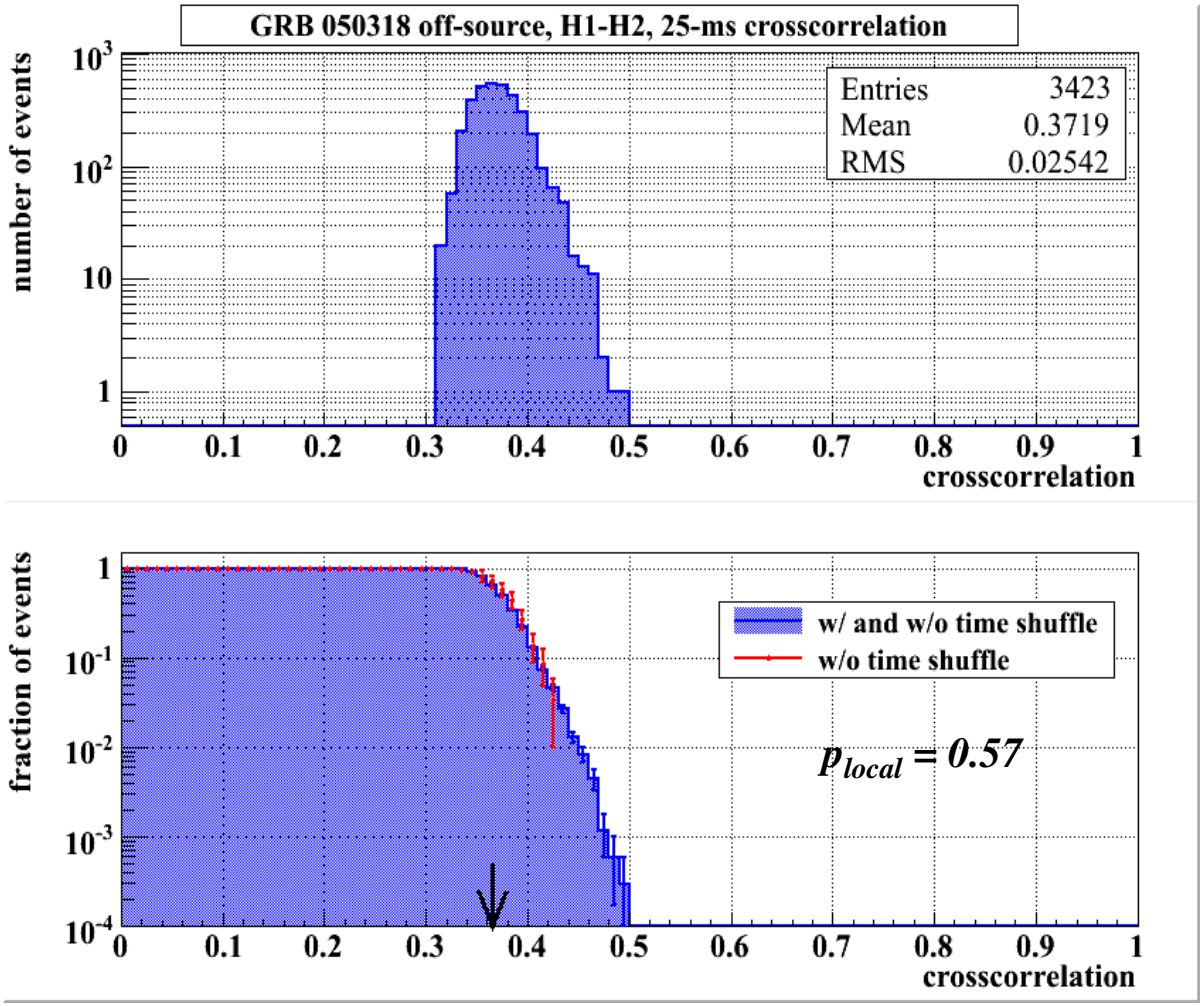


use 180-second LIGO on-source data surrounding GRB trigger

crosscorrelate output of two IFOs

look for largest crosscorrelation within 180-second on-source segment

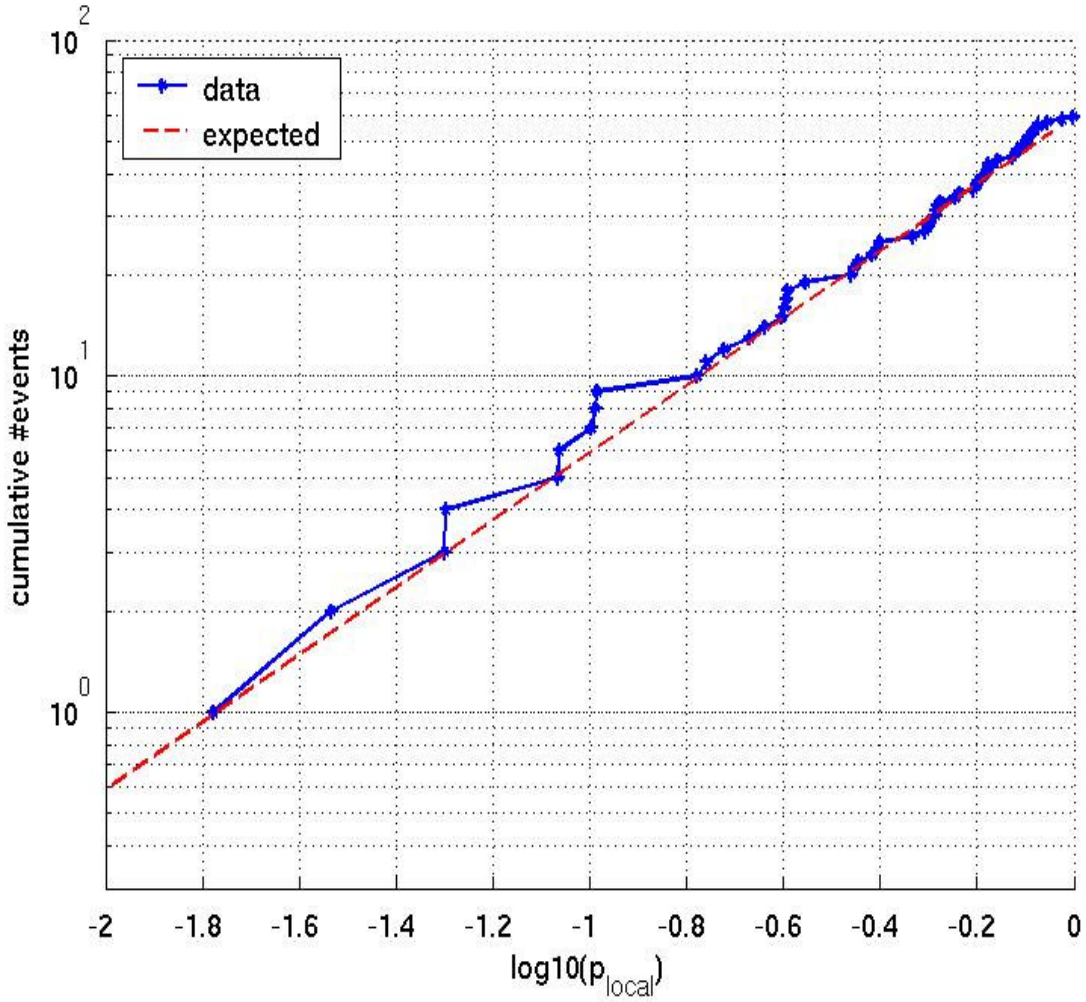
Estimating probability of measured on-source largest crosscorr: Sample off-source distribution using 25-ms cc length



- apply search to off-source segments to obtain crosscorrelation distribution
- use time shifts to get enough statistics
- largest crosscorrelation found in on-source search indicated by black arrow
- **probability is estimated using this distribution**
- off-source crosscorrelation distribution is determined for each IFO pair for each GRB trigger

Results: Cumulative distribution of local probabilities

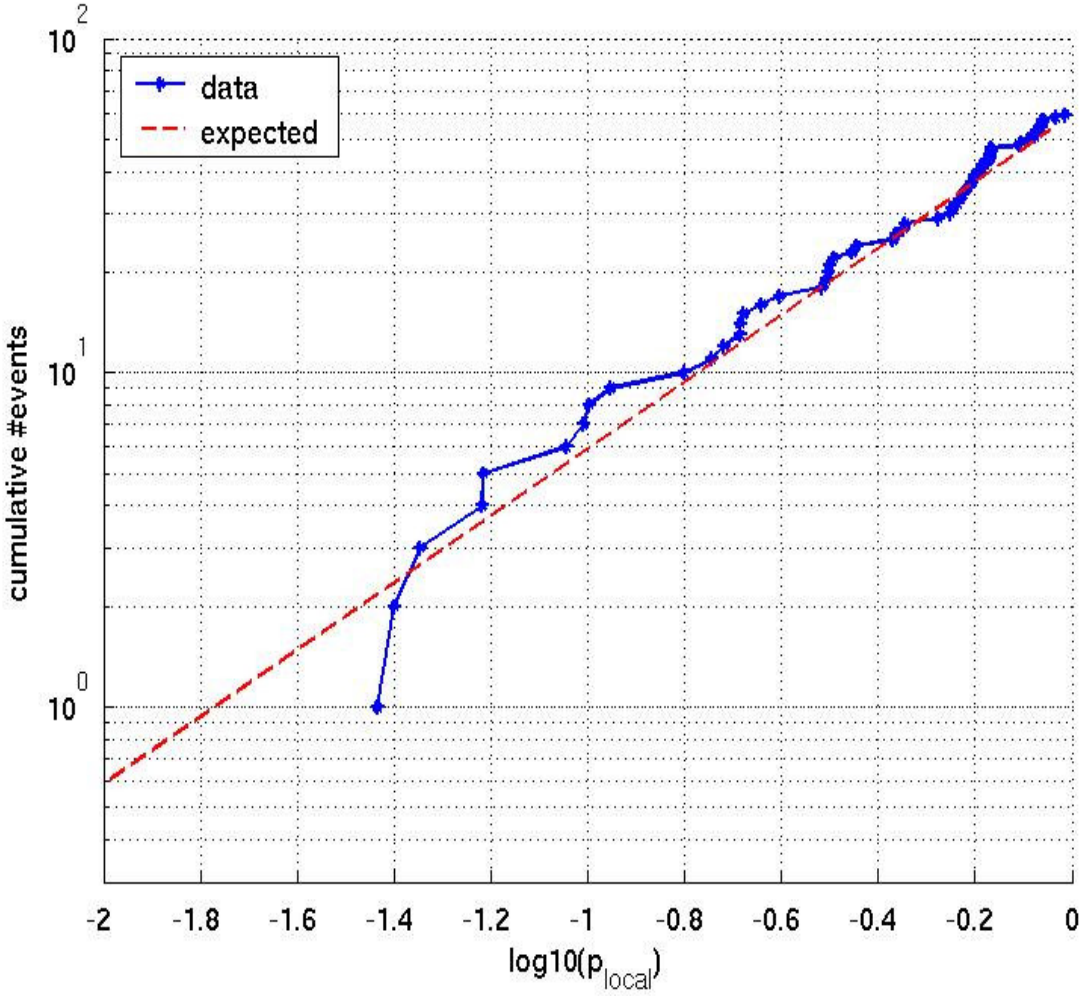
25-ms crosscorrelation length



- 59 entries -- includes all GRBs, all IFO pairs
- expected distribution of probabilities under null hypothesis is uniform from 0 to 1
- **no loud event from any GRB**
- perform statistical test on this distribution

Results: Cumulative distribution of local probabilities

100-ms crosscorrelation length



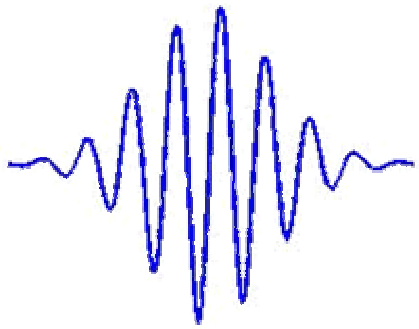
- 59 entries -- includes all GRBs, all IFO pairs
- expected distribution of probabilities under null hypothesis is uniform from 0 to 1
- **no loud event from any GRB**
- perform statistical test on this distribution

Statistical tests

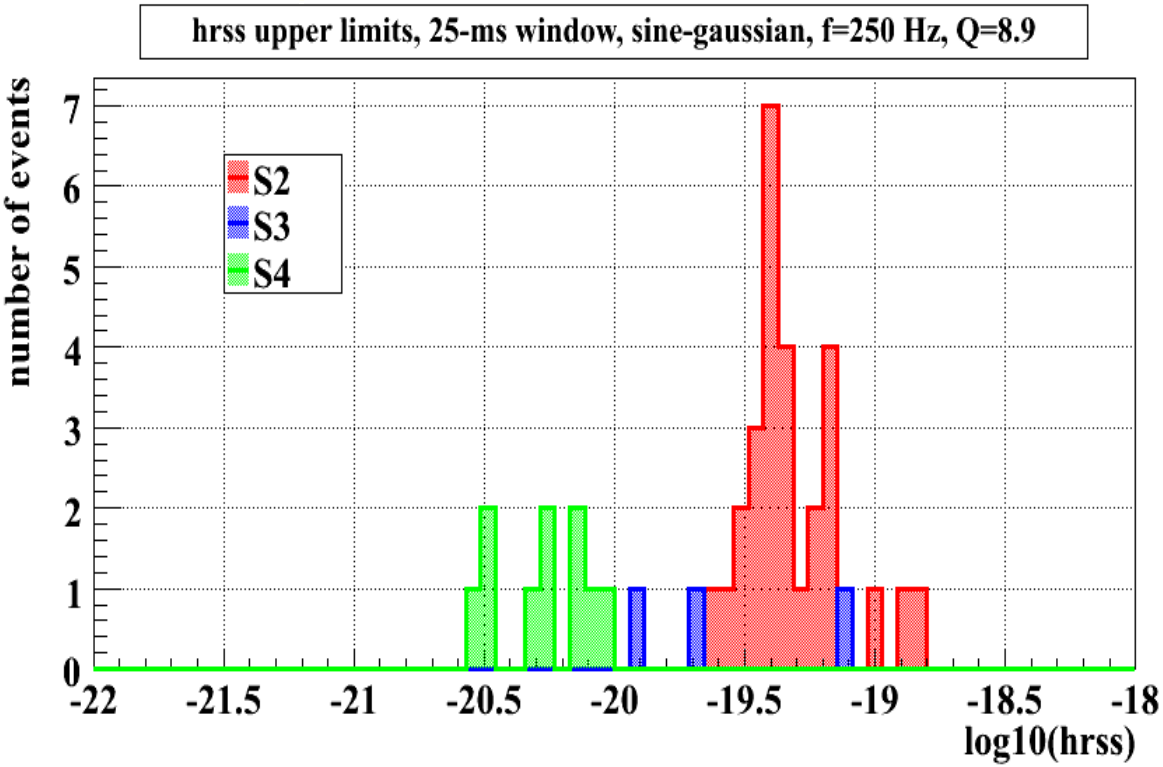
- statistical search: search for weak signals which, individually, would not comprise a detection, but together could have a detectable cumulative effect on measured distributions
- binomial test: search local probability distribution for deviation from expected distribution
- rank-sum test: test if medians of on-source crosscorrelation distribution and off-source crosscorrelation distribution are consistent with each other

Result of tests: On-source and off-source crosscorrelation distributions are statistically consistent.
Null hypothesis cannot be rejected.
No GW signal seen from statistical search.

S2/S3/S4 $\mathbf{h_{rss}}$ 90% upper limits for sine-gaussians



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



- GW waveforms not known
- inject simulated sine-gaussians into data to estimate search sensitivity
- use linear polarization
- take into account antenna response of interferometers

- S2 best $\mathbf{h_{rss}}$ limit (250 Hz):
  - **2.5E-20 $Hz^{-1/2}$**
- S3 best $\mathbf{h_{rss}}$ limit (250 Hz):
  - **1.2E-20 $Hz^{-1/2}$**
- S4 best $\mathbf{h_{rss}}$ limit (250 Hz):
  - **3.0E-21 $Hz^{-1/2}$**

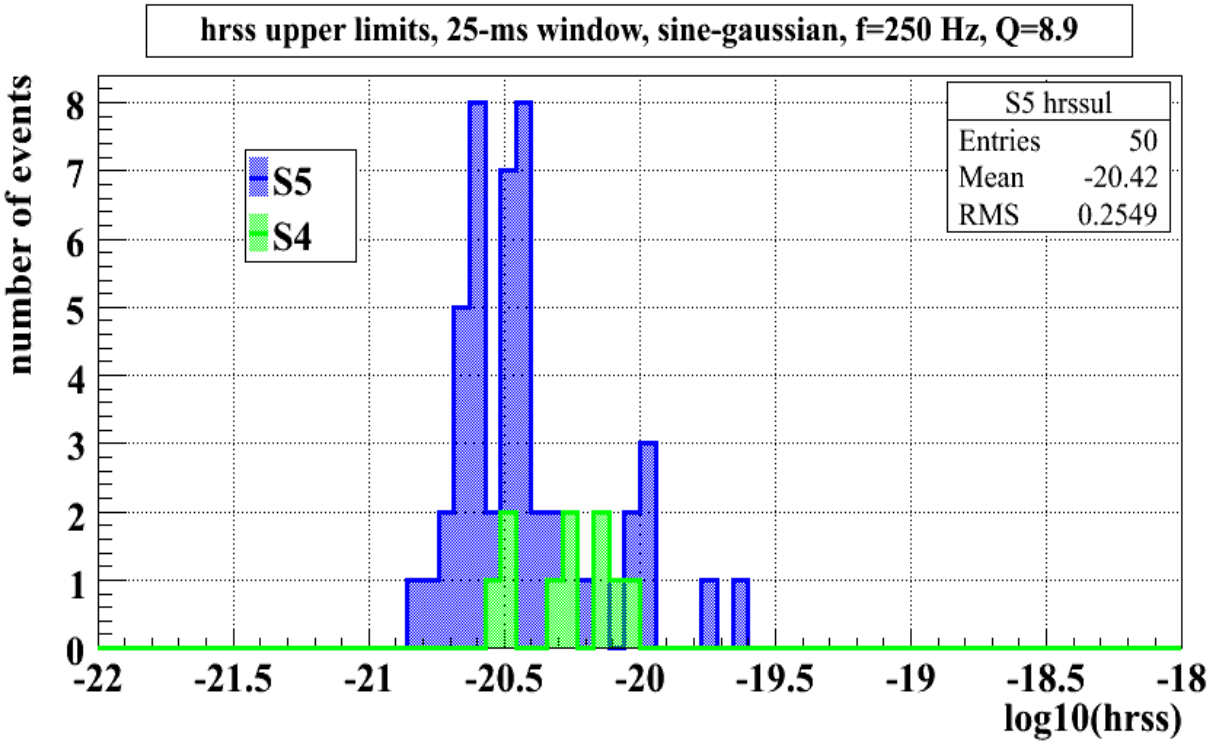
S5 GRB-GWB Search: Preliminary Results

- Goal: One year of coincident science run at LIGO-1 design sensitivity
- currently ongoing
- commenced November 4, 2005

The GRB sample for LIGO S5 run

- 53 GRB triggers in 5 months of LIGO S5 run (as of April 10, 2006)
  - most from Swift
  - 16 triple-IFO coincidence
  - 31 double-IFO coincidence
  - 6 short-duration GRBs
  - 11 GRBs with redshift
    - z = 6.6, farthest
    - z = 0.0331, nearest
- performed GW burst search on this sample using same pipeline
  - No loud events seen that are inconsistent with expected probability distribution

S5 GRB-GWB preliminary sensitivity: Upper limits on $\mathbf{h_{rss}}$ at 250 Hz



- 90% UL on $\mathbf{h_{rss}}$
- Q = 8.9, f = 250 Hz sine-gaussian
- S5 best $\mathbf{h_{rss}}$ (so far):

1.5E-21 $Hz^{-1/2}$

Relating $\mathbf{h_{rss}}$ sensitivity to an astrophysical quantity

- Energy radiated by a source in gravitational waves:

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

- We might expect to be sensitive to GW bursts out to a distance of:

$$D \sim 100\ Mpc \left(\frac{100 Hz}{f_c}\right)\left(\frac{10^{-21} Hz^{-1/2}}{h_{rss}}\right)\left(\frac{E_{GW}}{M_\odot c^2}\right)^{1/2}$$

factor depends on GW polarization, source position and orientation

S4: ~3E-21 $Hz^{-1/2}$
S5: ~1.5E-21 $Hz^{-1/2}$

Summary

- We have performed a search for short-duration GW bursts associated with 39 GRBs detected by satellite experiments during dates of LIGO's S2, S3, and S4 runs
- We found no evidence for GW bursts associated with GRBs using this sample
- Using simulated sine-gaussian waveforms, we have estimated the search sensitivity and set 90% upper limits on the root-sum-square strain amplitude, with a best $\mathbf{h_{rss}}$ limit for the S4 run of ≈3.0E-21 $Hz^{-1/2}$ at 250 Hz
- We are using the same method to search for GW bursts associated with GRBs detected by Swift (mostly) and other satellite experiments during LIGO's ongoing S5 run
- The best S5 GRB-GWB sensitivity at 250 Hz, i.e. 90% $\mathbf{h_{rss}}$ upper limit, is ≈1.5E-21 $Hz^{-1/2}$