Searching for Gravitational-Wave Bursts (GWBs) associated with Gamma-Ray Bursts (GRBs) during the LIGO S5 run

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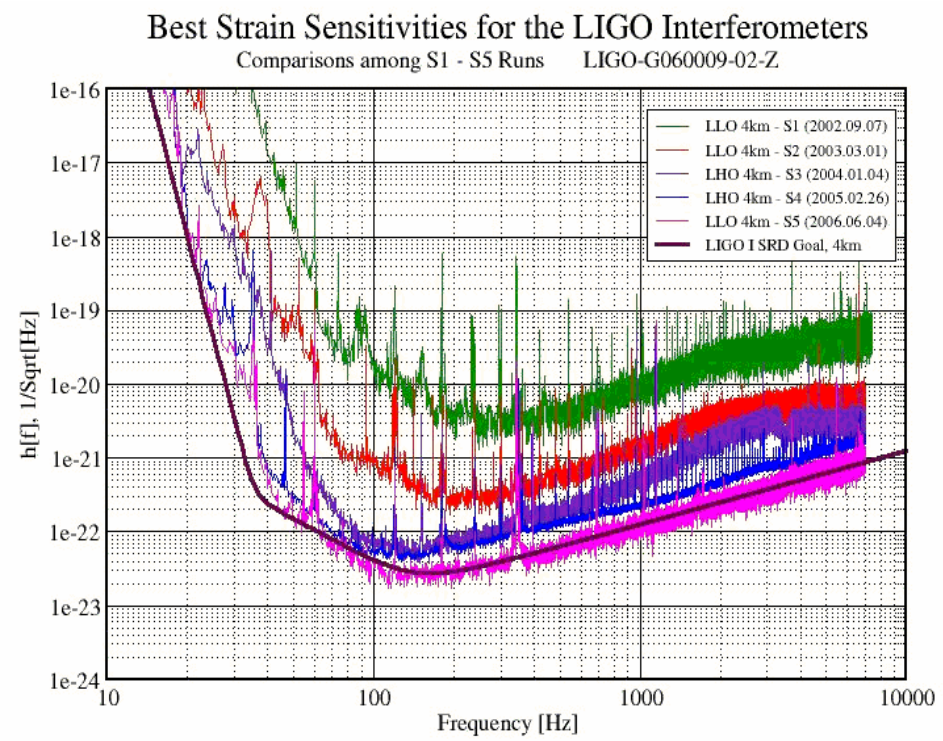
Brief description of LIGO S5 run

- Goal: one year of inter-site, two-interferometer coincident data at LIGO-1 sensitivity
- commenced Nov. 4, 2005
- currently ongoing, about 75% of the way through the S5 goal



Some GRB-GWB models

search method independent of model

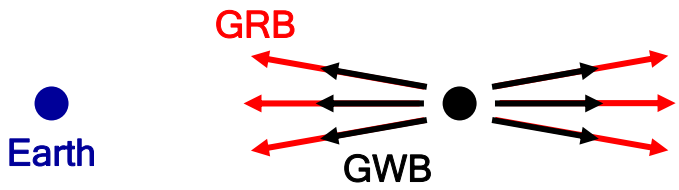
- short-duration GRBs
  - coalescing compact binaries
  - e.g. neutron star–neutron star mergers
  - possible scenario: circularly polarized gravitational waves

$$h_+ \propto 1+\cos^2\theta; \quad h_x \propto \cos\theta$$

where θ is the angle wrt symmetry axis

  - measured redshifts are smaller

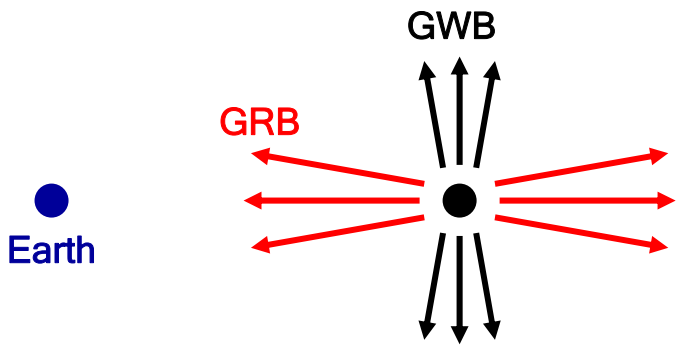
➔ more favorable for detection of gravitational waves



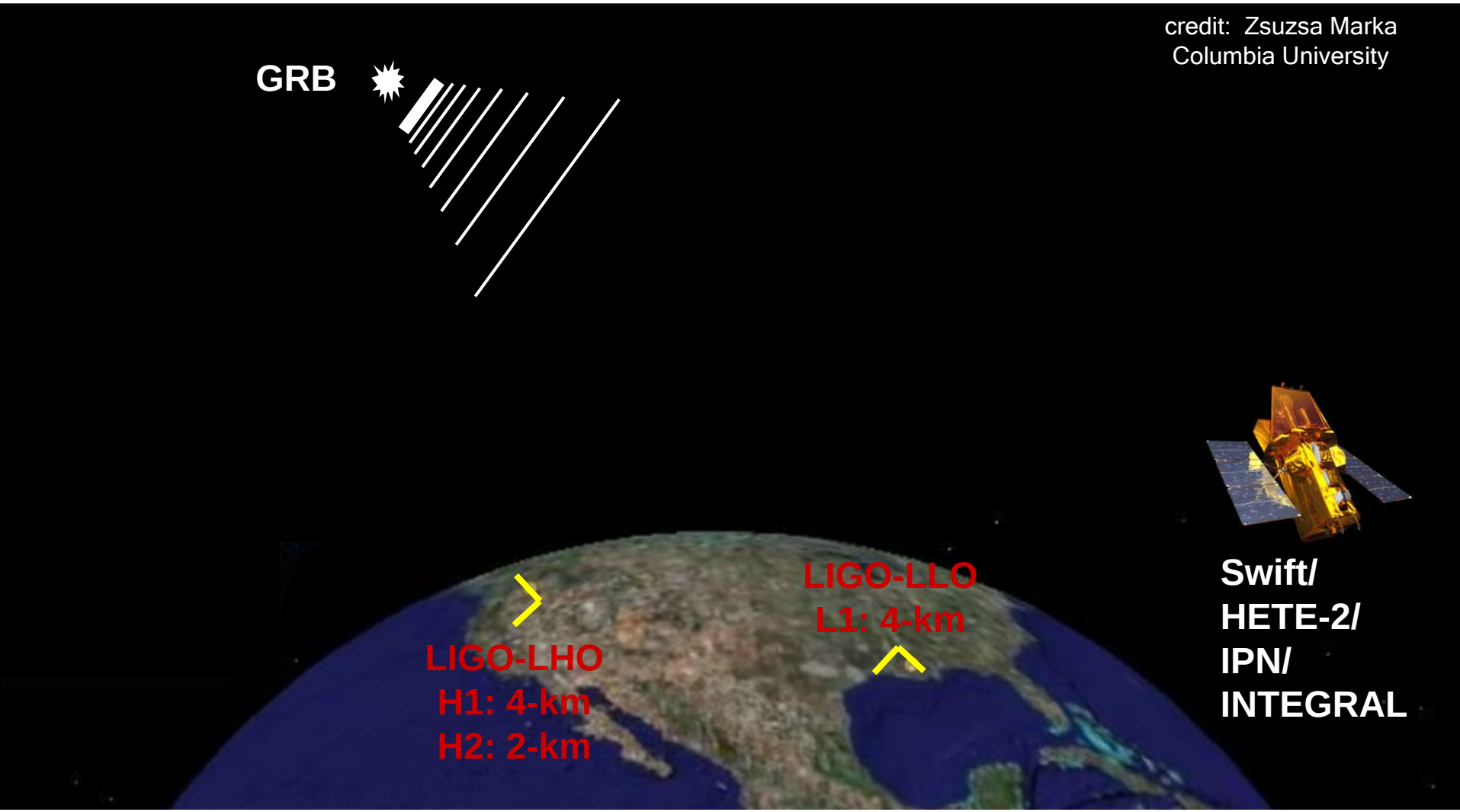
- long-duration GRBs
  - core-collapse supernovae
  - possible scenario: linearly polarized gravitational waves

$$h \propto \sin^2\theta$$

➔ not very favorable for detection of gravitational waves

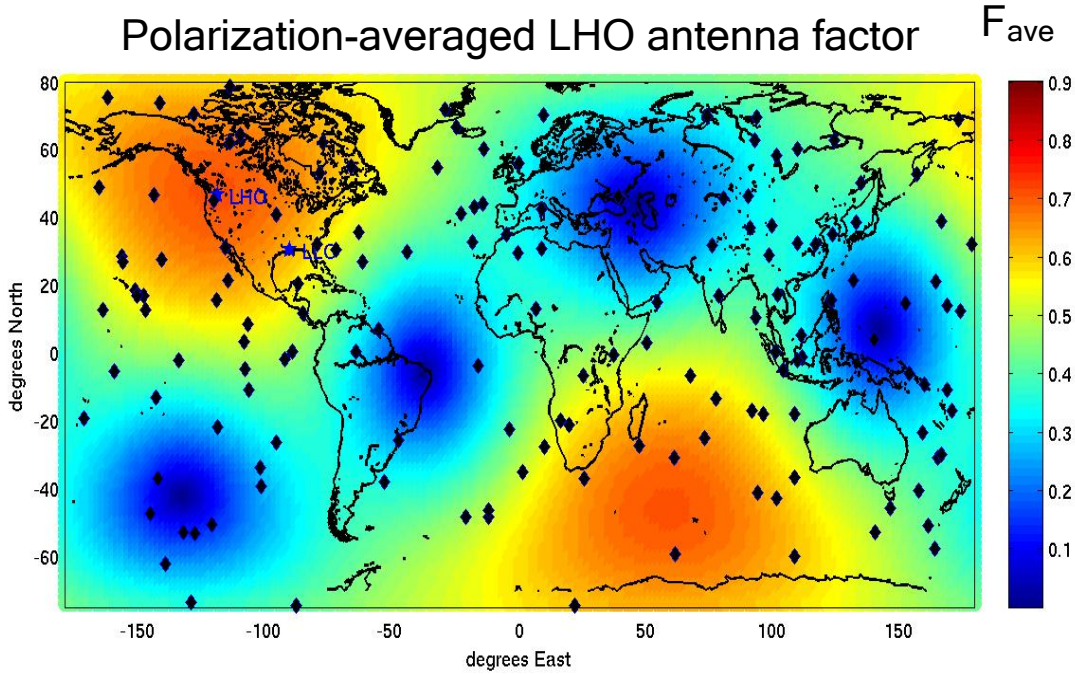


GRB-GWB search overview



The current GRB sample for the LIGO S5 run

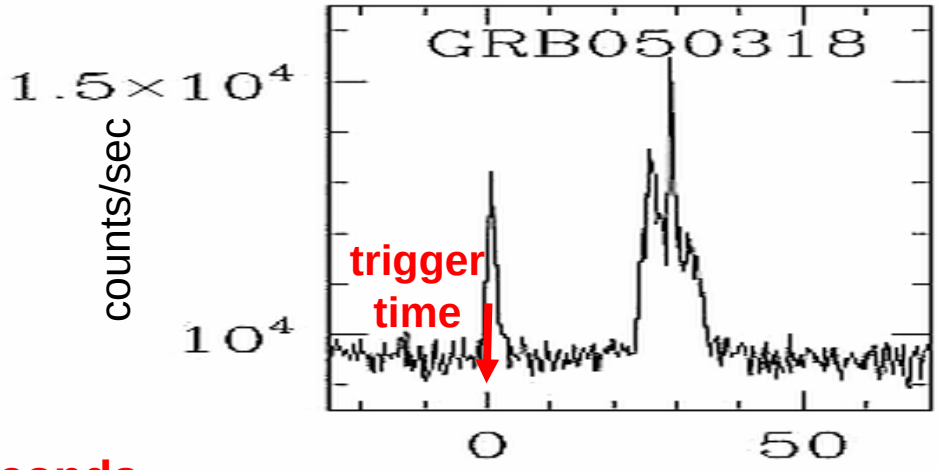
- 157 GRB triggers from November 4, 2005 to March 31, 2007
  - ~70% with double-IFO coincidence LIGO data
  - ~40% with triple-IFO coincidence LIGO data
  - ~25% with redshift
  - ~10% short-duration GRBs
  - all but two have have position information



LIGO sensitivity depends on GRB position

- analysis is ongoing

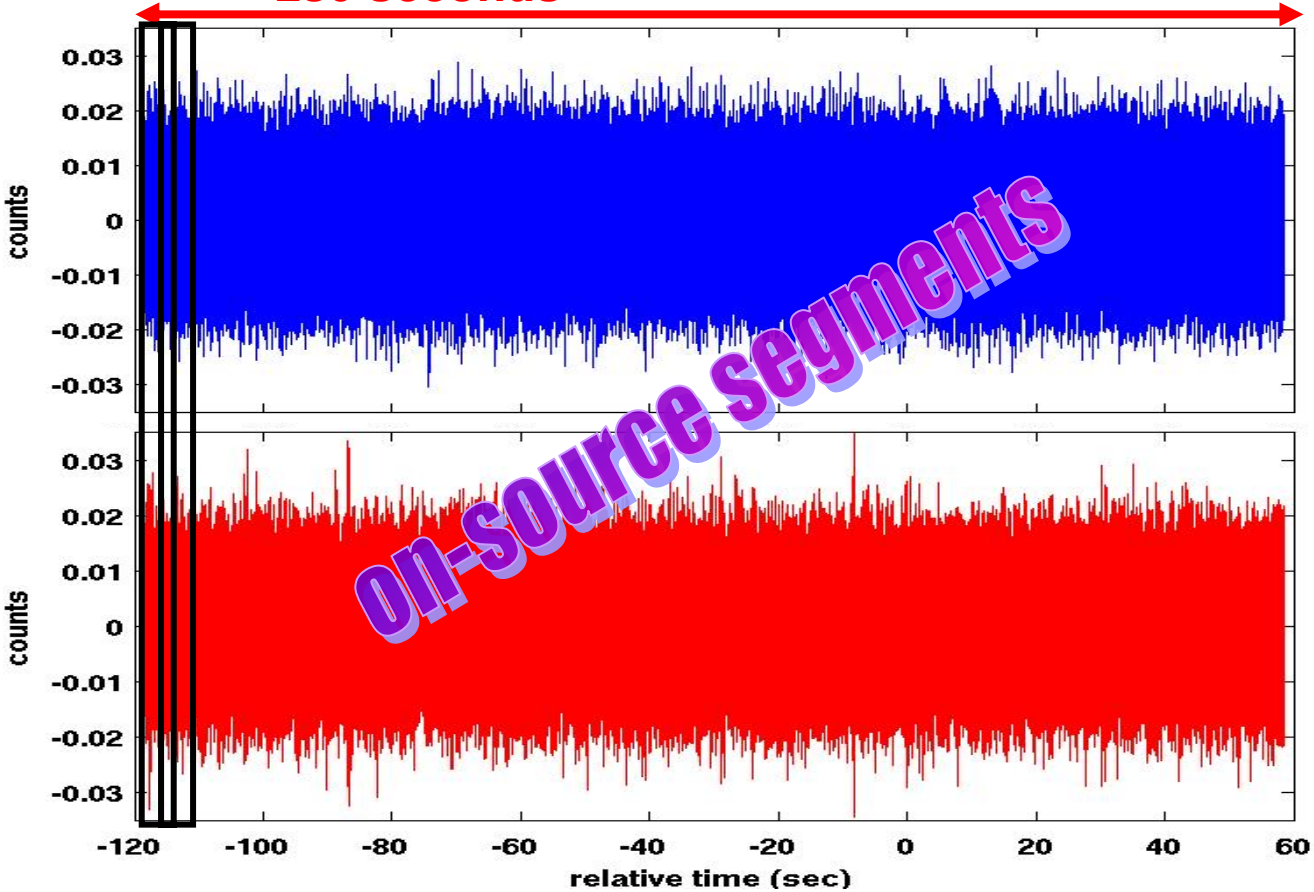
sample GRB lightcurve (Swift)



180 seconds

LIGO IFO 1

LIGO IFO 2

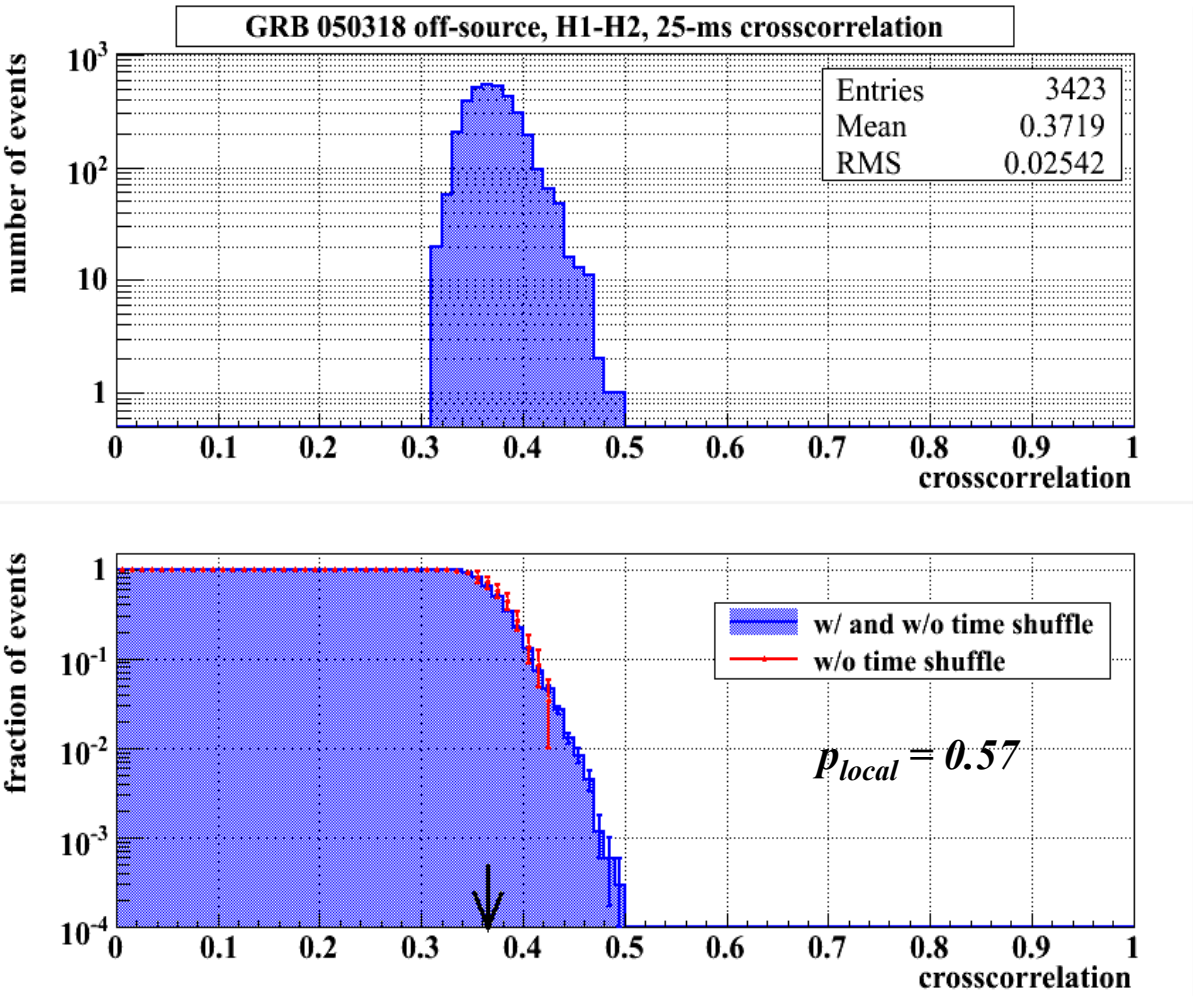


use 180-second LIGO on-source data surrounding GRB trigger

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

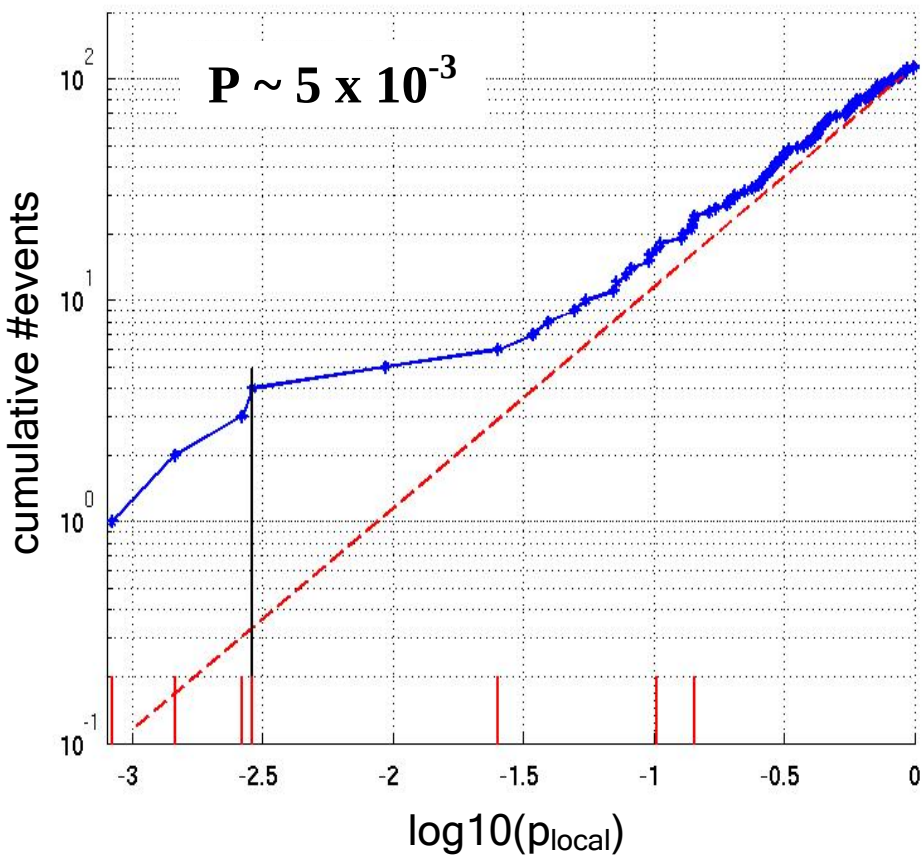


- apply search to off-source segments to obtain crosscorrelation distribution
- use time shifts to get enough statistics
- largest crosscorrelation found in on-source search indicated by black arrow
- probability is estimated using this distribution
- off-source crosscorrelation distribution is determined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

Statistical tests

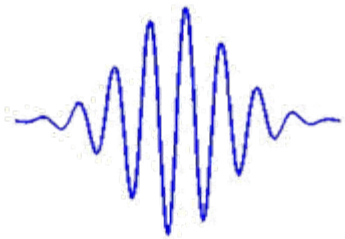
- statistical search: search for weak signals which, individually, would not comprise a detection, but together could have a detectable cumulative effect on measured distributions
- binomial test: search local probability distribution for deviation from expected distribution
- rank-sum test: test if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

Example from simulations: binomial test



Estimating $\mathbf{h_{rss}}$ sensitivity using sine-gaussian waveforms

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



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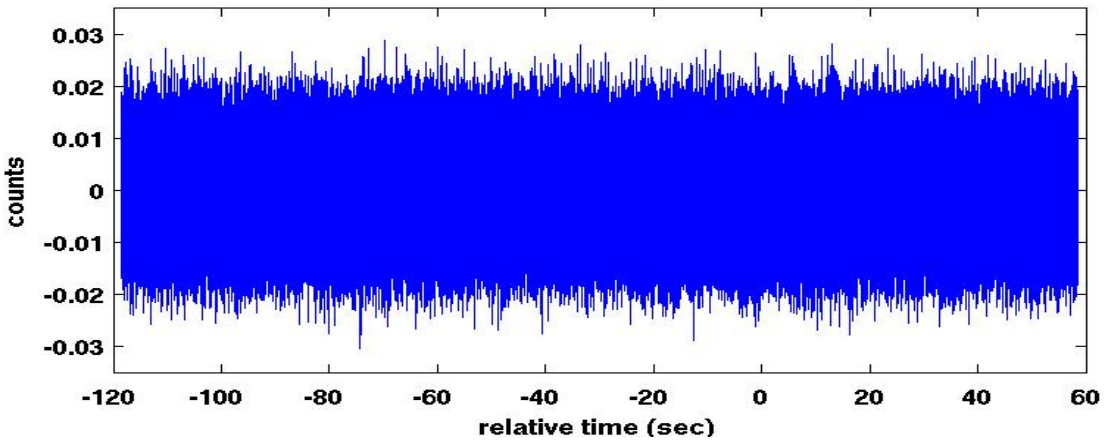

- GW waveforms not known
- inject simulated sine-gaussians into data to estimate search sensitivity
- use linear polarization and circular polarization
- take into account antenna response of interferometers
- average sensitivity at 250 Hz:

$\mathbf{h_{rss} \sim 7E\text{-}22\ Hz^{-1/2}}$

Estimating $\mathbf{h_{rss}}$ sensitivity using sine-gaussian waveforms

- 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:

$$D \sim 20\ \mathrm{Mpc} \left(\frac{250\,Hz}{f_c}\right)\left(\frac{10^{-21}\,Hz^{-1/2}}{h_{rss}}\right)\left(\frac{E_{GW}}{0.5 M_{sun} c^2}\right)^{1/2}$$

factor depends on GW polarization, source position and orientation

$\mathbf{h_{rss} \sim 7E\text{-}22\ Hz^{-1/2}}$

Summary

- more than 100 GRB triggers available to use in search for coincident gravitational-wave bursts using LIGO S5 data
- analysis is ongoing using crosscorrelation-based search
- search sensitivity depends on GRB sky position
- average sensitivity, using 250-Hz sine-gaussian waveform, is $h_{rss} \sim 7E\text{-}22\ Hz^{-1/2}$
- estimate of astrophysical reach depends on model of gravitational-wave emission