Searches for unmodeled Gravitational Waves associated with Gamma-Ray Bursts

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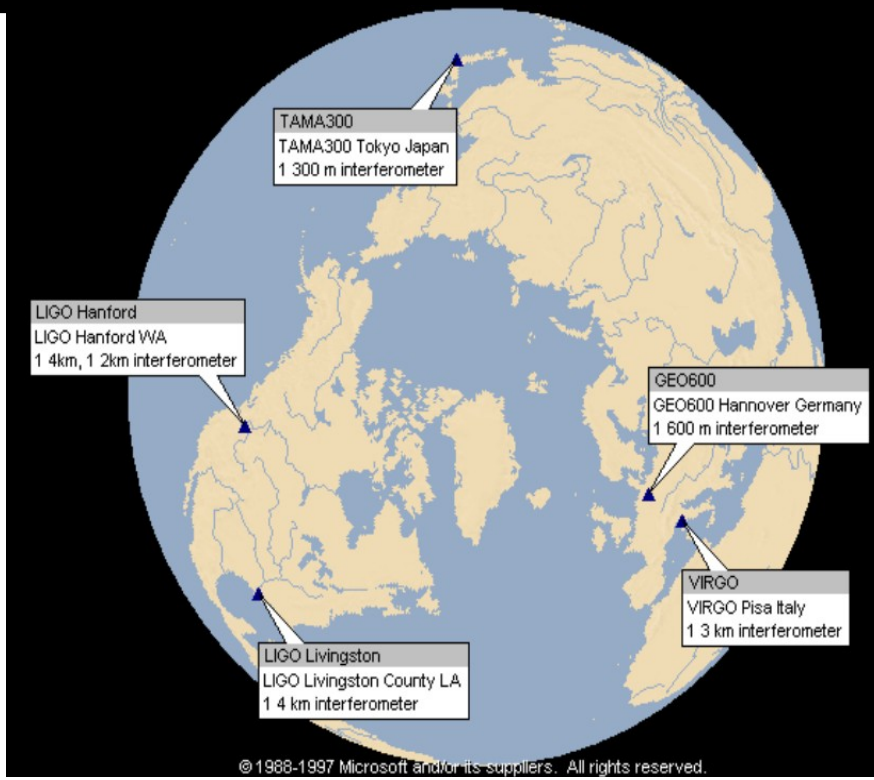
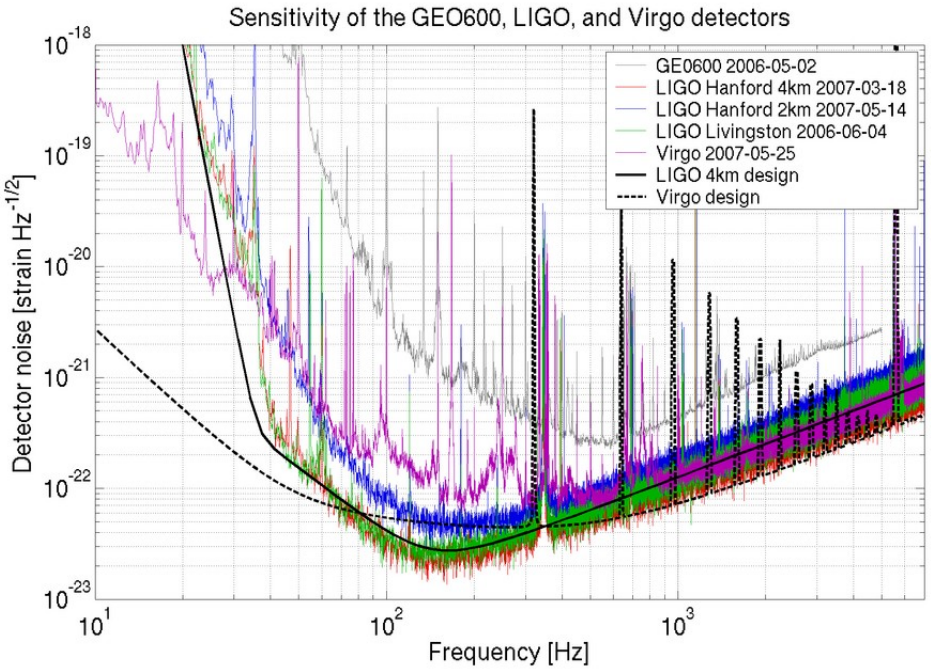
Motivation

- Gravitational wave observations will be powerful complement to EM observations and provide tests of relativity
- Short GRBs: widely thought to be produced by NS-NS or NS-BH coalescence
  - GW emission well modeled (previous talk by Nick Fotopoulos)
- Long GRBs: most likely associated with hypernovae.
  - GW emission not well modeled
- This talk: search for **unmodeled** GWs from GRBs making use of the time and sky location obtained by EM observations
  - externally triggered GW searches benefit from reduced data set
  - fewer false alarms, higher detection confidence
  - http://www.lsc-group.phys.uwm.edu/ligovirgo/exttrig/

Data set: S5 and VSR1

- LIGO Science Run 5 (S5)
  - Nov 4 2005 – Oct 1 2007
- LIGO S5 + Virgo Science Run 1 (VSR1)
  - May 18 2007 - Oct 1 2007

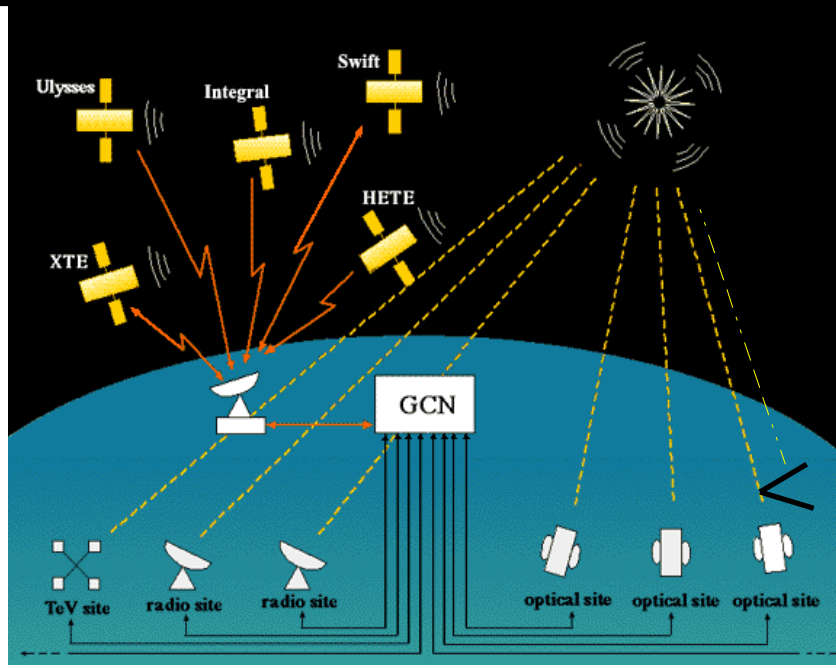




GRBs observed during S5 & VSR1

- GCN circulars: http://gcn.gsfc.nasa.gov/
  - GPS times, sky position, redshift

- Validated list of EM observed GRBs
  - 213 GRBs during S5 times
  - ~70% with double detector LIGO data
  - ~45% with triple detector LIGO data
  - ~13% short GRBs
  - ~20% in joint LIGO-Virgo S5/VSR1 times

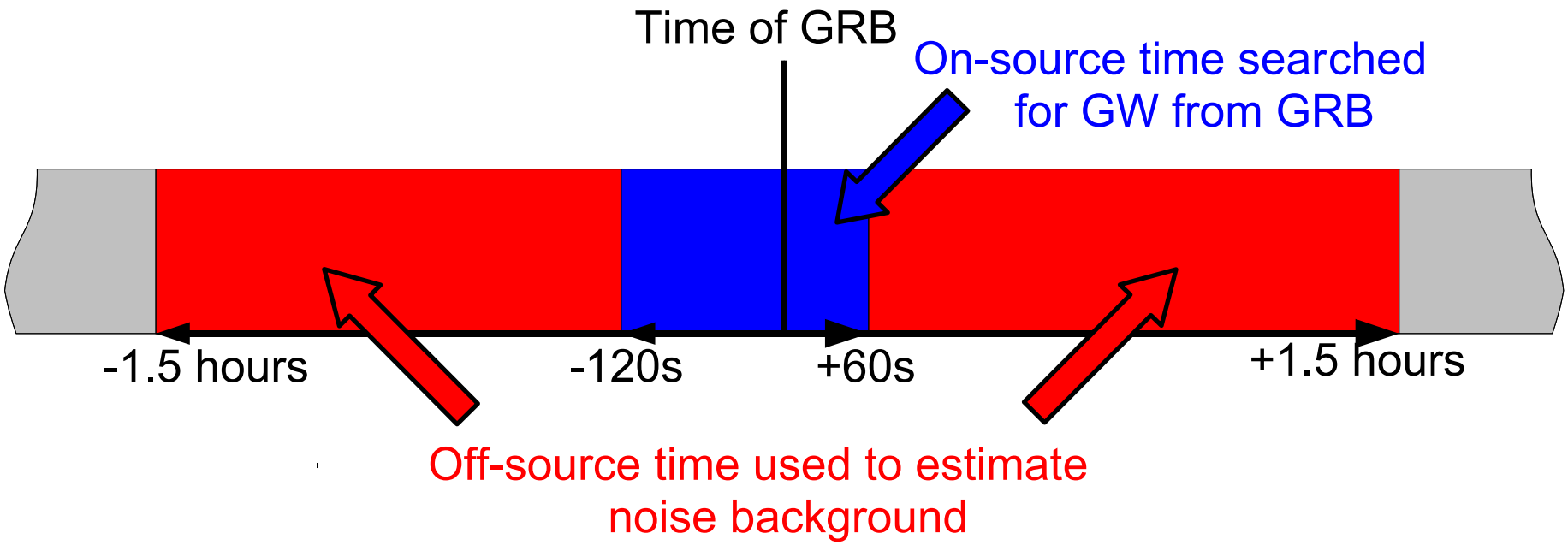


http://gcn.gsfc.nasa.gov/

Goal: Search for GW coincident in time and sky position with each GRB
  - Statistical analysis of entire GRB population for weak signals

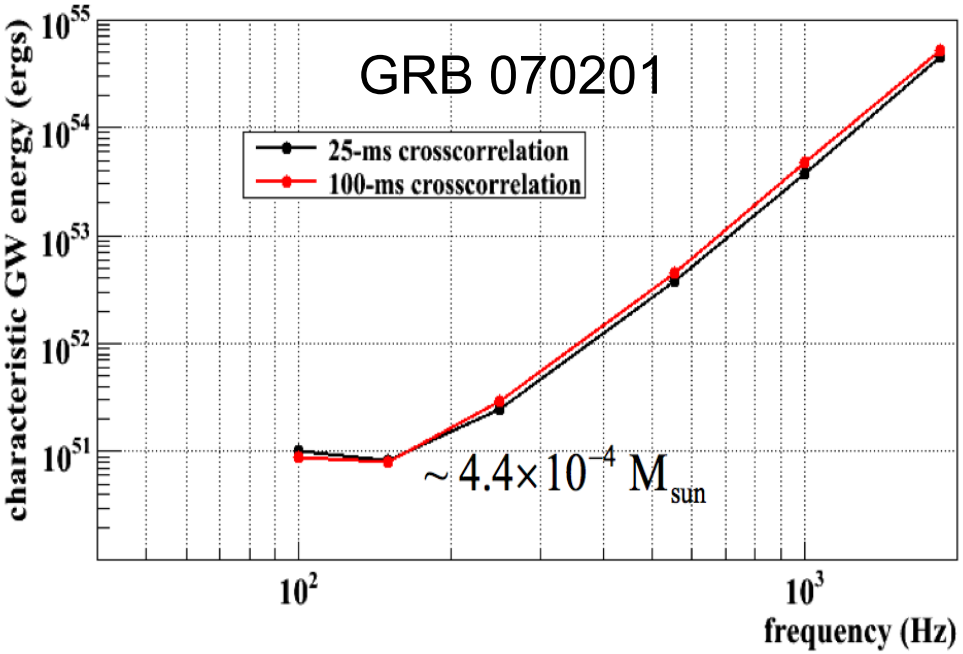
Searching for GRBs

- Multiple search pipelines used to analyse GW detector data
  - detection in multiple pipelines increases confidence
  - cross-correlation, coherent, excess power algorithms



Cross-correlation search

- Cross-correlate data from pairs of detectors
  - 25ms and 100ms time resolutions
- Used previously for LIGO S2-S4 searches (39 GRBs)
  - PRD 77 062004
  - statistical analysis of GRB set

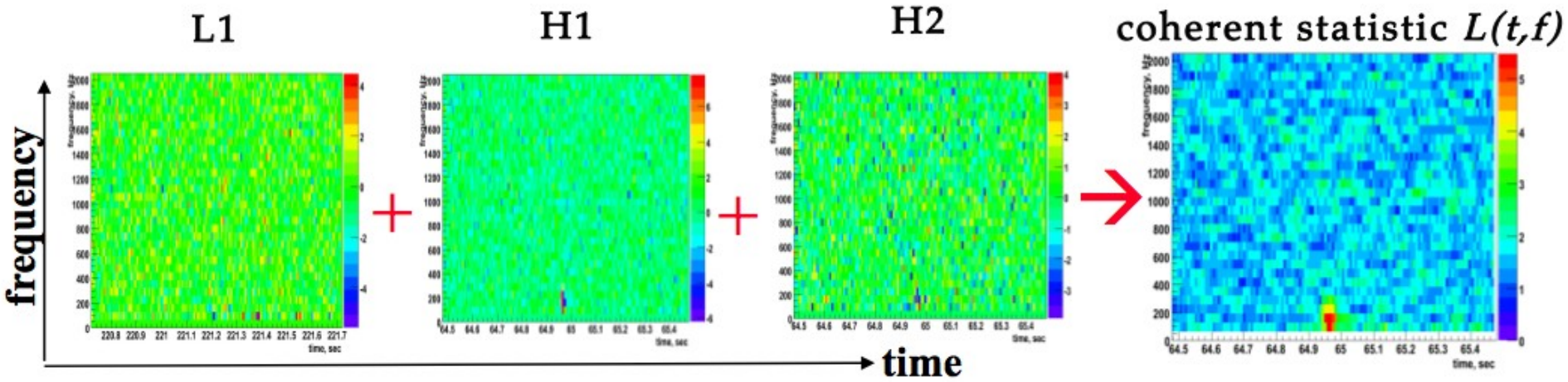


- LIGO search for GRB 070201
  - ArXiv:0711.1163 (to appear in ApJ)
  - Soft Gamma-ray Repeater (SGR) models predict energy release <= 10^{46} ergs
  - GW energy limits cannot exclude SGR in M31

- S5 pre-Virgo: On-line search results for 152 GRBs
  - upper limits on amplitude ~few x 10^{-21} $Hz^{-1/2}$
  - off-line analysis in progress (better data quality and calibration)

Coherent Network Searches

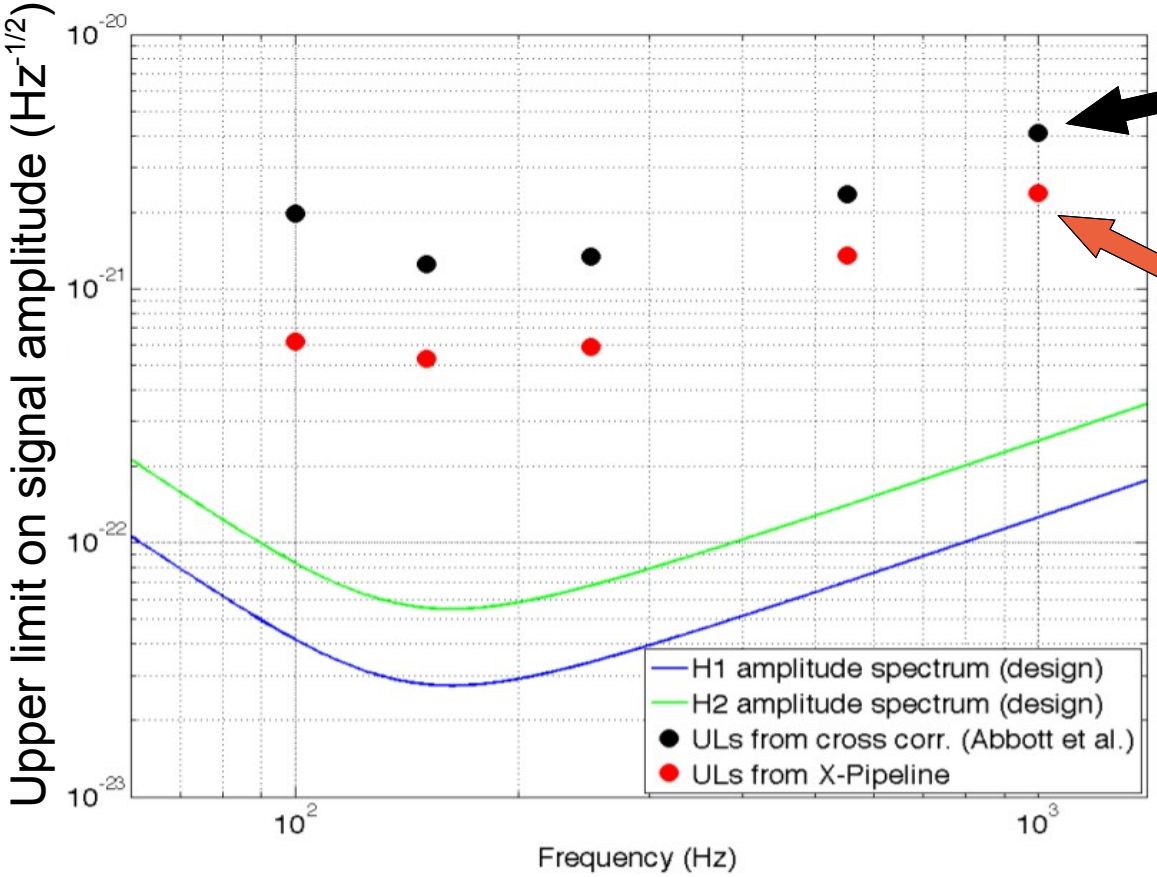
- Use known sky position to coherently combine data from multiple detectors
  - maximize or minimize the signal-to-noise ratio of a GW with a given polarization
  - expect higher sensitivity than non-coherent methods
- Several coherent analysis packages have been developed and will be used to analyse LIGO-Virgo data:
  - coherent Wave Burst (Klimenko et al, PRD 72 122002 (2005))
  - Flare (Kalmus et al, CQG 24 S659-S669 (2007))
  - X-Pipeline (Chatterji et al, PRD 74 082005 (2006))



Klimenko et al, arXiv: 0802.3232v1, (to appear in CQG)

Sensitivity improvement

- Simulation of GRB 070201
- Injection of narrow-band simulated GW signals



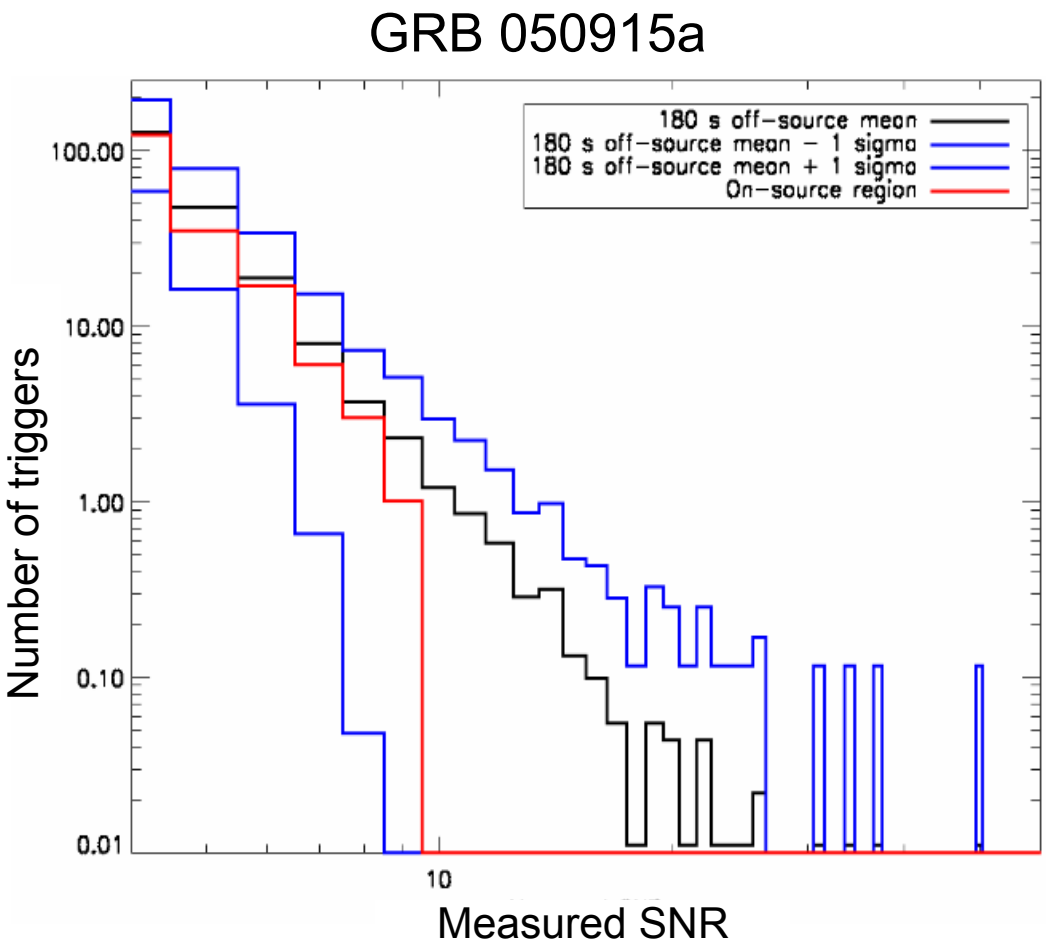
Sutton, Jones, Was (to appear in CQG)

Cross-correlation results from ArXiv:0711.1163 (to appear in ApJ)

X-Pipeline using simulated data

Wavelet detection filter

- Wavelet Detection Filter
  - excess power method for single detectors
  - wavelet decomposition of whitened data
  - search for coincidences between multiple detectors
- Used for Virgo search for GRB 050915a
  - arXiv:0803.0376v1
  - upper limit on hrss amplitude O(10^{-20}) $Hz^{-1/2}$
- Coherent approach to be implemented for S5/VSR1



Estimating search sensitivities

- Software injection of simulated GW signals into real detector data

- Use a common simulation engine to test all pipelines: **Mock Data Challenge waveforms**
  - linearly and circularly polarized sine-Gaussians
  - white noise bursts
  - inspiral and ringdown waveforms

$$\text{efficiency} = \frac{\text{number of injected waveforms recovered}}{\text{total number of injected waveforms}}$$

Calculating upper limits

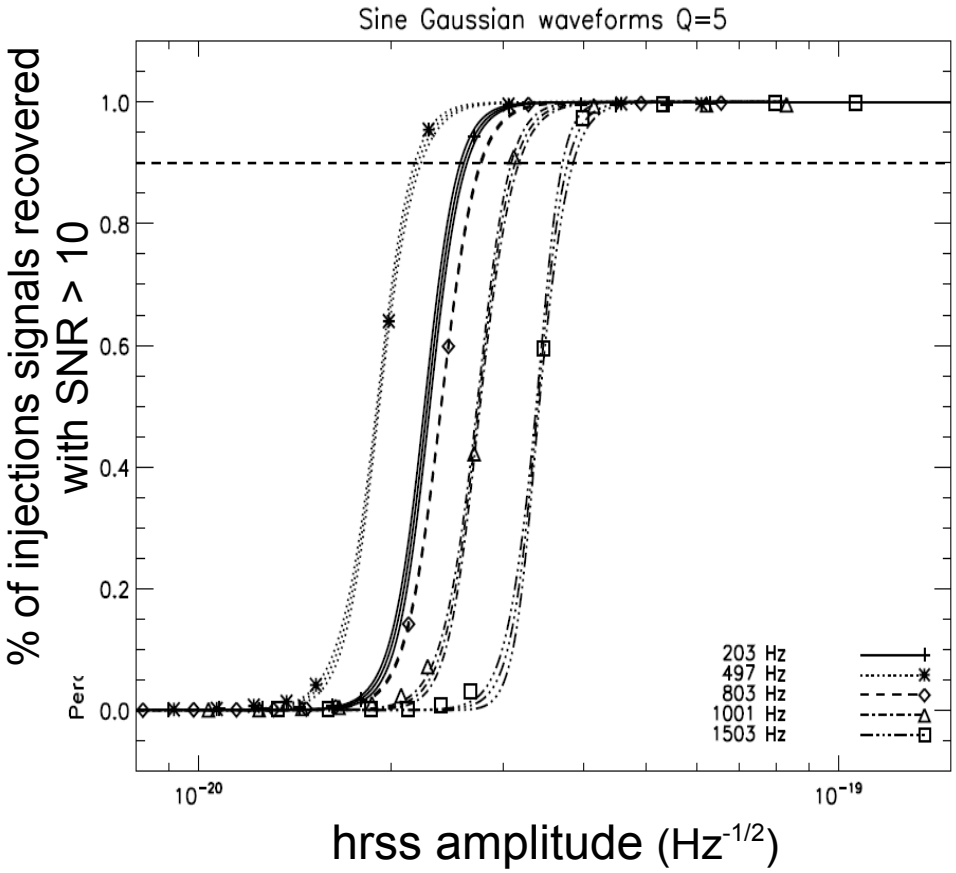
- Loudest event upper limit on hrss amplitude

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

  - $O(10^{-22} – 10^{-20})$ $Hz^{-1/2}$
- Upper limits on energy if GRB distance is known
  - z measured for ~30% of S5 GRBs
  - for narrow band signals:

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

  - $O(10^{50})$ ergs for GRBs in M31
  - $O(10^{54})$ ergs for GRBs at 100Mpc



arXiv:0803.0376v1

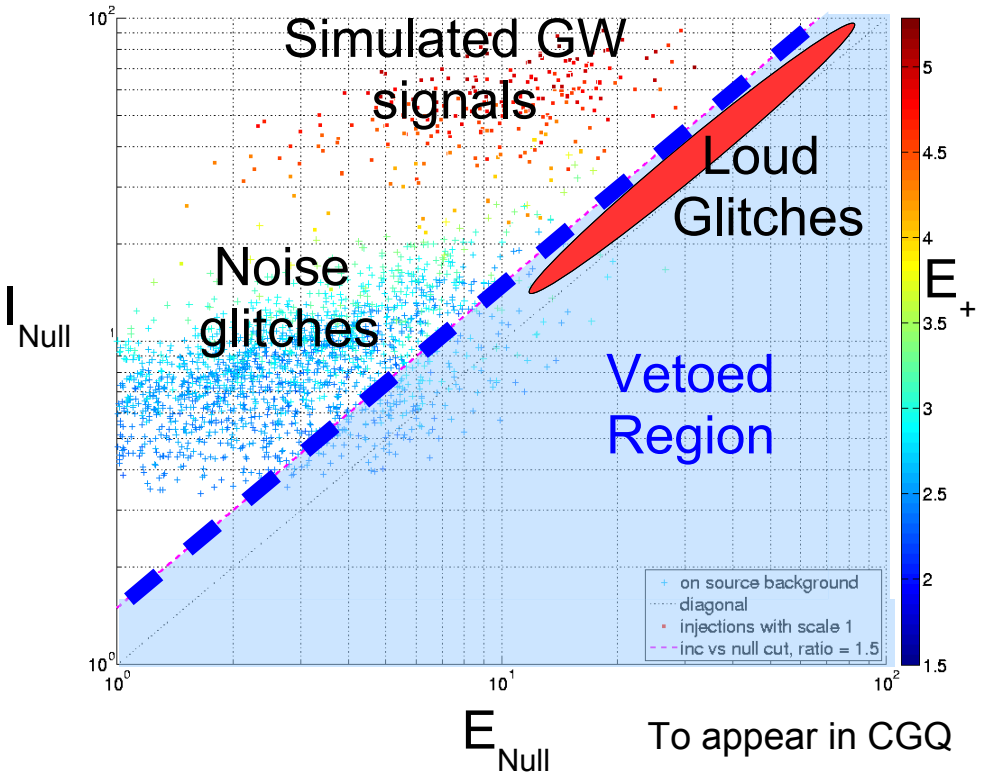
Summary

- GRB search of S5 LIGO data underway
- On-line cross-correlation method has results
- Coherent search methods promise better sensitivity
  - coherent combinations of LIGO detector data
- Results from multiple pipelines to be combined in single publication
  - Detection statements and amplitude upper limits
- Preparations for GRB search of S5/VSR1 data in progress
  - LIGO and Virgo data
  - new search technique (Wavelet detection filter)

Coherent Glitch rejection

- Coherent methods typically measure several properties of a GW candidate including energies of both GW polarizations and a null stream
  - Null stream type tests for glitch rejection
    - Chatterji et al, PRD 74 082005 (2006)
    - Schutz et al, CQG 22 S1321 (2005)
    - Klimenko et al, arXiv: 0802.3232v1, (to appear in CQG)
  - Loud Glitches: $E_{Null} \sim I_{Null}$
  - GW Signals: $E_{Null} < I_{Null}$

Analysis of simulated H1-H2 data



Statistical analysis of GRBs

- S2-S4 burst search for GRBs
  - PRD 77 062004
- Local probability, p_{local} = probability of off-source (background) yielding maximum cross correlation measured in the on-source
- Distribution under null hypothesis (dashed line)
- Most significant excess has a 1 in ~7 chance of occurring