All-sky search for gravitational-wave bursts in LIGO, GEO600, and Virgo S5/VSR1 data

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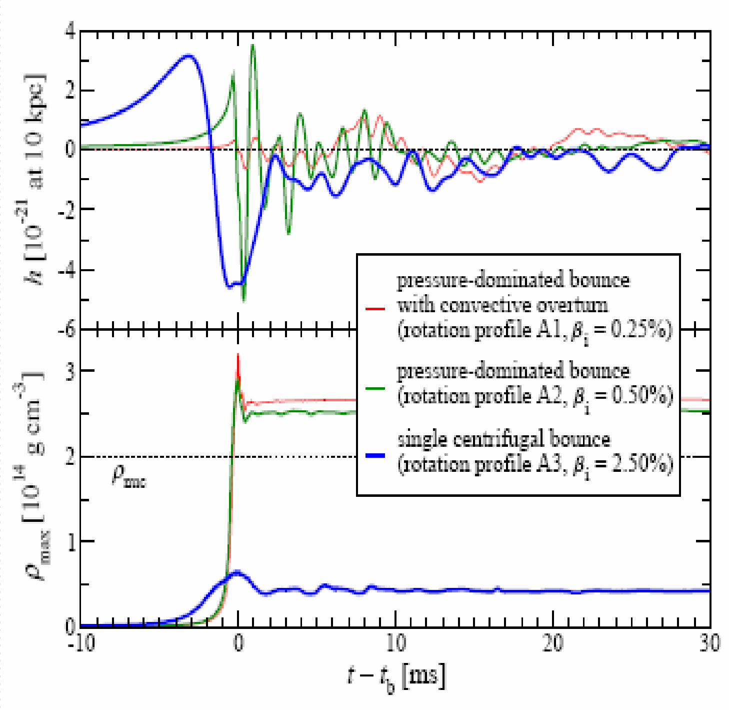
Outline

- What are gravitational-wave bursts
- Data and goals
- Results from the first half of S5 (LIGO S5 year 1)
- Search methods for S5y2/VSR1
- Tuning and background estimation
- Data Quality and event-by-event vetoes
- Simulations
- Summary

Gravitational-Wave Bursts

- Short-lived signals, lasting only a few cycles within the frequency band of the instruments
  - Typically from few milliseconds to few seconds and with frequency content in the 100 Hz - few kHz regime
  - Unknown or poorly known waveforms
- Sources
  - Core-collapse supernova
  - Merger phase of binary compact objects
  - Neutron star instabilities
  - Cosmic string cusps and kinks
  - The unexpected!

rotating stellar core collapse



Dimmelmeier et al., astro-ph/0702305

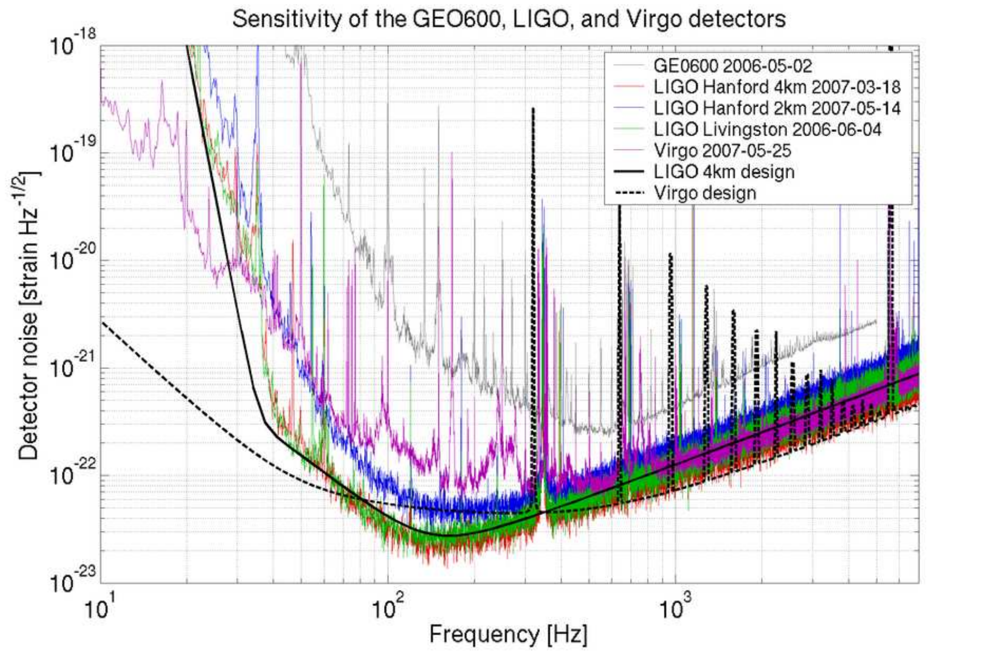
Goals & Data

Virgo May 07 – Nov 07

LIGO Nov 05 – Nov 07 S5 1st year

GEO600 Jan 06 – Nov 07

- Direct detection of gravitational-wave bursts from astrophysical sources, or otherwise upper limits on their rate or energy emitted into gravitational waves.
- Eyes wide open search for burst-like signals with minimal or no assumption about their waveform details → "untriggered" searches performed over the whole sky and over all collected data
- 1-year of H1H2L1 data
- 70 days of H1H2L1V1 quadruple coincident data

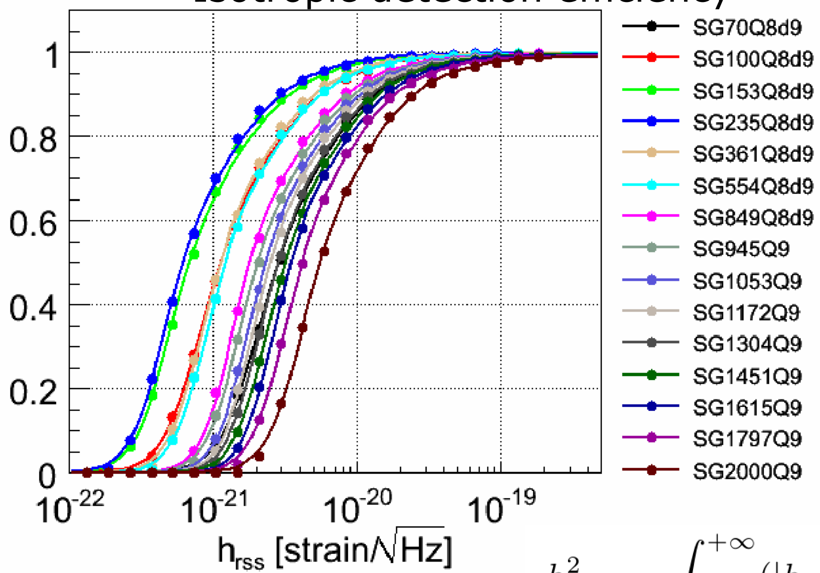


Total: 502 days of analyzable livetime (415 days of GEO data to be used in the case of a loud detection)

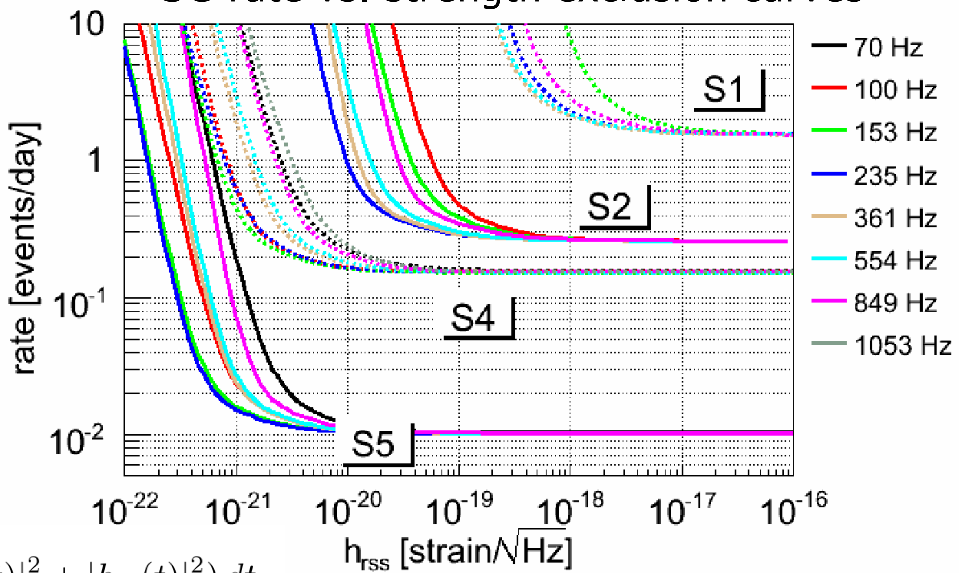
LIGO S5 First Year Result [gr-qc:0905.0020]

- No events observed above upper limit thresholds
  - Frequentist upper limit of 3.6 detectable events per year at 90% confidence

Isotropic detection efficiency



SG rate vs. strength exclusion curves

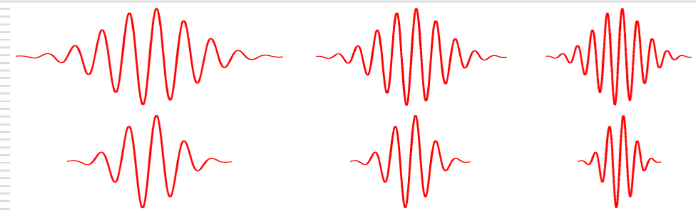


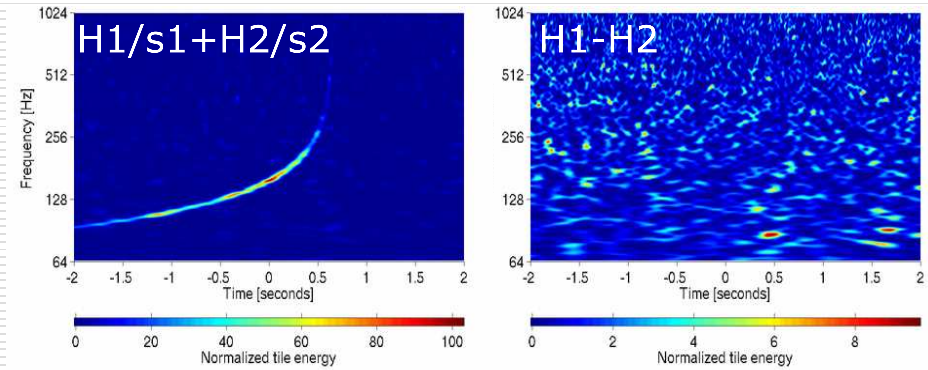
$$h_{\rm rss}^2 = \int_{-\infty}^{+\infty} \left(|h_+(t)|^2 + |h_\times(t)|^2\right) dt$$

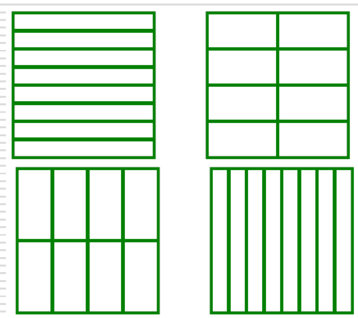
- 0.044 solar masses radiated in SG153Q9 for 50% efficiency at Virgo cluster
- 100/100 solar mass BH/BH merger detectable out to 180 Mpc
- Core collapse supernova models detectable out to 0.6-24 kpc

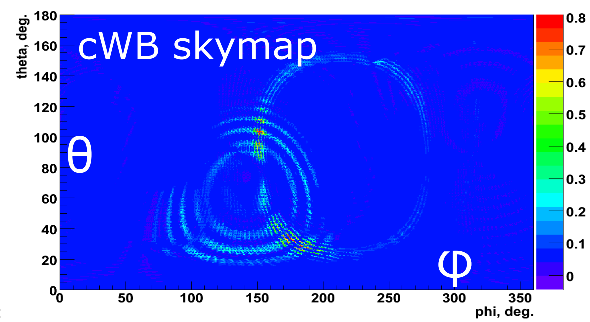
S5y2/VSR1 Search Methods

- EGC (300-5000 Hz)
  - Filters the data over Gaussian-enveloped sine waves and ranks the transients with a matched filter SNR.
  - Time-coincidence requirements along with H1H2 amplitude consistency and network energy disbalance.
- Omega Pipeline (48-2048 Hz)
  - Filters the data over windowed sine waves and ranks the transients with a matched filter SNR.
  - Coherent combinations of H1 and H2 increase sensitivity and reject background.
- Coherent Waveburst (64-6000 Hz)
  - Meyer wavelet packet decomposition.
  - Fully coherent search statistic based on a Gaussian likelihood function.
  - Also uses energy inconsistency to reject background.



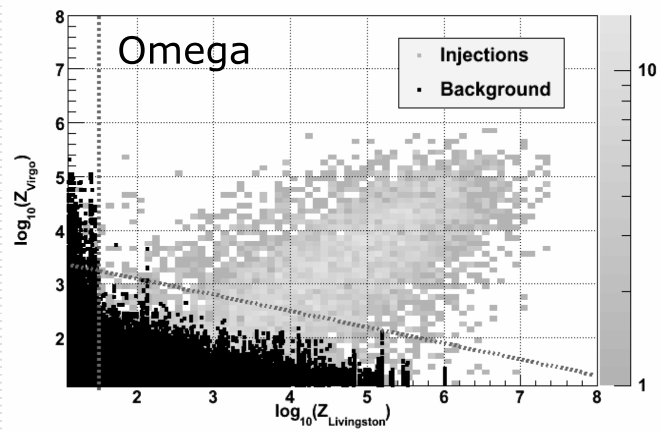


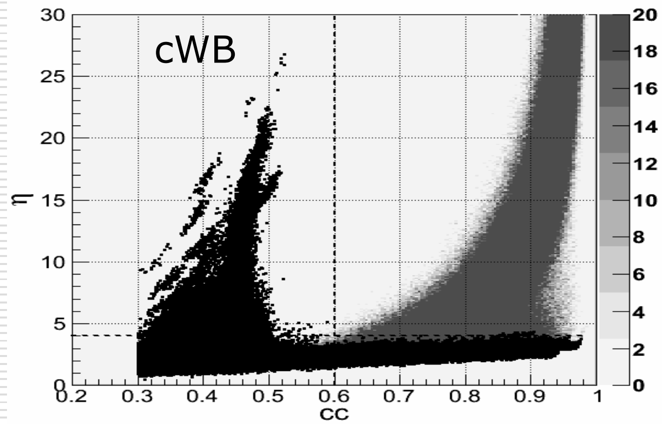




Tuning and Background Estimation

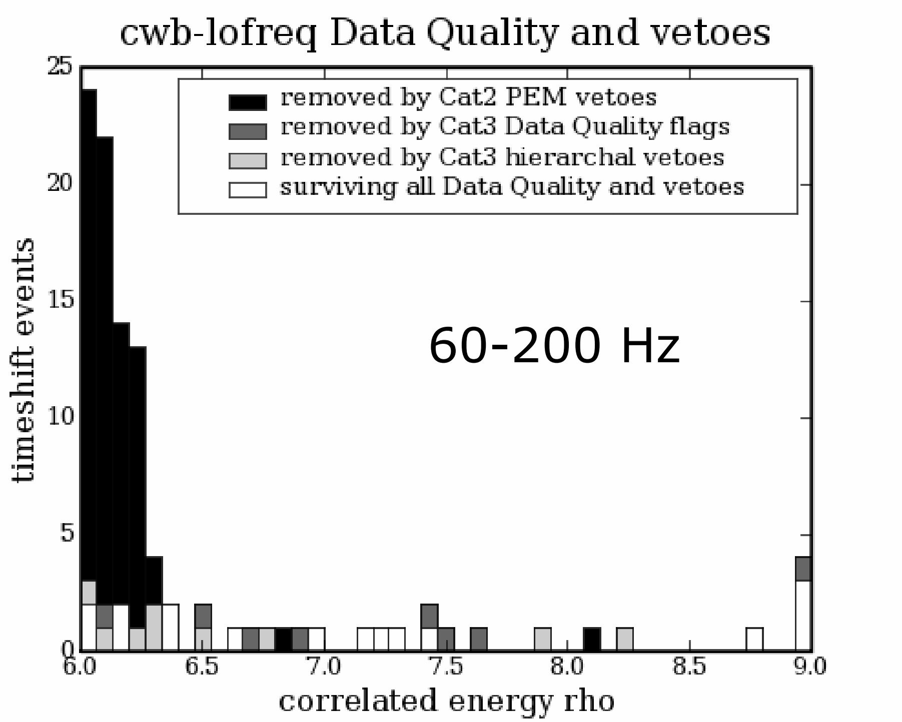
- Background for each method is estimated using time-shift analysis:
  - Artificially time-shift one detector from the others by several seconds.
  - Assume expected background distribution for time-shifted analysis is the same as for un-shifted analysis.
  - Run many time-shifts (up to 1000) and average to better estimate expected background distribution.
- Tuning is done in a blind way using the expected background distribution from time-shift analysis and the distribution of simulated gravitational-wave signals.
- Upper limit cuts are made to optimize detection efficiency for a variety of waveforms while maintaining a total cumulative false-alarm-probably across all pipelines of ~10%.

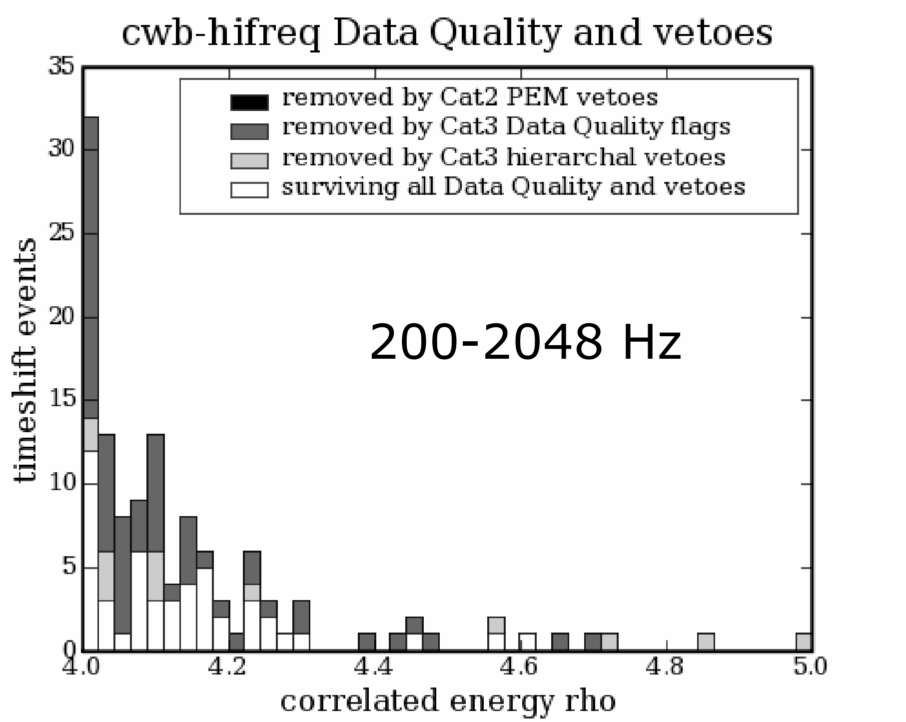




Data Quality and Vetoes (un-physical time-shift events)

Burst search (Coherent Waveburst) H1H2L1 background (1000 time shifts)



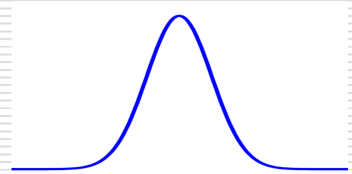


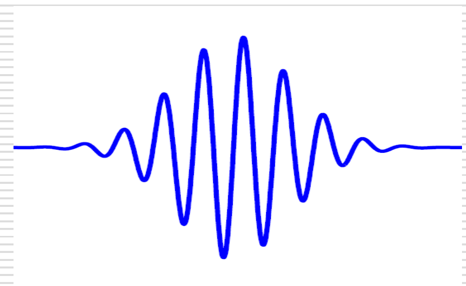
About 50% of the cWB outliers are rejected with a total dead-time of ~15%

Simulations

- Simulated (all-sky, random polarization angle) gravitational-wave events are injected in the data stream and passed through the full pipeline to test efficiency for various waveforms:
  - Gaussian 0.05ms<τ<8ms:

    $$h_+(t_0 + t) = h_0 \exp(-t^2/\tau^2)$$

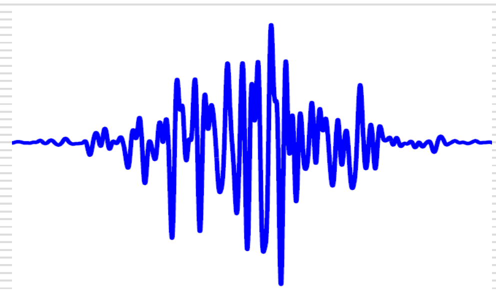




  - Sine-Gaussian 70<f<2000 Hz, Q=3,9,100:

    $$h_+(t_0 + t) = h_0 \sin(2\pi f_0 t) \exp[-(2\pi f_0 t)^2/2Q^2]$$

  - Unpolarized band-limited white noise-Gaussian:
    - f_{start} = 100, 250, 1000 Hz
    - bandwidth = 10, 100, 1000 Hz
    - duration = 1, 10, 100 ms



- High frequency (2000-6000 Hz) Sine-Gaussian and circularly polarized ringdown waveforms (see talk by F. Salemi)

Summary

- No burst events below 2000 Hz identified in the first year of LIGO S5 data
- LIGO S5 first year result most sensitive upper limit produced to date, astrophysical reach ~3x that of S4
- S5 year 2 + Virgo VSR1 provides another 262 days of analyzable livetime
- 70 days of H1H2L1V1 coincident operation represents the first burst all-sky joint analysis of LIGO/Virgo data, and makes full use of new coherent methods.
- Analysis complete, waiting on finalized review. Combined results coming soon…