All-sky Search for Gravitational-wave Bursts in the Second Joint LIGO-Virgo Run

Amber L. Stuver
for the LIGO Scientific Collaboration
and the Virgo Collaboration

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LIGO-G1200013-v3

Burst Sources

- Gravitational wave (GW) bursts are GWs with short duration (~<1 sec) and may be emitted by unknown, unanticipated or poorly modeled sources.
- Examples include:

Merging compact binary systems	GRBs
Core collapse supernovae	SGRs (magnetars)
Cosmic string cusps	Etc.

- Data analysis challenge: cannot assume waveform properties.

S6 (LIGO)-VSR2/3 (Virgo)

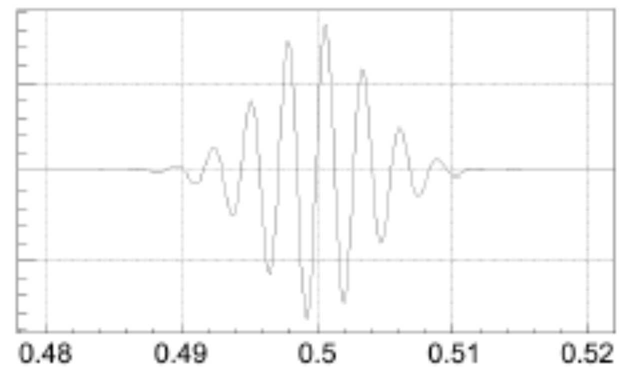
- Total S6-VSR2/3 time analyzed (after quality cuts): 207 days
- Network of 3 detectors: LIGO (H1 & L1) & Virgo
- Data acquired from July 2009-Oct. 2010 (LIGO), and July 2009-Jan. 2010 & Aug.-Oct. 2010 (Virgo).
- Data from times when at least 2 detectors were operating was analyzed.
- First use of low-latency analysis to produce triggers for EM follow-up use.

Burst Search Overview

- Times of known poor data quality (DQ) are removed from calibrated data.
- Vetoes from auxiliary/environmental channels are applied to the data.
- Data processed with Coherent WaveBurst search algorithm
- Simulated GW signals are added to data and used to test the sensitivity of the data analysis.
- Analyses are applied to data with unphysical time shifts to estimate the background rate.
- Blind cuts are made to tune analysis parameters to yield a false alarm rate (FAR) of 1/(8 years) or less (combines to yield a false alarm probability of ~15%).
- Thorough follow-up and significance estimation of any candidate events above threshold is performed.

Simulations

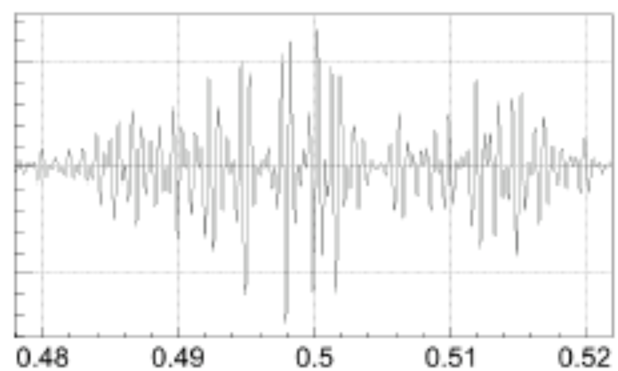
- Linearly pol. sine-Gaussian waveforms; $70 \geq f_0 \geq 3799$ Hz, Q = (3, 9, 100) ➔



- Elliptically polarized waveforms

$$\begin{bmatrix} h_+ \\ h_\times \end{bmatrix} = A \begin{bmatrix} \frac{1+(\cos\iota)^2}{2} \\ \cos\iota \end{bmatrix} \begin{bmatrix} \sin(2\pi f_0 \tau) \\ \cos(2\pi f_0 \tau) \end{bmatrix} \exp[-(2\pi f_0 t)^2 / 2Q^2]$$

- White noise bursts ➔



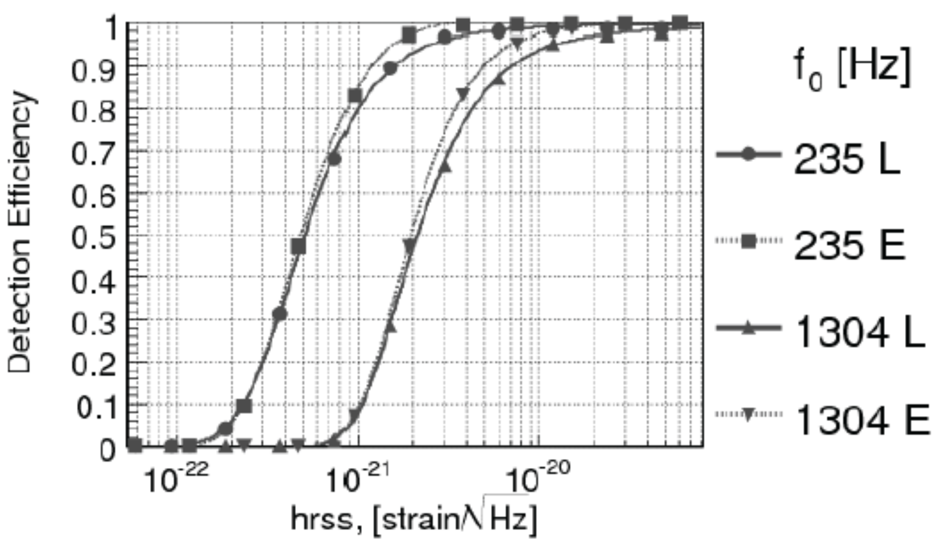
- Also:
  - » Gaussian waveforms
  - » Harmonic ringdowns
  - » NS collapse waveforms

Sensitivity

$$h_{rss} = \sqrt{\int \left[h_{+}^{2}(t) + h_{\times}^{2}(t) \right] dt}$$

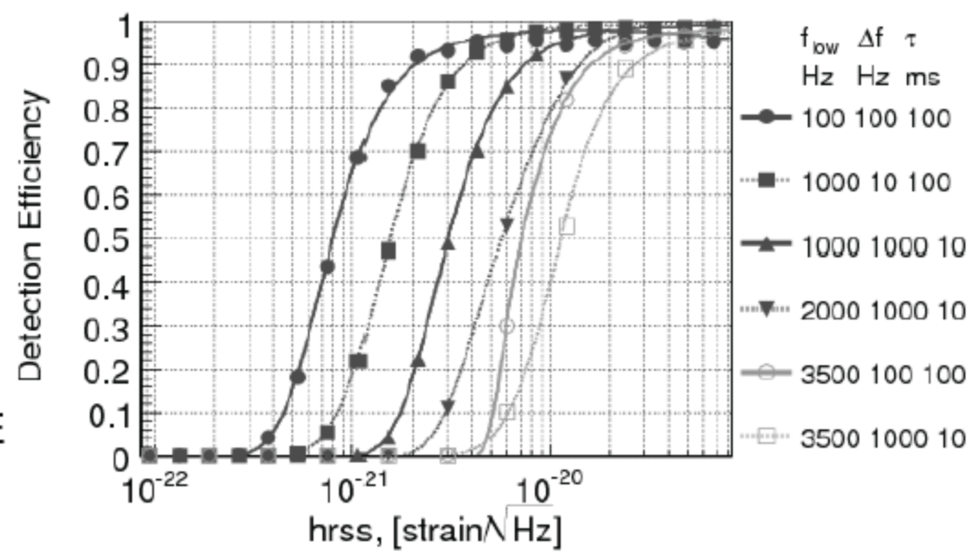
Sine-Gaussians, Q=9

h_{50}=4.6-81.7.4$\times 10^{-22}/\sqrt{\text{Hz}}$



White Noise Bursts

h_{50}=7.5-114$\times 10^{-22}/\sqrt{\text{Hz}}$



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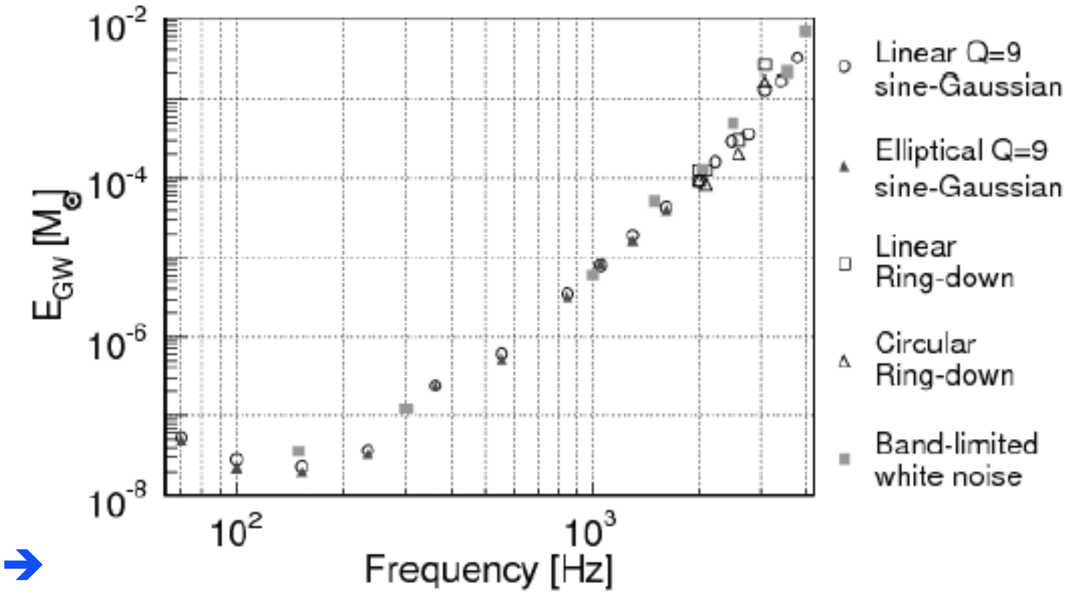
Astrophysical Sensitivity

- For an isotropic GW emission, the amount of mass converted into GW energy (M_{GW}) is:

$$E_{GW} = \frac{\pi^2 c^3}{G} f^2 r^2 h_{rss}^2$$

The plot assumes a 10kpc standard candle ➔



- For a sine-Gaussian at 150 Hz at a distance of 10 kpc: $M_{GW}=2.2\times10^{-8}M_\odot$.

- … or in the Virgo cluster (r=16 Mpc), $M_{GW}=0.056M_\odot$.

Candidate Events

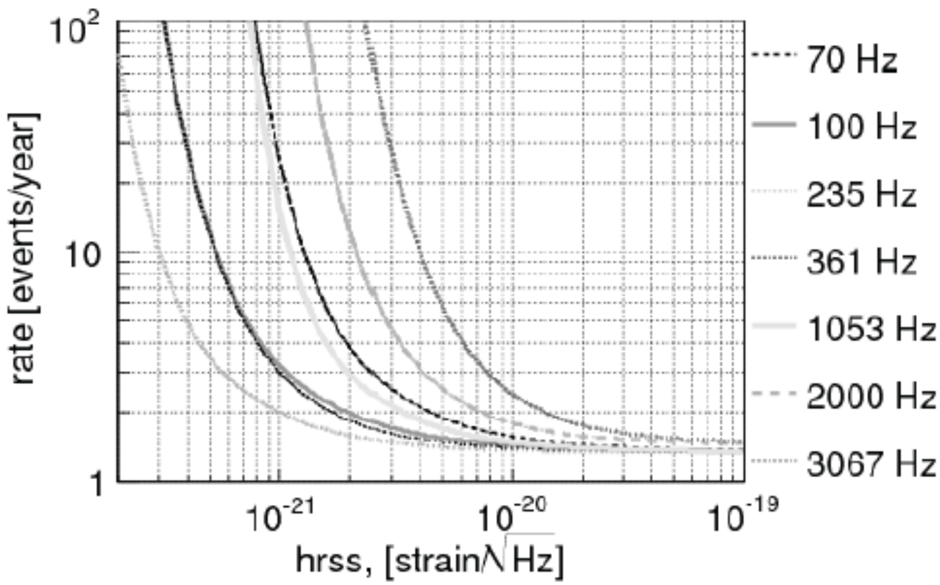
- No event passed the FAR of 1 event in 8 years.
- Most significant event:
  - » Chirping signal compatible with compact binary coalescence
  - » SNR ~17; false alarm rate ~0.9/year
  - » Found within a few minutes with low-latency search and followed up on in EM
- It was later revealed that this signal was a “blind injection challenge” and was removed from the analysis.
  - » This event is colloquially known as the “Big Dog” and officially as GW100916
- Next most significant event:
  - » From H1L1 network, SNR ~11, 200-1600 Hz band

Combined Upper Limits: Event Rates

Combined S5/VSR1 data with those presented here to produce upper limits (1.74 years since Nov. 2005):

- This combined data produces an improvement in UL event rate: ~1.3/yr (64-1600 Hz), ~1.4/yr (>1.6k Hz)
- Previously: 2/yr & 2.2/yr, respectively

Sine-Gaussians, Q = 9



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Upper Limits: Isotropic Sources

- For an isotropic distribution of sources with amplitude h_0 at a distance r_0, the 90% confidence level rate density limit is:

$$R_{90} = \frac{2.3}{4\pi\left(h_0 r_0\right)^3 \int_0^\infty \varepsilon(h) h^{-4} dh}$$

- This can be expressed in terms of GW emission of $E_{GW}=M_0 c^2$:

$$h_0 r_0 = (\pi f)^{-1} \sqrt{\frac{GM_0}{c}}$$

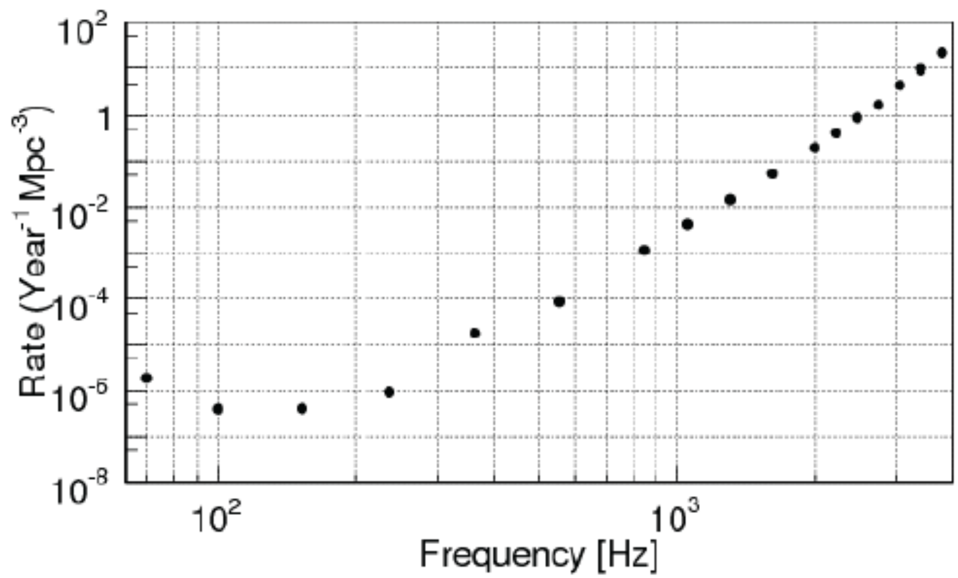
Combined Upper Limits: Astrophysical

- Rescaling in terms of solar mass ($M_\odot$):

$$R_{90}(f,M) = R_{90}(f,M_{Sun})\left(\frac{M_{Sun}c^2}{E_{GW}}\right)^{3/2}$$

- For a source emitting at $E_{GW}=0.01M_\odot c^2$ at 150 Hz, $R_{90}\sim 4\times 10^{-4} yr^{-1} Mpc^{-3}$

Linearly polarized sine-Gaussians



Summary and Conclusions

- Similar sensitivity to last joint run with 50% increase in combined observation time.
  - » 1.74 years since Nov. 2005
- No detection candidates
- Limit on the rate of burst GW signals:

  < 1.3 events/yr at 90% confidence level with sensitivity between 5-100 $\times 10^{-22}$ $Hz^{-1/2}$
- The most stringent ULs to date
- First use of low-latency burst data analysis for rapid EM follow-up of detection candidates