Reaching for Gravitational Wave Bursts

Peter Shawhan

The University of Maryland
&
The LIGO Scientific Collaboration

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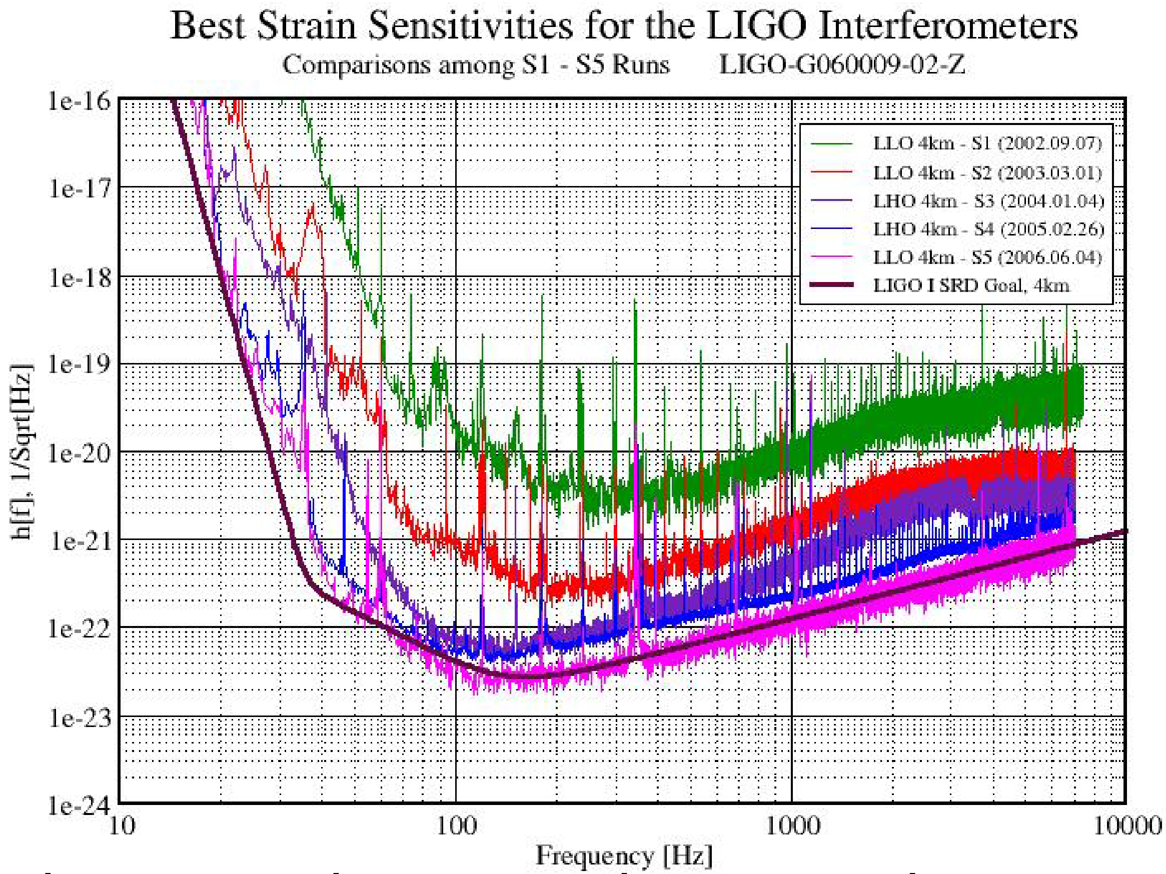
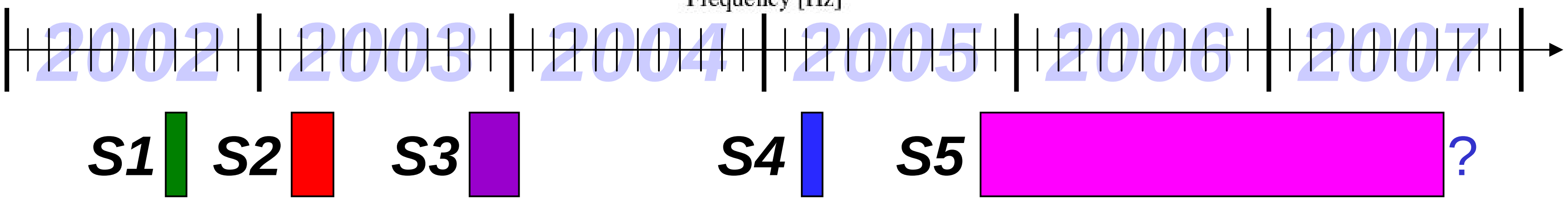
Overview

- **LIGO is collecting lots of good data**
  - The S5 science run is 3/4 of the way to its goal of 1 year of coincident data
  - GEO has collected a lot of data too; VIRGO beginning soon
- **The LSC is carrying out "eyes wide open" searches for gravitational wave bursts**
  - Example: the S4 LIGO all-sky burst search
- **We are trying to improve connections to astrophysics**
  - What could the S4 LIGO all-sky burst search have seen?
  - Current and future ways of making connections
- **Discussion time at the end …**

Data Runs So Far





The S4 LIGO All-Sky Burst Search

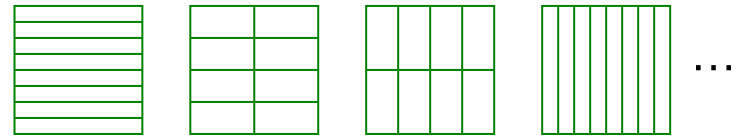
- **Searched triple-coincident (H1+H2+L1) LIGO data for short (<1 sec) signals of arbitrary form with frequency content in the range 64–1600 Hz**
- **Used WaveBurst to generate *triggers* at times with excess power in data streams, followed by CorrPower cross-correlation tests**
- **Search done "blind"**
- **Studied background using time-shifted coincidences**

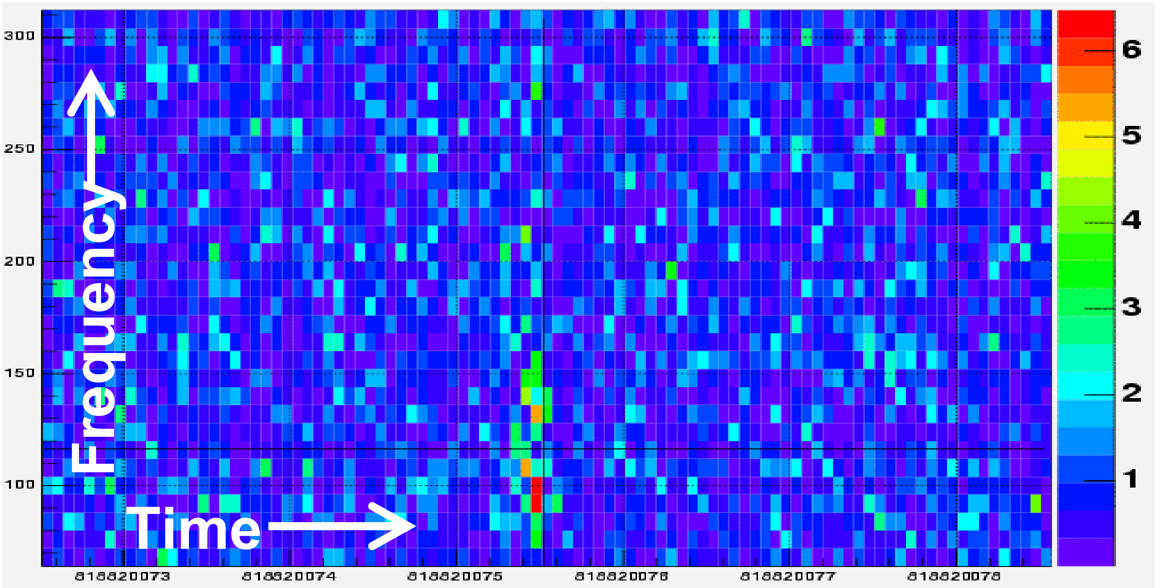
Preprint will be posted soon

WaveBurst in a Nutshell

WaveBurst processed all 3 GW data channels simultaneously

Wavelet decompositions with 6 different resolutions from
1/16 sec × 8 Hz to 1/512 sec × 256 Hz





Pixel power thresholding, cross-stream pixel coincidence, clustering

Trigger properties: time, duration, frequency, amplitude, significance **Z_g**

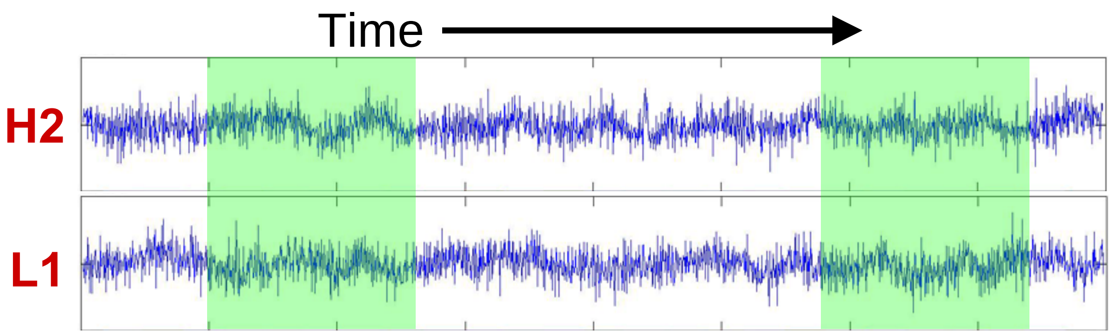
CorrPower in a Nutshell

CorrPower run on raw data at times of WaveBurst triggers

Calculates normalized cross-correlations (***r*-statistic**) for pairs of detectors

Integration window lengths: 20, 50, 100 ms

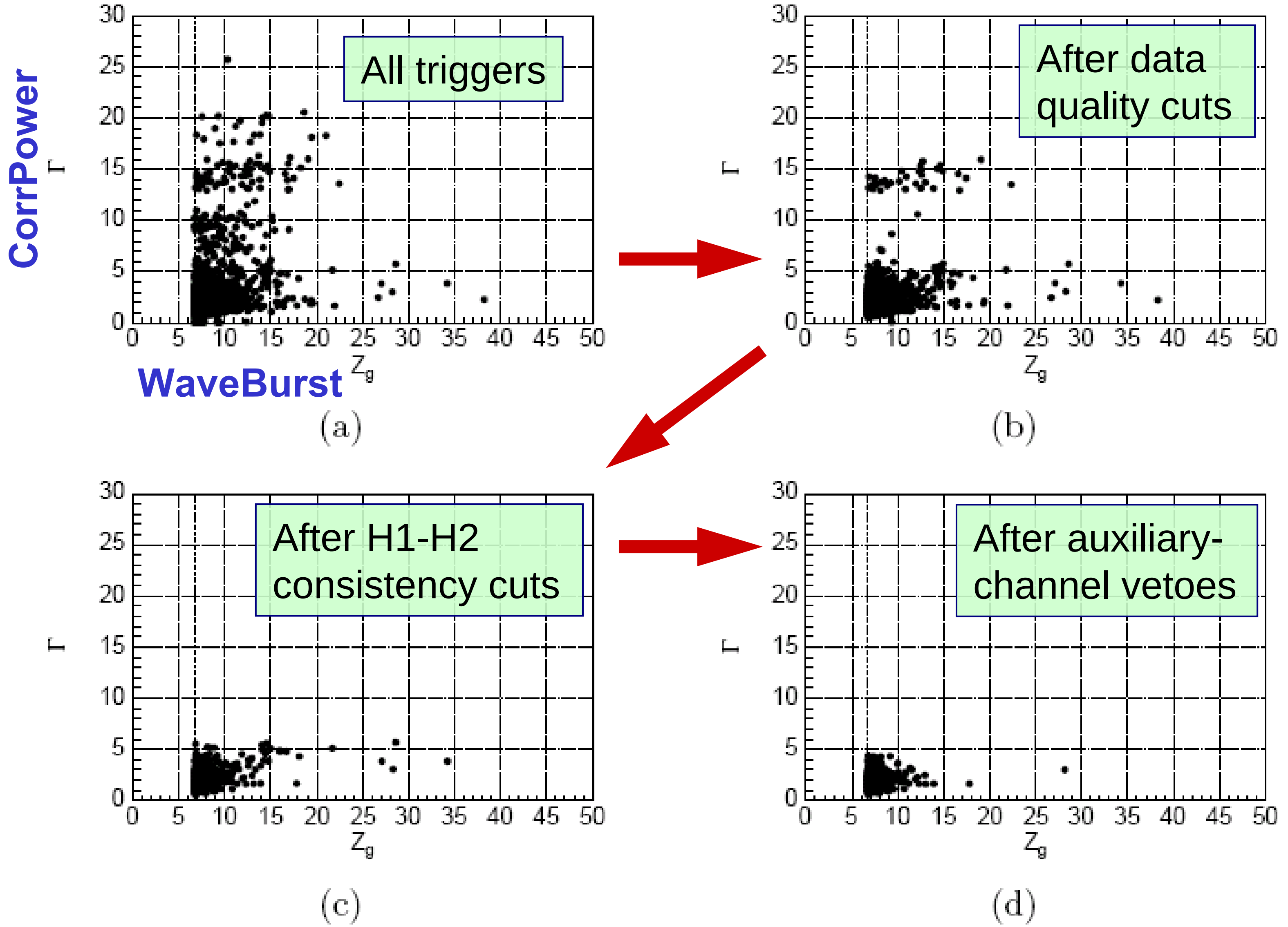
Relative time shifts: up to 11 ms for H1-L1 and H2-L1



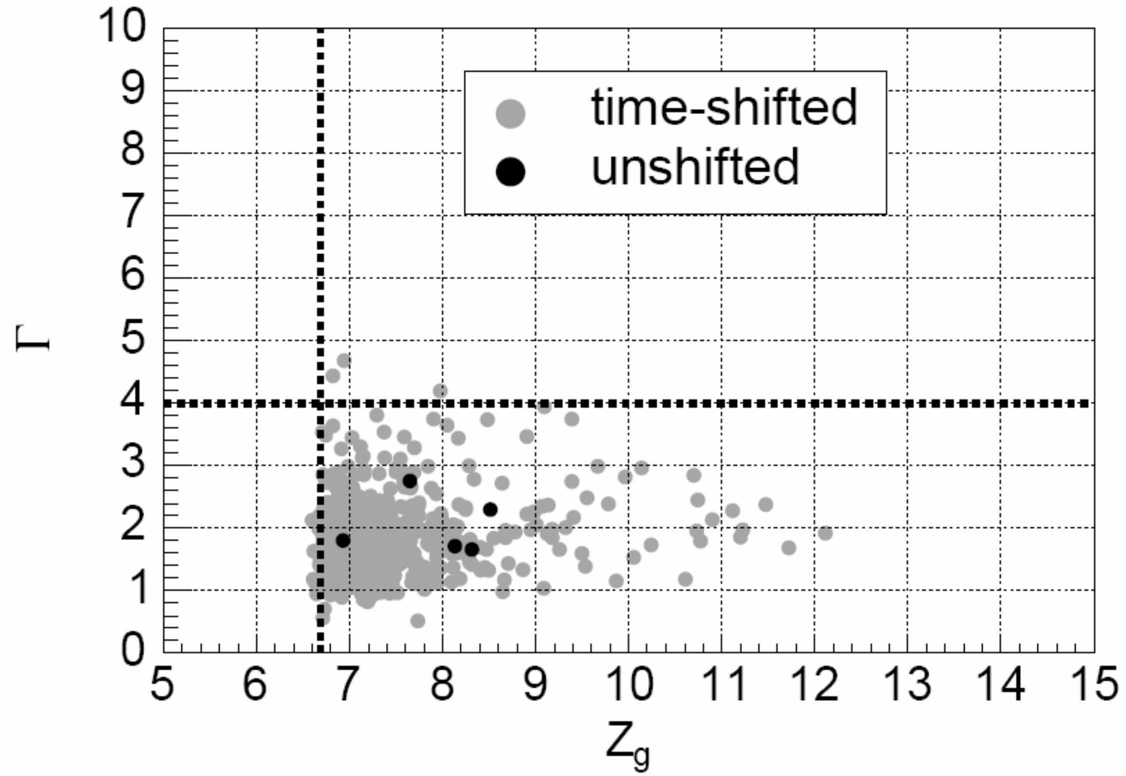
Find maximum correlation over window lengths and time shifts

Calculate overall significance statistic Γ by combining the 3 pairs

Analysis Cuts and Vetoes



The Search Result



Frequentist one-sided upper limit (90% C.L.)

$$\boldsymbol{R_{90\%}} = \frac{2.303}{15.5 \text{ days}} = \textbf{0.15 per day}$$

What Could the Search Have Seen?

Use a Monte Carlo Simulation — "BurstMDC"

- Generate a strain waveform at a random time and sky position
- Calculate signal at each detector with correct time delay and antenna response *(code by Amber Stuver and Keith Thorne)*
- Add to real detector data and analyze with the same search pipeline

Obtain efficiency of the search pipeline as a function of amplitude

- Our basic amplitude measure: root-sum-squared strain

$$h_{\mathrm{rss}} \equiv \sqrt{\int \left(|h_+(t)|^2 + |h_\times(t)|^2\right) \mathrm{d}t}$$

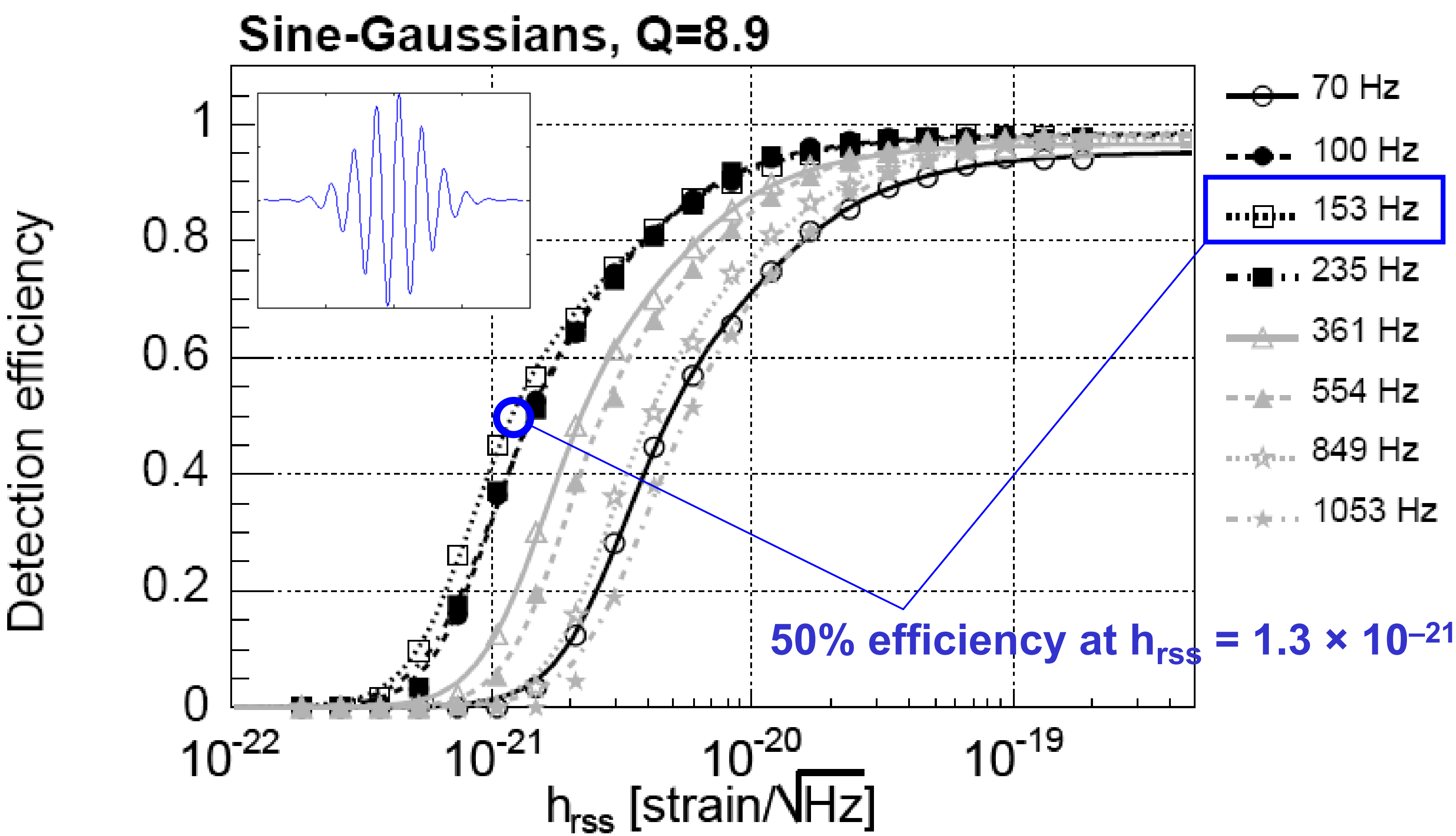
Ad-hoc waveforms used to evaluate S4 all-sky search

- Sine-Gaussians
- Gaussians

  } ← Linearly polarized

- Band-limited white noise bursts ← Two independent polarizations

Example Efficiency Curves



Generally expect similar sensitivity for different waveforms with similar frequency, bandwidth, and duration

Connect with Energy Emission

Instantaneous energy flux:

$$\frac{\mathrm{d}^2 E_{\mathrm{GW}}}{\mathrm{d}A\,\mathrm{d}t} = \frac{1}{16\pi}\frac{c^3}{G}\left\langle (\dot{h}_+)^2 + (\dot{h}_\times)^2 \right\rangle$$

Assume isotropic emission to get simple rough estimates

For a sine-Gaussian with Q>>1 and frequency f_0 :

$$E_{\mathrm{GW}} = \frac{r^2 c^3}{4G}(2\pi f_0)^2 h_{\mathrm{rss}}^2$$

For a 153 Hz, Q =8.9 sine-Gaussian, the S4 search could see energy emission as small as:

~ 8 × 10^{-8} $M_\odot c^2$ at 10 kpc (typical Galactic distance)

~ 0.2 $M_\odot c^2$ at 16 Mpc (Virgo cluster)

Reach for Supernova Waveforms

Ott, Burrows, Dessart and Livne, PRL 96, 201102 (2006)

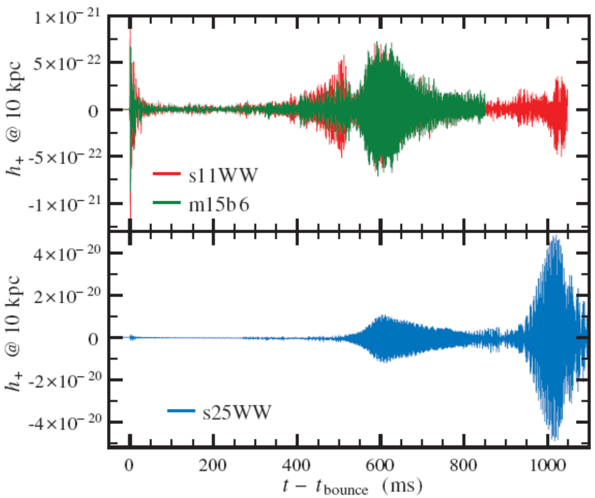


TABLE I. MODEL SUMMARY.

Model	Δt^{a} (ms)	$\lvert h_{+,\max}\rvert^{b}$ (10^{-21})	$h_{\mathrm{char,max}}^{b,c}$ (10^{-21})	$f(h_{\mathrm{char,max}})$ (Hz)	E_{GW}^{d} $(10^{-7} M_\odot c^2)$
s11WW	1045	1.3	22.8	654	0.16
s25WW	1110	50.0	2514.3	937	824.28
m15b6	927.2	1.2	19.3	660	0.14

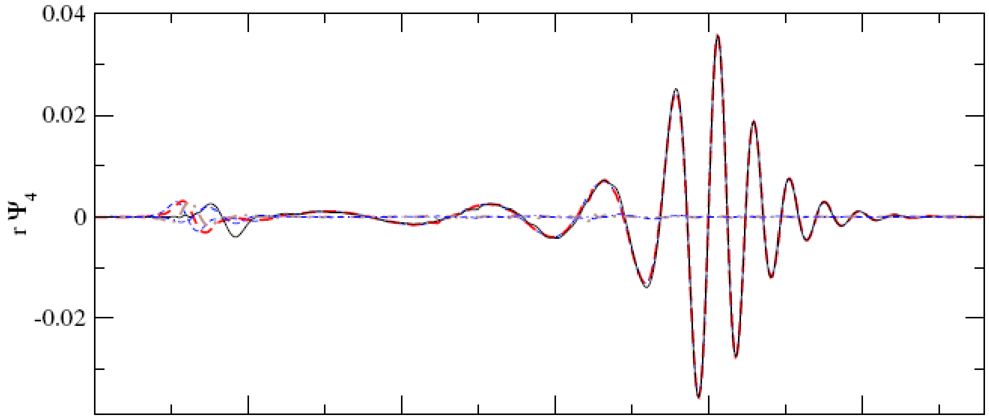
Estimate h_{rss} sensitivity for these waveforms by relating to sine-Gaussians and white noise bursts used in Monte Carlo

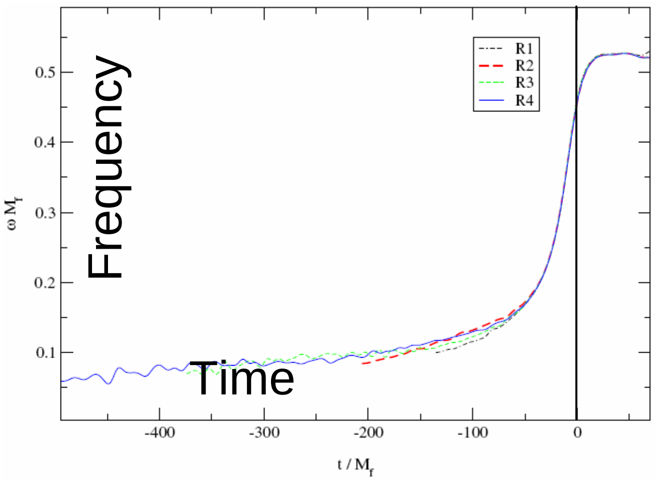
11 or 15 $M_\odot$ progenitor: $h_{rss}(50\%) \approx 6\times10^{-21}$ $\Rightarrow$ reach ≈ 0.2 kpc

25 $M_\odot$ progenitor: $h_{rss}(50\%) \approx 8\times10^{-21}$ $\Rightarrow$ reach ≈ 8 kpc

Reach for Merger Waveforms

Example: Baker et al, PRD 73, 104002 (2006)





~ 3.5% of total mass is radiated

$$f_{\rm peak} \approx \frac{0.46}{2\pi M_f} \approx \frac{15\ \rm kHz}{(M_f/M_\odot)}$$

Estimate h_{rss} sensitivity for these waveforms by relating to low- Q sine-Gaussians used in Monte Carlo

10+10 $M_\odot$ binary: h_{rss}(50%) ≈ 5×10^{-21} ⇒ reach ≈ 1.5 Mpc

50+50 $M_\odot$ binary: h_{rss}(50%) ≈ 1.4×10^{-21} ⇒ reach ≈ 60 Mpc

Work in Progress

Search the more sensitive S5 data !

The LSC-Virgo Burst Group

Get full inspiral+merger+ringdown waveforms into BurstMDC

Sean McWilliams (U of Maryland / GSFC)

Interpret limits (or detections) in the context of a *population* of astrophysical sources

Sam Finn and Penn State colleagues