Eyes Wide Open:

Searching for Gravitational Wave Bursts

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Philosophy

We're listening to the whole sky – who knows what's out there?

Models are OK, but don't put *too* much faith in them!

Goal: be able to detect *any* signal

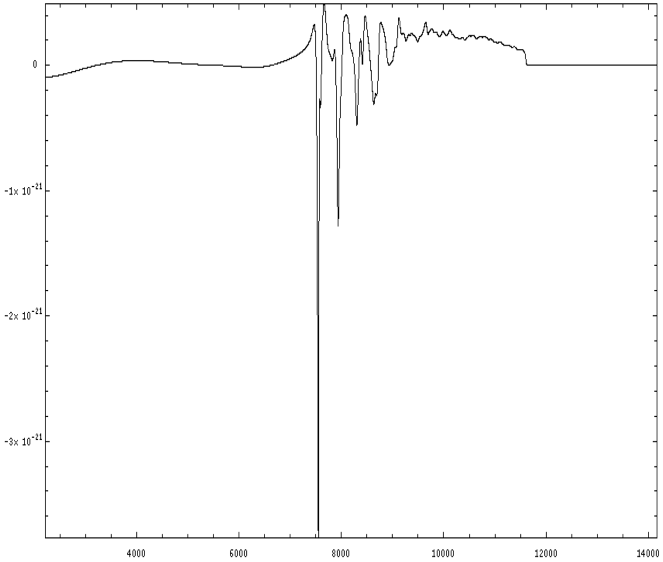
… if it has sufficient power within the sensitive frequency band

… and is "short"

Use signal analysis methods that don't require detailed knowledge of waveforms

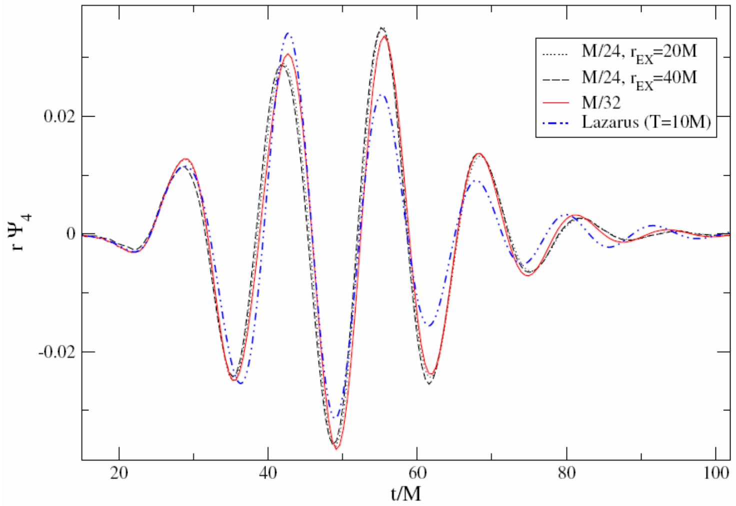
Some Specific Astrophysical Targets

Stellar core collapse



Zwerger and Müller, Astron. Astrophys. **320**, 209 (1997)

Binary coalescence with in-band merger



Baker et al., Phys. Rev. Lett **96**, 111102 (2006)

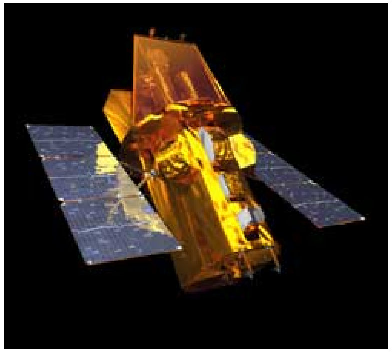
Also back up the matched-filtering search for rapid inspirals

Cosmic string cusp or kink, instability in a rotating system, something else…

Correlating GW Events with Other Observations

GW burst sources may also emit EM or particles

e.g. see Sylvestre, Astrophys. J. **591**, 1152 (2003



Swift

"Externally triggered" searches:
GRBs, SGR flares, pulsar glitches, supernovae, neutrinos, ...

Active subgroup of the Burst Group devoted to this

Time of GW signal may not exactly match time of EM/particle signal – depends on astrophysics

Eventually will want to use GW events to trigger prompt EM follow-up observations

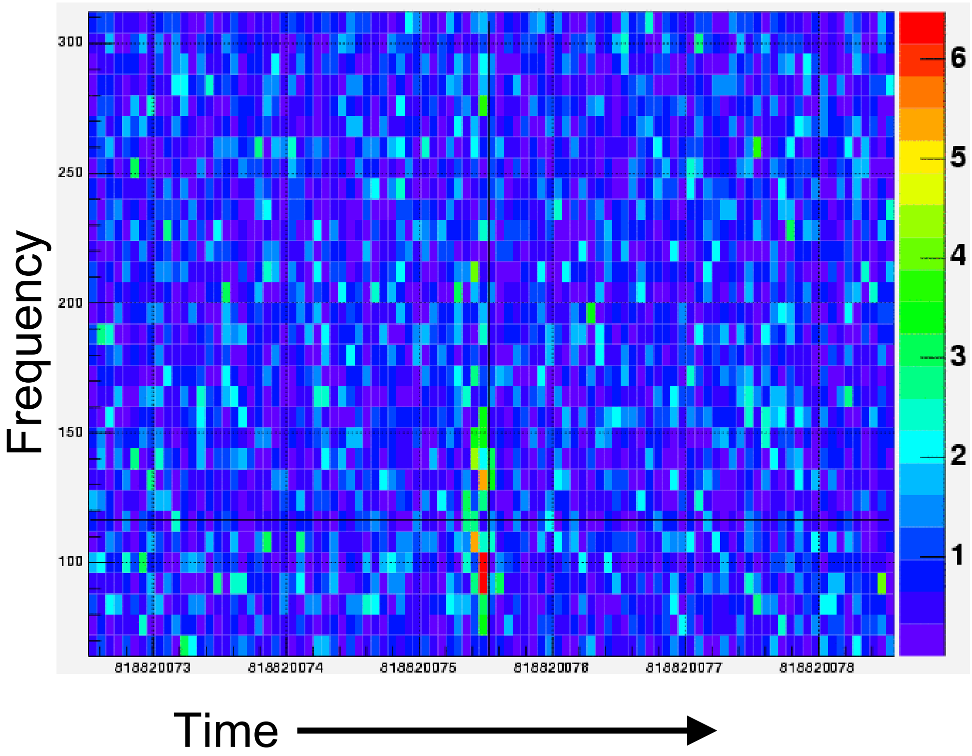
“Excess Power” Search Methods

Decompose data stream into time-frequency pixels

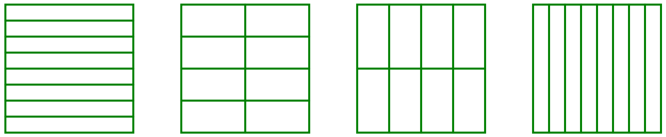
- Fourier components, wavelets, “Q transform”, etc.
- Several implementations of this type of search

Normalize relative to noise as a function of frequency

Look for “hot” pixels or clusters of pixels



Can use multiple (Δt,Δf) pixel resolutions



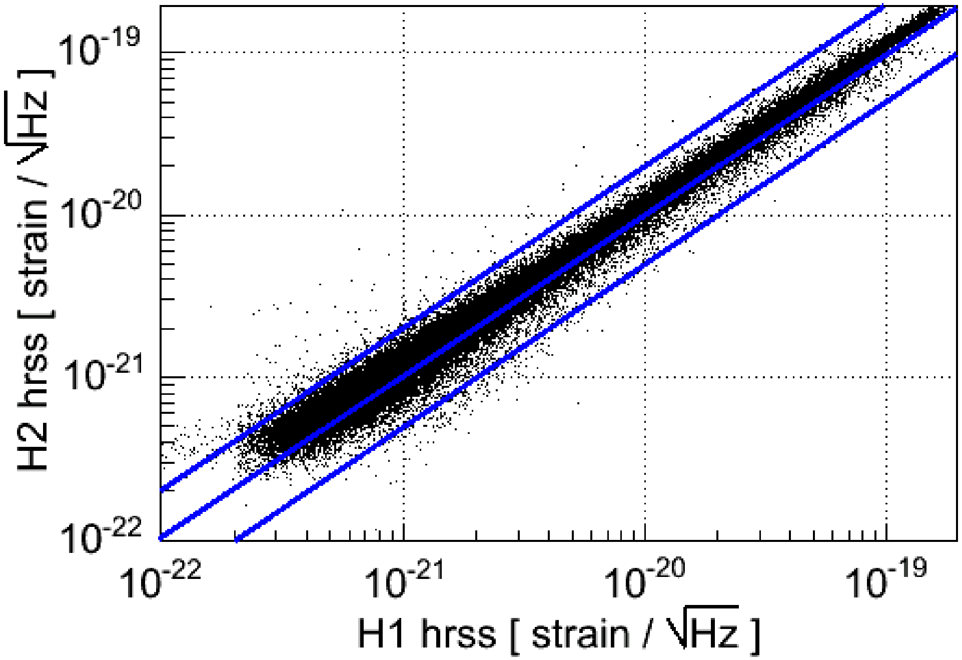
…

Coincidence / Consistency Tests

Crucial since a GWB may look just like an instrumental glitch

Require coincidence in time, frequency, etc.

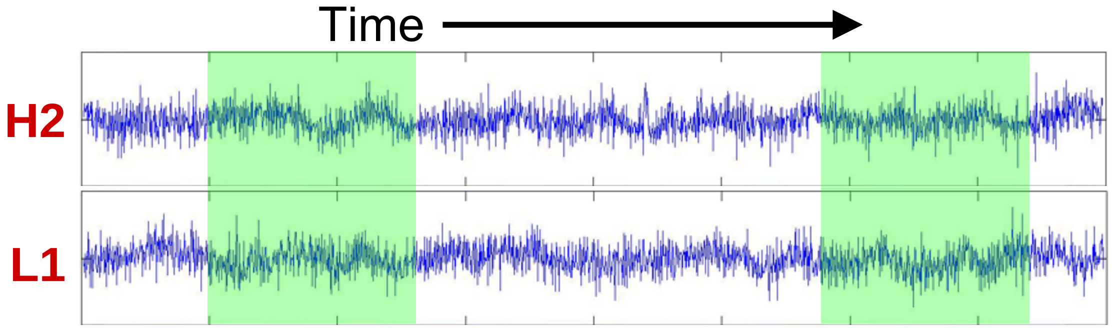
Example: H1/H2 amplitude consistency cut from S4 all-sky burst search



Generally apply same tests to time-shifted data streams to estimate rate of false coincidences

Cross-Correlation Methods

Look for same signal buried in two data streams



r-statistic checks for consistent shape, regardless of relative amplitude

Integrate over a time interval comparable to the target signal

Coherent Analysis Methods

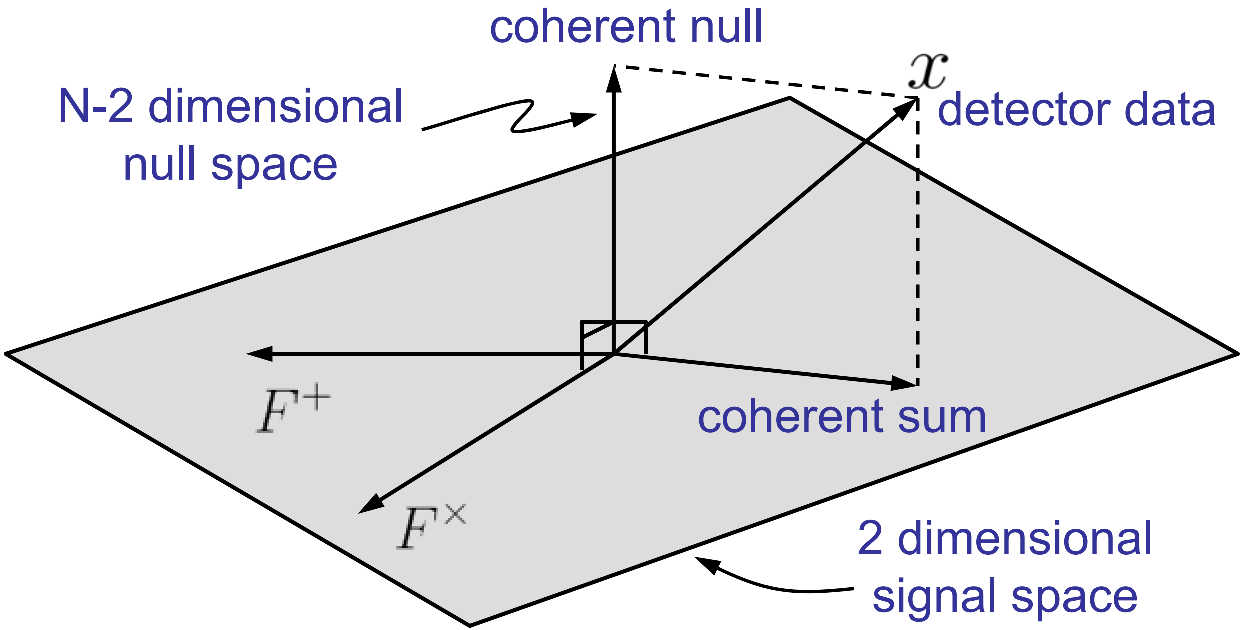
$$\begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_N \end{bmatrix} = \begin{bmatrix} F_1^+ & F_1^\times \\ F_2^+ & F_2^\times \\ \vdots & \vdots \\ F_N^+ & F_N^\times \end{bmatrix} \begin{bmatrix} h_+ \\ h_\times \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \\ \vdots \\ n_N \end{bmatrix}$$

data = *response* x *signal* + *noise*

Coherent sum:
Find linear combinations of detector data that maximize signal to noise ratio

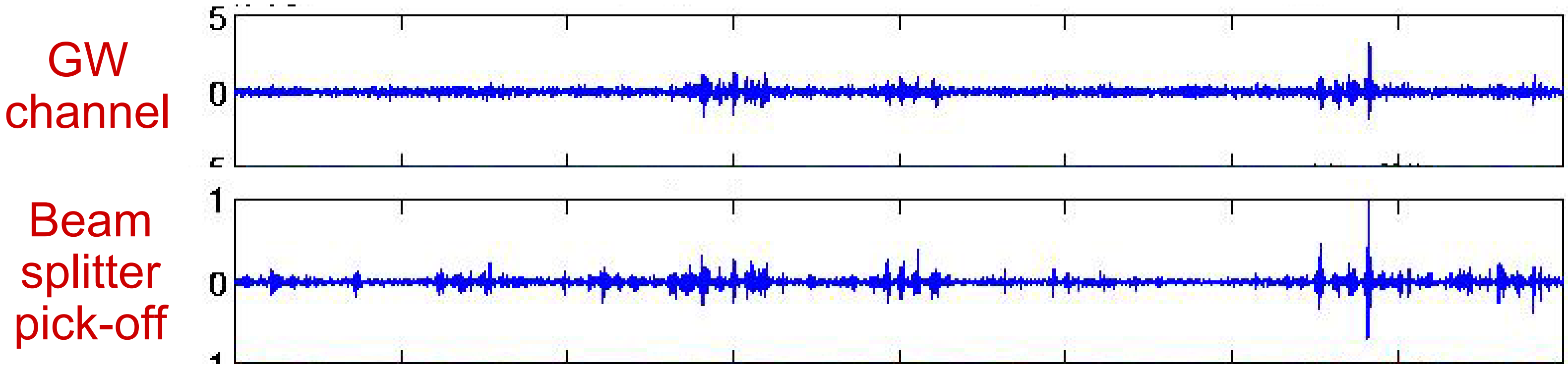
X = F h + n

Null sum:
Linear combinations of detector data that cancel the signal provide useful consistency tests.



The Burst-Search Bazaar

- **Multiple burst search methods are in active use**
  - Mathematical arguments about optimality only go so far
  - Implementation details are critical
  - Data conditioning, robustness against non-stationary noise, …
- **Some degree of competition and cross-pollination**
- **Big emphasis on data quality and vetoes**
  - To reduce trigger rate, possibly allow thresholds to be lowered, and help us judge whether an event candidate may be real



Evaluating Detection Efficiency

Test / tune searches using simulated signals

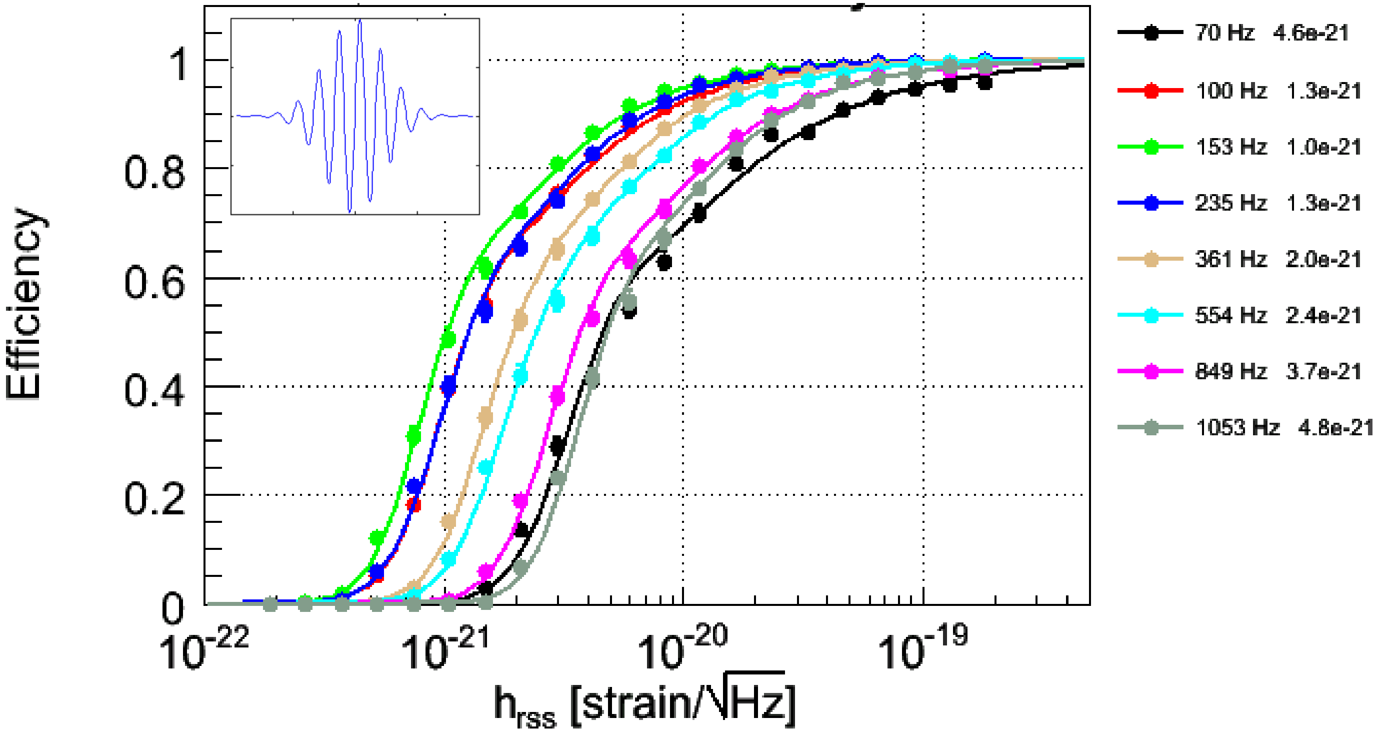
Astrophysically modeled, or ad hoc

Sine-Gaussians, Gaussians, white noise bursts

$h(t) = h_0 \sin(2\pi f t) \exp(-2(\pi f t/Q)^2)$ $h_{rss} = h_0 (Q/4f)^{1/2} / \pi^{1/4}$

Linearly polarized; random sky position & polarization angle

f =



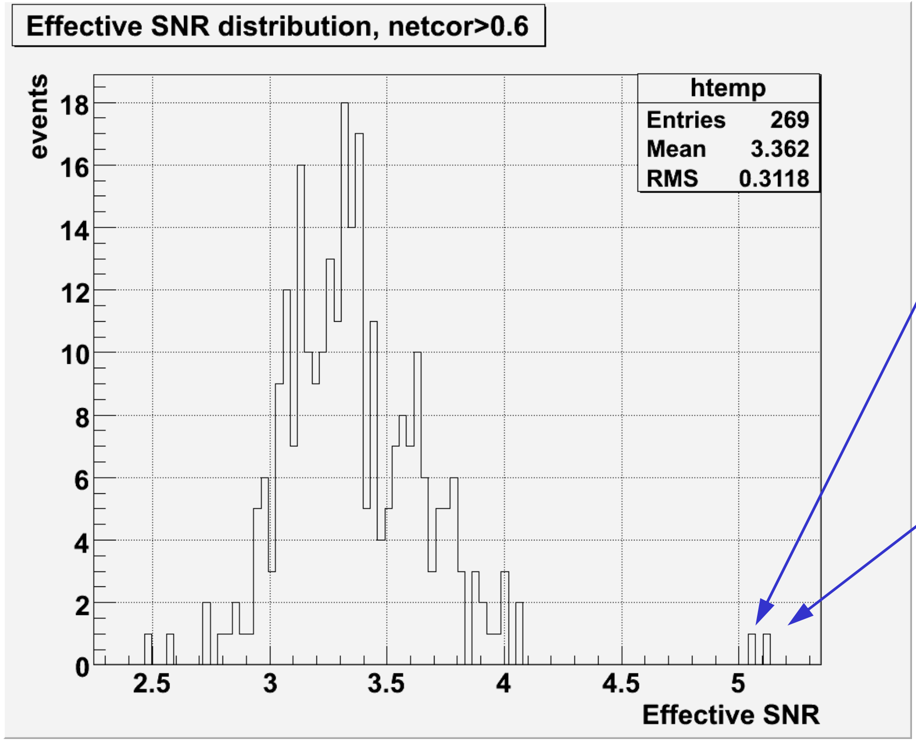
How Sensitive are Burst Searches?

Not as sensitive as matched filtering for known signals

Generally require much less computation to cover a wide parameter space

But not *too* much worse for short signals

Coherent WaveBurst results from blind injection test period on June 5-6:



Binary inspiral/merger
16.8 + 4.4 Msun

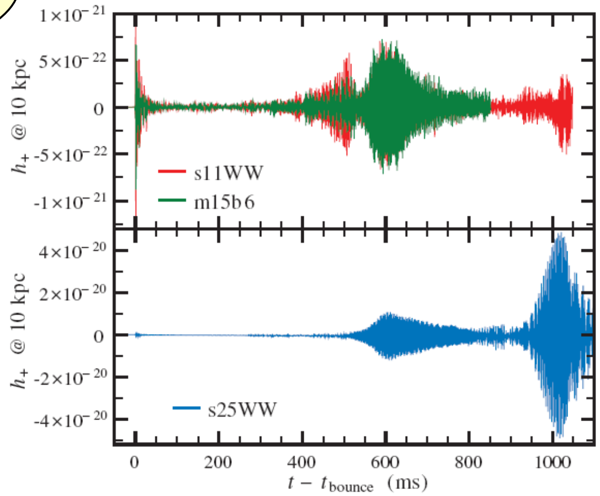
SNRs from inspiral search:
H1 12.4, L1 8.5

Binary inspiral/merger
6.1 + 5.4 Msun

SNRs from inspiral search:
H1 12.9, H2 7.5, L1 11.4

Order-of-Magnitude S5 Range Estimates for Supernovae and BH Mergers

Model dependent!



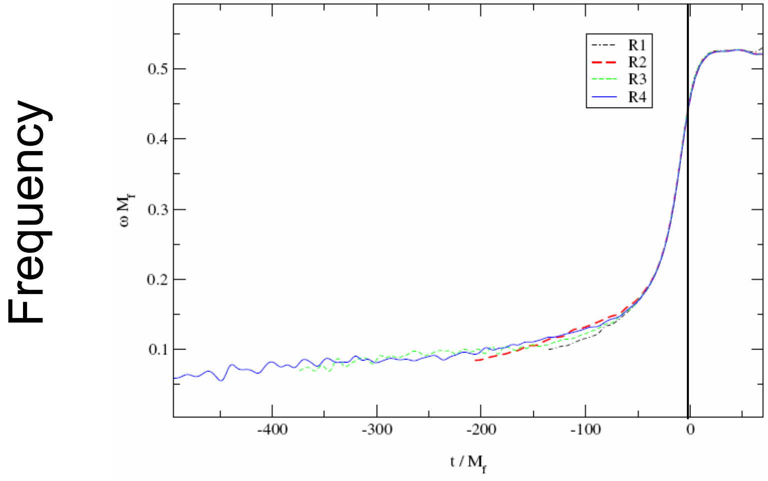


TABLE I. MODEL SUMMARY.

Model	$\Delta t^{\rm a}$ (ms)	$\lvert h_{+,\rm max}\rvert^{\rm b}$ (10^{-21})	$h_{\rm char,max}{}^{\rm b,c}$ (10^{-21})	$f(h_{\rm char,max})$ (Hz)	$E_{\rm GW}{}^{\rm d}$ ($10^{-7} M_\odot c^2$)
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

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

$11\ M_\odot$ progenitor (s11WW model)
$\Rightarrow$ reach ≈ 0.4 kpc
$25\ M_\odot$ progenitor (s25WW model)
$\Rightarrow$ reach ≈ 16 kpc

Assuming ~3.5% mass radiates in the merger:
$10+10\ M_\odot$ binary $\Rightarrow$ reach ≈ 3 Mpc
$50+50\ M_\odot$ binary $\Rightarrow$ reach ≈ 100 Mpc

Taking Full Advantage of the Global Network

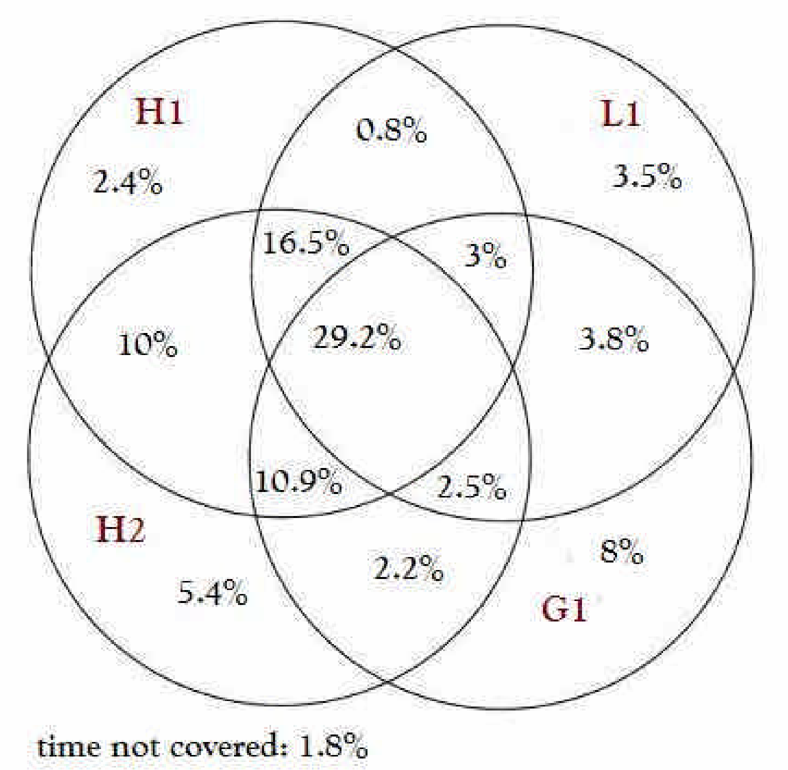
Increased emphasis on making use of all available data

- Various detector networks during S5 / VSR1

Advantages:

- More observation time
- Better sky coverage
- Better detection confidence
- Better source reconstruction

S5 first calendar year



What Else Could We Be Doing Better?

Longer-duration signals

Wider range of simulated signals

- Including available modeled signals

More-prompt analysis

The Burst Group:
Eyes Wide Open, Eager to Learn

Cute Boy (No.6) by Martin Paul, http://photo.net/photodb/photo?photo_id=5321993