New LIGO Results in the Search for Gravitational Wave Bursts

LIGO Hanford Observatory

LIGO Livingston Observatory

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For the LIGO Scientific Collaboration

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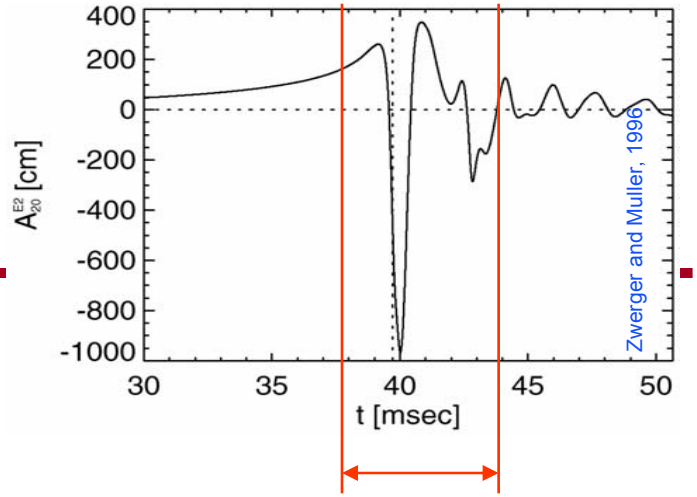
Burst Search



δt ~ 0.005s

Goal:

"wide-eye" search for un-modeled signals

minimal assumptions

open to unexpected sources and serendipity

Un-triggered Search

Broadband search (100-2000Hz) for short transients (few ms - 1 sec) of gravitational radiation of unknown waveform (e.g. supernovae, black hole mergers).

Method: *excess power* or *excess amplitude* techniques; coincidence between detectors

Results from first science run (S1): Phys. Rev. D 69 (2004) 102001

Externally Triggered Search -- Supernovae & Gamma Ray Bursts

Exploit coincidence with electromagnetic observations.

Waveforms still unknown, but time, direction potentially known.

Method: interferometer-interferometer cross-correlation techniques.

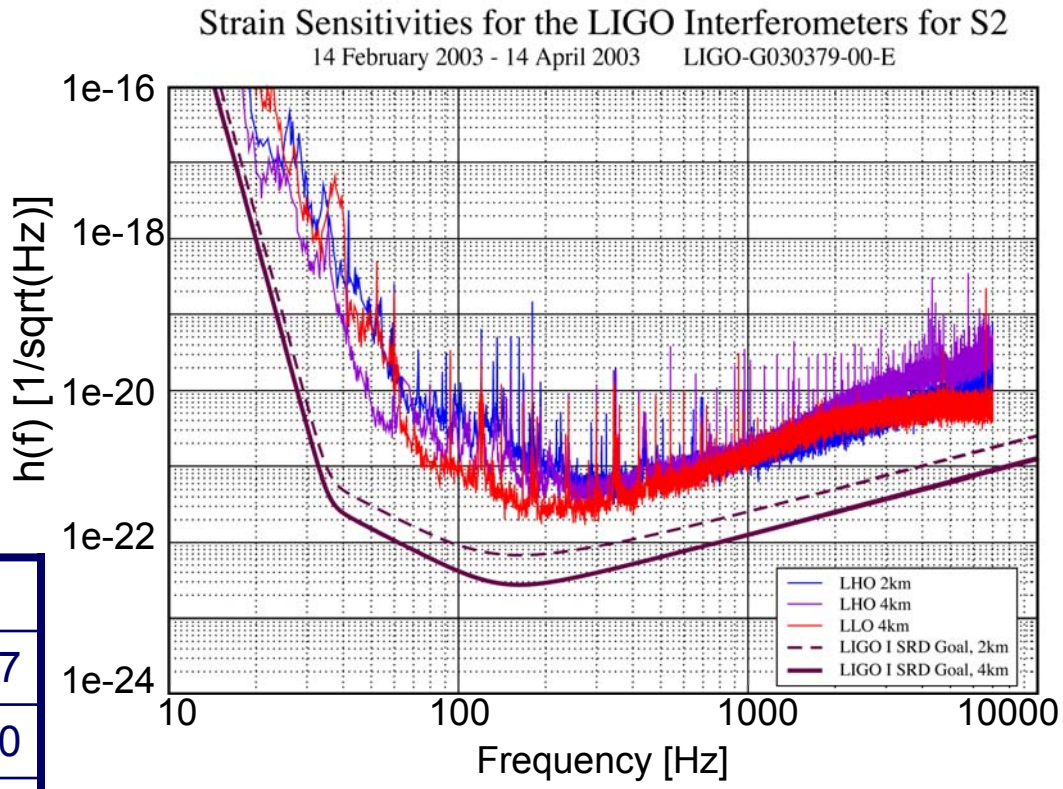
No close supernovae/GRBs occurred during the first science run.

Second science run: we analyzed GRB030329. gr-qc/0501068 (Submitted to PRD)

S2: Second Science Run

Improvements over S1 relevant to the burst search:

- 60 days of running (19 in S1)
- ~ 10 times more live time with three detectors
- ~ 10 times better sensitivity than S1



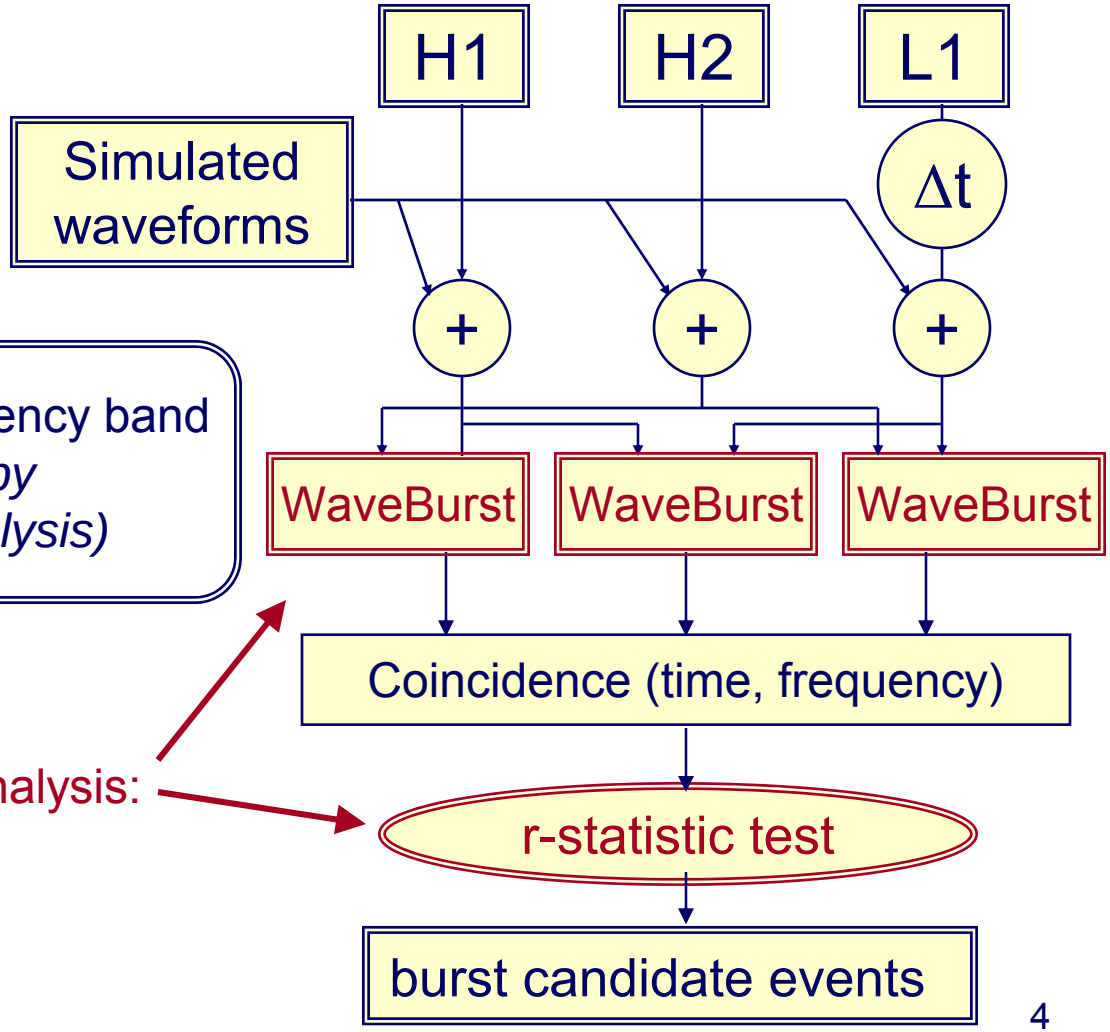
S2 Science Mode Running

Interferometer	hours	%
LHO-4km (H1)	1043.7	73.7
LHO-2km (H2)	821.8	58.0
LLO-4km (L1)	536.4	37.9
H1·H2·L1	318.0	22.5
Used for burst result	239.5 (10 live days)	16.9

data quality cuts,
exclusion of 10% data set for tuning,
pipeline inefficiencies

S2 Burst Analysis Pipeline

The search uses all three LIGO interferometers (H1, H2, L1)



Search in 100-1100 Hz frequency band *(higher frequencies covered by LIGO-TAMA coincidence analysis)*

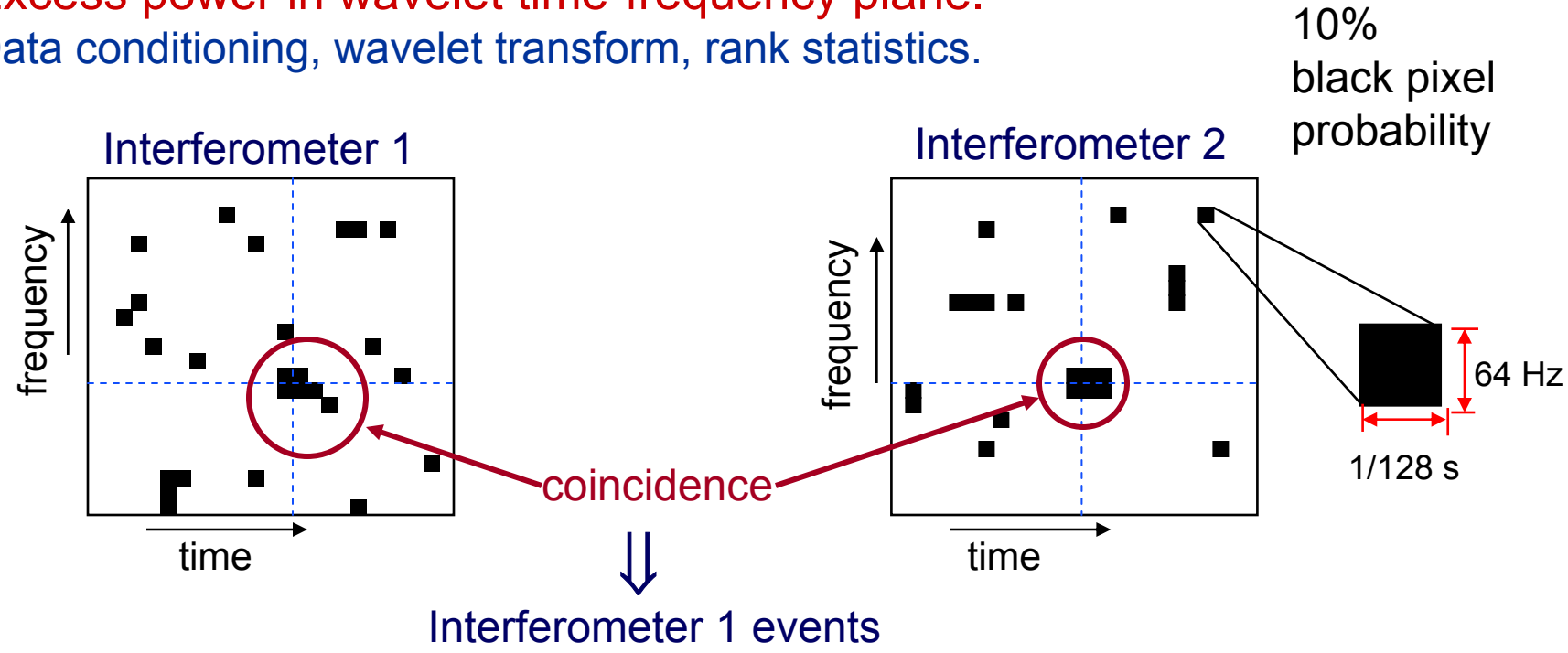
Novelties since the S1 analysis:

WaveBurst: Candidate Events Generation

Replaces the algorithm used in S1 (TFClusters)

Excess power in wavelet time-frequency plane.

Data conditioning, wavelet transform, rank statistics.



Repeat on 3 pairs, to obtain events from 3 interferometers and their significance..

Threshold on combined significance of triple coincidence events.

Ref: Class. Quantum Grav. 21 (2004) S1819

r-statistic Waveform Consistency Test

Process **pairs** of interferometers (whitened data, 100-2000 Hz)

What is the probability that the 2 data sequences are un-correlated ?

r-statistic:

$$r_k = \frac{\sum_i (x_i - \bar{x})(y_{i+k} - \bar{y})}{\sqrt{\sum_i (x_i - \bar{x})^2}\sqrt{\sum_i (y_{i+k} - \bar{y})^2}}$$

Significance of null-hypothesis:

$$S = \mathrm{erfc}\left(\sqrt{r^2 \frac{N}{2}}\right)$$

The incident GW direction is unknown
→ allow time delay (Δt) between the two data series

$$C_M = \max_{\Delta t} (-\log_{10} S(\Delta t))$$

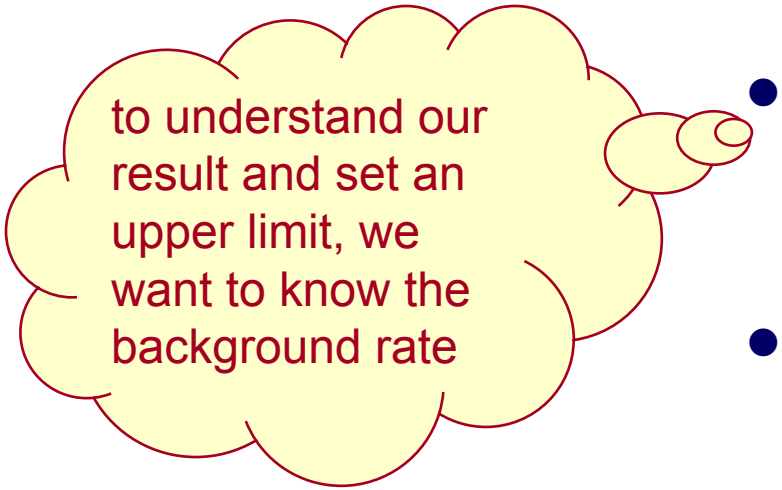
Combine IFO pairs and search possible signal duration to maximize the final statistic Γ

$$\Gamma = \max(C_M^{L1H1} + C_M^{L1H2} + C_M^{H1H2})/3$$

Ref: *Class. Quantum Grav. 21 S1695-S1703*

Pipeline Tuning and Background Estimation

- Blind Analysis: the pipeline is tuned on a ~10% “playground” sub-sample, not used in final analysis.



- The background is estimated using time-shifted 3-fold coincidences.
  - » LLO data shifted relative to LHO data
  - » 46 × 5s time shifts (5s ≤ |Δt| ≤ 115s)
- Identical pipeline, cuts for all shifted data

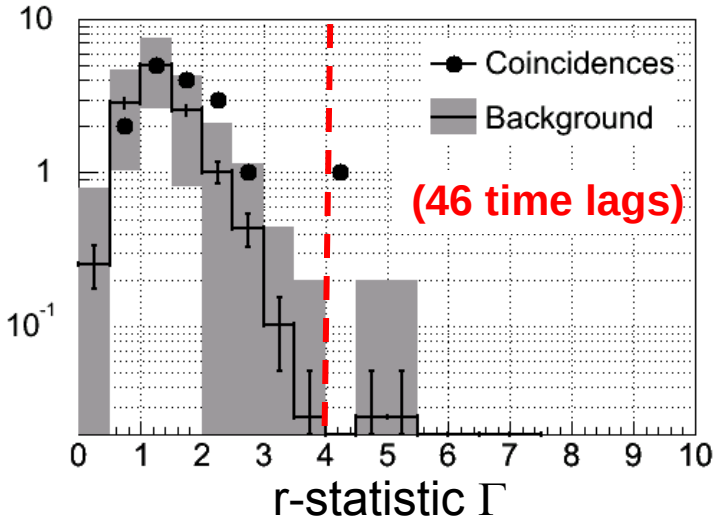
- The WaveBurst global significance threshold is tuned to produce O(10 μHz) coincidence rate (before *r*-statistic) .
- The *r*-statistic aims at ~99% reduction in final rate. Threshold set to Γ>4.
- Expected background in the S2 live time is <0.1 events.

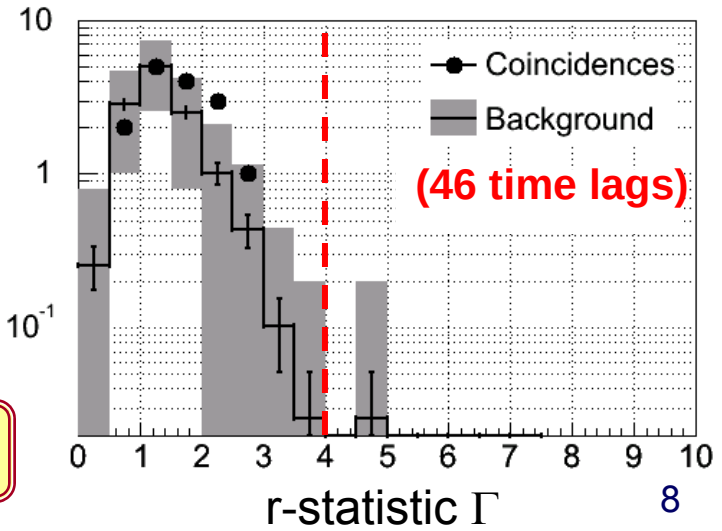
Upper Limit on Rate of Detectable Bursts

- The blind procedure gives one candidate
  - » Event immediately found to be correlated with airplane over-flight at Hanford.
  - » Acoustic noise detected in microphones and known couplings account for Hanford burst triggers (solved before the S3 run)
- Background estimate is 0.05

- Introducing a post-facto acoustic veto
  - » power in 62-100 Hz band in PSL table microphone
- Background estimate is 0.025
- 90% CL upper limit is 2.6 events
  - » Account for modified coverage due to introduction of post-facto veto

Rate upper limit = 0.26/day (1.6/day in S1)

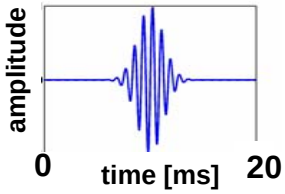


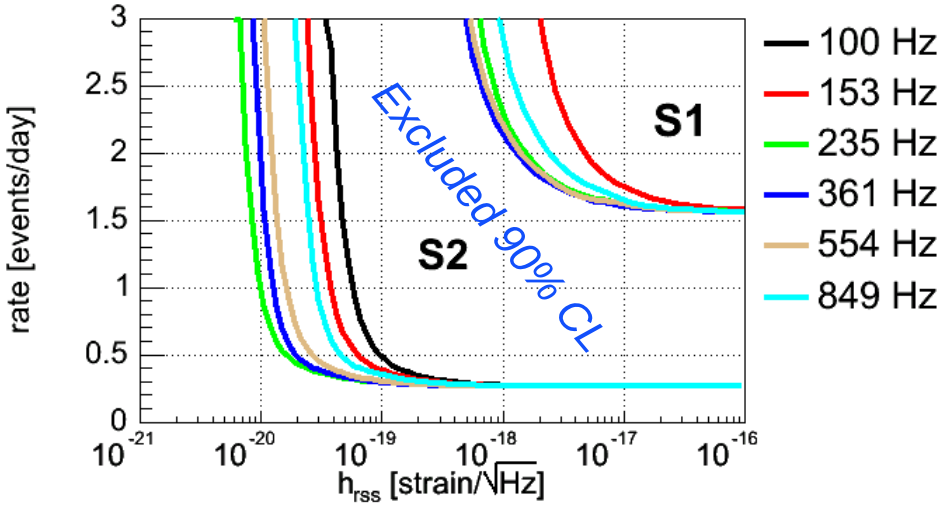


"Interpreted" Upper Limit

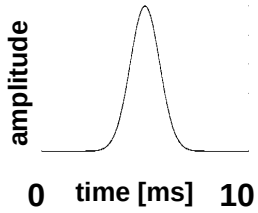
To measure our efficiency, we must pick a waveform!

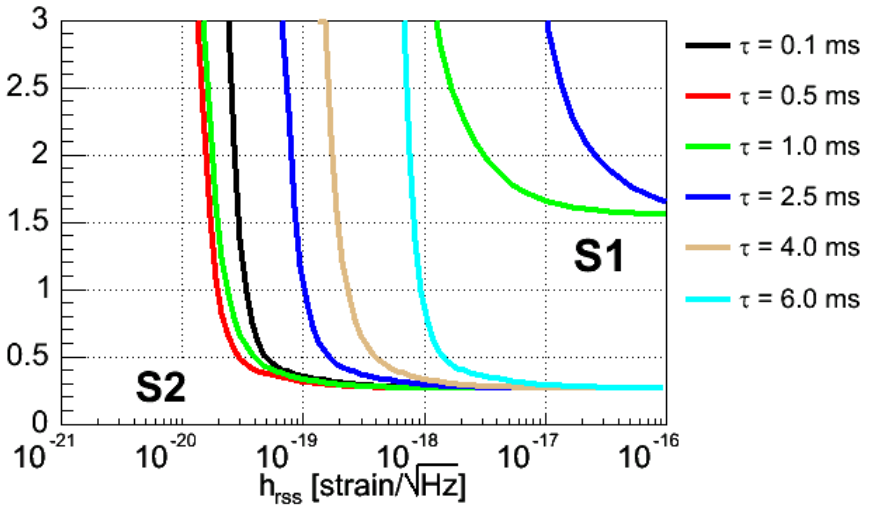
sine-Gaussians





Gaussians





$$h_{rss} = \sqrt{\int |h(t)|^2 dt}$$

$$R(h_{rss}) = \frac{\eta}{\varepsilon(h_{rss}) \times T}$$

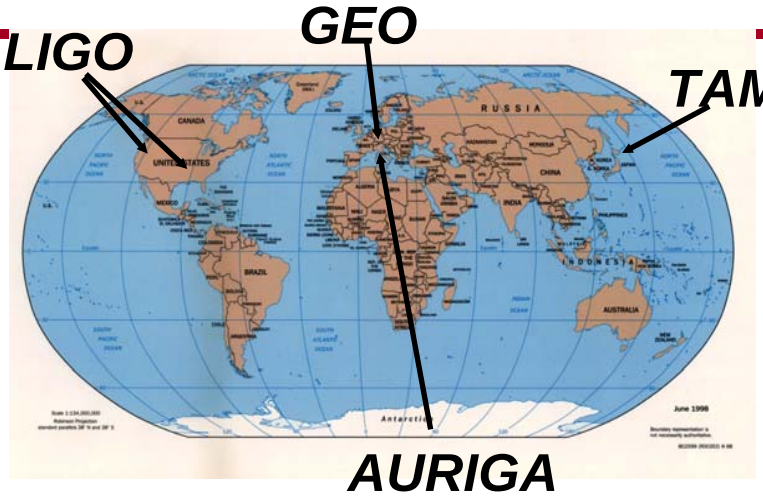
η=upper limit on event number

T=live time

$\varepsilon(h_{rss})$=efficiency vs strength

Exclusion curves account for 8% systematic calibration uncertainty and MonteCarlo statistical error

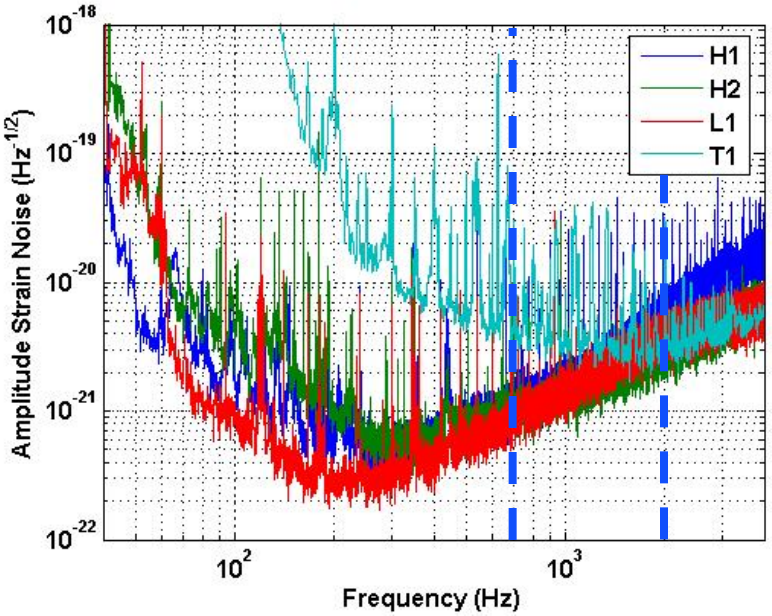
700-2000 Hz : Collaborative Analysis

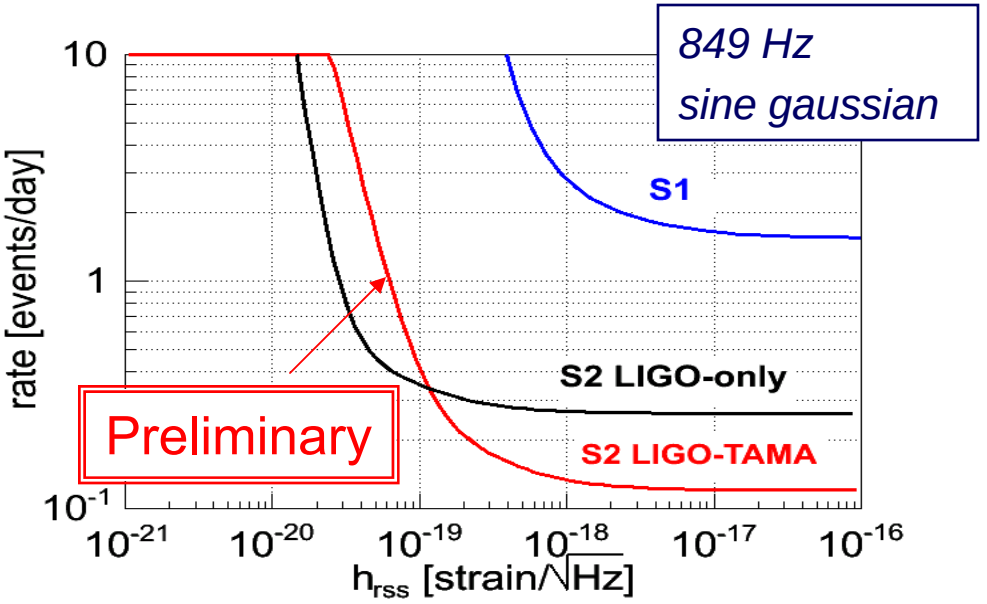


Ongoing joint analyses:
S2: TAMA (700-2000 Hz)
S3: GEO (700-2000 Hz) AURIGA (850-950 Hz)

benefits and costs:

- » Reduction of false alarm rate (4X)
- » Increase in observation time (3X & 4X)
- » Sensitivity restricted to common (high-frequency) band, limited by least sensitive detector





Summary

The Burst analysis team has completed the analysis of triple coincidence data from the S2 science run.

- Improvements since S1:
  - More sensitive interferometers; longer triple-coincidence live-time;
  - a new wavelet-based search code;
  - *r*-statistic test for waveform consistency in the 3 IFOs.
- Results:
  - The upper limit for detectable bursts in the 100-1100Hz band is 0.26/day
  - Rate vs. strength curves were calculated for Gaussian and sine-Gaussian waveforms.
- Higher frequency band (700-2000 Hz) explored in conjunction with TAMA:
  - Increased observation time (x3, x4 coincidence) at a (reasonable) cost in sensitivity

More data is available now…

S3 run: Oct. 31, 2003 – Jan 9, 2004

- Live time comparable to S2; better sensitivity but larger transient rate; overall 50% improvement in burst detection efficiency for test waveforms.

S4 run: Feb. 22, 2005 – Mar. 23, 2005

- All interferometers within a factor ~2 of the initial LIGO science goal
- Data quality assessment in progress - analysis is just starting, stay tuned…