THE LSC AND ITS ROLE

NSF/ LIGO Review

Rainer Weiss, MIT

Cambridge, Mass October 23, 2002

LIGO Scientific Collaboration Member Institutions

University of Adelaide ACIGA
Australian National University ACIGA
Balearic Islands University
California State Dominquez Hills
Caltech CACR
Caltech LIGO
Caltech Experimental Gravitation CEGG
Caltech Theory CART
University of Cardiff GEO
Carleton College
Cornell University
Fermi National Laboratory
University of Florida @ Gainesville
Glasgow University GEO
NASA-Goddard Spaceflight Center
University of Hannover GEO
Hobart – Williams University
India-IUCAA
IAP Nizhny Novgorod
Iowa State University
Joint Institute of Laboratory Astrophysics
Salish Kootenai College

LIGO Livingston LIGOLA
LIGO Hanford LIGOWA
Loyola New Orleans
Louisiana State University
Louisiana Tech University
MIT LIGO
Max Planck (Garching) GEO
Max Planck (Potsdam) GEO
University of Michigan
Moscow State University
NAOJ - TAMA
Northwestern University
University of Oregon
Pennsylvania State University
Southeastern Louisiana University
Southern University
Stanford University
Syracuse University
University of Texas@Brownsville
Washington State University@ Pullman
University of Western Australia ACIGA
University of Wisconsin@Milwaukee

LSC Membership and Function

- Recommended by Barish and McDaniel Committee
- Founded in 1997: now, includes 44 collaborating groups with over 440 members
- Open to all interested research groups
- Membership and roles determined by MOU between LIGO Lab and institution
- MOU updated yearly and posted
- Agreement by LSC

LSC functions

- Determine the scientific needs of the project
- Set priorities for the research and development
- Present the scientific case for the program
- Carry out the scientific and technical research program
- Carry out the data analysis and validate the scientific results
- Establish the long term needs of the field

Additional LSC roles during operations

- Maximize scientific returns in the operations of LIGO Laboratory facilities
- Determine the relative distribution of observing and development time
- Set priorities for improvements to the LIGO facilities.

- LSC has become integrated into:
- Detector commissioning
- Detector operation and scientific guidance at the sites
- Advanced detector research and development
- Data analysis
- Software validation

Reports and examples of activities in the breakout session presentations

Mechanisms

- LSC White Paper on Detector Research and Development
  - describes near term program and goals
  - areas of research for long range program
  - iterated as new results become available
  - second iteration
- LSC Data Analysis White Paper
  - algorithm development for astrophysical sources
  - techniques for detector characterization
  - validation and test of software
  - long range goals for software and hardware
  - second iteration
- Publications and presentations policy
  - assure integrity of scientific and technical results
  - provide recognition of individual and institutional contributions
- Proposal driven data analysis
  - formation of groups to make specific analysis proposals
  - proposals posted and open to the entire collaboration
  - proposals reviewed by LSC executive committee

ORGANIZATION

- **LSC working committees**

Technical development committees

Suspensions and isolations systems - control of stochastic forces

David Shoemaker MIT

Optics -reduction in sensing noise

David Reitze University of Florida

Lasers - reduction in sensing noise

Benno Willke University of Hannover GEO

Interferometer configurations - detector control and response

Ken Strain University of Glasgow GEO

Work has led to advanced LIGO planning, groups are integral to the research ,development and implementation.

Major contribution by GEO to advanced LIGO **(Advanced LIGO)**

ORGANIZATION

Software and data analysis committees

Astrophysical sources and signatures

Bruce Allen University of Wisconsin @ Milwaukee

Barry Barish LIGO lab liaison

Detector characterization and modelling (detector commissioning)

Keith Riles University of Michigan

Daniel Sigg LIGO lab liaison

Software coordination committee and change control board

Alan Wiseman Data analysis and software coordinator

University of Wisconsin @ Milwaukee

LIGO Lab/LSC Computing Resources

Albert Lazzarini Caltech

GOVERNANCE and OPERATIONS

- LSC meetings in March and August

  LSC Council meeting (membership, governance…..)
- Executive committee meetings monthly

  Spokesperson, data and software Coordinator, committee chairs, Director and Deputy Director of LIGO Laboratory
- Working committees meet monthly or more frequently

Astrophysical source upper limit groups

- Combined groups of experimenters and theorists
- Develop data analysis proposals

Purpose:

- Test the LIGO Data Analysis System
- Set scientifically useful upper limits using engineering and early science data
- Publish first astrophysically interesting results from LIGO

Groups: (Data Analysis)

Burst sources : Sam Finn, Penn State, Peter Saulson, Syracuse

Inspiral sources: Pat Brady, Univ of Wisconsin, Gabriela Gonzalez, LSU

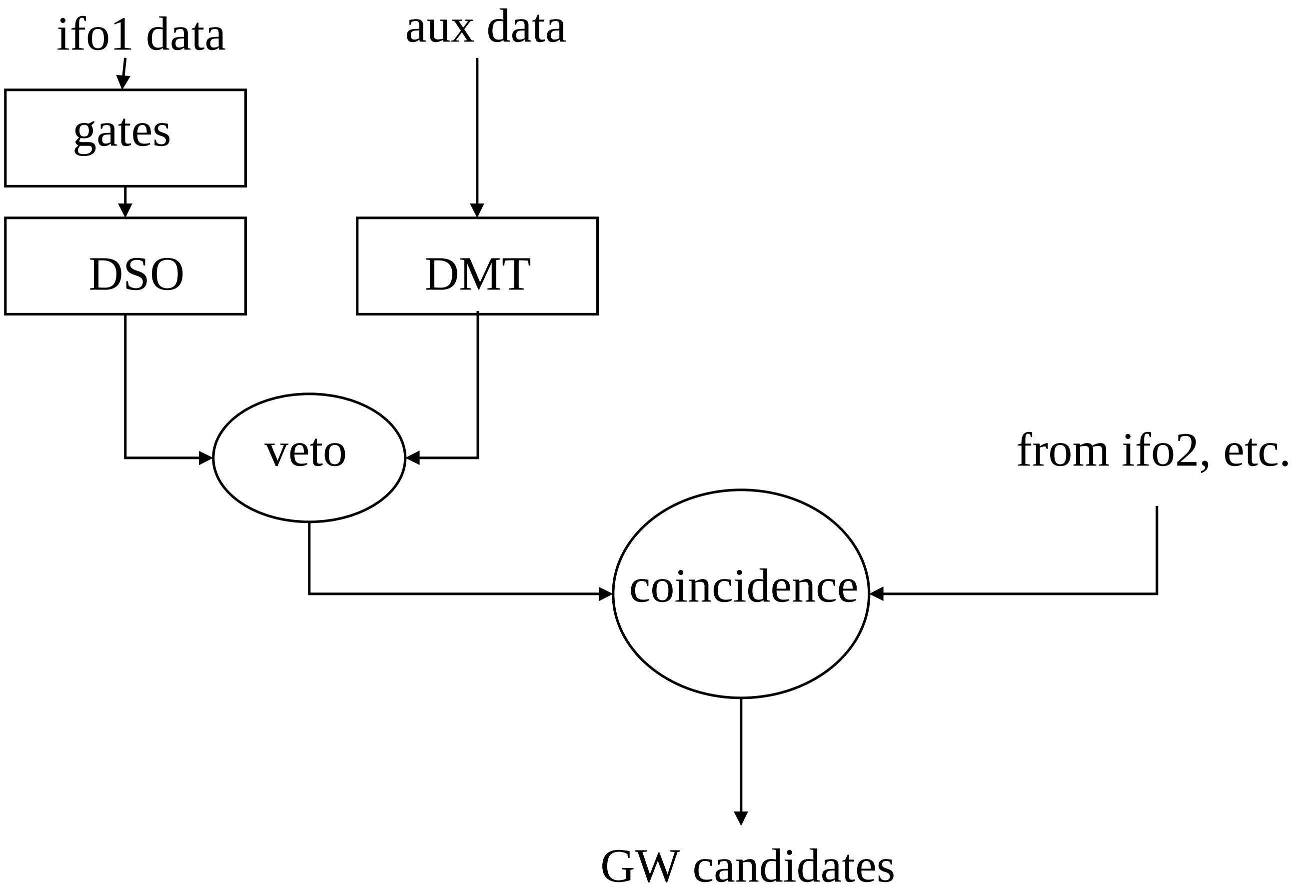
Periodic sources: Maria A Papa , AEI , Michael Landry, LIGO Hanford

Stochastic background: Joe Romano, UT Brownsville, Peter Fritschel, MIT

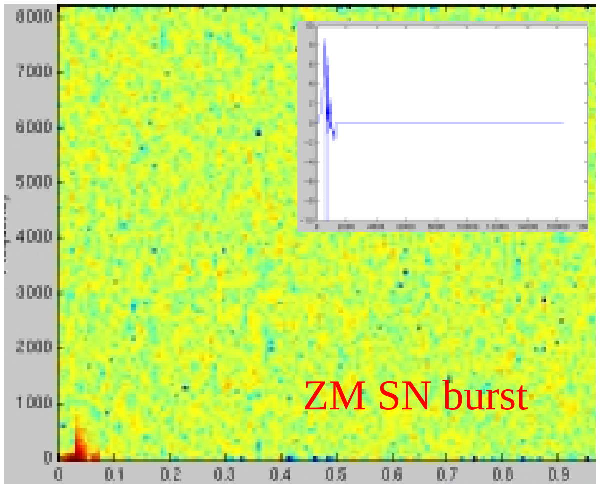
Burst Group membership

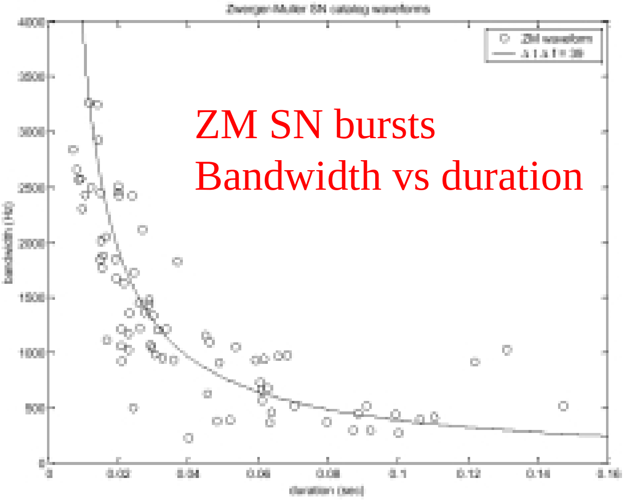
Rana Adhikari, Warren Anderson, Stefan Ballmer, Barry Barish, Biplab Bhawal, Jim Brau, Kent Blackburn, Laura Cadonati, Joan Centrella, Ed Daw, Ron Drever, *Sam Finn*, Ray Frey, Ken Ganezer, Joe Giaime, Gabriela Gonzalez, Bill Hamilton, Ik Siong Heng, Masahiro Ito, Warren Johnson, Erik Katsavounidis, Sergei Klimenko, Albert Lazzarini, Isabel Leonor, Szabi Marka, Soumya Mohanty, Benoit Mours, Soma Mukherjee, David Ottoway, Fred Raab, Rauha Rahkola, *Peter Saulson*, Robert Schofield, Peter Shawhan, David Shoemaker, Daniel Sigg, Amber Stuver, Tiffany Summerscales, Patrick Sutton, Julien Sylvestre, Alan Weinstein, Mike Zucker, John Zweizig

Untriggered search pipeline (simplified schematic)



Burst waveforms: t-f character





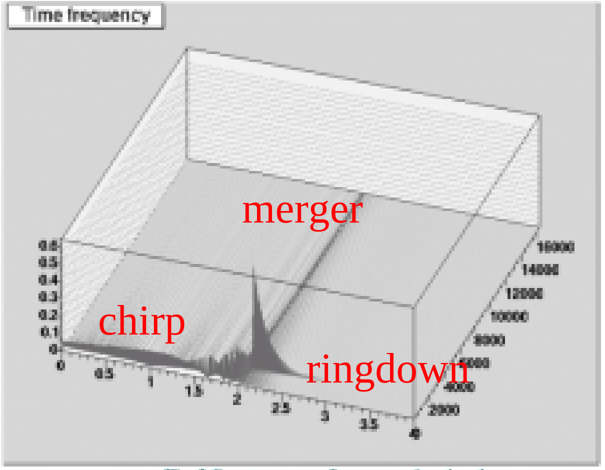


Fig. 3 Spectrogram of a composite signal

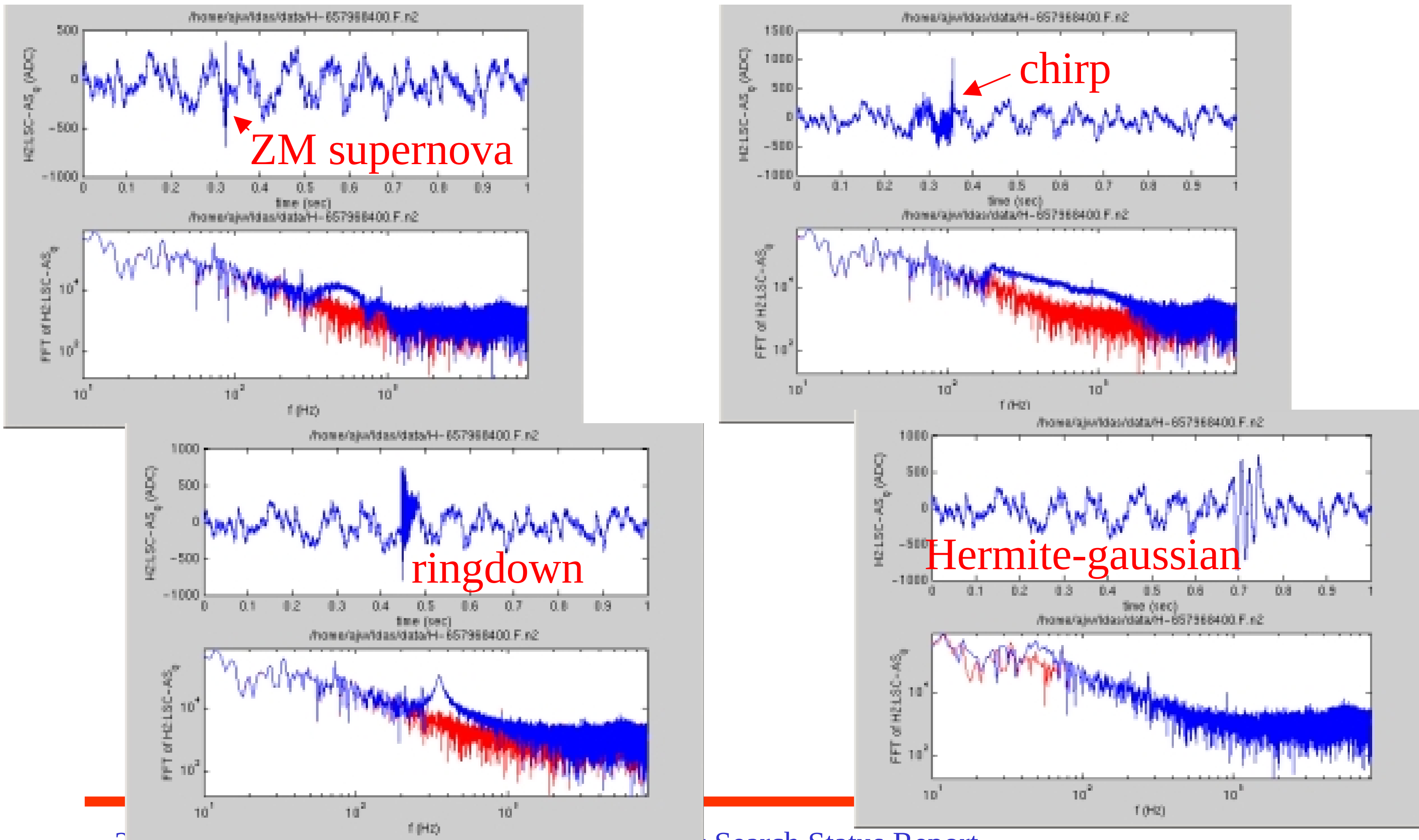
Generic statements about the sensitivity of our searches to poorly-modeled sources need to take account of the t-f “morphology”…

- Ringdowns: long duration & small BW to short duration & large BW
- Chirps: long duration, large BW
- Merger: short duration, large BW
- Zwerger-Muller or Dimmelmeier SN waveforms: in between

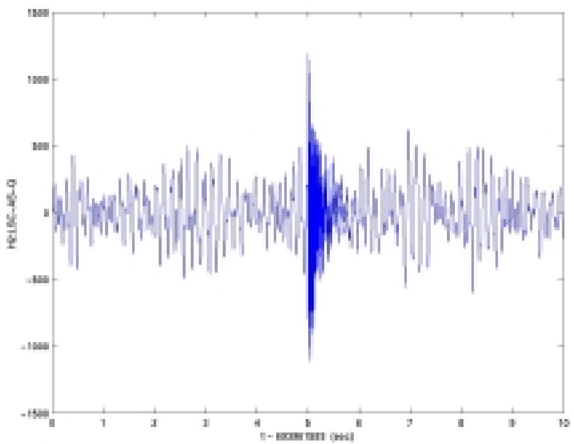
    (These SN waveforms are *distance*-calibrated; all others are parameterized by a peak or rms strain amplitude.)

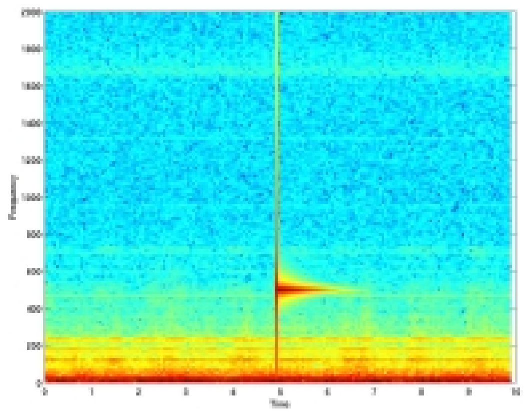
Menagerie of burst waveforms

buried in E2 noise, including calibration/TF

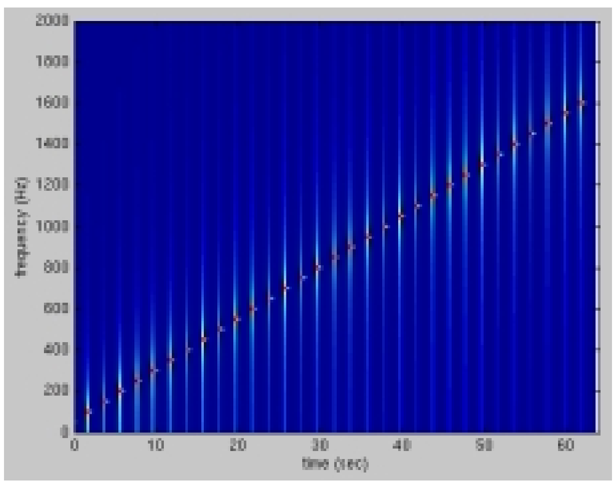


Damped sinusoid waveform (“ringdown”)





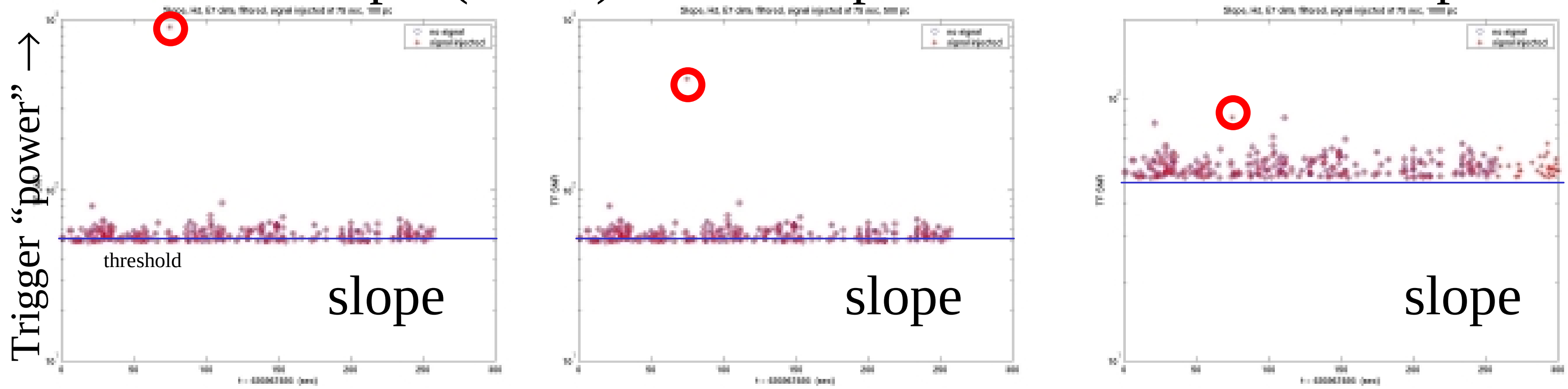
Damped sinusoid in 10 seconds of data from H2:LSC-AS_Q from E7 playground



A series of damped sinusoids can be used as a “swept sine” calibration of burst search efficiency

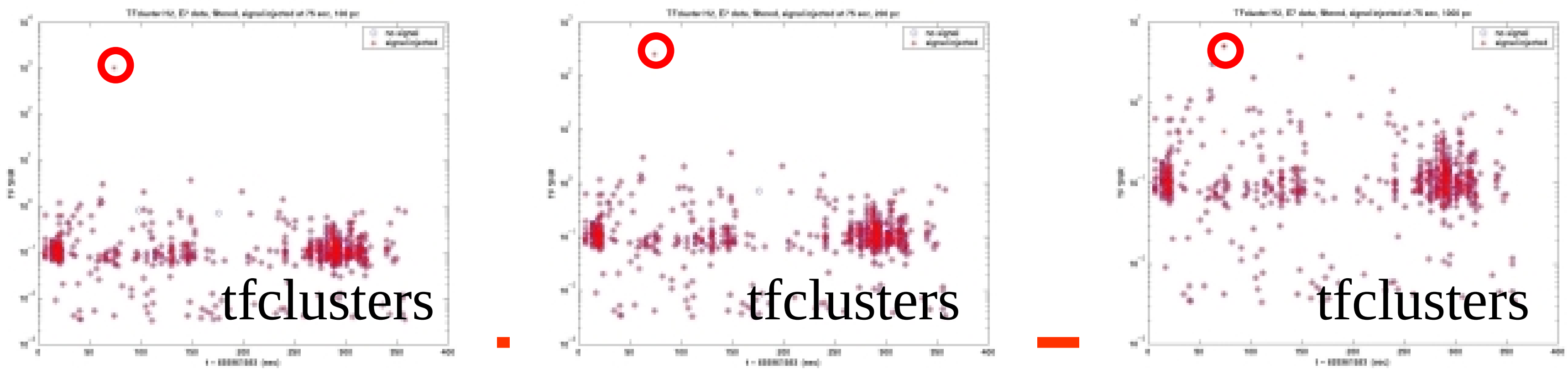
Search code triggers vs. time for Z-M waveform injected at 75 seconds

SN at 0.1 pc (ouch!) 0.2 pc 1.0 pc



Time →

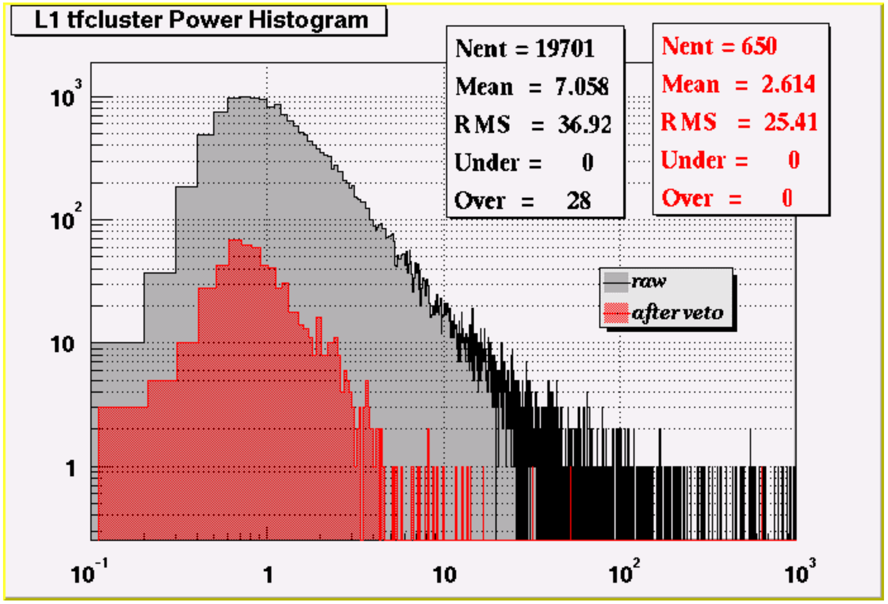
* With signal; o without signal injected.
NO VETOES APPLIED. Vetoes get rid of most of these triggers!

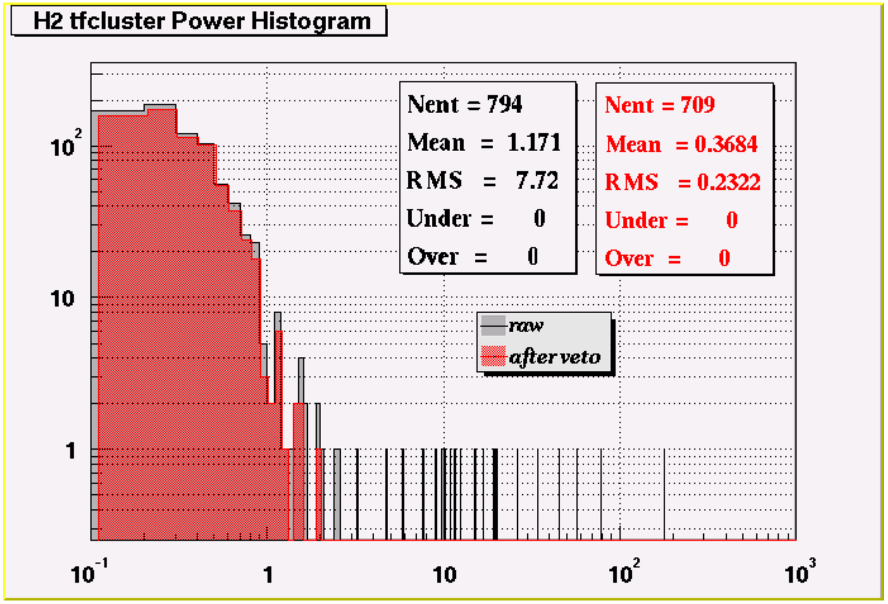


TFCLUSTERS event histogram, before and after vetoes

At both ifos, broad tail of events is cleaned up by vetoes.

L1 had lots of PSL glitching, so bulk of histogram is affected. H2 was much cleaner to start with, so only tail is removed.



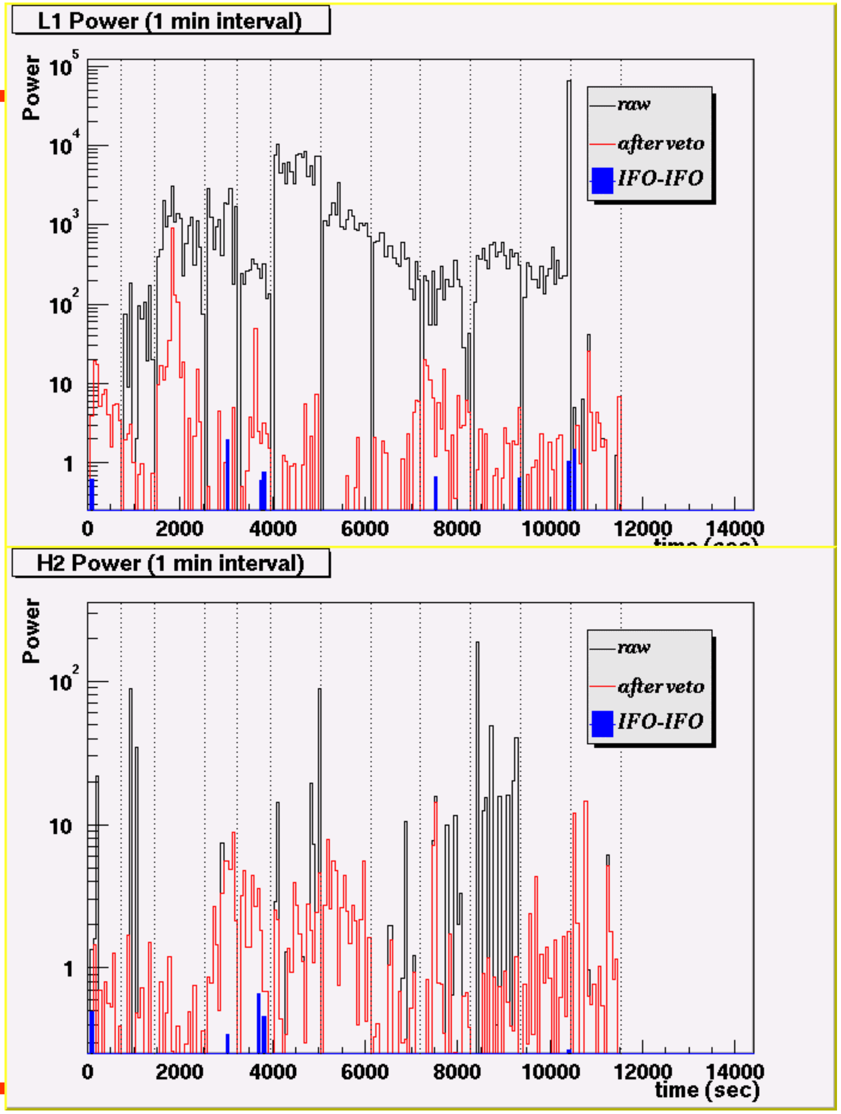


Ifo-ifo coincidence

Many events remain after vetoes. (Rates not too dissimilar at 2 ifos, ~few per minute.)

Next, require events be coincident in time, within +/- 0.5 sec.

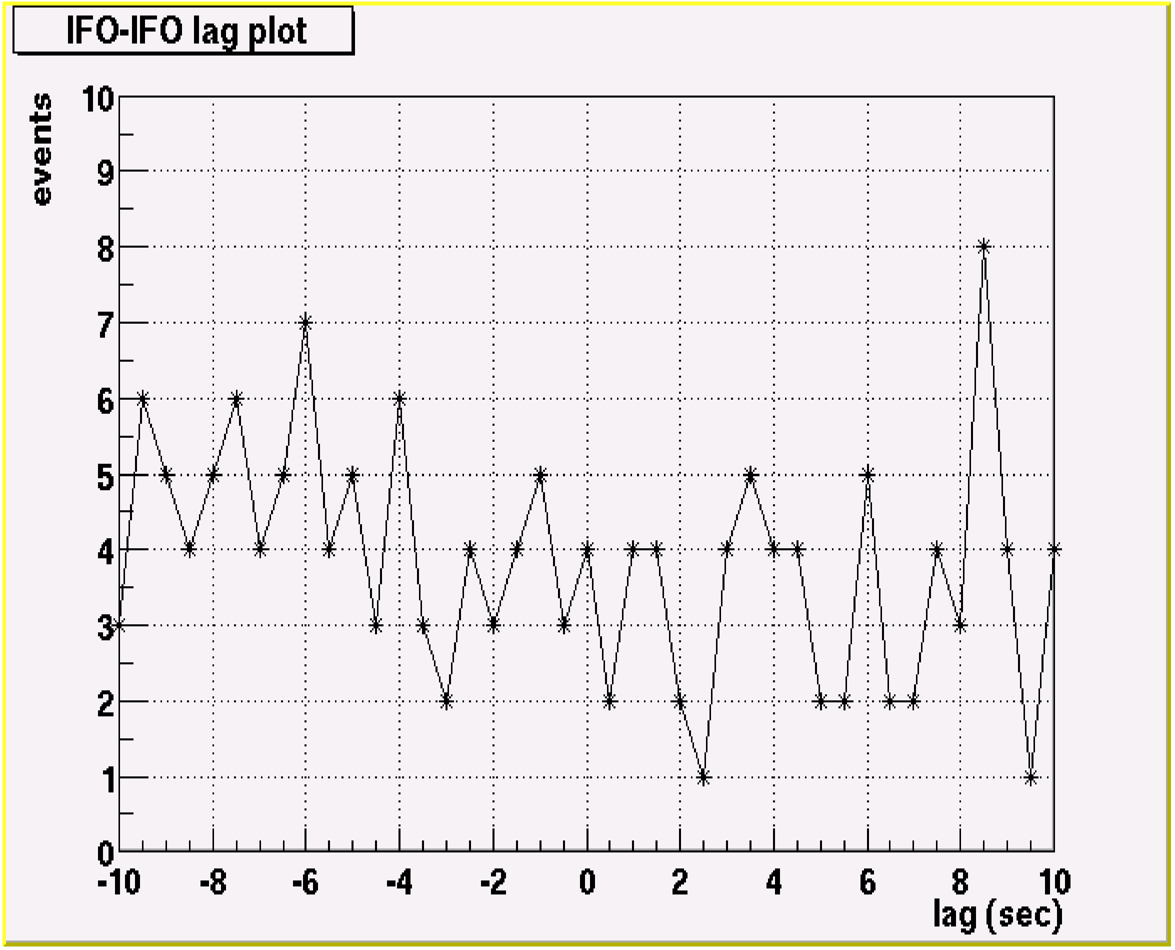
Only 10 events in 3 hours meet this requirement.



Coincidence Lag Plot

Compare number of coincidences with number of false coincidences from many trials using non-physical time shifts between data streams. (0.5 to 10 sec.)

Clearly, nothing special about zero lag.



Stochastic UL Group: Prospects for S1

LSC Stochastic Sources Upper Limit Group

LIGO-G020411-00-Z

September 20, 2002

B. Allen, W. Anderson, S. Bose, N. Christensen, E. Daw, M. Diaz, R. Drever, S. Finn, P. Fritschel, J. Giaime, B. Hamilton, S. Heng, R. Ingley, W. Johnson, B. Johnston, E. Katsavounidis, S. Klimenko, M. Landry, A. Lazzarini, M. McHugh, T. Nash, A. Ottewill, P. Perez, T. Regimbau, J. Rollins, J. Romano, B. Schutz, A. Searle, P. Shawhan, A. Sintes, C. Torres, C. Ungarelli, E. Vallarino, A. Vecchio, R. Weiss, J. Whelan, B. Whiting

Stochastic GW Background

- Random GW signal produced by a large number of weak, independent, unresolved GW sources.

- Detect by cross-correlating output of two GW detectors.

- Strength specified by ratio of energy density in GWs to total energy density needed to close the universe:

$$\Omega_{\rm gw}(f) := \frac{1}{\rho_{\rm critical}} \frac{d\rho_{\rm gw}}{d \ln f} = \frac{10\pi^2}{3H_0^2} f^3 \, S_{\rm gw}(f)$$

- For upper limit runs, consider $\Omega_{\rm gw}(f) = {\rm const}$.

- Current upper limits:

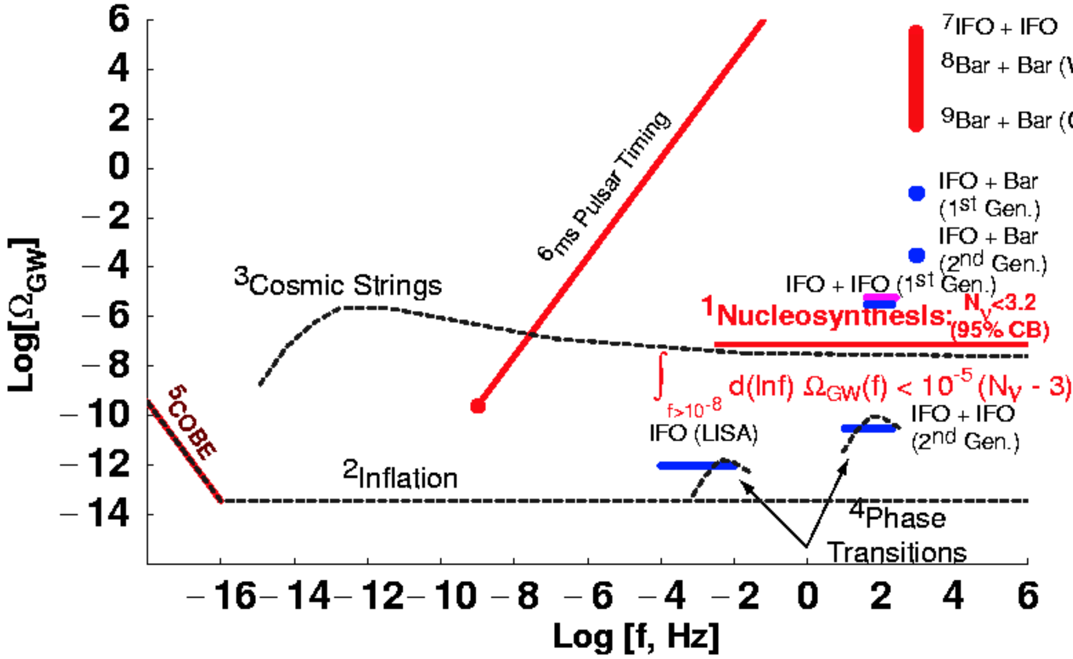
  - Low frequency constraints from observed isotropy in CMBR and millisecond pulsar timing.

  - Broad band constraint from standard model of big-bang nucleo-synthesis: $\Omega_{\rm gw}(f) \leq 1 \times 10^{-7}$ in LIGO band

  - Garching-Glasgow prototype IFOs (Compton et al, 1994): $\Omega_{\rm gw}(f) \leq 3 \times 10^5$

  - EXPLORER & NAUTILUS bars (Astone et al, 1999): $\Omega_{\rm gw}(907{\rm Hz}) \leq 60$

Upper limits



1 Kolb & Turner (The Early Universe, 1990)
Burles, Nollet, Trunan, Turner (PRL 82, 1999)
2 Grishchuk (SPJETP 40, 1975)
3 Allen & Brustein (gr-qc9609013)
Allen (gr-qc9604033)
4 Kamionkowski, Kosowoski & Turner (PRD 49, 1994)
5 Allen & Koranda (PRD 50, 1994)
6 Thorsett & Dewey (PRD 53, 1996)
Kaspi, Taylor, Ryba (ApJ 428, 1994)
7 Compton, Nicholson, Schutz, Proc. MG7 (1994)
8 Hough, Pugh, Bland, Drever, Nature 254 (1975)
9 Astone, et. al., Astr. Astroph. 351 (1999)

Cross-correlation statistic

- Look for a cross-correlated GW signal in the output of two detectors (assumes noise is uncorrelated with the signal and with the noise in the other detector):

$$\begin{aligned} Y_Q &= \int dt_1 \int dt_2 \, h_1(t_1) \, Q(t_1 - t_2) \, h_2(t_2) \\ &= \int df \, \tilde{h}_1^*(f) \tilde{Q}(f) \, \tilde{h}_2(f) \end{aligned}$$

- Mean due to cross-correlated SB signal:

$$\mu = \frac{T}{2} \int df \, \gamma(f) S_{\text{gw}}(f) \, \tilde{Q}(f)$$

- Variance dominated by noise in individual detectors:

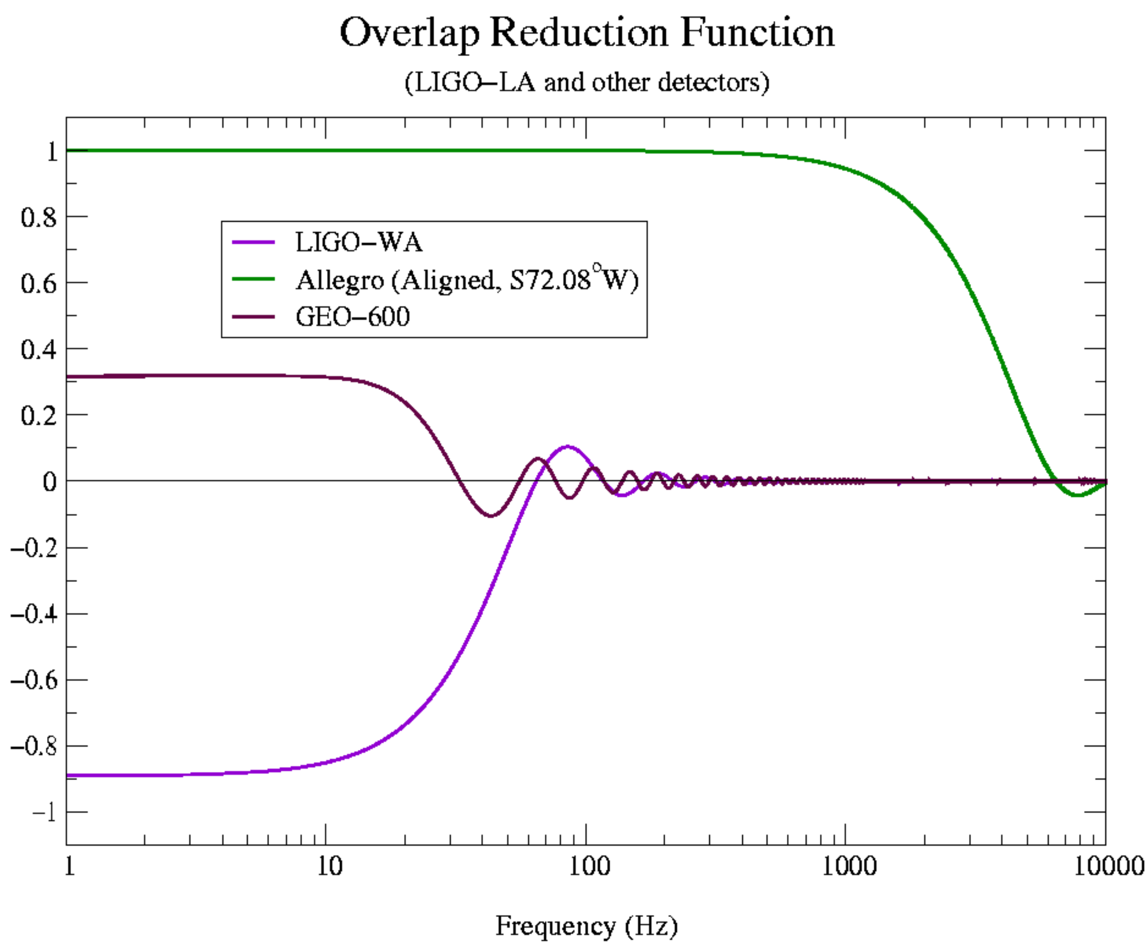
$$\sigma^2 \approx \frac{T}{4} \int df \, P_1(f) |\tilde{Q}(f)|^2 \, P_2(f)$$

- Optimal filter maximizes SNR ($\propto \sqrt{T}$):

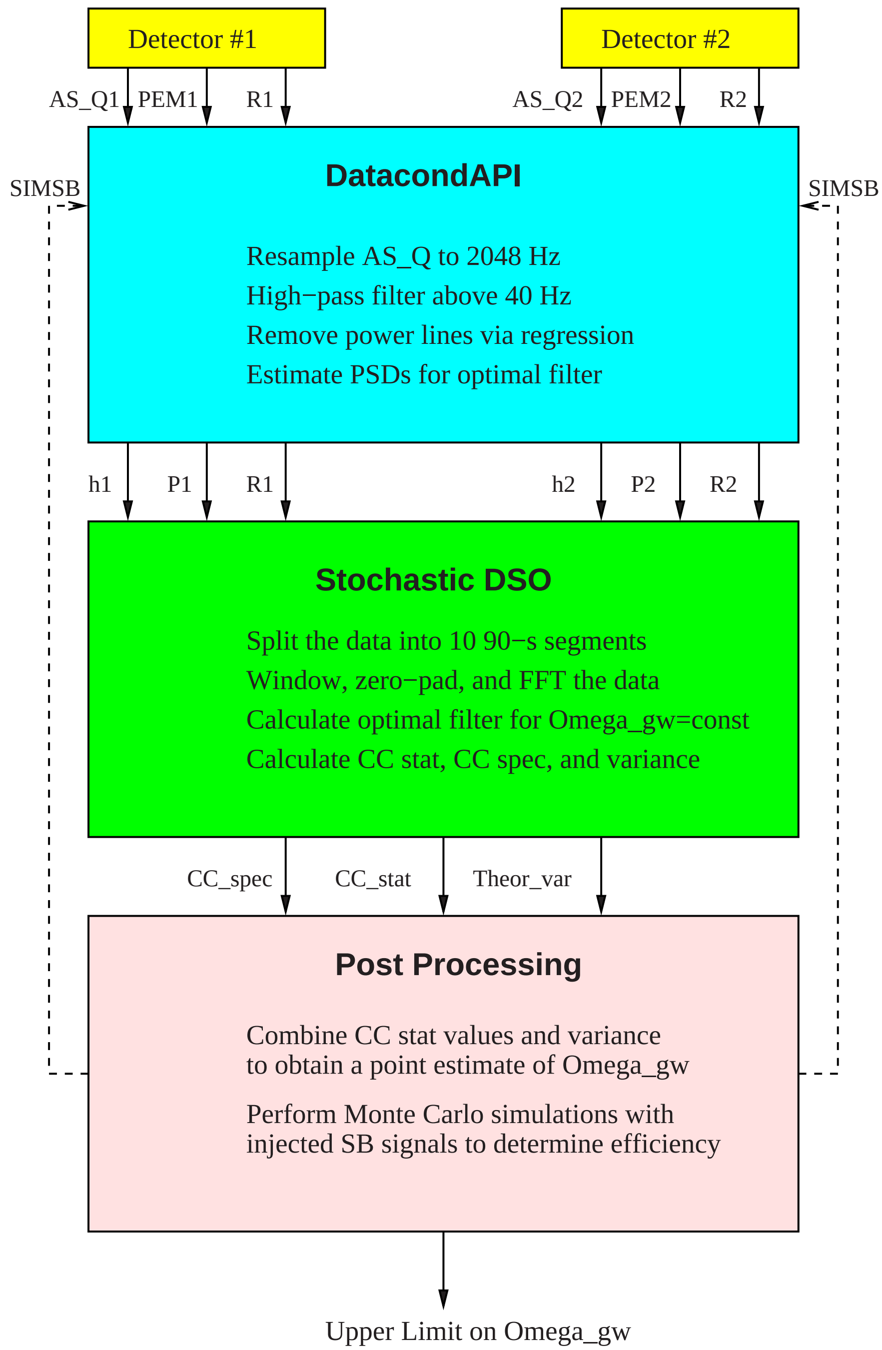
$$\tilde{Q}(f) \propto \gamma(f) \frac{S_{\text{gw}}(f)}{P_1(f) P_2(f)} \propto \gamma(f) \frac{f^{-3} \, \Omega_{\text{gw}}(f)}{P_1(f) P_2(f)}$$

Overlap reduction function

Specifies the reduction in sensitivity due to the separation and orientation of the two detectors:



Data analysis pipeline

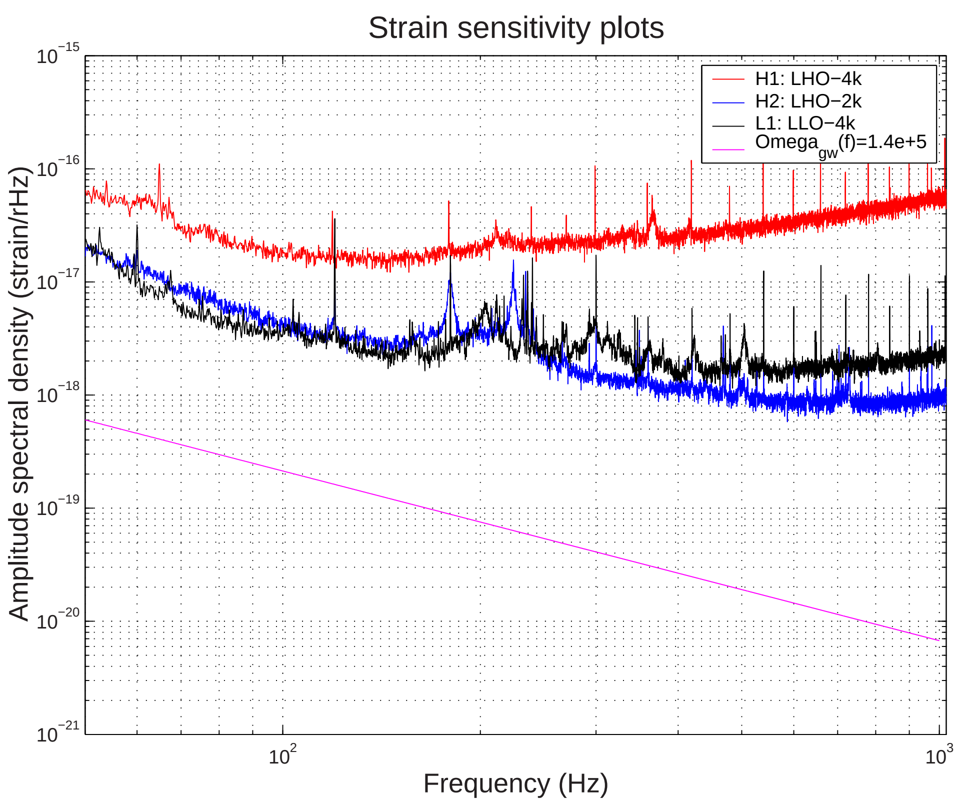


E7 expected upper limit

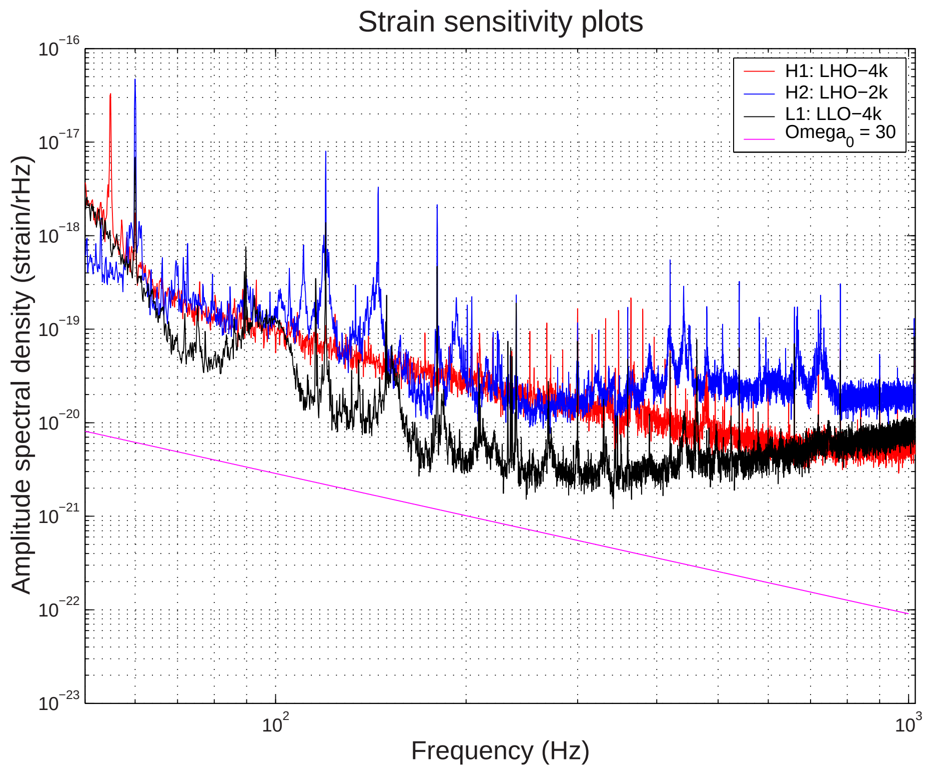
- Analytic calculation of 90% upper limit yields: $\Omega_{gw}(f) \leq 1.4 \times 10^5$ in 40-1000 Hz band for 70 hours of coincident L1-H2 data.

- Major contribution to SNR is from 64 to 128 Hz band.

- Variations in noise floor over course of E7 give factor of 10 uncertainty in above value.



Expected upper limit for S1



Upper limit: (90% CL, 70 hrs H2-L1 data)

$$\Omega_0 \leq 30 \quad \text{for} \quad 40 \text{ Hz} < f < 215 \text{ Hz}$$

NOTE: Factor of 2×10^3 improvement over E7.

Inspiral Group Membership

- Bruce Allen, Russ Bainer, Kent Blackburn, Sukant Bose, *Patrick Brady*, Duncan Brown, Jordan Camp, Vijay Chickarmane, Nelsen Christensen, David Churches, Jolien Creighton, Teviet Creighton, S.V. Dhurander, Carl Ebeling, *Gabriela Gonzalez*, Andr M. Gretarsson, Gregg Harry, Vicky Kalogera, Joe Kovalik, Nergis Mavalvala, Brian O Reilly, Valera, Adrian Ottewill, Ben Owen, Tom Prince, David Reitze, Anthony Rizzi, David Robertson, B.S. Sathyaprakash, Peter Shawhan, Julien Sylvestre, Massimo Tinto, Linqing Wen, Benn Wilk , Alan Wiseman, Natalia Zotov.

Continuous Waves Searches ULs

B. Allen, S.Anderson, S.Berukoff, P.Brady, D.Chin, R.Coldwell, T.Creighton, C.Cutler, R.Drever, R.Dupuis, S.Finn, D.Gustafson, J.Hough,M.Landry, G. Mendell, C.Messenger, S.Mohanty, S.Mukherjee, M.A. Papa, B.Owen, K.Riles, B.Schutz, X. Siemens, A.Sintes, A.Vecchio, H.Ward, A. Wiseman, G.Woan, M. Zucker

www.lsc-group.phys.uwm.edu/pulgroup