LSC Data Analysis: overview

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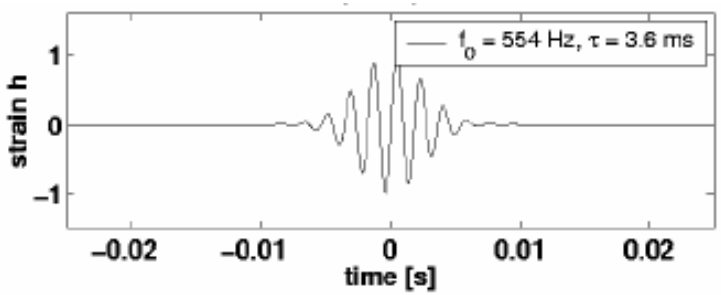
LSC data analysis groups

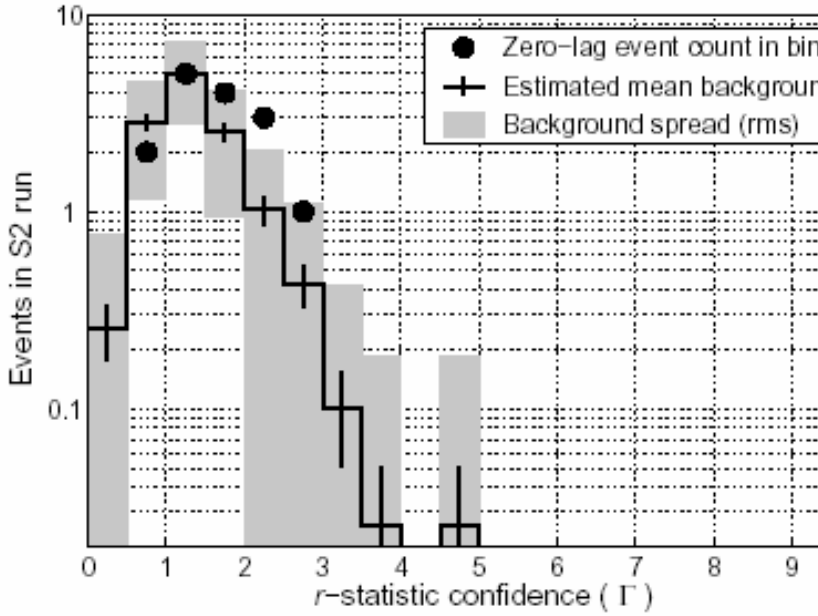
- **Gravitational Wave Sources: 4 search groups**
  - » Inspiral group: binary systems: neutron stars; black holes with small mass (MACHOs); black holes with high mass (>3 Ms).
  - » Burst group: transient sources: untriggered searches; triggered searches.
  - » CW group: Continuous, periodic sources: known pulsars; blind searches (time domain, frequency domain; coherent and incoherent)
  - » Stochastic group: looks for cosmological, frequency independent $\Omega(f)$.
- **Also, Detector Characterization group,** including
  - » Data quality investigations
  - » "Glitch" group
  - » Calibration team
- **Science runs and results:** Four science runs in 2002-2005, with increasing sensitivity and duty cycle.
  - » S1 (fall'02): published results (4 papers in PRD, 2004)
  - » S2 (spring'03): some results published (CW PRL!), others in gr-qc already.
  - » S3 (spring'04): some results soon to be submitted (Stoch), some in progress
  - » S4 (spring '05): several searches in real time!

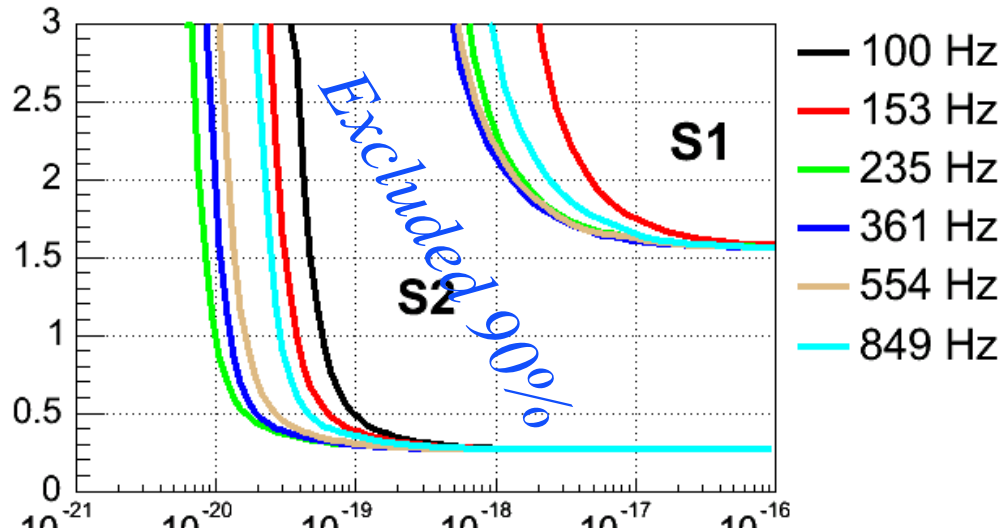
LIGO searches (S2): untriggered burst sources

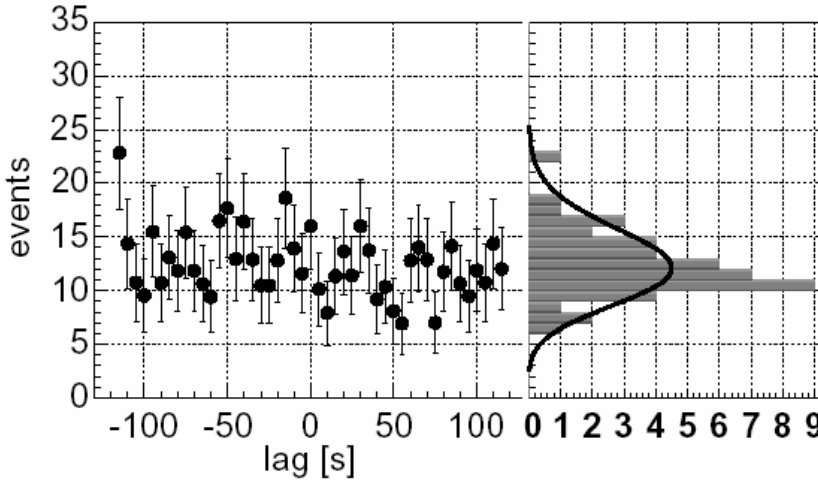
Improvements in the search method allow exploring weaker signals, relative to the detector floor, while maintaining a low false alarm rate, $O(0.1)$ μHz. The sensitivity in terms of the *root-sum-* (rss) strain amplitude lies in the range of $h_{\rm rss} \sim 10^{-20} - 10^{-19}$ Hz$^{-1/2}$. No gravitational wave signals etected in 9.98 days of analyzed data. We interpret the search result in terms of a frequentist upper limit rate of detectable gravitational wave bursts at the level of 0.26 events per day at 90% confidence level.

"Sine Gaussians" with Q~9







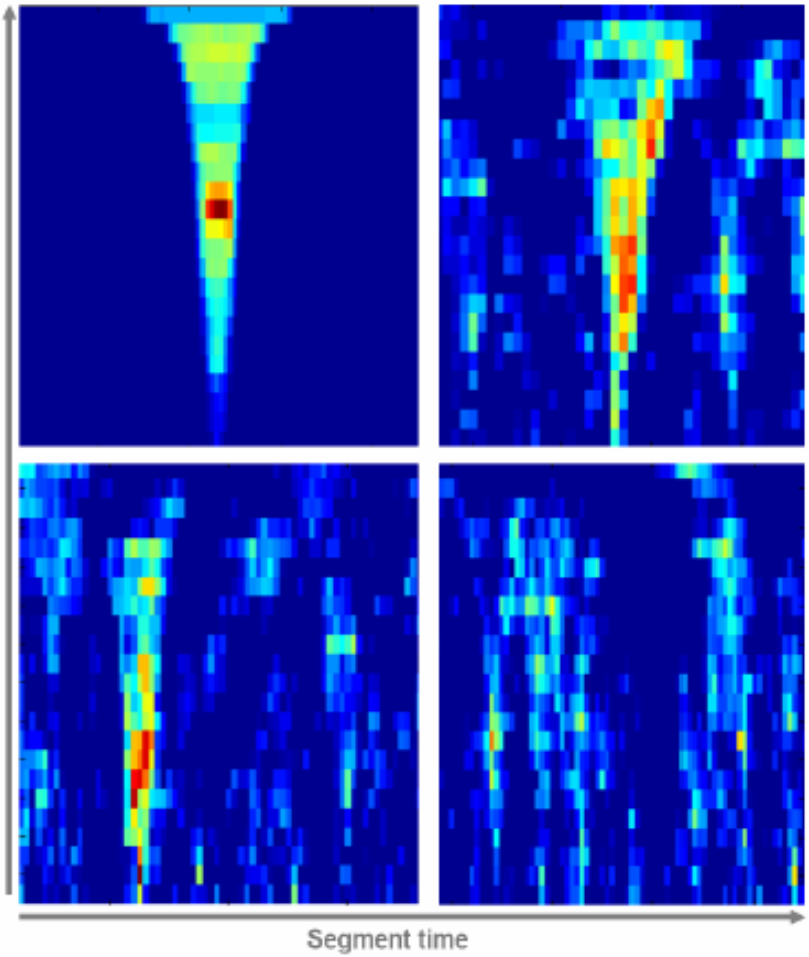


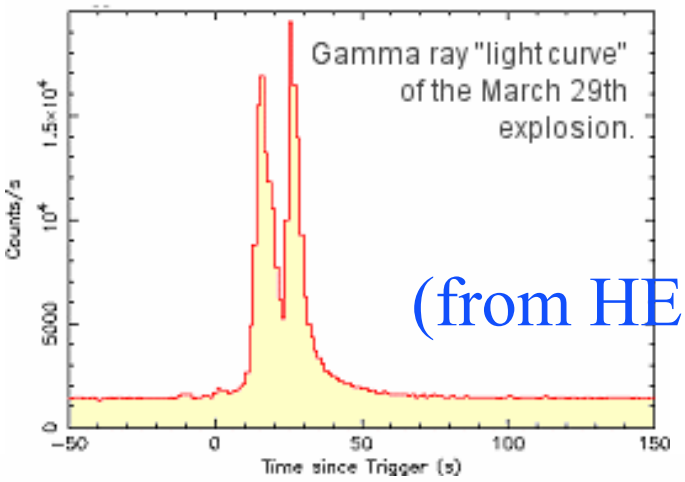
LIGO searches: GRB030329

A supernova! z~0.17~ 800Mpc away

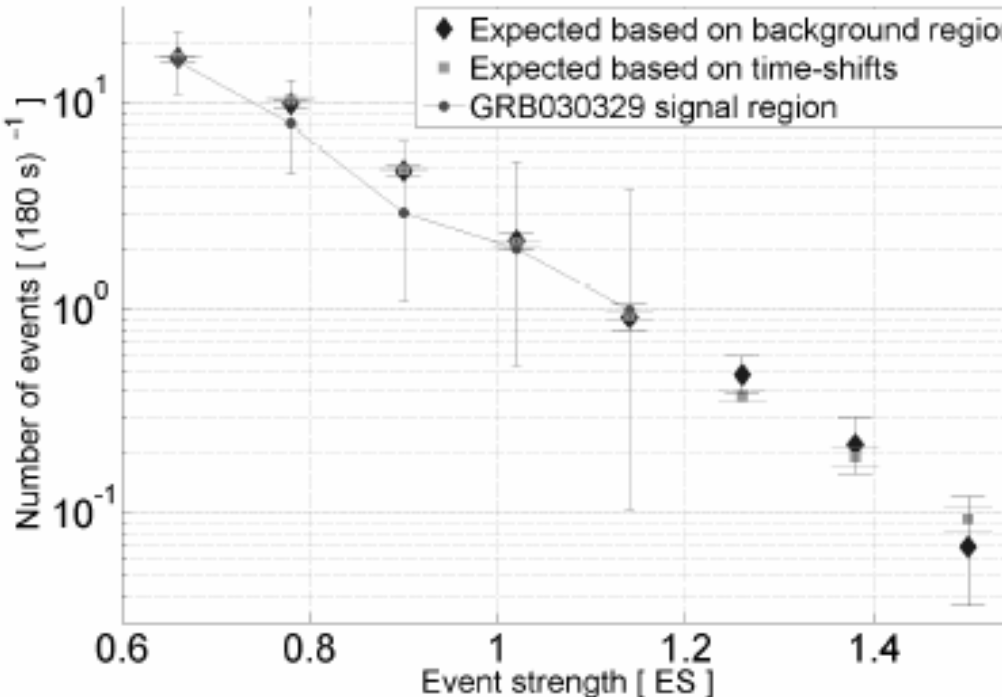
H1, H2 were in operation during S2.

A targeted search resulted in no detection





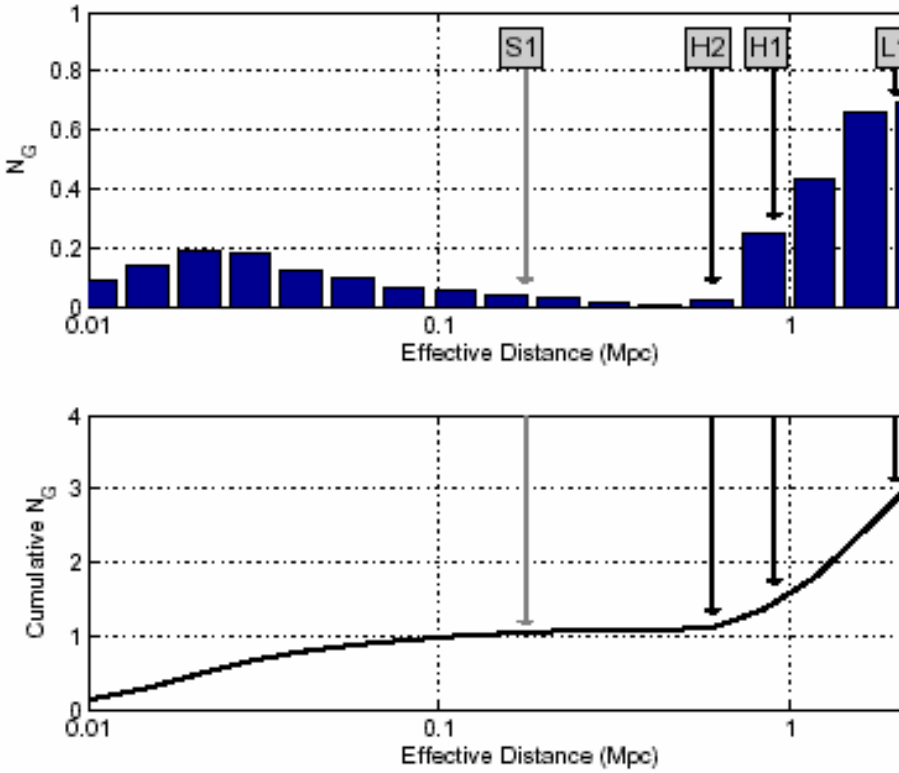
(from HET



Search for BNS inspiral sources

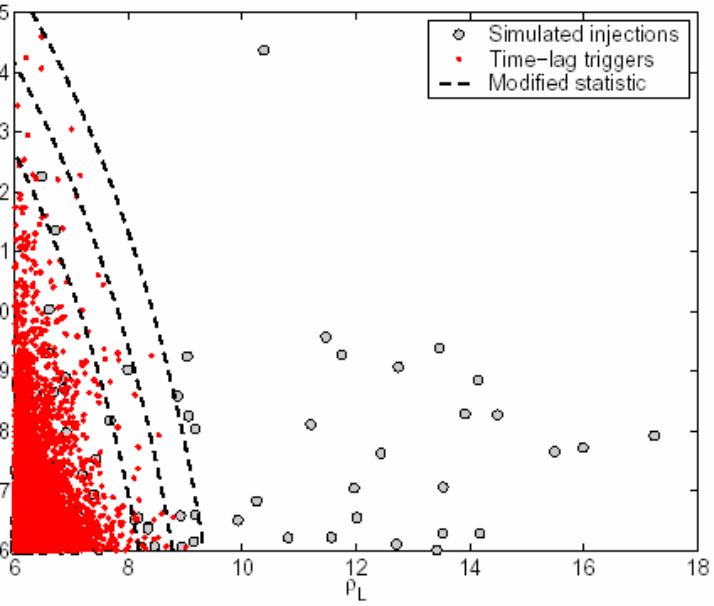
o detection! But simulations from up to 1.5 Mpc away were etected" in S2.

ame	Distance (kpc)	Blue light luminosity relative to Milky Way	Detected/Injected with $\rho^2 > 89$
ilky Way	—	1	686/686
MC	49	0.128	57/57
MC	58	0.037	8/8
GC6822	490	0.01	0/4
GC185	620	0.007	1/3
110	815	0.018	5/100
31	770	2.421	108/1791
32	805	0.019	9/129
10	825	0.031	1/10
33	840	0.319	9/219
GC300	1200	0.052	1/40
81	1400	0.196	1/147
GC55	1480	0.175	2/122



Effective distance of sources considered, and cumulative number of galaxies searched for in S2.

S2 BNS search



False alarm coincident triggers, and simulated injections

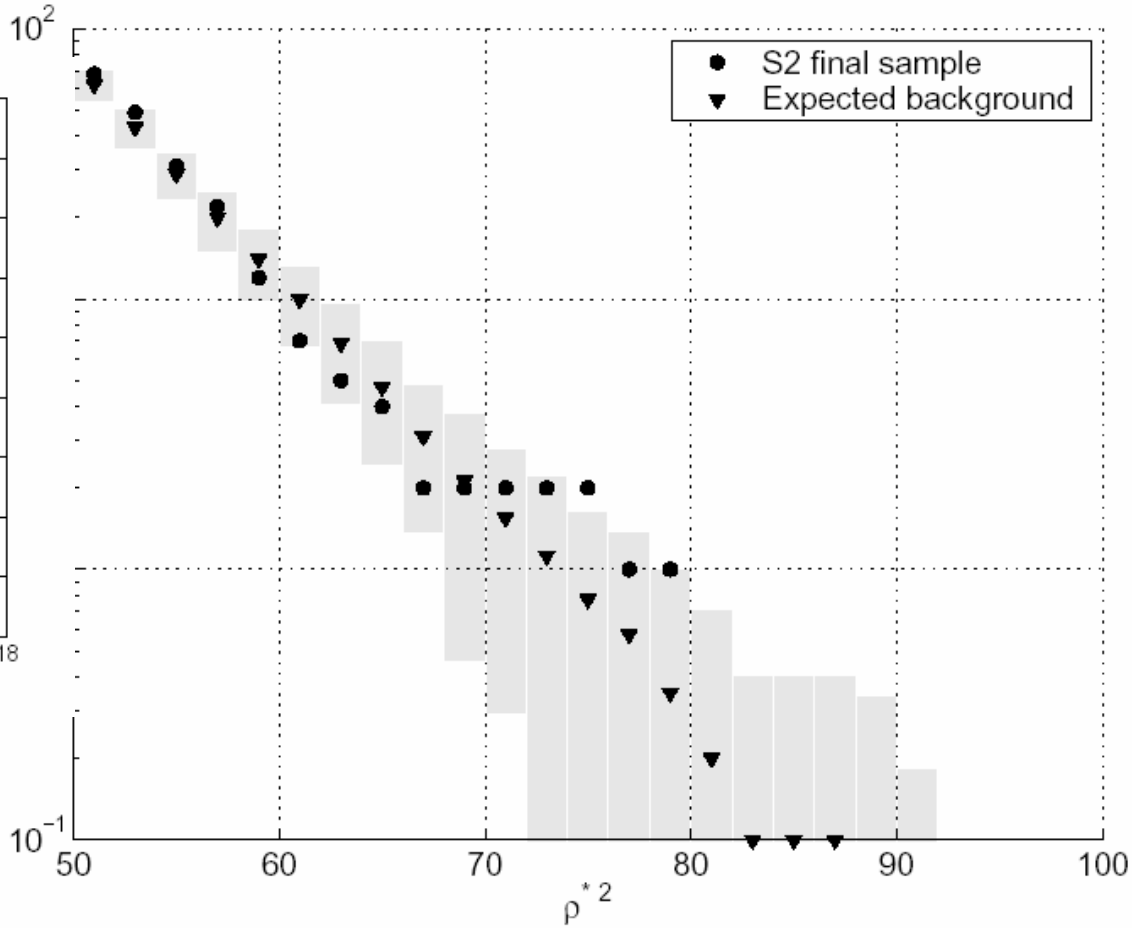
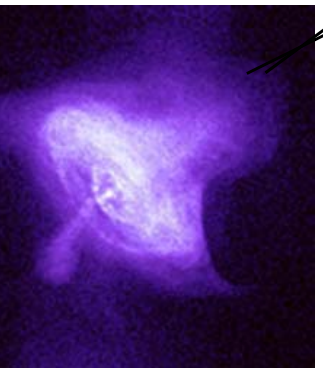
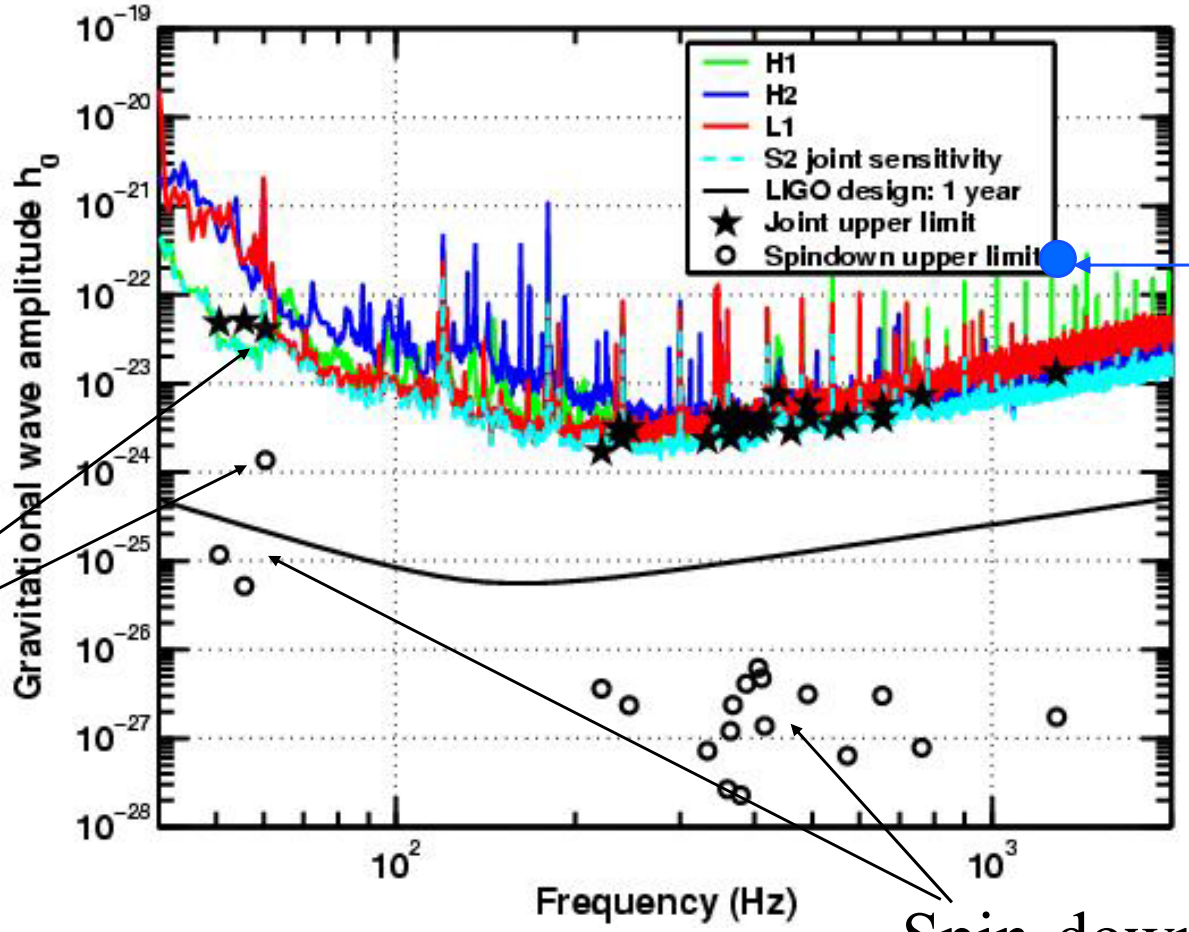


FIG. 8: The number of triggers per S2 above combined SNR ρ^*.

Gravitational wave searches: pulsars



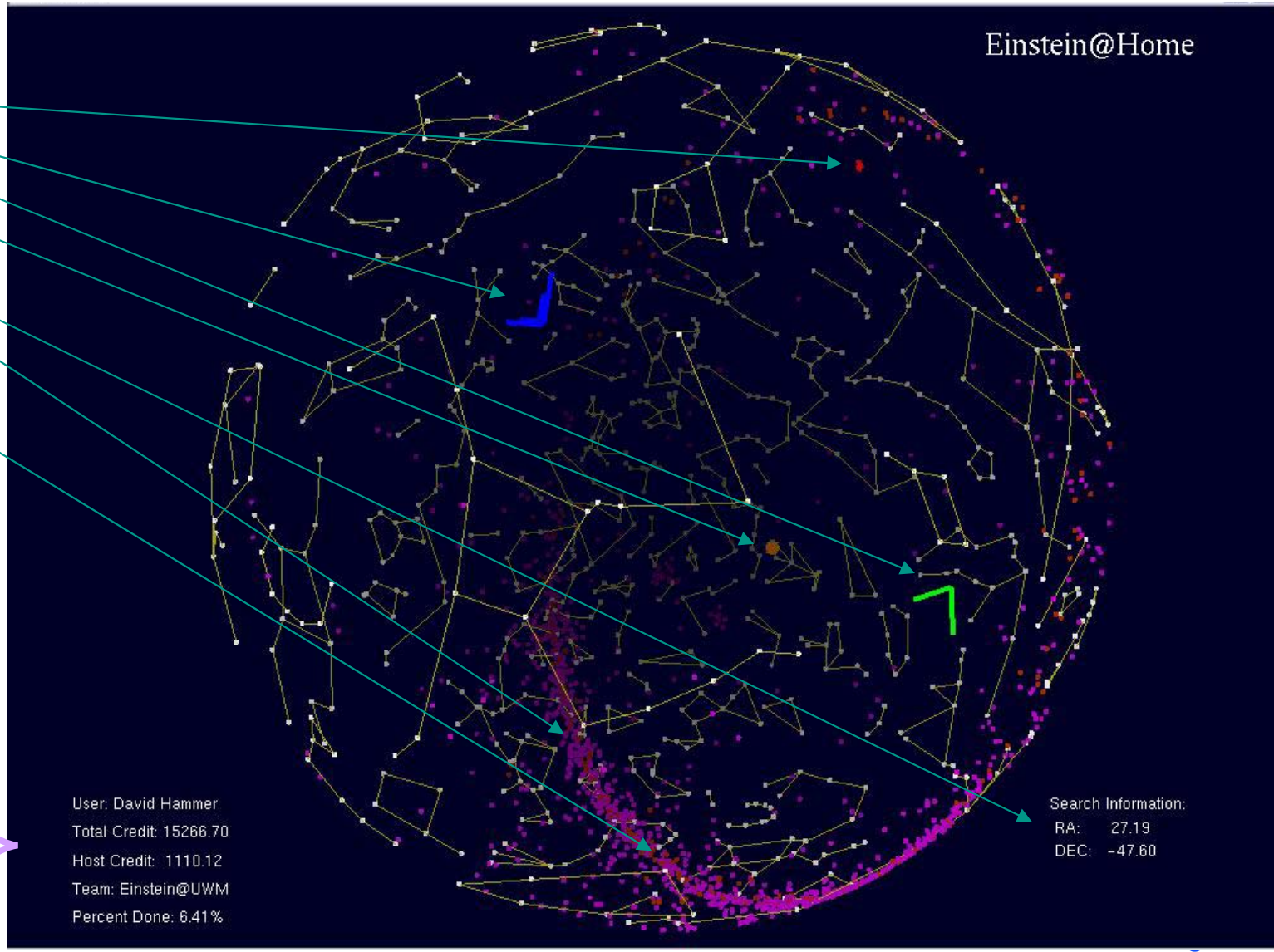
Crab pulsar



S1 result

Spin-down limits

Einstein@home

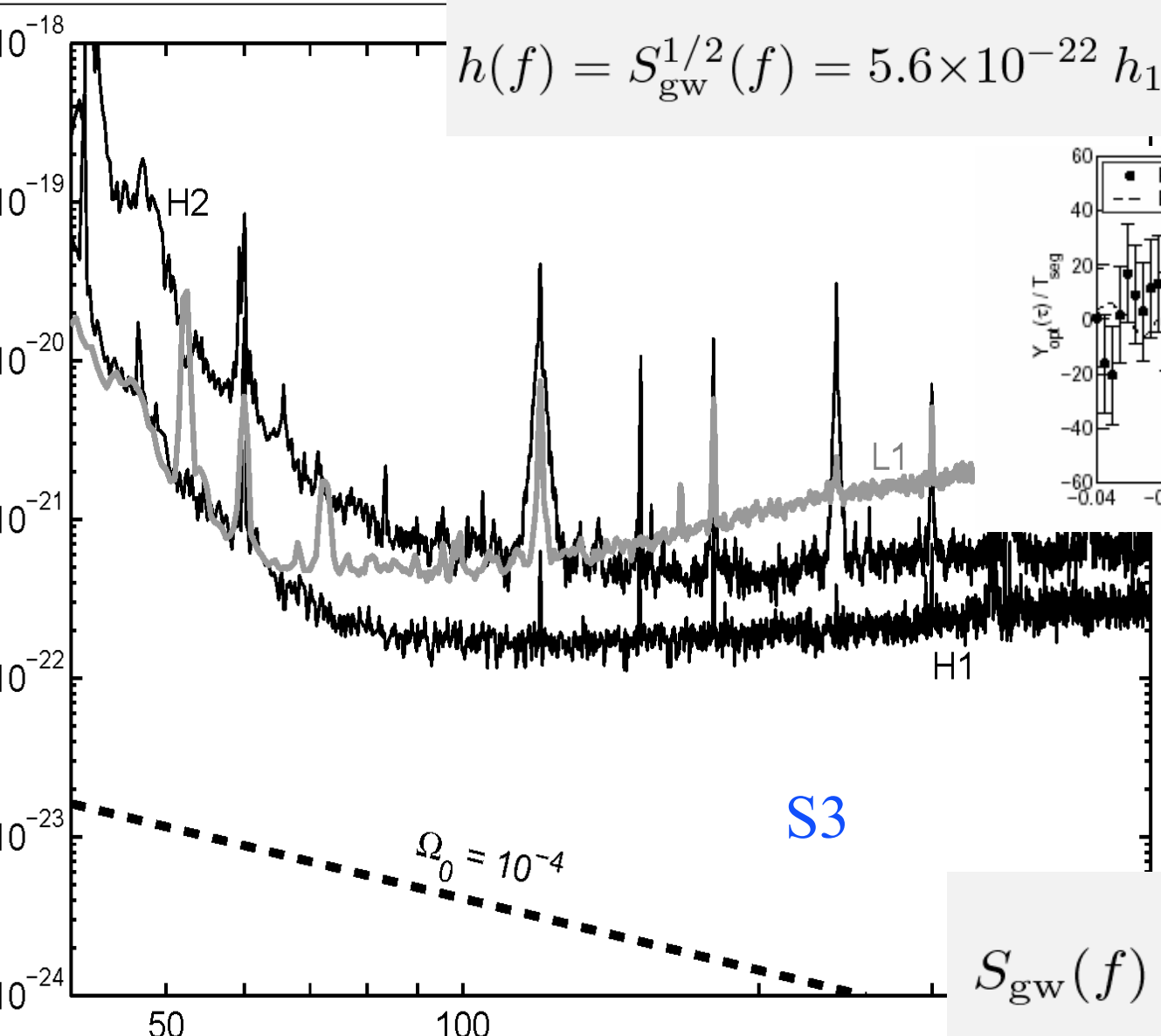


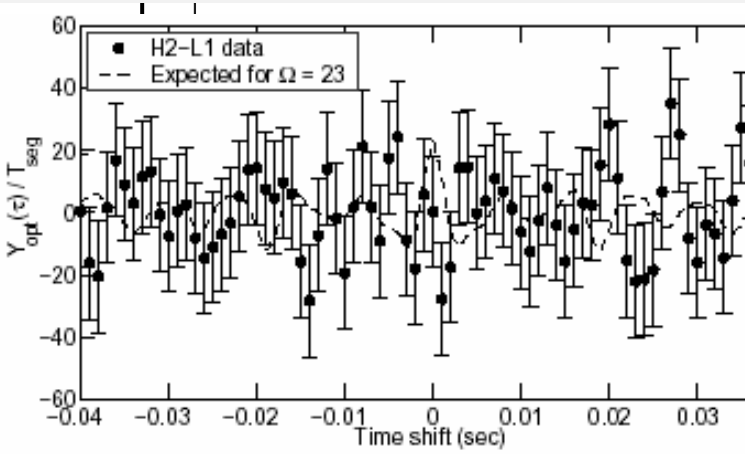
GEO-600 Hannover
LIGO Hanford
LIGO Livingston
Current search point
Current search coordinates
Known pulsars
Known supernovae remenants

User name
User's total credits
Machine's total credits
Team name
Current work % complete

LIGO search for a Stochastic Background

$$h(f) = S_{\rm gw}^{1/2}(f) = 5.6\times10^{-22}\, h_{100}\sqrt{\Omega_0}\left(\frac{100\text{Hz}}{f}\right)^{3/2}\text{Hz}$$





$$S_{\rm gw}(f) = \frac{3H_0^2}{10\pi^2}\, f^{-3}\Omega_{\rm gw}(f)$$

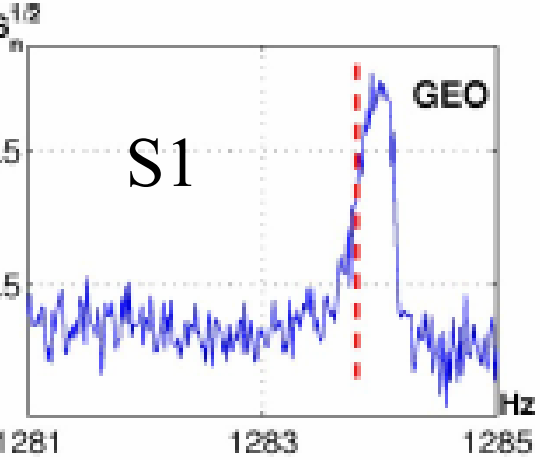
LIGO Results on $\Omega_0 h_{100}^2$

LIGO run	H-L	H1-H2	Frequency Range	Observation Time
S1 PRD 69(2004)	< 23 +/- 4.6 (H2-L1)	Cross-correlated instrumental noise found	40-314 Hz	64 hours (08/23/02 – 09/09/02)
S2 Preliminary	< 0.018 +0.007- 0.003 (H1-L1)	Cross-correlated instrumental noise found	50-300 Hz	387 hours (02/14/03 – 04/14/03)
S3 In progress	$<4.4\ 10^{-4}$ (H1-L1)	Trying to account for instrumental noise in bounding Ω	70-160 Hz	350 hrs (H1-L1) 550 hrs (H1-H2) (10/31/03 – 01/09/04)
S4 Starting Analysis	~few 10^{-5}			447 hrs (H1-L1) 510 hrs (H1-H2) (02/22/05 – 03/24/05)

Initial LIGO (1 yr) : $\Omega_0 h_{100}^2 < 2 \times 10^{-6}$

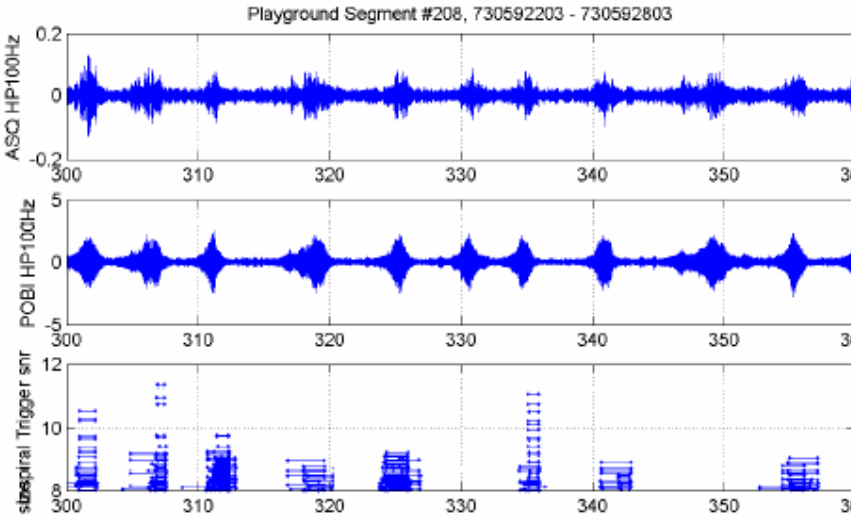
Advanced LIGO (1 yr) : $\Omega_0 h_{100}^2 < 7 \times 10^{-10}$

Not-GW signals are found too!



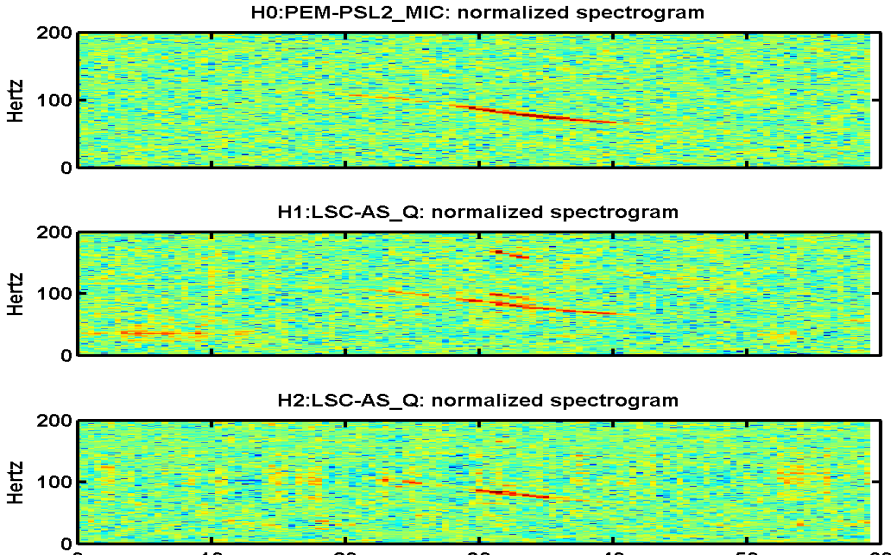
Spurious lines in the spectrum near interesting frequencies (Crab!)

S2



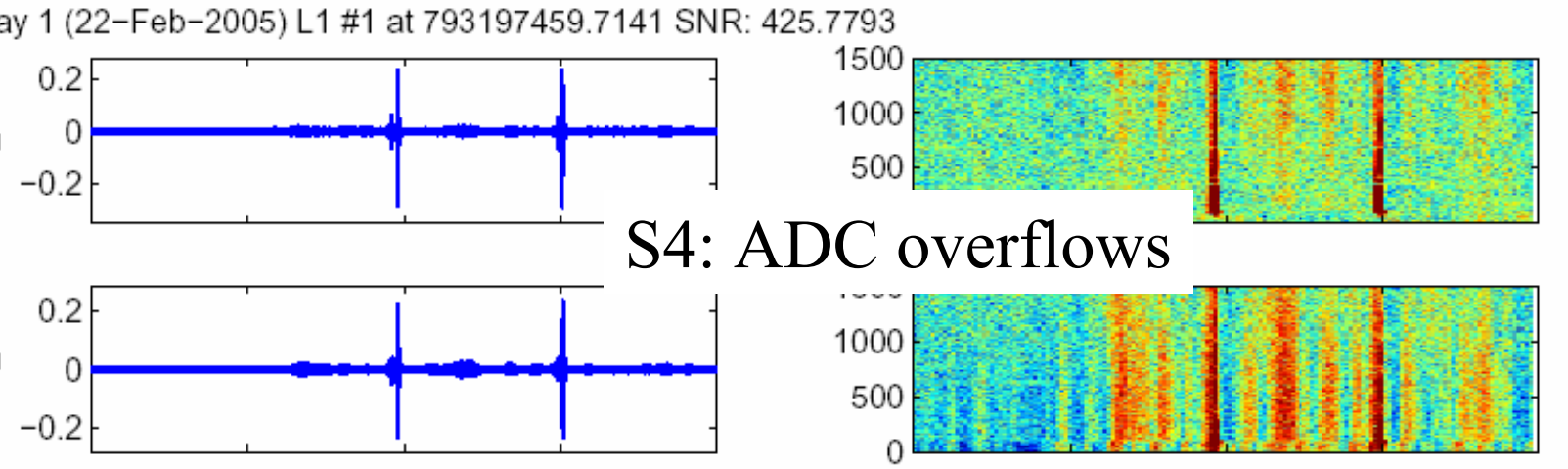
Spurious coupling among different degrees of freedo

Airplanes…

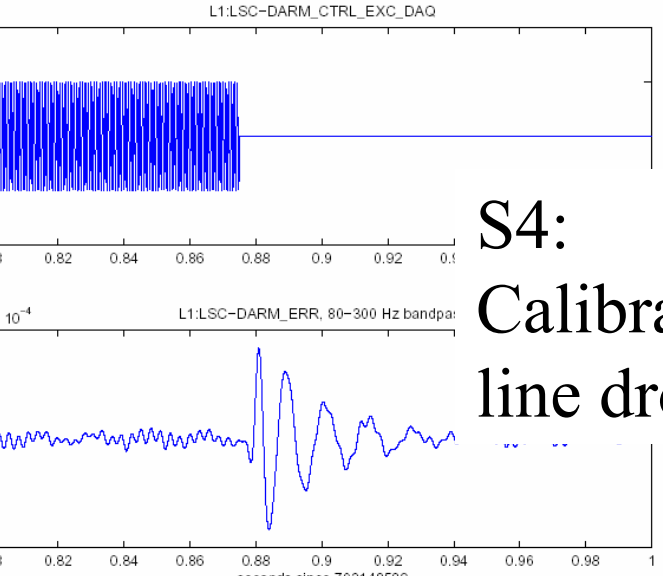


S3

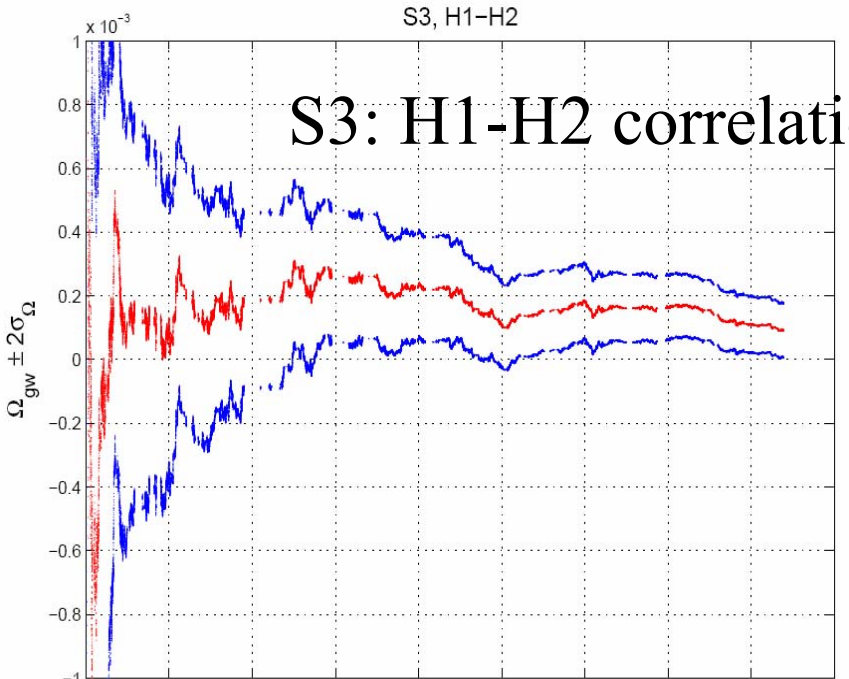
Not-GW signals are found too!



S4: ADC overflows



S4: Calibration line droputs



S3: H1-H2 correlations (?)

Ongoing projects and (yet) unpublished results

LIGO-TAMA burst, inspiral searches

LIGO-VIRGO simulation efforts laying the ground for future searches

New projects in each group:

- New targets for optimal filtering: binary black holes and spinning binary system
- New methods for CW searches: “power flux”, “stack slides”, time domain…
- New methods for burst searches: “excess power”, “block normal”,…
- Targeted search for a stochastic background (“radiometer”)
- S2, S4 ALLEGRO-LLO search for a stochastic background

Transition from improving “upper limits” to “detection searches

- Not expecting a new upper limit paper per run
- Astrowatch: stay alert for triggered searches during commissioning

Conclusions

- Four S1 (fall ’02) papers published in PRD in 2004.
- Many technical and “status” papers published in CQG.
- S2 (spring ’03) CW paper published in PRL 2005 (!)
- S2 bursts, BNS, MACHO papers in gr-qc, to be submitted to PRD.
- S3 (spring ’04) results and papers upcoming; an S3 stochastic draft exists.
- S4 (spring ’05) searches progressing much faster: some done on line
- Much diagnostics to do: non-stationary noise, spurious lines and correlations.

Burst searches: publications

- Gravitational wave burst vetoes in the LIGO S2 and S3 data analyses, Alessandra Di Credico (for the LIGO Scientific Collaboration), gr-qc/0504106 (CQG-GWDAW9)
- A first comparison of search methods for gravitational wave bursts using LIGO and Virgo simulated data L.Blackburn, et al. (The joint LIGO/Virgo working group); gr-qc/0504060 (CQG-GWDAW9)
- **S2 search: Upper Limits on Gravitational Wave Bursts in LIGO's Second Science Run**, to be submitted to PRD; gr-qc/0505029
- **A Search for Gravitational Waves Associated with the Gamma Ray Burst GRB030329 Using the LIGO Detectors**, The LIGO Scientific Collaboration: B. Abbott et al. , to be submitted to PRD; gr-qc/0501068
- Plans for the LIGO–TAMA joint search for gravitational wave bursts, Patrick J Sutton et al., Class. Quantum Grav. 21 No 20 (21 October 2004) S1801-S1807
- Search algorithm for a gravitational wave signal in association with gamma ray burst GRB030329 using the LIGO detectors, S D Mohanty, et al. Class. Quantum Grav. 21 No 20 (21 October 2004) S1831-S1837
- Multiresolution techniques for the detection of gravitational-wave bursts, S Chatterji et al., Class. Quantum Grav. 21 No 20 (21 October 2004) S1809-S1818
- Performance of the WaveBurst algorithm on LIGO data, S Klimenko et al., Class. Quantum Grav. 21 No 20 (21 October 2004) S1685-S1694
- Coherent waveform consistency test for LIGO burst candidates, L Cadonati, Class. Quantum Grav. 21 No 20 (21 October 2004) S1695-S1703
- **S1 search: First upper limits from LIGO on gravitational wave bursts**, The LIGO Scientific Collaboration: B. Abbott et al.; Phys. Rev. D 69, 102001 (7 May 2004); gr-qc/0312056
- First upper limits from LIGO on gravitational wave bursts; Alan J Weinstein (for the LIGO Scientific Collaboration); Class. Quantum Grav. 21 No 5 (7 March 2004) S677-S684
- Gamma ray bursts and gravitational waves: triggered search strategy in the LIGO science runs, S D Mohanty et al., Class. Quantum Grav. 21 No 5 (7 March 2004) S765-S774
- Status of the search for gravitational wave bursts with the LIGO detectors, L Cadonati, E Katsavounidis for the LIGO Scientific Collaboration's Bursts Working Group, Class. Quantum Grav. 20 No 17 (7 September 2003) S633-S643

Inspiral searches: publications

- **Search for Gravitational Waves from Binary Black Hole MACHOs in the Galactic Halo**, The LIGO Scientific Collaboration, 2005, gr-qc/0505042, to be submitted to PRD
- **Search for gravitational waves from galactic and extra–galactic binary neutron stars**, The LIGO Scientific Collaboration, 2005, gr-qc/050504, to be submitted to PRD
- Status of the joint LIGO--TAMA300 inspiral analysis, Stephen Fairhurst, for the LIGO Scientific Collaboration, Hirotaka Takahashi, for the TAMA Collaboration, gr-qc/0504128 (CQG, GWDAW-9)
- Veto Studies for LIGO Inspiral Triggers, Nelson Christensen (for the LIGO Scientific Collaboration), gr-qc/0504067 (CQG, GWDAW-9)
- Report on the first binary black hole inspiral search in LIGO data, Eirini Messaritaki, for the LIGO Scientific Collaboration, gr-qc/0504065, (CQG, GWDAW-9)
- A First Comparison Between LIGO and Virgo Inspiral Search Pipelines, L.Blackburn et al. (The joint LIGO/Virgo working group), gr-qc/0504050 (CQG, GWDAW 9)
- A new waveform consistency test for gravitational wave inspiral searches, Peter Shawhan and Evan Ochsner, Class. Quantum Grav. 21 No 20 (21 October 2004) S1757-S1765
- Vetoes for Inspiral Triggers in LIGO Data, Nelson Christensen, et al., for the LIGO Scientific Collaboration, Class.Quant.Grav. 21 (2004) S1747-S1756
- Searching for gravitational waves from binary inspirals with LIGO, Duncan A Brown et al., Class. Quantum Grav. 21 No 20 (21 October 2004) S1625-S1633
- **Analysis of LIGO data for gravitational waves from binary neutron stars**, The LIGO Scientific Collaboration: B. Abbott, et al; Phys. Rev. D 69, 122001 (2 June 2004)
- Search for inspiralling neutron stars in LIGO S1 data, Gabriela González (for the LIGO Science Collaboration), Class. Quantum Grav. 21 No 5 (7 March 2004) S691-S696
- Testing the LIGO inspiral analysis with hardware injections, Duncan A Brown (for the LIGO Scientific Collaboration), Class. Quantum Grav. 21 No 5 (7 March 2004) S797-S800

Search for pulsars: publications

- **Limits on Gravitational-Wave Emission from Selected Pulsars Using LIGO Data**, B. Abbot et al., LIGO Scientific Collaboration; M. Kramer and A. G. Lyne, Phys Rev Lett **94,** 181103 (12 May 2005)
- Chi-square test on candidate events from CW signal coherent searches Y Itoh, M A Papa, B Krishnan and X Siemens Class. Quantum Grav. 21 No 20 (21 October 2004) S1667-S1677
- **Setting upper limits on the strength of periodic gravitational waves from PSR J1939+2134 using the first science data from the GEO 600 and LIGO detectors,** Phys Rev D **69**, 082004 (30 April 2004)
- Upper limits on the strength of periodic gravitational waves from PSR J1939+2134 B Allen, G Woan, (for the LIGO Scientific Collaboration) *Class. Quantum Grav.* **21** No 5 (7 March 2004) S671-S676

Search for a stochastic background: publications

- First upper limit analysis and results from LIGO science data: stochastic background, John T. Whelan, for the LIGO Scientific Collaboration, Class.Quant.Grav. 21 (2004) 685-690
- **Analysis of First LIGO Science Data for Stochastic Gravitational Waves,** LIGO Scientific Collaboration: B. Abbott, et al; Phys.Rev. D69 (2004)
- Stochastic background search correlating ALLEGRO with LIGO engineering data, J T Whelan, E Daw, I S Heng, M P McHugh and A Lazzarini, Class. Quantum Grav. 20 No 17 (7 September 2003) S689-S695
- Towards the first search for a stochastic background in LIGO data: applications of signal simulations, S Bose, B Allen, M Landry, A Lazzarini, I Leonor, S Marka, T Regimbau, J Romano, P Shawhan, D Sigg and J Whelan, Class. Quantum Grav. 20 No 17 (7 September 2003) S677-S687