Observing the Bursting Universe with LIGO: Status and Prospects

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Sources: known and unknown phenomena emitting short transients of gravitational radiation (supernovae, black hole mergers, Gamma Ray Bursts engines)

- **Untriggered**: Waveforms unknown or poorly modeled; generic features assumed:
  - Durations in the few ms to hundreds of ms
  - Enough power in the LIGO sensitive band of 100-4000Hz
  - No astrophysical assumption about the nature and origin of the burst

- **Untriggered**: Waveforms suggested; templated search possible
  - Zwerger-Muller/Dimmelmeir supernovae modeling
  - Black Hole Ringdowns

- **Triggered**: Waveforms generally unknown; concentrate on inter-detector cross-correlation search with GRBs
Anticipated Analysis Goals

- Broad frequency band search for transients in order to
  - establish a bound on their rate at the instruments
  - interpret bound on a rate vs. strength exclusion plot by assuming bursts were originating from fixed strength sources fixing on a sphere centered around the earth
  - invoke source population models
  - perform analysis of energy spectrum of candidate events
  - compare with bar results
  - bound transient strengths coincident with gamma-ray bursts (see Marka’s presentation)
  - operate as part of an international network of detectors, e.g., by performing an up to 4-fold coincidence analysis with TAMA (see Sutton’s/Kanda’s presentation) during LIGO’s Science Run 2
  - search to establish a detection
Burst Search Analysis Path

**Data Quality:**
- Identify data that do not pass quality criteria
  - Instrumental errors
  - Band Limited RMS
  - Glitch rates from channel
  - Calibration quality

**Veto Analysis:**
- Goal: reduce singles rates without hurting sensitivity
- Establish correlations
- Study eligibility of veto
A Veto Analysis Example

- **Strategy**: Selection of auxiliary channels with glitches that correlate better with burst triggers
  - Choice among: Interferometer channels, Wavefront Sensors, Optical Levers, PEM channels
- **Method**: Coincidence analysis and time-lag plots
- **Preliminary - Currently being investigated**
Burst Search Analysis Path

**Data Conditioning:**
- High pass filtering and whitening using adaptive predictive algorithms, dynamically trained during the run
- Base-bandning

**GW Burst Trigger Generators:**
- TFCLUSTERS (Fourier domain)
- Slope (Time domain)
- Excess Power (Fourier domain)
- WaveBurst (Wavelet domain)
- Blocknormal (Time domain)
Burst Trigger Generators

- **Excess power** *(Brady et al, see later talk)*
  - Works in the Fourier domain looking for signal power in a $\Delta f, \Delta t$ tile that is statistically unlikely to come from noise fluctuations

- **TFCLUSTERS** *(Sylvestre, see later talk)*
  - Searches for patterns of tiles with excess signal power in the Fourier time-frequency plane

- **Waveburst** *(Klimenko et al, see later talk)*
  - Searches for patterns of tiles with excess signal power in the wavelet time-frequency plane

- **Blocknormal** *(Finn et al, see later talk by McNabb)*
  - Time domain algorithm looking for changes of mean, variance of data

- **Slope** *(Pradier et al, Daw)*
  - Time-domain templates for large slope or other simple features
**Burst Search Analysis Path**

**Simulations:**
- Use to optimize ETGs
- Employ astrophysically (and non) waveforms to measure efficiencies of the search
- Employ template matching to confront to optimal detection

**Coincidence Analysis:**
- Tighter time and frequency coincidence
- Use of amplitude matching among IFOs
- Waveform consistency: perform a fully coherent analysis on candidate events

Talks by: Cadonati
The first science run (S1) of the LIGO detectors (Aug 23 – Sep 9, 2002) has given the opportunity to make a first and a very significant step in prototyping the LIGO burst search pipeline. This was an upper limit search; first paper pre-print in the archives gr-qc/0312056. It represents the most sensitive broad-band search for bursts. It reflects progress toward better understanding of our detectors, exercising our data analysis procedures. Many things were learnt; several improvements are currently being pursued in the Science Run 2 (‘S2’) analysis.
Burst S1 Search Results

- End result of analysis pipeline: number of triple coincidence events
- Use time-shift experiments to establish number of background events
- Use Feldman-Cousins to set 90% confidence upper limits on rate of foreground events:
  - TFCLUSTERS: <1.6 events/day
- Determine detection efficiency of the end-to-end analysis pipeline via signal injection of various morphologies.
- Assume a population of such sources uniformly distributed on a sphere around us: establish upper limit on rate of bursts as a function of their strength
- Obtain rate vs. strength plots

Burst model: Gaussian/Sine gaussian pulses
Strain Sensitivities for the LIGO Interferometers for S2
14 February 2003 - 14 April 2003   LIGO-G030379-00-E

Frequency [Hz]

$h_i(f)$, $1/\text{Sqrt}[\text{Hz}]$

- LHO 2km
- LHO 4km
- LLO 4km
- LIGO I SRD Goal, 2km
- LIGO I SRD Goal, 4km
Science Run 2 (‘S2’)  

- Feb 14, 2003 – Apr 14, 2003  
- Major operational improvements with respect to ‘S1’:  
  » Improved detector sensitivity by a factor 10 for all three detectors  
  » Four times longer run: at least 300 hours of triple coincidences  
  » Instruments more stationary, data quality cuts less severe than in S1  
- Analyses well under way:  
  » Many ‘lessons learnt’ from S1 are implemented on all fronts of the pipeline  
  » Several complimentary ways of searching for unmodeled bursts  
    - Time-frequency/Time domain  
    - Alternative T-F tiling methods currently being investigated  
    - Detailed method talks presented in this session by members of the LSC  
    - Sensitivities are comparable (within x2) among all methods at the $h_{rss} \sim$ few $10^{-21}$  
  » Significant improvements all across the pipeline:  
    - special emphasis on tightening the coincidence window (resolution at the <10ms) for triggers coming for the interferometers  
    - frequency resolution at the 10-20% level  
    - invoking for the first time time coherence analysis of the remaining triggers  

Talk by: Chatterji
Summary

- **Science** analyses looking for Bursts with LIGO have begun
  - S1 results demonstrate analysis techniques
  - S2 data already ‘in the can’ are x10 more sensitive, analyses currently underway, results expected in Spring 2004

- A third science run (S3) started on Oct 31, 2003, expected to last till early January
  - Instruments are improving and they are making steady progress toward design sensitivity

- **Design** performance both in terms of sensitivity and duty cycle should be achieved within 2004 and together we expect to:
  - Prepare burst analyses for the long sensitive LIGO-I run
  - Mature on how to operate the instruments as transient detectors that are part of a worldwide network of gravitational, electromagnetic and particle burst detectors
  - Evolve our analyses and our thinking from ‘upper limits’ to ‘real searches’
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<td>Sylvestre</td>
<td>TFCLUSTERS: detection efficiency and parameter estimation</td>
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<td>15:30</td>
<td>Brady</td>
<td>Excess power event trigger generator</td>
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<td>Study of the WaveBurst detection efficiency using the LIGO S2 data</td>
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<td>Coherent coincident analysis of LIGO burst candidates</td>
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<td>Tuning BlockNormal: comparative studies</td>
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