

## LSC Six-Month Progress Report

**Organization** Carleton College Relativity Group (CCRG)

**Report Date** July 27, 2004

Attachment A / LIGO I

We continue to be extremely busy with LIGO related research. Carleton College is an active member of the LIGO Scientific Collaboration (LSC), and our research is coordinated with the LIGO laboratory and the full LSC through memoranda of understanding. A description of our activities is presented below.

### 1. Markov chain Monte Carlo (MCMC) technique for parameter estimation

#### a) Pulsar Signals

Prof. Nelson Christensen is continuing to work on the development of a Metropolis-Hastings algorithm (a MCMC technique) in order to detect and estimate parameters for gravity wave signals from periodic sources (such as pulsars). This work is being done in collaboration with Graham Woan, John Veitch and Rejean Dupuis of the University of Glasgow, and statisticians Renate Meyer and Richard Umstaetter of the University of Auckland. Meyer and Umstaetter are working only on the development of MCMC techniques, which is where their interest lies; they never work with LIGO data.

Christensen and the Glasgow group are aiming their work on a possible signal from SN1987a. We are using a 6-parameter MCMC technique to search for a signal in the S3 data, and in the absence of a detection, set an upper limit on its strength. The unknown parameters in this search are the gravity wave amplitude, polarization, pulsar rotation inclination angle, phase, the uncertainty in the signal frequency, and the frequency derivative  $df/dt$ . The basics of a MCMC search for a pulsar signal were recently published in:

"Metropolis-Hastings algorithm for extracting periodic gravitational wave signals from laser interferometric detector data", Nelson Christensen, Réjean J. Dupuis, Graham Woan, Renate Meyer, *Physical Review D* 70, 022001 (2004).

A detailed look at a MCMC search when both frequency and the frequency derivative are unknown is presented in:

"Detecting gravitational radiation from neutron stars using a six-parameter adaptive MCMC method," Richard Umstätter, Renate Meyer, Réjean J. Dupuis, John Veitch, Graham Woan, Nelson Christensen, gr-qc/0404025, and in-press, *Classical and Quantum Gravity*.

The SN1987a work with the Glasgow team is concentrating in a 5 Hz band about 935 Hz, which is twice the frequency given by Middleditch et al. in their alleged detection of a SN1987a pulsar. We are presently analyzing data from the S3 science run. No signal was detected so far in the H1 data. We are now injecting (via software) signals into the H1 S3 data in order to conduct a Monte Carlo study of to find the upper limit

on the gravity wave strength. The status of this search will be presented at the August 2004 LSC meeting.

b) Binary Inspirational Parameter Estimation with Markov Chain Monte Carlo Methods  
Nelson Christensen, along with Carleton students Adam Libson and Mark Knight, have worked on the application of a MCMC Metropolis-Hastings program for binary inspiral signal detection and parameter estimation. Libson graduated from Carleton in June 2004, and stopped his LIGO work at that point. Libson helped to develop a MCMC program that works off of the LALAPPS program inspiral. The details of how this method works have recently been published in:

"A Metropolis-Hastings routine for estimating parameters from compact binary inspiral events with laser interferometric gravitational radiation data." Nelson Christensen, Renate Meyer and Adam Libson. *Classical and Quantum Gravity*, Vol. 21, pp. 317 (2004)

Carleton student Mark Knight is helping to shift the code to MATLAB. This will allow easier use, as templates can more easily be changed. Both the MATLAB and LAL/inspiral MCMC programs can find events and estimate the signal parameters in the simplest sense; masses of the two binary stars, amplitude of the signal. The work is presently being extended in order to search for signals created by binary black hole inspiral events; this is most easily done with the MATLAB code, as it is more versatile.

S3 injections are being analyzed with both versions of our MCMC code. The LAL inspiral-based MCMC code uses 2.0 post-Newtonian (PN) templates that are generated in the frequency domain. The S3 hardware injections were 2.0 PN signals in the time domain. There is not an exact correspondence between these 2.0 PN time and frequency domain signals. This is likely the reason why when examining the S3 hardware inspiral injections good estimates are made for the "chirp mass" and the effective distance, but not the mass parameter "eta". Presently we are running the MATLAB code to 2.5 PN in the frequency domain, and it will be simple to extend it to higher PN order. All of these results will be presented to the LSC at the August 2004 meeting.

## 2. Detector Characterization for LIGO S2 and S3 runs

Nelson Christensen is part of a LIGO detector characterization investigation led by Prof. Keith Riles (Dept. of Physics, University of Michigan). Nelson Christensen is leading the group that is investigating correlations between LIGO interferometer signals and signals from environmental monitors. Carleton students Issa Kawas and Sarah Vigeland are also contributing to this effort.

The Carleton team is examining data from the LIGO S2 and S3 scientific runs. We have computed numerous correlations between interferometer control channels and environmental monitors in order to decipher sources of noise. Numerous correlations were observed, as well as a few places where LIGO noise was coherently coupled at differing frequencies. For the S3 data we are concentrating on acoustic coupling into the gravity wave signal channel. Initial results for LLO are posted at

<http://physics.carleton.edu/Research/ligo/S3LLO/S3-LLO-Corr.html>  
 while results for LHO are posted at  
<http://physics.carleton.edu/Research/ligo/H1mics/S3H1MicsCorr.html>

The results above were presented to the LSC at the March 2004 meeting. During that meeting it became clear that it would be very useful to catalog all of the observed correlations. This catalog should be especially useful for the CW group. We have established a webpage where these catalogs are posted; see

<http://ligo.physics.carleton.edu/results/S2S3Correlations.html>

Correlations are calculated between the interferometer output AS\_Q, and environmental monitors (microphones, accelerometers, magnetometers). Correlations are being cataloged for H1, H2 and H3 during S2 and S3. The catalogs list the PEM channel, correlation location (frequency), correlation width (in frequency), and the correlation magnitude.

### 3. Staffing shifts for LIGO Scientific Runs

There have been no scientific runs since the last report.

### 4. Inspiral Group - Detector Characterization and Vetoes

Nelson Christensen is an active member in the LSC's effort dedicated to using LIGO data to set upper limits on astrophysical sources. One of the tasks is in the Inspiral Group, and especially its Detector Characterization Sub-Group. Nelson Christensen spends much time contributing to this detector characterization and veto development sub-group, and is working with many other LSC members on this effort. Carleton undergraduate Hans Bantilan has contributed significantly to this research task. The sub-group has conducted extensive studies on numerous environmental monitor channels in order to quantify when environmental events influence the quality of the interferometer output data. We developed code in order to present veto flags for the data. We spent significant amounts of time analyzing data from various interferometer control signals in order to develop potential veto flags for spurious inspiral-like events in the AS\_Q data. Calculations and plots were made to display the veto efficiency verses dead-time for potential vetoes. Studies into the safety of vetoes were also conducted. Some of our results are posted on the web:

S3 vetoes

<http://ligo.physics.carleton.edu/results/S3glitch.html>

### 5. LIGO-Virgo Data Analysis Collaboration

Nelson Christensen is on the committee that is planning the LIGO-Virgo data analysis collaboration for burst and binary inspiral searches, and is representing LIGO, the LSC and the LSC inspiral group. Christensen attended working meetings at the March 2004 LSC meeting, plus in June at Virgo in Pisa, Italy. Christensen contributed to the drafting of the White Paper, which will be discussed at the August 2004 LSC meeting. Christensen will continue to participate in this effort, and will be one of the LSC inspiral group members working on the LIGO-Virgo data analysis.