

## LSC Six-Month Progress Report

**Organization:** German/British Collaboration for Detection of Gravitational Waves (GEO600)

**Report Date:** August 15, 2002

Attachment A / LIGO I

### HANNOVER-GLASGOW

#### EXPERIMENTAL:

On account of experimental issues discovered following the engineering run in December/January detector development proceeded along different lines from that planned, and comprised

- 1) work on beamsplitter suspension to bring mode frequencies into specification
- 2) replacement of beamsplitter because of excessive reflection at antireflection coating on rear
- 3) repair of electrostatic drive system on one inboard mass
- 4) enhancement of autoalignment systems
- 5) preparation of suspension system for the signal recycling mirror
- 6) significant improvement of sensitivity by reducing light scattered back into output of interferometer by beam handling optics.

#### DATA ANALYSIS:

1. Completed LAL code for coarse heterodyning with robust filtering and statistical diagnostics
2. Completed LAL code for fine heterodyning, including pulsar parameter and proper motion corrections
3. Completed the model fitting algorithms (fine and coarse)
4. Tested nearly all software with mock data
5. Submitted heterodyne codes to LAL repository with documentation
6. Applied this software to E7 data and study the algorithm performance
7. Set an upper limit for the observed strain from PSR1937+21 in GEO E7 data

### ALBERT EINSTEIN INSTITUT

#### DETECTOR CHARACTERIZATION

( also refer to [http://www.aei-potsdam.mpg.de/~sintes/GEO\\_DC/](http://www.aei-potsdam.mpg.de/~sintes/GEO_DC/)):

- Investigations have been done using the entire LIGO Hanford 2K Playground data to look for slow non-stationarity present in the noise floor. Preliminary results have been reported at the March '02 LSC meeting (Livingston): "Non-stationarity in LIGO E7 data. LIGO Technical document G020037-00-Z, 2002, Soma Mukherjee".

A LIGO technical note featuring more detailed results is underway. This will also be discussed during the LIGO Burst group External Triggers telecons.

- Work towards the preparation of GEO burst "event list" for exchange with LIGO:

The following gives a status report of the activities so far.  
For further details see the GEO Burst Analysis web page on  
<http://www.aei.mpg.de/~soma/burst.html>.

Search pipeline: The search pipeline is almost ready. Frame reading utilities, line removal codes, writing triggers on to the database are all in place. For the search filter (Excess Power Statistics), integration of the existing LAL codes in the pipeline is in progress.

Veto: Our veto strategies are based on the 'Classification of Burst' method. Work is in progress (see Mukherjee's March 2002 LSC presentation). Since this requires information from the auxiliary channels, work on vetoes is directly tied to another project, the Detector Characterization Robot (<http://www.aei.mpg.de/~mohanty/DCR/DCRindex.html>). DCR codes are in place (see Mohanty's report for details). In addition, GEO also has several detector characterization monitors running in the GEO++ environment (<http://www.astro.cf.ac.uk/pub/R.Balasubramanian/geo++/index.html>).  
Event list preparation: Once a list of events is prepared, this will be exchanged with LIGO in connection with the Ext. Trig. subgroup work.

- Data mining methods have been developed to analyze the GEO January '02 data run. The results can be found at:  
<http://www.aei-potsdam.mpg.de/~soma/geo++.html>  
and  
[http://www.aei-potsdam.mpg.de/~soma/dcr1\\_1day.html](http://www.aei-potsdam.mpg.de/~soma/dcr1_1day.html).

- The following presentations have been made at the GEO Data Analysis Workshop, Golm, Feb. 20-22 '02.

- (i) DC Data Analysis - Discussion of Results, SEI/SUS (Suspensions & Seismic Isolation, K. Koetter & Soma Mukherjee.
- (ii) Bursts Upper Limit groups for coincidence run with LIGO: - Software integration, Data Analysis Plans & Results and Discussions, Soma Mukherjee.
- (iii) The DC Robot Results, Soma Mukherjee.

- The following presentations have been made at the GEO Data Meeting, Glasgow, May 13-15, 2002.

- (i) GEO Burst search - status report, Soma Mukherjee.

- The DMT monitor for the PSDCD transient detection algorithm was completed and tested. A presentation about the monitor was made at the March 2002 LSC meeting. This monitor has not been deployed on the E7 data because AEI continues to lack a DMT installation which is mainly due to manpower and time constraints here. Experience with working remotely on the DMT machines at Hanford and Louisiana have been less

than satisfactory because of an often poor connection. However, the same codes have been adapted to run locally within the DCR software (see below). Thus, the same algorithm will be employed on LIGO/GEO E7 and S1 data when it is analyzed using the DCR locally.

- Research done on semi-adaptive non-parametric spectral methods to be applied to LIGO /GEO engineering data:  
Matlab codes being tested. No results from data yet.

- Continue with transient classification schemes with more variables and newer algorithms.

The following presentation was made at the March '02 LSC meeting, Livingston: "Automated classification of bursts with LIGO E7 data. LIGO Technical document G020038-00-Z, 2002, Soma Mukherjee".

- Data/Detector characterization Robot: (see <http://www.aei-potsdam.mpg.de/~mohanty/DCR/DCRindex.html> for more details.) The Central idea behind the DCR is to construct a tool for ingesting raw data and generate a \*reliable\* database of change points in the statistical character of the data. The reliability requirement is formulated in terms of the false alarm rate being a \*known\* quantity even though the data may be non-stationary or otherwise poorly characterized (such as the environmental channels). This may prove essential in data mining types of analyses.

All the codes needed to implement a restricted version of the DCR, called rDCR, have been completed and tested. At the core is a general purpose C++ Digital Signal Processing library called TSSP (Template based Statistics and Signal Processing library; Mohanty 2002). A brief report on TSSP can be found at [http://www.aei-potsdam.mpg.de/~mohanty/DCR/status\\_aug02.html](http://www.aei-potsdam.mpg.de/~mohanty/DCR/status_aug02.html). At the moment TSSP has all the DSP components that are needed to implement rDCR algorithms. TSSP is designed to be self contained so it should be quite straightforward to integrate it within data analysis environments such as TRIANA or DMT.

The rDCR pipeline consists of frame reading, line removal using the MBLT algorithm, transient detection using PSDCD and writing triggers into a MySQL database. Efforts are now on to supplement PSDCD with other non-parametric transient detection algorithms since it is well known that no single algorithm is good enough to catch all classes of transients observed in the data.

Eventually rDCR is supposed to run with minimal outside interference on a Beowulf type cluster. The cluster version is not ready yet. This is not a high priority right now because the only requirement so far has been the distribution of independent segments of data to different nodes. The main emphasis right now is to study the data mining aspects, what the demands are on reliability of a database for interferometric

detectors and whether the algorithms of DCR meet or exceed those requirements.

Presentations on the DCR concept were made at the March 02 LSC meeting and several subsequent and earlier GEO internal meetings. Progress on completion of rDCR was delayed by the diversion of manpower into the development of GEO++ (which was initiated by Mohanty as a the core DSP library for DCR) as an independent DMT like monitor development environment. Hence, though the full pipeline has been tested on short data stretches, deployment on full E7 data was not achieved. rDCR will now be used for analysis of both E7 and S1 data.

- Automated identification of line frequencies and bandwidths in a sample Power Spectral Density:

This was not in the milestones set out in the last report but it forms a part of LSC work. An algorithm was developed by Mohanty (2002) which is being implemented by Yousuke et al. (see Yousuke's report (?)).

- Use restricted DCR on both LIGO E7 and GEO data. (see DCR report above.)

- Integrate MBLT into DMT so that restricted DCR can also run within the DMT: No progress.

- Finish modifications to the Finn, Mohanty, Romano algorithm (see Prog. Rep. for Aug2001-Feb2002): No substantial progress.

- GEO Data transfer: the DC group at the AEI (in collaboration with Hannover and Cardiff) has been involved in the design, implementation and test of the GEO-data transfer scheme, pushing data from Ruthe to Hannover, AEI-Golm and Cardiff.

During and after E7, data were transferred via the network to the AEI, then copied into tapes and sent to Cardiff.

For S1 run, both network transfer and tape writing facilities are in placed.

- GEO Data access:

A frame-server has been installed at AEI\_Golm that can serve data (full frame-files or only a subset of channels) just by making a requests. This frame server is intended for internal AEI- use, but actually data can be requested from the outside without restrictions. Moreover the full calibrated  $h(t)$  and lock status are now available for both E7 and S1.

[Note: other frame-servers in Hannover and Cardiff also exist].

Data can easily be access by using Triana or GEO-Tools (developed and maintained by M. Hewitson, Glasgow).

- Data Analysis:

The Detector Characterization group (DC) has been involved in the analysis of E7 data for detector characterization purposes. Investigations have focused on understanding the causes of loss lock, Gaussianity and stationarity of the data, line noise and noise propagation. Analysis of trend data, time-frequency diagrams and coherence studies have also been performed. The results are posted on the GEO-DC logbook

<https://info.geo600.uni-hannover.de/cgi-bin/dcnote.pl>  
(internal to the GEO collaboration). Subgroups have been formed to investigate different DC issues related to GEO data.

An efficient and robust method for automatic line detection and measurement of their characteristics has been developed (Borger, Itoh, Sintes). The method is based on calculating running medians and quartiles and was originally suggested by S. Mohanty. The method requires some improvement in order to avoid tuning free parameters to particular data. Analysing of S1 data using the method is being carried out.

A database has been constructed in which all lines instrumental or environmental, are cataloged. The database is made based on MySQL and during this period we learnt to use MySQL. The information is then used by the online line tracking monitor.

## CONTINUOUS WAVES

Please refer to the milestones set in the Attach. A from the previous semester:

- defined SFT format and produced FFTs for E7 GEO data
- studied non stationary behaviour of data to define suitable time baseline for FFTs (60s). Results presented at August LSC meeting.
- did not install Merlin Beowulf cluster (mainly due to delays in getting the final approval from the funding agency). However, made significant progress (see Merlin's CVS archive at <http://pandora.aei.mpg.de>). Invitation to tender in a national open bid was sent out in mid August.
- no improvements were made to LALBarycenter
- New version of LALDemod that computes optimal detection statistic for a signal that is also amplitude modulated was submitted to LAL.

## UNIVERSITY OF BIRMINGHAM CONTINUOUS WAVES

We have produced a C code to carry out a flat matched-filter based search of Sco X-1 on a single CPU. In more detail:

- We have generalised the LALDemod function to demodulate the orbital motion

of a binary pulsar assuming that the orbit is circular; the code is completed, and the documentation is in progress; the code will be submitted soon to the CVS repository.

- We have written a LAL function (not yet fully compliant to the LAL specs) to place filters on the 3-dimensional parameter space of the orbital parameters of a pulsar in circular orbit including correlations. The code is tested and will be submitted to the repository later in the Fall once it is fully compliant to the LAL specs and the documentation is in place. We have also a version of the code which generalises the present one and is able to handle a higher number of dimensions, but it still needs testing.
- Using the previous functions and the relevant ones that are already available in LAL we have put together a code to search for monochromatic signals from neutron stars in circular orbit where the position of the source is exactly known. The code is currently being tested on E7 GEO data.

As far as the catalogue of "targets" for pulsar searches is concerned, we are still working on the web-interface, but the catalogue is complete.

## INSPIRAL BINARIES

In the context of binaries undergoing spin-orbit precession, we have completed the first stage of our analysis - in collaboration with P Glanclement and V Kalogera (Northwestern University) - of the FF which is achieved by an improved 5-parameter template family. A paper summarising the main results has been recently submitted to PRD (and is available on [gr-qc](#) and [astro-ph](#)).

## STOCHASTIC BACKGROUND

The work has been entirely dedicated to the analysis of the E7 data, in particular the development of the necessary functionalities to carry out GEO-LIGO cross-correlations. The key issue that still needs to be addressed before being ready to perform the analysis is the ingestion of calibrated LIGO data into the code that handle calibrated GEO data. This represents the main focus of the activity right now (as well as testing), which is carried out within the stochastic background upper-limit group.

This work has slowed down the delivery of the LAL functions that extend the functional form of Omega that can be searched; the completion of these functions is postponed to Feb 2003.

## UNIVERSITY OF CARDIFF

The Cardiff group participates in the ASIS, Inspiral Upper Limits and Bursts Upper Limits subgroups of the LSC. The group has recently acquired a Beowulf cluster consisting of 85 dual pentium III, 1.6 GHz nodes. The cluster has been funded by a special award to Cardiff and will be used in all our data analyses.

This report is based on the milestones for the period Feb 02-August 02.

Participate in the inspiral and burst upper limit analyses, specifically carrying out the inspiral upper limit analysis on GEO data  
Inspiral Searches (BSS, DC, SB)

The Cardiff group has continued to participate in the inspiral search analysis. The results of the analysis are regularly posted on our web site (which is password protected with the combination reader/readonly).

We ran both an inspiral monitor, that records the sensitivity of the instrument to inspirals to three archetypal binaries - BH-BH, BH-NS and NS-NS, and astrophysical search on GEO playground.

The inspiral monitor showed oscillatory features with a periodicity of 12 Hrs and 24 Hrs. The cause for these oscillations have been identified and recorded in the GEO log book.

For the inspiral search we have also implemented the chi-square test and found that by using a chisquare threshold of 10 our loudest events in the playground data are at about 10.

During S1 inspiral signals were injected by hardware into the data stream. Our search algorithms were successful in identifying the times when the injections were done although the parameters found don't quite agree. We are currently working on diagnosing the reasons for this disagreement.

During Oct 25-26 the inspiral group had a face-to-face meeting at Penn State Univ during which three hours of GEO

playground data were transferred to the UWM site. The inspiral DSO was run on GEO data producing an event table. Similar analysis has been carried out in GEO and we are currently comparing the results of the two analyses.

The Cardiff group has strongly campaigned for using the existing BH-BH signal models for setting upper limits as well as for carrying out astrophysical searches. But a major hurdle has been not only are the signal models unreliable in this case, since the merger phase of the coalescence takes place within the LIGO band, but we do not have the software tools ready to carry out the most generic analysis including spins. This problem was addressed at the Aug 02 LSC and BSS was charged to come up with a strategic plan. A document has now been prepared by the IUL group which clearly explains the goals of the analysis and the milestones required to achieve that goal.

We plan to carry out BH-BH upper limit analysis using a convenient characterisation of the all the existing approximation methods for signal models worked out recently by Buonanno, Chen and Vallisneri. After accomplishing this (by Jan 2003) we will then begin implementing post-Newtonian models spinning BH-BH binaries.

#### Burst Analysis (BSS, RB, SB)

Cardiff group is responsible for running the various monitors on instrumental channels. GEO++ monitors were developed and run on pre-selected channels. Currently, the event lists are being used to study efficiency of vetoes in burst searches.

Tests the performance of the bank code when the random signals used are from a family other than the post-Newtonian family for which it is intended (namely, the stationary-phase approximation)  
No progress has been made on this front.

Develop a two-step hierarchical code under GEO++ for inspiral searches  
No progress has been made on this front.

Support other astrophysical searches within GEO++ (CW, burst, stochastic) (RB, SB)  
Much of the infrastructure for automated DC analyses have

been now developed under GEO++. We are periodically receiving requests from GEO analysts and experimentalists to develop monitors based on their study of what might be a useful analysis. Facilities in GEO++ have allowed us to develop the following monitors: glitchmon, inspiralmon, powermon, psdmon, and powertrackermon.

No requests have been made from CW and stochastic.

Continue with the database support for various searches and DC (DC, RB)

GEO uses MySQL to store its events. Cardiff has led the development of database table definitions for the various GEO++ monitors. Database access is provided on our server [weber.astro.cf.ac.uk](http://weber.astro.cf.ac.uk) for anyone in the collaboration who wants to access the data. The triana tool dbExplore is being enhanced to make data mining easier.

Begin code development for spinning black-hole binaries (much delayed because of our pre-occupation with other things) (BSS, SB)

We have developed and tested the codes for the post-Newtonian approximation giving the waveform for arbitrary values of the parameters. These are currently being written in LAL.

Take part in the GEO-LIGO science run and the analysis of data resulting from that run (BSS, DC, RB, SB)

This has been covered above.

Develop the main DC Monitor data distribution code (RB)

Completed. GEO++ has now completed the development of frame reading and data distribution aspects. Currently, the group is concentrating on implementing search codes in GEO++ (see our plan).

Develop simple monitors to test the entire pipeline (RB, SB, and other GEO colleagues)

Many monitors have been written and the GEO++ has been testing to a great extent. However, there has been no documentation of what has been tested and we plan to schedule a test phase with a specific aim of validating certain GEO++ monitors with exactly the same monitors constructed using matlab, or other similar, time-tested software.

Set up a GEO++ website with the following documents

Overall aims of GEO++ and basic description (RB)

How to build a simple monitor in GEO++ (RB)

Coding conventions document (RB)

Database Issues. How to set up a database and initialise the database with table definitions. How to use database at other locations etc. (DC)

50% done; many gaps needs to be filled.

Adapt Grid applications of Triana for astrophysical searches. (DC)

David Churches has been working on using Globus tools for data transfers. He is also planning to run templated search using P2P (peer-to-peer) processing under Triana.