



**Attachment DAT to the
Memorandum of Understanding LIGO-M970077-00
between the German/British Collaboration (GEO 600) for the
Detection of Gravitational Waves (GEO600)
and the
Laser Interferometer Gravitational Wave Observatory (LIGO)
For The Period
August 15, 2008 - August 14, 2009**

This Attachment DAT to the Memorandum of Understanding LIGO-M970077-00 defines the role of the German/British Collaboration (GEO 600) for the Detection of Gravitational Waves (GEO600) as a Member of the LIGO Scientific Collaboration (LSC). In particular, it addresses data analysis activities in support of the initial LIGO interferometers. The period of performance for the activities in this Attachment is from August 15, 2008 - August 14, 2009.

1. Collaboration

Together, the LIGO Laboratory and the LIGO Scientific Collaboration (LSC) are responsible for implementing and exploiting the initial LIGO detector through its science data runs. The LSC has organized the data analysis effort into search groups which coordinate analysis, review, and publication on behalf of the collaboration. LSC groups are encouraged to participate in one or more of these groups.

MOU Attachment DAT defines the contributions of each participating group to the data analysis development groups.

2. Participation

During the period August 15, 2008 - August 14, 2009, the members of GEO600 will participate in the analysis of initial LIGO data in the following areas:

a. Binary Inspirals

Cardiff University:

- (a) Finish S5 low-mass search [Fairhurst, Cokelaer, Harry, McKechnan, Van Den Broeck]
Finish the analysis of second year of S5 data with the new infrastructure developed by Cokelaer and Fairhurst
- (b) Conclude S5 high-mass search [Sathyaprakash, Robinson, Predio]
Strengthen the high-mass search so that the astrophysics result from the search is interesting and conclude the search

- (c) Develop inspiral-merger-ringdown search with EOBNR [Sathyaprakash, Robinson, Fairhurst, New postdoc 1]
Test the new filtering code developed over the past six months to look for the inspiral and merger parts of the signal using the effective-one-body signals that are matched to numerical relativity simulations
- (d) Prepare the ground for S6 analysis [Fairhurst, Harry, McKechnan, New postdoc 1, 2]
Set the science goals, prioritize and identify the available and missing infrastructure for S6. Assign people to work on road blocks
- (e) Assess the importance of harmonics in parameter estimation [McKechnan, Van Den Broeck, Sathyaprakash]
It is well known that harmonics of the inspiral signal other than the one that is currently used in our searches improve parameter estimation. Carry out a detailed study of the improvement in real detector noise by using software/hardware injections.
- (f) Search for Gamma-ray bursts in S5 data [Pathak, Clark, Fairhurst, Harry]
Identify *all* S5 gamma-ray bursts that are potentially compact binary mergers and search for them using inspiral matched filters.
- (g) Study the effect of spin effects in parameter estimation [Harry, Van Den Broeck, Fairhurst, Sathyaprakash]
Estimate how well spin effects can be helpful in improving estimation of parameters, in particular directionality.
- (h) Einstein Telescope science case and trade-offs [Sathyaprakash, Van Den Broeck, New postdoc 1]
The ET design study will begin in the summer of 2008. Contribute to the ET science case coming from binary inspiral sources.

Albert Einstein Institute:

Members:

Hannover: Bruce Allen, Carsten Aulbert, Oliver Bock, Henning Fehrmann, Martin Hewitson, Bernd Machenschalk, Chris Messenger, Ajith Parameswaran (until July 2008), Holger Pletsch, Reinhard Prix, Christian Röver Long term visitors in 2007-2008: Klimenko (UFL), Bose (UP), Wette (ACIGA).

Golm: Berit Behnke, Sascha Husa, Badri Krishnan, P. Leaci, M.Alessandra Papa, Carlos Peralta, Lucia Santamaria, Bernard Schutz, John Whelan. Long term visitors in 2007-2008: Sintès and Sancho (UIB), Chung (ACIGA), Krolak.

Note:

Reports and plans are given separately for the Hannover and the Golm divisions. However there is extensive exchange between these two divisions and you will see Golm staff on the Hannover reports/plans and vice versa or similar contributions listed under both divisions with different names.

Golm:

- Continue development of software infrastructure to enable injections of numerical relativity waveforms in inspiral pipeline (Krishnan, Santamaria)
- Run 2 months of high mass search and also contribute to any software development and other tasks that might be required for this search. (Santamaria, Husa)
- Continue running 1 month of S5 low mass search and contribute to any necessary pipeline development work. (Santamaria)
- Implement the inspiral-merger-ringdown search using phenomenological waveforms based on matching numerical relativity and PN results (Krishnan, Husa, Santamaria, Whelan)
- Investigate the systematic errors in IMRI parameter estimation due to the use of waveform templates that are accurate only to leading order in the mass ratio of the binary. (Drasco, with Cutler and Vallisneri)

Hannover:

- further development of Bayesian follow-up code, extension to coherent analysis (C. Röver)
- Development of inspiral+merger+ring down waveform injection pipeline for (non-precessing) spinning black holes (A. Parameswaran).
- IMR injection pipeline with waveforms containing higher harmonics from non-spinning black-hole binaries (A. Parameswaran).
- Development of a template bank for the non-spinning binary black-hole phenomenological waveforms (A. Parameswaran).

Birmingham CBC Group (J Veitch & A Vecchio):

We will complete the development of the model-selection code with the goal of making it available in the pipeline for follow-ups and signal-based vetoes/coherent analysis. As part of this activity we will:

- Evaluate the performance of the code/method (and compare with alternative approaches) using 2PN SPA waveforms for the low-mass analysis
- Evaluate the performance of the code/method (and compare with alternative approaches) using other approximants (such as EOB, EOBNR and IMR) for the high-mass search.
- Evaluate the possible use of this code/method in triggered (such as GRB) searches.
- Evaluate the possible use of this code/method to aid and complement MCMC parameter estimation approaches (in collaboration with NUGWAG, AEI and CCRG).

b. Bursts

Glasgow University:

We will contribute waveform reconstruction code towards the Omega pipeline for Burst analysis.

Cardiff University:

- (a) Finish S5 LIGO-only and S5-VSR1 LIGO-Virgo GRB searches [Jones, Sutton]
- (b) Rapid-response triggered search for GRBs in S6 data [Jones, Sutton] Use reviewed X-Pipeline package for automated, low-latency analysis of all GRBs.
- (c) Coherent follow-up of candidate events in S6 [Edwards (PhD student), Sutton] Implement coherent follow-up in the Omega pipeline all-sky, low-latency search. Will study performance of the follow-up for source position reconstruction and background rejection.
- (d) Improved background/foreground separation [Sutton, Jones] Apply multi-variate analysis methods (such as neural networks or decision trees) to triggers from coherent analysis, and quantify usefulness.
- (e) Studying astrophysics that can be obtained from triggered and directed GW searches [Sutton, Jones, Edwards] Emphasis on the science results that can be obtained from burst detections or strong upper limits, and developing the science case for joint observations external collaborations.
- (f) Census of GWB sources [Grindley (undergraduate)] Review of the literature to conduct a census of possible GWB sources and their properties (especially time-frequency signature) to inform burst searches.

AEI, Hannover:

Continue collaborating with the Florida group in customising the Coherent Waveburst algorithm with spinning/higher harmonics waveform injections (A. Parameswaran).

c. Stochastic

AEI, Golm:

- Complete isotropic search using LSC and Virgo data [Robinson, Whelan]
- Development and implementation of a search pipeline for a specific class of non-Gaussian stochastic background produced by bursts from cosmic strings. (Drasco (with Siemens and Regimbau))

University of Birmingham (E. Robinson & A. Vecchio):

- We will continue the S5 LIGO-VIRGO(-GEO) analysis with the aim of placing an upper-limit on the isotropic contribution of a stochastic background in the frequency range above ~ 600 Hz.
- We will continue the development of a Bayesian approach to search for isotropic stochastic backgrounds of arbitrary spectrum using multiple interferometers, by systematically running on software/hardware injections. We will then evaluate possible changes to the analysis pipeline, based on the results from this study.

d. Continuous

University of Glasgow:

[Clark (until October 2008), Gill (from October 2008) Heng, Pitkin, Woan, A.N. Other (from November 2008)]

- (a) We will develop the targeted pulsar code so that it can include glitch change-points routinely.
- (b) We will publish the S5 targeted pulsar paper.
- (c) We will perform a thorough investigation of the noise environment close to the Crab frequency to see whether additional sensitivity can be achieved by using more sophisticated noise management schemes.
- (d) We will contribute to the development of local area search techniques for pulsars of uncertain frequency and for r-mode emission.
- (e) We will run the evidence-based code a follow-up to matched filter ring-down search.
- (f) We will investigate ways of extracting glitch waveforms.
- (g) We will have preliminary results of ring-down search from a Vela glitch in S5.

Albert Einstein Institute:

Members:

Hannover: Bruce Allen, Carsten Aulbert, Oliver Bock, Henning Fehrmann, Martin Hewitson, Bernd Machenschalk, Chris Messenger, Ajith Parameswaran (until July 2008), Holger Pletsch, Reinhard Prix, Christian Röver Long term visitors in 2007-2008: Klimenko (UFL), Bose (UP), Wette (ACIGA).

Golm: Berit Behnke, Sascha Husa, Badri Krishnan, P. Leaci, M.Alessandra Papa, Carlos Peralta, Lucia Santamaria, Bernard Schutz, John Whelan. Long term visitors in 2007-2008: Sintes and Sancho (UIB), Chung (ACIGA), Krolak.

Note:

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Golm:

- Continue development of cross-correlation search and apply it to full S5 data set (Krishnan, Whelan)
- Extend the cross-correlation search to look for CW signal from binary systems (Whelan, Krishnan)
- Use Hierarchical hough code to search for CW signals from the galactic center (Behnke, Krishnan, Peralta)
- Investigate the feasibility of a galactic center search for transient CW signals lasting days or weeks. (Behnke, Krishnan, Peralta)
- Development and completion of the post processing of the E@H S5R2 and R3 results (Papa, Leaci)
- Set up and run of a new Einstein@Home search on S5-data (S5R4) (Krishnan, Papa, Sintes)

Hannover:

- Einstein@Home S5R1 postprocessing (H. Pletsch, B. Machenschalk, O. Bock)
- Einstein@Home project maintenance (B. Allen, B. Machenschalk, O. Bock)
- Einstein@Home application support and improvement (B. Allen, B. Machenschalk, R. Prix, O. Bock)
- Einstein@Home development of a radio pulsar search (C. Messenger, B. Allen, H. Pletsch, R. Prix)
- prepare paper on random template-banks and relaxed lattices (C. Messenger, R. Prix, MA Papa)
- prepare paper on flat-metric approximation for CW searches (R. Prix) ; prepare paper on parameter-space correlations of the optimal detection statistic (H. Pletsch)
- study optimization of Hierarchical search algorithms (R. Prix)
- study detection statistic for “transient” (lasting few days) CW signals (R. Prix)
- Implement and develop the “sideband” search for low-mass X-Ray binaries (C. Messenger)
- Apply the RXTE Sco X-1 search to other X-Ray sources (C. Messenger, R. Prix)
- Prepare paper on the RXTE Low-mass X-Ray binary searches (C. Messenger)
- Implement an XML format for reading/writing intermediate and final CW search results, including full history trails (R. Prix, O. Bock)
- Set up and run a new Einstein@Home search on S5-data (S5R4) (B. Allen, B. Machenschalk, R. Prix, O. Bock)
- Development of a generalized Einstein@Home/BOINC workunit-generator in order to simplify setting up new BOINC projects (O. Bock, R. Prix)
- Search for a CW signal from Cas A with Karl Wette and Ben Owen (C. Messenger, MA Papa, R. Prix)

e. Other Contributions

Cardiff University:

- Hardware/Support [Gerald Davies]
 - (a) Maintain and operate the Explorer and Coma clusters strengthening the code base. In particular, upgrade the OS on our systems.
 - (b) With the view to increase usage, install the necessary grid tools on Coma so that the cluster is more easily suitable for LSC searches.
 - (c) Explore the possibility of moving data on our spinning media to tape storage on the new ARCCA HPC facility.
 - (d) Keep up-to-date GEO astrowatch data and prepare hardware for LIGO S6 strain data at Cardiff. Also explore transferring data from Virgo during S6.
- Committees
 - (a) Steve Fairhurst: Co-chair of the inspiral search group, LSC Council
 - (b) B.S. Sathyaprakash: Coordinator of the WP4 of Einstein Telescope Design Study, LSC Council, GEO Exec Comm
 - (c) Patrick Sutton: ExtTrig co-ordinator, burst review committee, LSC-PP, GEO Exec. Comm

AEI, Golm:

- Computing
Continue reported activities
- Management and service
Continue reported activities

AEI, Hannover:

- Computing
 - Operating and extension ATLAS cluster (5400 cores) (H. Fehrmann, B. Allen, C. Aulbert)
 - Data management for AEI/Hannover (C. Aulbert, O. Bock, H. Fehrmann)
 - Computing support for Einstein@Home postprocessing and future searches (B. Allen, C. Aulbert, H. Fehrmann, O. Bock, B. Machenschalk)
- Hardware
 - Continued operation and possibly expansion of current resources (C. Aulbert, H. Fehrmann, B. Allen)
 - Taking over some GEO data duty from Steffen Grunewald (C. Aulbert, H. Fehrmann, M. Hewitson)
- Other
 - Improvement of DASWG development process and version control scheme (O. Bock, R. Prix)
 - Maintenance and improvement of Twiki system for CW group and other groups (O. Bock, R. Prix)
 - GEO600 calibration, data collection and movement (M. Hewitson)

University of Birmingham:

D Stops

We will continue the support of our 210 CPU Beowulf cluster (Tsunami) and make it available to the LSC for data analysis exploratory work.

3. Resource Sharing

The LIGO Laboratory will contribute resources including allocation of appropriate scientific and engineering personnel, research facilities, and funding in support of the effort in Item No. 2, as indicated below.

- a. Research accommodations for GEO600 group members while on LIGO research assignment at any LIGO Laboratory site.

Not Applicable

- b. Access to LIGO data through established LSC channels in support of this work.

Not Applicable

4. Coordination and Reporting

GEO600 will perform research within the structures established by the LIGO Laboratory and the LSC where appropriate.

In particular, with reference to activities described above:

2a will be carried out within the LSC Inspiral Search Group.

2b will be carried out within the LSC Burst Search Group.

2c will be carried out within the LSC Stochastic Search Group.

2d will be carried out within the LSC Continuous Waves search Group.

This includes keeping the Group leaders informed of activities and plans, reporting to the group at meetings and telecons, and through technical documents submitted to the LIGO Document Control Center.

In addition, an annual report will be submitted with the update to this Attachment, giving a summary status on research by topic as indicated in Item No. 2, including progress against the milestones if any, significant accomplishments such as new insights/discoveries or publications, issues of concern if any, and an indication of invested time.

This Attachment will be updated at least annually with a plan of activities for the succeeding one-year period. These documents will be due one month before the close of the period of performance under this Attachment.

5. Computer Code

All computer code delivered to the LSC under this Attachment must be developed in consultation with the LSC Data Analysis Software Working Group (DASWG) and archived, documented and reviewed as determined by that group.



Jay Marx
LIGO Laboratory Director



Karsten Danzmann
Principal Investigator(s)
GEO600



David Reitze
LSC Spokesperson