Attachment DAT to the

Memorandum of Understanding (LIGO-M0970077-00-M)

between the

German/British Collaboration (GEO 600) for the Detection of Gravitational Waves and the

Laser Interferometer Gravitational Wave Observatory (LIGO)

August 15, 2005

This Attachment DAT to the Memorandum of Understanding LIGO-M0970077-00-M defines the role of the German/British Group (GEO 600) as a Member of the LIGO Scientific Collaboration (LSC), in particular, its activities in data analysis in support of the initial LIGO interferometers. The period of performance for the activities in this Attachment is from August 15, 2005 to August 15, 2006.

1. Together, the LIGO Laboratory and the LIGO Scientific Collaboration 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 the analyses, perform detailed reviews, and prepare publications on behalf of the collaboration. LSC groups are encouraged to participate in one or more of these groups. MOU Attachments define the contributions of each participating group to the data analysis groups.

2. During the period August 15, 2005 to August 15, 2006, the members of German/British Group will participate in the analysis of initial LIGO data in the following areas:

   a) *CW Analyses*: (I. Gholami, B. Krishnan, A. Krolak, B. Machenschalk, M.A. Papa, R. Prix and H. Takahashi, who is to start in September 05
   - Submit Fstats all-sky wide band search paper for publication
   - Continue to support of E @ h and BOINC development , during the next year emphasis will probably shift on code/algorithm optimization
   - Figure out what hierarchy of searches to perform with E @ H on large data sets (with UWM)
   - Prototyping of first coherent multi-detector Fstat search
   - Development of more efficient tiling algorithms and parameter space parametrizations (see also Glasgow and PSU)
   - Sensitivity improvement of the Hough search
   - Deployment of Hough search on stretches of Fstat
   - Benchmarking of Fstat code with other implementations

   b) *Binary Inspiral*: (S. Babak, Y. Chen)
   - Complete S3-S4 LIGO-GEO BNS search (S. Babak, H. Takahashi)
   - S5 LIGO-GEO BNS search (On-line analysis, parameters tuning, running the search)(S. Babak, H. Takahashi).

- See 5), 7), 8) under inspiral analysis plans of the Cardiff group (S. Babak, Y. Chen)
- Working on design and implementation of the search for spinning binaries using physical models (waveforms). This includes design of the template bank. (S. Babak, Y.Chen, A. Pai, H. Takahashi in collaboration with Buonanno, Pan, Vallisneri)

c) *Service Work*: (S. Grunewald, C. Aulbert, B. Machenschalk*)*
- Maintenance of Merlin cluster
- Maintenance of LDR system for distribution of LIGO data to the GEO collaboration and publishing of GEO data
- Responsibility for permanent archival of GEO data at ZIB
- Maintenance of E @ H server

d) *Network Analysis – Null-Stream Method:*
- Two main areas of burst group work have started in Hannover: network analysis using the null-stream method, and instrumental veto development. (M. Hewitson, A.Parameswaran)
- Software injections into 2 detector white noise to get false-alarm/efficiency rate (done)
- Software injections into H1-H2 data (playground or time-shifted) to get false-alarm/efficiency rate (in progress)
- Analysis of H1-H2 triggers from burst search
- Software injections into three-detector white noise
- Software injections into L1-H1-G1 data (playground or time-shifted) to get false-alarm/efficiency rate
- Analysis of L1-H1-G1 triggers from burst search
- Extensions to using ETG on null-stream (far future)
- Extensions to inspiral events using template matching (very far future)

e) *Instrumental Veto Development:*
- Finalise formulation of the time, frequency, and amplitude consistency windows
- Test on real data for channels whose coupling to the detector output is well understood
- Look for more channels that could be useful
- Compare the method using different ETGs (need to get waveburst running in Hannover)
- Generate veto lists for science runs using the LSC burst group's chosen ETG

f) *CW Analyses*: (D. Kasprzyk, V. Re and A. Vecchio) - We shall continue the development of data analysis pipelines to search for radiation emitted by accreting neutron stars and the analyses of the data to place upper-limits on radiation emitted by selected sources.
- Finalize the end-to-end coherent frequency domain pipeline to place upper-limits on the6 accreting neutron stars that show coherent X-ray pulsation: produce technical document and initiate the review process (D Kasprzyk, A Vecchio and C Messenger (Glasgow))
- Produce preliminary upper-limits on S4 data (3 IFOs and likely the whole span of the run) for the above sources (D Kasprzyk, A Vecchio and C Messenger (Glasgow))
- Produce upper-limits on Sco X-1 using 6 hr of S4 data based on the same pipeline used for the S2 analysis (D Kasprzyk)
- Finalize the end-to-end pipeline for a stack-slide search built on STFs over a frequency band 200-800 Hz and three IFOs to place upper-limits on radiation from

Sco X-1: produce technical document and initiate review process (V Re, A Vecchio and C Messenger (Glasgow))
- Produce preliminary upper-limits on S4 data for the above search (V Re, A Vecchio and C Messenger (Glasgow))

g) *Stochastic Background*: (C.N. Colacino, A Mercer, C Ungarelli and A Vecchio)
We shall continue the development of data analysis pipelines and the analysis of the data to set upper-limits on stochastic backgrounds.
- Produce preliminary upper-limits on isotropic stochastic signals characterised by a generic spectrum using S4 data: produce technical document and initiate review process (C N Colacino, A Mercer and C Ungarelli)

h) *Computer Hardware/Software Infrastructure*: (D. Kasprzyk, A. Mercer)
- Ensure high-duty cycle of Tsunami and relevant infrastructure.
- Increase disk storage in preparation of the S5 run

i) *Inspiral Analysis*:
- Complete S3 search for spinning black hole binaries using phenomenological templates. A publication on the first ever search for spinning BBH in gravitational wave data. November 2005. [Gareth Jones]
- Complete S3 and S4 search for BBH binaries using the fully optimized phenomenological BCV templates. One joint publication with BNS search. November 2005. [Thomas Cokelaer]
- Complete the S3 and S4 search for BBH binaries using time-domain templates representing the physical models derived using post-Newtonian, effective one-body and P-approximants and write a joint publication on S3 and S4 searches. March 2006. [Craig Robinson]
- Implement clustering in the parameter space using an algorithm that Sengupta studies For his thesis. Also, begin implementing a hierarchical algorithm for BNS and BBH searches that Sengupta studies for his thesis with Dhurandar and Lazzarini. August 2006. [Anand Sengupta]
- Integrate the new template bank code developed by Tagoshi into LAL by replacing the numerical recipes routines with either new codes or with routines in gsl or other similar library. Carry out S4 and S5 searches with the new template bank. This will be first full parameter space search involving hundreds of thousands of templates and will take the full next year to complete. August 2006. [Chris van den Broeck, Gareth Jones, Sathyaprakash in collaboration w. Stas Babak, AEI Golm]
- Compare the BCV searches with time-domain searches with regard to detection efficiency, false alarm rate, and computing efficiency. One publication on comparison of BCV and time-domain search. March 2006. [Thomas Cokelaer, Craig Robinson]
- Develop tools for parameter estimation of black hole binaries and apply it to S4 and S5 data set. August 2006. [Craig Robinson, Anand Sengupta, Sathyaprakash in collaboration w. Stas Babak, AEI Golm]
- Automate the parameter space region for search using the phenomenological BCV templates and integrate that with the current template bank generation codes. November 2005. [Anand Sengupta, Thomas Cokelaer n collaboration w. Stas Babak, AEI Golm]
- Begin implementing the new effective one-body search templates for spinning black hole binaries. We will first develop time-domain waveform generation and then implement a template bank to search in the full parameter space of spinning black hole

binaries. We will begin this in April 2006 and may take up to two to three years to complete. [Crhis van den Broeck, Sathyaprakash]

j) *Burst Analysis*:
- Complete the triggered search for NS QNM by November 2005 [Chris van den Broeck In collaboration with Pitkin and Woan]
- Optimize WaveBurst to search for merger signals predicted by the effective one-body formalism. [Sathyaprakash, Chris van den Broeck in collaboration with Sergei Klimenko]

k) *Stochastic Analysis*:
- See the S3 paper through the refereeing process to eventual publication in PRL. (It was posted to astro-ph in July 2005). [Joe Romano]
- Finish the S4 H1-L1 analysis for isotropic stochastic backgrounds. [Joe Romano with Vuk Mandic (Caltech)]
- Consider extensions or modifications of the standard cross-correlation statistic procedure that might allow us to estimate the strength of cross-correlated (environmental or instrumental) noise. This is important, for example, for the H1-H2 correlation, as well as for LHO-LLO as the sensitivity of the interferometers improves. [Joe Romano with Vuk Mandic and Albert Lazzarini (Caltech)]
- Write up the results of the S4 analysis (including the results for isotropic backgrounds, the targeted search, different power laws, etc.). Submit for publication as a normal article in PRD or Astrophysical Journal. [Joe Romano with the rest of the Stochastic Analysis Group]
- Begin analyzing the S5 data, producing running estimates of the sensitivity and coherence of the H1-L1 and H1-H2 detector pairs. Obtain point estimates and error bars for Omega_gw for the first 6 months of the S5 run, possibly leading to a publication if the results are of sufficient astrophysical interest (e.g., if we beat the nucleosynthesis bound). [Joe Romano with the rest of the Stochastic Analysis Group]

l) *Hardware / Support*:
- Our cluster is now being upgraded to double its current size to a total of 360 nodes. In April 2006 there will be a second upgrade, with an expected additional 250 CPUs. Our current storage capacity is 25 TBytes which will be upgraded to 50 TBytes in September 2005 and 75 TBytes in April 2006. We will have all GEO600 data on RAID arrays and level-3 RDS LIGO data on cluster disks. [Gerald Davies].

m) *CW Searches*:
- To adapt the existing time domain search code so that it is suitable for tackling the extended S5 run. This will involve restructuring the data flow so that it can efficiently process ~1.5 yr of data from 4 interferometers. A later milestone will be to use SFTs for the heterodyning stage. (Pitkin, Woan)
- Revise and recompute the parameter and error models for the targeted pulsar list. (Pitkin, Woan)
- Initiate the development of a Bayesian formalism for directed searches that takes advantage of the distinction between intrinsic and extrinsic parameters.(Clark, Messenger, Woan)

- Develop the MCMC search routine to be used in followup observations of all-sky triggers (Veitch, Woan)
- Development of an efficient tiling algorithm for multi-dimensional parameter spaces (in collaboration with PSU and AEI) (I. Jones)
- Astrophysical targets: Produce realistic estimates of computational costs of supernova searches and use this to determine depth of possible searches (e.g. for an Einstein@Home search). In collaboration with PSU quantify the completeness of optical and X-ray surveys for nearby neutron stars and assess impact of this on choice of parameter space for all-sky gravitational wave searches. (I. Jones)

n) *Burst Searches*:

- Generate LIGO-GEO S4 triggers for an all-sky Burst gravitational wave search and have these triggers incorporated in coherent network analyses for the LIGO-GEO network. (Clark, Heng)
- Perform a search for possible gravitational wave bursts associated with glitches observed in the pulsar timing. This will be a triggered search performed only on data around the time of the glitches observed by radio astronomers. A list of sources include the Crab and Vela as well as the huge flare observed in magnatar SGR 1806 in December 2004. (Pitkin, Heng)
- Have the LIGO-GEO S3 analysis reviewed by the Burst Review Committee.

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 GEO 600 group members while on LIGO research assignment at any LIGO Laboratory site,
   b) Access to LIGO data through established LSC channels in support of this work.

4. Coordination and Reporting – GEO 600 Group will perform this research within the structures established by the LIGO Laboratory and the LSC where appropriate. In particular activities described in Item 2a) will be carried out within the LSC Inspiral Search Group, Item 2b) will be carried out within the LSC Burst Search Group, and Item 2c) will be carried out within the LSC Stochastic Search Group. Coordination will include 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.

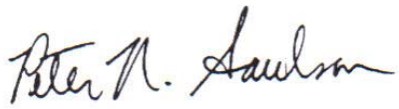
   In addition, an annual report will be submitted with the update to this Attachment, giving a summary status on research by topic as indicated in Item No. 2, including progress against the milestones if any, significant accomplishments such as new insights/discoveries or publications, issues of concern if any, and an indication of invested time. This Attachment will be updated at least annually with a plan of activities for the succeeding on-year period. These documents will be due one month before the close of the period of performance under this Attachment.

5. 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.

Approved:

Jay Marx
LIGO Laboratory Director

NNNN
GEO 600 Principal Investigator



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