Attachment Number A to the
Memorandum of Understanding (LIGO-M000125-00-M)
between the
Carleton College Relativity Group (CCRG)
and the
Laser Interferometer Gravitational Wave Observatory (LIGO) Laboratory
February 15, 2000

This Attachment A to the Memorandum of Understanding LIGO-M0000125-00-M covers the role of the Carleton College Relativity Group (CCRG) as a Charter Member of the LIGO Scientific Collaboration (LSC) and a member of the LIGO I Development Group (L1DG). The period of performance for the activities in this Attachment is from February 15, 2000 to August 15, 2000. This period may be modified by agreement to a revision of this Attachment.

1. LIGO Scientific Collaboration - The LIGO Scientific Collaboration (Collaboration) is organized as a separate organization from the LIGO Laboratory. It includes scientists from the LIGO Laboratory, and those from collaborating institutions, and has its own leadership and governance. The Collaboration will ensure equal scientific opportunity for individual participants and institutions. It will organize the research, publications, and all other scientific activities. The Collaboration will report to the Laboratory Directorate for final approval of its research program, technical work, observational physics publications, and talks announcing new observations and physics results. This will be done through regular semi-annual reports to the Directorate and its PAC.

2. Charter Membership - An initial period for formation of the Charter group of institutions in the LIGO Scientific Collaboration commenced on March 1, 1997 and ended following the first full meeting of the Collaboration at which the Collaboration Council assumed its role.

   Following the charter period, proposals will be evaluated and approved, as appropriate, through the Collaboration Council. An MOU with the LIGO Laboratory, including Attachments defining specific work, will be required for any participating institutions.

3. This document is an agreement between the Carleton College Relativity Group (CCRG) and the LIGO Laboratory concerning the activities of CCRG as a Collaborating Institution in the LIGO Scientific Collaboration (LSC) and in the LIGO I Development Group (L1DG), and as indicated in Items No. 8 and No. 9 below.

4. LIGO I Development Group - The LIGO I Development Group is the scientific collaboration for implementing and exploiting the initial LIGO detector and physics through the initial science data run. Only groups who establish a specific Attachment approved by the LIGO Labo-

ratory, which defines a sufficient contribution and participation in LIGO I development, implementation or data analysis will be part of this initial LIGO data run and science. Participation in future data runs and science that follow LIGO I will be possible for other groups, with guidelines to be determined by the LIGO Scientific Collaboration. It is anticipated that LIGO I data will only be made available through formal collaboration within the LIGO I Development Group during the first two years following its collection.

The general guideline for institutional membership in the LIGO I Development Group is that the contribution per collaborator of any new group to the design, construction, and implementation of the initial LIGO detector and to the first data run be comparable to that of the LIGO Laboratory scientists.

5. Report of Progress - CCRG will provide a status report on its activities in support of LIGO every six months. The report will consist of: a) a summary status on research by topic as indicated Items No. 8 and No. 9 below 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, b) updated List of Collaborators, and c) a plan of activities for the succeeding six-monthly period. The report will be due one month before the close of the period of performance under the Attachment in question.

6. Term of Membership - The Membership will be renewed every six months upon evidence of satisfactory performance of agreed upon duties.

   The coordinates of CCRG members are included in the Attachment Z to the Memorandum of Understanding LIGO-M000125-00-M.

7. Intellectual Property Rights - The rights to intellectual property developed under this Attachment will be subject to the National Science Foundation Grant Policy as indicated in Section 730, Intellectual Property.

8. LLAL Software Conventions - It is necessary that any delivered code conforms to the LLAL style as laid out in the LLAL specification T990030. This includes: 1) coding style, headers, etc.; 2) use of function calls, etc.; 3) organization of software in the directory structures indicated in the document; 4) inclusion of test codes and validation tests to enable users to verify successful installation of implementation; and 5) documentation and users manuals (html or pdf) to enable users to understand and adopt code.

9. During the period February 15, 2000 to August 15, 2000, Professor Nelson Christensen and up to three undergraduate students will conduct research in the areas of data analysis algorithm development and coding, and R&D related to the LIGO facilities. The following are CCRG's research goals for the six month period under this agreement:

   Data Analysis, Statistics and Parameter Estimation for Binary Inspiral Searches

   a) N. Christensen will derive and develop optimized code for applying Markov Chain Monte Carlo (MCMC) techniques to the parameter estimation problem for coalescing binary observations. Current strategies call for the data to be run through an extensive library of template waveforms, and the template with the highest signal-to-noise ratio would determine the value of the parameters. This maximum likelihood technique does not provide the associated probability distributions for the parameters. A random walk through parameter space, as accomplished via the MCMC, would determine these distributions, determine and assign confidence intervals for the parameters. A prime objective of this study would be to determine the number of computational operations for this MCMC approach, and to compare it to the present template raster scan strategy. Even if the MCMC approach is more computationally demanding (which at this point is clearly undetermined), the added information provided with the probability distributions functions for the multiple parameters may be determined to be too valuable to neglect. The calculational time required for the MCMC scales linearly with parameter number, so it may prove to be advantageous as the number of parameters for the templates is expanded to include post-Newtonian terms and the spins of the compact objects. Detailed issues pertaining to the optimization of MCMC techniques will be conducted in association with Dr. Renate Meyer, Senior Lecturer of Statistics, University of Auckland, New Zealand. Dr. Meyer is a statistician specializing in MCMC techniques, and when necessary she will contribute to the research effort. This work will also be done in collaboration with Prof. Lee S. Finn of Penn State University.

In order to quantify the usefulness of this method CCRG will:

1. Simulate LIGO data containing (post-Newtonian) coalescing binary events with existing software.

2. Generate post-Newtonian templates, again using with existing software.

3. Construct a likelihood function with the simulated data and templates.

4. Generate a priori distributions for the signal parameters via basic astrophysical assumptions.

5. Incorporate the data, template generation, likelihood function and a priori distributions into a Gibb's sampler MCMC. The output of the MCMC would generate as its output the probability distribution functions for each parameter of the model.

6. Determining the computational cost of implementing these MCMC procedures for use in the LIGO environment would be a prime research concern.

Maximum likelihood analysis versus integrated likelihood analysis

b) N. Christensen, in collaboration with L. Finn (Penn State), will investigate the relative efficiency of a maximum likelihood analysis as compared to an integrated likelihood (e.g., a Bayesian approach with a uniform prior) analysis of the same significance. This would be explored in the context of the binary inspiral problem. The concern is the need to more efficiently process the outputs from the parallel Wiener-filter (i.e. template) analysis in a way that uses present inherent information rather than simply identifying the "loudest" (i.e. maximum likelihood) event. The task would be to quantifiably demonstrate that such an analysis is more powerful than a maximum likelihood analysis, and also to identify the computational costs associated with its implementation.

In order to quantify the usefulness of this method CCRG will:

1. Simulate LIGO data with and without (post-Newtonian) coalescing binary events with existing software.

2. Generate post-Newtonian templates, again using with existing software. c. Construct a likelihood function with the simulated data and templates.

3. Using uniform a priori distributions for the signal parameters incorporate the data, template generation, likelihood function and a priori distributions into a Gibb's sampler MCMC.

4. Search sets of data (with and without embedded signal) over some time window and region of parameter space using both the maximum likelihood and integrated likelihood techniques. A comparison between the maximum likelihood and integrated likelihood techniques by examining the generated probability distribution functions (i.e. determine characteristics such as the mean, variance, skew and kutosis).

5. For the maximum likelihood and integrated likelihood techniques find the fraction of the time that an "actual" event is detected, and compare it to false alarm rates. By picking an acceptable false alarm rate for given signal rates and strengths, one would then find the associated false dismissal rate.

6. Study the computational requirements for these maximum likelihood and integrated likelihood techniques.

10. During the period February 15, 2000 to August 15, 2000, the LIGO Laboratory will provide, as requested and necessary, LIGO data of relevance to the research topics in Item No. 9 above.

11. The research effort pursuant to this Attachment A will be coordinated by Nelson Christensen and Albert Lazzarini on behalf of CCRG and the LIGO Laboratory, respectively.

12. 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. 9, as indicated below. These resources will be in addition to the coordination effort and data to be made available per Item No. 10 above.

    a) Accommodations for CCRG investigators while on LIGO research assignment at Caltech, and /or LIGO sites.

Approved:

Barry Barish
LIGO Laboratory Director

4/3/00
Date

Nelson Christensen
CCRG Principal Investigator

4-10-00
Date

Albert Lazzarini
LIGO Laboratory Data and Computing Group Leader

29 March 2000
Date