Attachment ACF to the Memorandum of Understanding LIGO-M050292-00 between the Caltech Relativity Group (CaRT) and the Laser Interferometer Gravitational Wave Observatory (LIGO) For The Period August 15, 2008 - August 14, 2009

This Attachment ACF to the Memorandum of Understanding LIGO-M050292-00 defines the role of the Caltech Relativity Group (CaRT) as a Member of the LIGO Scientific Collaboration (LSC), and a member of the Advanced Detector Configurations Development Group (ADCDG). The period of performance for the activities described in this Attachment is from August 15, 2008 - August 14, 2009.

1. Collaboration

The Advanced Detector Configurations Development Group (ADCDG) is the scientific collaboration for defining and developing entirely new advanced interferometers. It is expected that this development group will pursue research in dual recycling, resonant sideband extraction, Sagnac interferometers, systems with non-transmitting optics, and other advanced configurations. MOU Attachment ACF defines the role and responsibilities of workgroups participating in this development group.

2. Participation

During the period August 15, 2008 - August 14, 2009, the members of CaRT will participate in the ADCDG in the following areas:

a. Interferometer Configurations

   (a) Further investigation of the polarization speed meter
   Chen will continue collaboration with McKenzie (JPL) and Whitcomb (Caltech) on investigating the practicality of the polarization speed meter.

b. Squeezed Light Generation

   Chen, in collaboration with AEI and MIT scientists, will finish their manuscript on conditional squeezing in double-optical-spring ponderomotive squeezers.

c. Other Contributions
(a) Macroscopic quantum mechanics with LIGO interferometers
Chen, Li, Mino and Somiya, in collaboration with AEI, MSU and MIT scientists, will continue this project, on the feasibility of performing macroscopic-quantum-mechanics experiments using LIGO interferometers. In particular, they will finish the writing of two manuscripts that describe systematically how one can create and verify Gaussian quantum states, while exploring whether one can create non-Gaussian states using single-photon sources, or using a ponderomotive squeezer. They will continue to explore whether alternatives to standard quantum mechanics could be explored with future LIGO interferometers.

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 CaRT 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

CaRT will perform this research within the structures established by the LIGO Laboratory and the LSC where appropriate.
In particular, activities described in Item 2 will be carried out within the Advanced Detector Configurations Development Group of the LSC.
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.
Attachment DAT to the Memorandum of Understanding LIGO-M050292-00 between the Caltech Relativity Group (CaRT) 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-M050292-00 defines the role of the Caltech Relativity Group (CaRT) 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 CaRT will participate in the analysis of initial LIGO data in the following areas:

a. Binary Inspirals

   (a) Spinning black-hole binary search.

   Fazi, Chen and Vallisneri will collaborate with Brown (SUERG) to complete the development of the PTF (“Physical Template Family” a.k.a. PBCV) search for spinning black-hole binary inspiral signals. Specifically, they will formulate a template placement strategy using the “directed stochastic” techniques developed by Vallisneri and Manca (see item 2 below). They will also examine Fazi’s existing and yet-to-be-produced results to determine how best the PTF search can be used in the CBC pipeline (as a stand-alone search or as a hierarchical follow-up to a non-spinning template bank).
(b) “Directed stochastic” template-placement algorithms.
Vallisneri and Manca will complete a technical article on the use of computational geometry to produce “directed” stochastic template banks modulated by the local density of signals in source-parameter space. They will produce prototype LAL code to create such banks for the signal families currently implemented in LAL.

(c) Nonspinning black-hole binary search in 2nd year of S5 and in S6.
Vallisneri will complete the analysis of one month of S5 data in the context of the search for low-mass inspiral signals, and will participate in the compilation of results for the entire S5 span, in collaboration with many in the CBC group. He will also participate in the development and testing of the CBC search pipeline for use as an online search in S6.

(d) Improvements to intermediate data handling in LAL.
In collaboration with Kipp Cannon (LIGO Lab CIT), Vallisneri will work on improving the handling of XML files in LAL, and specifically of the inspiral and injection tables used by the CBC search pipeline. On the basis of the prior planning of Cannon and Fairhurst (Cardiff), Vallisneri will collaborate in implementing the use of “coinc tables” to represent event coincidences in the pipeline.

(e) Application of Numerical Relativity into LIGO Data Analysis
Ajith will develop LAL/LALApps-based pipelines for injecting 1) phenomenological inspiral+merger+ring down (IMR) waveforms containing higher harmonics from non-spinning binaries and 2) leading harmonics waveforms from spinning binaries with no precession. These phenomenological waveforms will be constructed based on the formalism proposed by Ajith, Chen and collaborators. He and Chen, in collaboration with WSU scientists, will also work on constructing a template bank in LAL/LALApps for the non-spinning phenomenological IMR waveforms.
Boyle will continue his collaboration with Syracuse scientists in using numerical-relativity information to improve efficiency of SPA templates.

(f) Symmetries and degeneracies in parameter estimation.
In collaboration with Ilya Mandel (Northwestern) and Richard O'Shaughnessy (PSU), Vallisneri will investigate the role of physical (quasi)symmetries in complicating the recovery of source parameters from measured gravitational-wave signals. The idea is to develop techniques to identify such global symmetries from the equations of motion, gravitational-wave generation and propagation. Vallisneri plans also to continue investigating the reliability of the Fisher-matrix formalism in predicting parameter-estimation accuracy; following up on his analytic work [Phys. Rev. D 77, 042001 (2008)], he plans numerical studies comparing Fisher-matrix and Markov-Chain Monte Carlo results.

(g) Use of effective-field–theory techniques for inspiral signal computations.
In collaboration with Ira Rothstein (CMU) and Rafael Porto (UCSB), Vallisneri and Manca will investigate the use of results from effective-field–theory computations (as pioneered by Yale’s Goldberger) in increasing the accuracy of the signals used in LSC searches, with a special attention to spinning systems. Where possible and useful, Vallisneri and Manca will implement newly computed terms to the LAL waveform-generation code, and investigate their impact.

(h) Use of FPUs to accelerate search codes.
Linqing Wen is going to work with collaborators at UWA and Caltech LIGO Lab
to develop GPU-accelerated search pipelines that exploit the data-parallelism of graphical processors.

(i) LIGO IMRIs
Cutler plans to study parameter estimation accuracy for LIGO IMRIs for which larger BH is rapidly rotating. He would also like to estimate systematic errors if ones template waveforms are only accurate to lowest nontrivial order in the radiation reaction force.

(j) Parameter Estimation for spinning BH mergers
Cutler will use the MCMC code — currently being developed for LISAs MLDCs — to calculate parameter-estimation accuracy for LIGO mergers as well, for case when both bodies are spinning.

b. Bursts

Linqing Wen is going to (1) work with UWA researchers and student and the Caltech LIGO group to develop GPU-accelerated search pipelines using the data-parallelism of the GPUs, (2) collaborate with Yanbei Chen and other Caltech scientists to further investigate the angular resolutions of a network of GW detectors and its efficiency in identifying electromagnetic counterparts of GW events.

c. Stochastic

. .

d. Continuous

Cutler plans to investigate further how worthwhile it would be to develop a CW search for the most recent SNe, assuming they spin down extremely fast — on timescale of days to months. This would be analogous to searching for GW bursts from close by SNe, except these bursts would be nearly continuous and much longer than the the bursts one normally thinks of. In any given year, the nearest SN might be roughly 10Mpc away. A rough estimate suggested that a reasonable search might be run on Einstein@Home.

e. Other Contributions

Not Applicable

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 CaRT 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.
4. Coordination and Reporting

CaRT 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.
This Attachment OPT to the Memorandum of Understanding LIGO-M050292-00 defines the role of the Caltech Relativity Group (CaRT) as a Member of the LIGO Scientific Collaboration (LSC), and a member of the Optics Development Group (LDG). The period of performance for the activities in this Attachment is from August 15, 2008 - August 14, 2009.

1. Collaboration

The Optics Development Group (ODG) is the scientific collaboration for defining and developing instruments in optics for use in advanced subsystems for the initial LIGO interferometers, or in entirely new advanced interferometers. MOU Attachment OPT defines the roles and responsibilities of groups in this development group.

2. Participation

During the period August 15, 2008 - August 14, 2009, the members of CaRT will participate in ODG in the following areas:

a. Optics Characterization
   
   Not Applicable

b. Other Contributions
   
   (a) Light scattering in the LIGO beam tubes and design of the baffles to control it. Thorne continued to work, but at a low level, on the final revision of his long, and long-delayed, Phys Rev paper with Eanna Flanagan on the theory of light scattering noise in beam tubes and its application to advanced LIGO. It is not yet completed.

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 CaRT 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

CaRT will perform research within the structures established by the LIGO Laboratory and the LSC where appropriate. In particular, activities described in Item 2 will be carried out within the Optics Development Working Group of the LSC.

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.
Attachment OUT to the
Memorandum of Understanding LIGO-M050292-00
between the Caltech Relativity Group (CaRT)
and the
Laser Interferometer Gravitational Wave Observatory (LIGO)

For The Period
August 15, 2008 - August 14, 2009

This Attachment OUT to the Memorandum of Understanding LIGO-M050292-00 defines the role of the Caltech Relativity Group (CaRT) as a Member of the LIGO Scientific Collaboration (LSC) in support of Education and Outreach to the broader community. The period of performance for the activities in this Attachment is from August 15, 2008 - August 14, 2009.

1. Education and Outreach

As a frontier physics effort, LIGO offers a unique opportunity to inspire interest in science among students and to educate the broader community. The LIGO Laboratory supports a broad program of education and outreach to take advantage of these opportunities. Activities to attract and educate visitors take place at both Observatories, as well as the development of educational materials for use there and elsewhere. The LIGO Laboratory is building a Science Education Center at the Livingston Observatory, and is participating with local partners to make it a vehicle for science education throughout the region. LSC groups are invited to participate in these activities, and to suggest others, with the goal of leveraging activities to make a greater impact. This MOU Attachments defines the role and responsibilities of groups in this development group.

2. Participation

During the period August 15, 2008 - August 14, 2009, the members of CaRT will participate in in LDG in the following areas:

a. Educational Materials Developed

   Not Applicable

b. Other Contributions

   (a) Outreach lectures:
   Thorne will give occasional lectures for nonscientists (the general public, undergraduates, minority students, ...) about gravitational-wave science and related issues.
(b) “Interstellar” A science fiction movie based on gravitational physics in which Thorne is co-author of the story and Executive Producer. During the coming year, the screenwriter (Jonah Nolan) is expected to complete the screen play. Thorne will work with Nolan on this to ensure that the science remains accurate and compelling, and will work with Nolan, the Producer (Lynda Obst) and Director (Steven Spielberg) on planning for computer-graphics renderings of gravitational waves, black holes, and other curved-spacetime phenomena.

(c) DVD on the science underlying the movie “Interstellar” Thorne will work with Obst, Spielberg and Nolan on planning and organizing the production of a DVD about the science of Interstellar - to which Spielberg has tentatively agreed.

(d) Visual Media Outreach Program Thorne will continue to work with Vallisneri and Phinney to flesh out their proposed Visual Media Outreach Program (joint Caltech/ USC Film School student media projects; advice to the TV and Movie film makers), and find funding for it.

(e) “Einstein’s Cosmic Messengers” multimedia show Vallisneri will assist composer Andrea Centazzo in completing the multimedia show “Einstein’s Cosmic Messengers” (working title), and in organizing presentations of the show (together with public lectures by LSC scientists) at LSC institutions, and elsewhere. The premiere of the show will be in Oct 2008 at Caltech’s Beckman Auditorium, and is being organized by Vallisneri in collaboration with LIGO Lab CIT.

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 CaRT 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

CaRT will perform research within the structures established by the LIGO Laboratory and the LSC where appropriate. In particular, activities described in Item 2 will be carried out with the LIGO Observatories Educational and Outreach Leaders. 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

Yanbei Chen
Principal Investigator(s)
CaRT

David Reitze
LSC Spokesperson
Attachment Z to the
Memorandum of Understanding LIGO-M050292-00
between the Caltech Relativity Group (CaRT)
and the
Laser Interferometer Gravitational Wave Observatory (LIGO)

For The Period
August 15, 2008 - August 14, 2009

This Attachment Z to the Memorandum of Understanding LIGO-M050292-00 lists the members of Caltech Relativity Group (CaRT) participating in LIGO Scientific Collaboration (LSC) development group activities in support of the initial LIGO interferometers. The period of performance for these activities is from August 15, 2008 - August 14, 2009.

Faculty:

The Faculty category includes all “faculty rank” LSC members. This includes professorial appointments, research faculty appointments, teaching faculty appointments, lecturer and reader appointments, and similar appointments, and visiting appointments in all these categories.

Name: Chen, Yanbei
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Fax: 1 626 796 5675
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Name: Cutler, Curt
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Voice: 1 818 393 3251
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Forwarding: cutler@tapir.caltech.edu
Technical Staff:

The Technical Staff category includes all non-PI LSC members with scientist, engineer, computer systems administrator or programmer, technician, and similar appointments, and visiting appointments in all these categories.

Postdoctoral Scholars:

Name: Mino, Yasushi
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Forwarding: Linqing.Wen@aei.mpg.de

Graduate Students:
Undergraduate Students:

Administrative Staff:

The Administrative Staff category allows the listing of administrative aides and other staff members who perform essential support services in or for LSC member groups, but are not involved in the LIGO Scientific Collaborations engineering or scientific work. Personnel who are involved in the LSC’s scientific or engineering work, including computer system administration and programming, should be listed under other categories. Personnel listed as Administrative Staff may be designated as a point of contact or proxy, but do not appear as authors on LSC publications, do not count toward a group’s council delegate allocation, may not serve as council delegates, and do not increase a group’s shift obligation.

FTE Commitment:

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<th>#</th>
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Total FTE: 2.58

Roles:

Principal Investigators: Chen, Yanbei

Membership Point-Of-Contact: Chen, Yanbei

Group PIO/Press Coordinator: Chen, Yanbei

Proxies:

Author Eligible: Chen, Yanbei, Wen, Linqing

Council Delegates: Chen, Yanbei
Approvals:

Jay Marx
LIGO Laboratory Director

Yanbei Chen
Principal Investigator(s)
CaRT

David Reitze
LSC Spokesperson