Attachment ACF to the Memorandum of Understanding LIGO-M050320-00 between the Northwestern University Gravitational Wave Astrophysics Group (NUGWAG) 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-M050320-00 defines the role of the Northwestern University Gravitational Wave Astrophysics Group (NUGWAG) 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 NUGWAG will participate in the ADCDG in the following areas:

a. Interferometer Configurations

The Experimental Sub Group at NU (ESGNU) is led by Dr. Selim Shahriar and its activities are part of the overall activities of NUGWAG.

1. ESGNU will test the concept of using a White Light Cavity (WLC) to enhance the sensitivity bandwidth product of an interferometric gravitational wave detector. Specifically, ESGNU will set up a table-top prototype of a WLC enhanced Advanced Interferometric Detector (WLC-AID), which will include power and signal recycling. The effect of gravitational waves will be simulated by electro-optic modulators. The prototype will be tested first to establish the baseline for the
sensitivity-bandwidth product. A photorefractive crystal will then be placed inside the signal recycling cavity. A pump beam will be used to activate the two-wave mixing process in the crystal. The resulting modification in the behavior of the signal recycling cavity will then be studied in detail, in order to demonstrate an enhancement in the sensitivity-bandwidth product. This result will be compared with theoretical models that have already been developed by the ESGNU. The system parameters will be optimized to maximize this enhancement.

2. ESGNU will study the noise characteristics of the WLC-AID, through a closely-coupled combination of experimental analysis and theoretical modeling. ESGNU will also initiate work to identify ways to minimize any excess noise resulting from the presence of the active crystal inside the signal recycling cavity.

3. If results of the tabletop prototype are promising, ESGNU will begin, in future years, to explore the idea of a larger-scale, suspended mass prototype, as a potential enhancement to AdvLIGO or future advanced detectors, in close consultation with LSC members.

4. ESGNU will consult with members of the AIC Workgroup (AWG) at every stage of these activities. ESGNU will share all its findings, theoretical as well as experimental, as well as any computer codes, with the AWG. ESGNU will seek advice from AWG regarding the details of the AdLIGO design and operation, and issues that may arise in adding the WLC elements to the full scale AdLIGO device.

5. ESGNU will submit a report on its activities and findings at the end of the period covered under this MOU.

b. Squeezed Light Generation

   Not Applicable

c. 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 NUGWAG 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

NUGWAG 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.

Signature Pending Approval

Jay Marx
LIGO Laboratory Director

Vassiliki Kalogera
Principal Investigator(s)
NUGWAG

David Reitze
LSC Spokesperson
Attachment DAT to the Memorandum of Understanding LIGO-M050320-00 between the Northwestern University Gravitational Wave Astrophysics Group (NUGWAG) 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-M050320-00 defines the role of the Northwestern University Gravitational Wave Astrophysics Group (NUGWAG) 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 NUGWAG will participate in the analysis of initial LIGO data in the following areas:

a. Binary Inspirals
The plan below is formulated taking into account that NUGWAG has NSF support for LSC work for one postdoctoral associate during the coming year. Two postdoctoral associates (Marc van der Sluys and Ilya Mandel) will devote 50% of their time on the projects described below. Graduate student (Vivien Raymond) will also devote all of his research time (beyond courses and qualifying exams) to LSC work. Kalogera devotes 50% of her research time to LSC work. The total estimated number of FTEs working contributing to the plan below is: 1.7 FTE (0.5 FTE for each van der Sluys, Mandel, Raymond, and 0.2 FTE for Kalogera).

All projects described below are developed in coordination with the CBC group members and any resulting papers will be submitted to the LSC P&P committee for review.

(i) Parameter Estimation

Van der Sluys with Raymond, Mandel, Kalogera: We will continue our MCMC work on parameter estimation for spinning binary inspirals; this work directly addresses near/intermediate-term goals of the CBC group. We will focus on further improving the MCMC implementation and current code to include: (a) a comparison of the Fisher matrix with the correlation matrix and with the PDFs produced by the MCMC; (b) a jump proposal distribution with coherent jumps between parameters corresponding to high-likelihood islands in the parameter space to improve the efficiency of sampling when near-degeneracies are present; (c) non-Markovian techniques for rapidly finding the local maximum likelihood peaks in order to quickly determine the maximum-likelihood parameters or to probe the structure of the parameter space (including near-degeneracies).

Raymond with van der Sluys, Mandel, Kalogera: During this code development we will continue testing the code on simulated data, but we will further expand our tests on S5 data, in preparation for S6. Raymond will take the lead within NUGWAG and in collaboration with other CBC members will work on porting the fully developed MCMC code into the analysis pipeline.

(ii) Astrophysical Rate Constraints

Mandel and Kalogera will develop a framework for gaining astrophysical information from LIGO upper limits on CBC events. Specifically, we will use upper limits from LIGO searches as additional constraints on the population synthesis models (e.g., O'Shaughnessy et al. 2008) to determine revised event rate estimates and to constrain the space of population-synthesis model parameters. We intend to standardize this procedure, so that any new upper limits or detections in the future can be rapidly translated into revised event rates and astrophysical model parameters.

(iii) Galaxy normalization for rate upper limits

Mandel and Kalogera will build on the rates work completed by O'Shaughnessy (now at PSU) and collaborators to develop a new normalization scheme for the derivation of upper limits and assessment of selection effects that takes into account the presence of elliptical galaxies and their contribution to CBC rates (this is a near-term goal relevant to all CBC analyses that reach beyond the Local Group of galaxies).
(iv) Astrophysical Rates
Mandel and Kalogera will continue their work on the CBC Rates document currently available to the LSC for rate quotes in presentations, funding proposals, publications. They will keep the document up-to-date to reflect the most recent results quoted in the literature.

Committees: Kalogera will continue serving on the CBC Review Committee.
b. Bursts
   *Not Applicable*

c. Stochastic
   *Not Applicable*

d. Continuous
   *Not Applicable*

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 NUGWAG 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

NUGWAG 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.

Signature Pending Approval

Jay Marx
LIGO Laboratory Director

Vassiliki Kalogera
Principal Investigator(s)
NUGWAG

David Reitze
LSC Spokesperson
Attachment OUT to the Memorandum of Understanding LIGO-M050320-00 between the Northwestern University Gravitational Wave Astrophysics Group (NUGWAG) 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-M050320-00 defines the role of the Northwestern University Gravitational Wave Astrophysics Group (NUGWAG) 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 NUGWAG will participate in in LDG in the following areas:

a. Educational Materials Developed

   Not Applicable

b. Other Contributions

   The PI will work in close coordination with the LSC Education and Public Outreach Committee on the following activities:
1. Kalogera will work towards strengthening the connections and interactions between the LSC and the astronomy and astrophysics community whenever opportunities arise. She will serve on the P&P committee with a particular focus on: identifying astronomy conferences where talks related to LIGO could be presented and advertising them to the LSC, suggesting LSC speakers for invited and contributed talks at astronomy conferences, and thinking about best strategies for LSC participation in astronomy conferences.

2. Kalogera will work towards bringing LSC outreach activities and developed exhibits to the Adler Planetarium and Astronomy Museum in the city of Chicago.

3. NUGWAG members will volunteer as presenters at the Space Visualization Lab of the Adler Planetarium and Astronomy Museum presenting LIGO-related material to the public.

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 NUGWAG 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

NUGWAG 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.

Signature Pending Approval

Jay Marx
LIGO Laboratory Director

Vassiliki Kalogera
Principal Investigator(s)
NUGWAG

David Reitze
LSC Spokesperson
Attachment Z to the Memorandum of Understanding LIGO-M050320-00 between the Northwestern University Gravitational Wave Astrophysics Group (NUGWAG) 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-M050320-00 lists the members of Northwestern University Gravitational Wave Astrophysics Group (NUGWAG) 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.

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Fax: 1 847 467 5319
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**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.

<table>
<thead>
<tr>
<th>Name</th>
<th>Postal Address</th>
<th>Phone</th>
</tr>
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<tbody>
<tr>
<td>Belczynski, Krzysztof</td>
<td>Department of Astronomy 1320 Frenger Mall</td>
<td>1 505 646 1699</td>
</tr>
<tr>
<td></td>
<td>New Mexico State University</td>
<td></td>
</tr>
<tr>
<td></td>
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<tr>
<td>Mandel, Ilya</td>
<td>2131 tech drive</td>
<td>1 847 467 1338</td>
</tr>
<tr>
<td></td>
<td>dearborn observatory</td>
<td></td>
</tr>
<tr>
<td></td>
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<tr>
<td>van der Sluys, Marc</td>
<td>Northwestern University</td>
<td>1 847 467 3017</td>
</tr>
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</table>

**Postdoctoral Scholars:**

Name: Belczynski, Krzysztof  
Phone: 
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Undergraduate Students:

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State: 
Postal Code: 60201
Country: USA

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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FTE Commitment:

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<td>faculty</td>
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<td>9</td>
<td>van der Sluys, Marc</td>
<td>postdoc</td>
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</table>

Total FTE: 5.40

Roles:
Principal Investigators: Kalogera, Vassiliki
Membership Point-Of-Contact: Kalogera, Vassiliki
Group PIO/Press Coordinator: Kalogera, Vassiliki
Proxies:
Author Eligible
Kalogera, Vassiliki
Mandel, Ilya
van der Sluys, Marc
Raymond, Vivien

Approvals:
Signature Pending Approval

Jay Marx
LIGO Laboratory Director

Vassiliki Kalogera
Principal Investigator(s)
NUGWAG

David Reitze
LSC Spokesperson