

Memorandum of Understanding (LIGO- M050270-00-M)
between the
Pennsylvania State University Relativity Group (PSURG)
and the
Laser Interferometer Gravitational Wave Observatory (LIGO)
August 15, 2005

The purpose of this Memorandum of Understanding (MOU) is to establish and define a collaborative relationship between the Pennsylvania State University Relativity Group (PSURG) and the Laser Interferometer Gravitational-Wave Observatory (LIGO). Both parties to this agreement share the broad goals of developing the instruments and techniques for detecting and studying gravitational waves, and subsequently using them as an astrophysical probe. Under this MOU, the PSURG Group will be a member group of the LIGO Scientific Collaboration.

1. The Pennsylvania State University Relativity Group (PSURG) consists of Professor Lee Samuel Finn, who will serve as Principal Investigator for research in the LIGO Science Collaboration, Professor Benjamin Owen, several postdoctoral scholars and research associates, several graduate students, several undergraduate students, several programming and system administration staff supporting the PSU LIGO Tier 2 Computing Center (Pleiades), and other faculty who may become involved from time to time. The principal focus of the work done by PSURG under this agreement will be on data analysis, detector characterization and commissioning, and support of LIGO Scientific Collaboration computing activities at the PSU LIGO Tier 2 Computing Center.
2. LIGO comprises two parts: the LIGO Laboratory and the LIGO Scientific Collaboration. These two entities report to the LIGO Directorate, consisting of the LIGO Director, the LIGO Scientific Collaboration Spokesperson, and the LIGO Laboratory Deputy Director. The design and construction of the LIGO Observatories were carried out by California Institute of Technology (Caltech) and the Massachusetts Institute of Technology (MIT) under a Cooperative Agreement between the National Science Foundation (NSF) and Caltech. The LIGO Oversight Committee supervises the realization of LIGO.
 - A. The LIGO Laboratory is responsible for the operation of the LIGO Observatories, the development and implementation of future detector systems, and participates in all aspects of the research with the LIGO detectors. LIGO is a system of three interferometric Fabry-Perot antennas,

two of them 4 kilometers long and the third one 2 kilometers long, aimed at the simultaneous detection of gravitational waves in the frequency range 40-6000 Hz. LIGO Observatories are located in Hanford, Washington and in Livingston Parish, Louisiana (USA) and began observations in the year 2002. The LIGO Laboratory is funded through a Cooperative Agreement between the National Science Foundation and Caltech, with the portion of the LIGO Laboratory at MIT funded through a subcontract from Caltech.

- B. The LIGO Scientific Collaboration (LSC) is organized as a separate entity from the LIGO Laboratory. It includes scientists from the LIGO Laboratory, and those from collaborating institutions, and has its own governance and leadership (which includes the LSC Spokesperson as a member of the LIGO Directorate). The Collaboration ensures equal scientific opportunity for individual participants and institutions. It organizes the research, publications, and all other scientific activities. The Collaboration reports to the LIGO 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 reports to the Directorate and its Program Advisory Committee. The organization of the LSC and its governance are defined in its Charter.
3. As a member group of the LSC, the PSURG Group will participate in the governance of the LSC and in setting its policies and procedures, as defined in the LSC charter. Similarly, it agrees to abide by the policies and procedures adopted by the LSC and posted on its website (<http://www.ligo.org/policies.html>), concerning publication, data access, software standards, and so on.
 4. Membership in more than one collaboration active in the same area of research may present complications. Members of the LSC contemplating joining other gravitational wave collaborations or participating in data analysis efforts with collaborations outside a framework established by the LSC should inform and consult with LSC and the LIGO Laboratory to ensure that no conflicts of interest exist.
 5. The LSC is the primary advocate of interferometric gravitational wave research in the U.S. To function effectively in this role, it needs to be informed in advance about major new initiatives. The PSURG Group agrees to inform the LSC of any major new proposals related to LIGO to be submitted to the NSF, and to consult with the LSC concerning the best approach to support the overall LIGO program. The final decision about the scope of any such proposal shall remain the prerogative of the ABC Group.
 6. LSC Service Functions - Participation in the LSC brings with it responsibility for service functions to support the overall effort in achieving high detector sensitivity and high data quality. In particular, each LSC group is expected to assist in the staffing of scientific monitoring shifts during organized data runs. The staffing of these shifts is notable for both its importance and the travel burden it places on

scientists. This burden makes an equitable shift allocation mechanism necessary.

A nominal guideline is that each LSC group should staff a fraction of the shifts comparable to its FTE fraction devoted to LSC activities. Benjamin J. Owen (PSURG Group) will be responsible for interaction with the designated LSC Shift Organizer with respect to the PSURG Group's Service Function commitments.

Groups making extensive contributions to the LSC in other service efforts that involve a substantial travel burden may request a reduction in their nominal share of shift staffing. Those efforts can include:

- Commissioning and instrument improvement
 - Participation in on-site detector characterization investigations
 - Development/operation of analysis software/hardware infrastructure and validation of analysis software that requires travel away from the home institution.
7. Each party to this agreement continues to be responsible for all support of its staff including travel costs associated with the activities under this agreement. Exceptional support of travel by the other institution may be allowed for travel requested by that institution.
 8. Attachments to this MOU will be prepared annually to define the specific activities and responsibilities of the PSURG Group and to define any resources to be provided by the LIGO Laboratory to the PSURG Group in support of those activities.
 9. PSURG Group will provide an annual status report on its activities in support of LIGO. The report will consist of a summary status on research by topic as indicated in the Attachments for that period 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 by each member of the group. The report will be due one month before the close of the period of performance under the Attachments in question.
 10. The LSC will review the progress report against the Attachments from the previous year and assess the Attachments for the up-coming year annually, under its established procedure, and recommend acceptance or rejection of each Attachment by the LIGO Director and the LSC Spokesperson.
 11. A list of PSURG Group members will be updated at least every six months. PSURG Group members and appropriate contact information will be provided in electronic form as Attachment Z to this Memorandum of Understanding. In cases where individuals who leave the group have had access to LIGO data and this access should be terminated, the PSURG Group Principal Investigator is responsible for timely notification to the Directorate and to the computing committee so access may be revoked.
 12. The LIGO Laboratory is responsible for obtaining NSF approval of collaborative

Memoranda of Understanding where required. All Memoranda of Understanding will be provided to NSF for their information.

13. The rights to intellectual property developed under this Attachment using LIGO Laboratory resources will be subject to the National Science Foundation Grant Policy as indicated in Section 730, Intellectual Property.
 - A. In the event a patentable invention is conceived or first actually reduced to practice during the work of a member(s) of the PSURG Group at LIGO Laboratory facilities, he/she will:
 - i) make prompt disclosure of the invention to the Director of the LIGO Laboratory; and
 - ii) cooperate with LIGO Laboratory and supply all information and execute all papers including invention reports, records of invention, patent applications and powers of attorney, necessary and proper to fulfill the obligations of the LIGO Laboratory to the U.S. Government sponsor.
 - B. The ownership of inventions conceived solely by members of the PSURG Group at LIGO facilities shall be owned by the Pennsylvania State University, although the LIGO Laboratory shall be granted a license to use such invention for noncommercial research purposes at LIGO facilities. Inventions that are conceived by both members of the PSURG Group and LIGO Laboratory staff as part of the LIGO project shall be jointly owned and any income from commercial licensing shall be shared in proportion to the number of joint inventors from each institution.

In all other regards, the rights to intellectual property developed by members of the PSURG Group under this Attachment will be in accordance with the policies of Pennsylvania State University.

14. This MOU supersedes the previous MOU between the LIGO Laboratory and the PSURG group (LIGO- M970058-00) and its amendments and attachments. This MOU will remain in force until the parties mutually agree to terminate it, or until it is terminated in accordance with LSC procedures.

Approved:

Barry Barish
LIGO Director

Lee Samuel Finn
Principal Investigator
PSURG Group

Peter Saulson
LSC Spokesperson

Attachment DAT to the
Memorandum of Understanding (LIGO- M050270-00-M)
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August 15, 2005

This Attachment DAT to the Memorandum of Understanding LIGO-M050270-00-M defines the role of the Pennsylvania State University Relativity Group (PSURG) 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 PSURG Group will participate in the analysis of initial LIGO data in the following areas:

a) Burst sources

1. Block-Normal implementation: Finn, Desai, McNabb, Stuver, Summerscales and Thorne will analyze S5 data using the Block-Normal pipeline and a distributional analysis for burst events. They will complete the analysis of S4 data using the Block-Normal pipeline to derive Bayesian upper limits. They will provide technical documentation of the S4 and S5 analyses for reviewers.
2. Block-Normal methods paper: Finn, Desai, McNabb, Stuver, Summerscales, and Thorne will complete the manuscript describing the statistical underpinnings of the Block-Normal changepoint analysis and submit it for publication.
3. Near-realtime analysis: Finn, Desai, McNabb, Stuver, Summerscales and Thorne will run their existing Block-Normal pipeline in near-realtime on S5 data, which will provide initial results for the S5 Block-Normal analysis.
4. Summerscales Dissertation: Summerscales will continue on her main Ph.D. dissertation project. For this project she will continue working with the supernova simulations group headed by Adam Burrows at the University of Arizona. She will insert

supernova waveforms into LIGO noise and will determine how well the method of maximum entropy is able to reconstruct signals from the data for various signal strengths. This will indicate which parts of the core-collapse evolution LIGO will be able to detect and give information on.

5. Stuver Dissertation: Stuver will continue her Ph.D. thesis research by undertaking a comparative study of the performance of burst event trigger generators (ETG's) on simulated signals of different types with the goal of determining the strengths of each type of trigger generator, the degree of (in)dependence of the triggers generated by each, and whether ETGs are more sensitive to time-domain or frequency-domain features of signals.

6. MATLAB simulation engine: Stuver will continue to maintain the MATLAB based GravEn simulation engine which can simulate all sky sources with both polarizations and projected onto specific detector antenna patterns and coincidence between detectors. Stuver will also add functionality to GravEn to convert GPS time to local sidereal time to allow the sky to move properly over the detectors and maintain the project web page.

7. BurstMDC package: Thorne and Stuver will complete the grid-based BurstMDC software package for accelerated production of Mock Data Challenge (MDC) burst simulations for the S4 and S5 burst analyses. This will include technical documentation and ongoing support to the Burst Group.

8. External-trigger burst analysis: Finn and Thorne will work on a Block Normal-based analysis of LIGO data for long-duration (1 second) bursts to extend the parameter space coverage of the externally-triggered LIGO burst data analysis.

9. Interaction with SWIFT: Thorne will provide liaison between LIGO and the SWIFT gamma-ray burst telescope team regarding joint data analysis efforts. This will take advantage of the location of the SWIFT Mission Operations Center at Penn State.

10. Astrophysical Interpretation: Finn and McNabb will develop general methods for interpreting burst analysis results in an astrophysical context. This work will be documented in a set of technical reports and, where appropriate, publications.

11. Waveform recovery: Finn, Summerscales, and other students and postdocs, will implement a maximum entropy based module for examining coincident burst events and identifying whether there is a common, underlying waveform that is responsible for them.

b) Inspiral sources

1. Template bank for precessing binaries: Owen and Yunes will finish debugging the parameter space metric code for arbitrary modulation strength and insert it into LAL. The current LAL code, which uses the strong modulation approximation, will be upgraded to use the new metric. The draft manuscript on the calculation of the metric will be finished and submitted for publication, including an explanation of the strong modulation approximation used in the existing code.

c) Periodic sources

1. Astrophysical guidance for searches: Owen, with Ian Jones (GEO600 MoU), will continue to inform the PULgroup's decisions on parameter limits for S4 and S5 searches. For instance, the minimum spindown age of an all-sky search can be dramatically lengthened (and the computational cost reduced) by taking into account the distribution in age and space of nearby supernova remnants, and the frequency range of such a search is influenced by the maximum ellipticity of a neutron star.

2. Einstein@Home: Owen, with the AEI group (GEO600 MoU), will update the calculations and code for dividing the parameter space of future searches into manageable work units as needed for upcoming searches.

Ramsunder will work with the UWM group to continue PSU's support an [Einstein@Home](#) mirror.

3. N-dimensional template banks: Owen, with Ian Jones and the AEI group (GEO600 MoU), will provide flexible algorithms and code for producing templates in more than two dimensions as will be needed for upcoming searches for periodic sources. This will be based on Owen's group's 3-dimensional LAL code for precessing binary template banks.

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 PSURG 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 – PSURG 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 Burst Search Group, Item 2b) will be carried out within the LSC Inspiral Search Group, and Item 2c) will be carried out within the LSC Pulsar 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:

Barry Barish
LIGO Laboratory Director

Lee Samuel Finn
PSURG Principal Investigator

Peter Saulson
LSC Spokesperson

Erik Katsavounidis
LSC Burst Search Group Leader

Albert Lazzarini
LIGO Laboratory Data and Computing
Group Leader

Patrick Brady
LSC Inspiral Search Group Leader

Mike Landry
LSC Pulsar Search Group Leader

Attachment OPS to the
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August 15, 2005

This Attachment OPS to the Memorandum of Understanding LIGO-M050270-00-M defines the role of the Pennsylvania State University Relativity Group (PSURG) as a Member of the LIGO Scientific Collaboration (LSC) in the areas of detector commissioning, detector characterization, and operations 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 (LSC) are responsible for implementing and exploiting the initial LIGO detector through its science data runs. LSC groups are encouraged to contribute to the commissioning, characterization, and operation of the LIGO detectors, as members of working groups established by the LIGO Laboratory and the LSC.
2. During the period August 15, 2005 to August 15, 2006, the members of PSURG Group will participate in the initial LIGO detector research program in the following areas:

a) Detector characterization

1. Spectral Line Cataloguing: Thorne will lead the Spectral Line Catalogue sub-group. This sub-group is tasked with providing updated catalogues of the spectral line features in S4 and subsequent data. This work will assist with line source identification and potential amelioration.
2. S5 Line-Finding Analysis: Finn, Desai and Thorne will use the near-realtime analysis pipeline for automated daily reporting of spectral line features during the S5 run.
3. S5 stationarity: Finn and Desai will use lineamp, medNoiseChar, and other tools to identify epochs where the S5 noise and calibration can be considered to be approximately stationary. Results will be documented in a technical document and posted on the web on a daily basis for use by the collaboration.
4. S5 Vetoes: Finn and Desai will identify potential channels in S5 to be used for vetoes, and tune their parameters for greatest veto effectiveness. They will also provide daily summaries of results of Block-Normal processing on various auxiliary channels.

5. Test for non-gaussianity: Summerscales will apply the Poisson test for detecting data segments with nonzero higher order moments caused by nonlinear correlations to recent science runs.

6. Detector investigations: Rakhmanov, who will be sited at LHO, will assist the PSU group and the LHO staff in diagnosing detector artifacts discovered through the analysis of detector data, and will recommend data diagnostics, to be implemented by PSURG, based on knowledge of the detector and its operation.

b) Computing infrastructure

1. Virtual Organization Administration: Ramsunder, assisted by Holmes, McNabb and Nucciarone, will administer and support the LIGO virtual organization within the OSG. This support will include maintaining the LIGO VOMS server, the LIGO computing account applications page, and the support center for outside OSG users.
 2. MATLAB based data analysis: Thorne, Finn, and McNabb will support MatApps.
 3. Einstein@Home: Ramsunder will with the Einstein@Home project to continue PSU's support of an Einstein@Home mirror at PSU.
 4. Grid infrastructure: Rakhmanov will work with Zweizig to support the DMT in the OSG environment.
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 PSURG 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 – PSURG 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 in coordination with the Detector Characterization Working Group, and Item 2b) will be carried out in coordination with the Data Analysis Software Working Group of the LSC. 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:

Barry Barish
LIGO Laboratory Director

Lee Samuel Finn
PSURG Principal Investigator

Peter Saulson
LSC Spokesperson

Keith Riles
LSC Detector Characterization Leader

Patrick Brady
LSC Data Analysis Software Leader

**Attachment Z to the
Memorandum of Understanding (LIGO- M050270-00-M)
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August 15, 2005**

This Attachment to the Memorandum of Understanding LIGO-M050270-00-M lists the coordinates of the members of the PSURG who will participate in the LIGO Scientific Collaboration (LSC) as members of LIGO Development Groups. The period of performance for the activities in this Attachment is from August 15, 2005 to August 15, 2006. This period may be modified by agreement to a revision of this Attachment. Scientific Collaboration Council Delegates: Lee Samuel Finn and Benjamin Owen.

Name	Address	E-Mail	Phone Nos.	Begin Date	End Date
Finn, Lee Samuel 100% LIGO I 90% AdLIGO 10% Faculty	Center for Gravitational Wave Physics, Pennsylvania State University, 104 Davey Laboratory, PMB 145, PA 16802	LSFinn@PSU.Edu	814-863-9598 Fax: 814-863-9608	Aug. 15, 2005	Aug. 15, 2006
Owen, Benjamin 50% LIGO I 50% AdLIGO 0% Faculty	Center for Gravitational Physics and Geometry, Pennsylvania State University, 104 Davey Laboratory, PMB 147, PA 16802	owen@gravity.psu.edu	814-863-9597 Fax: 814-863-9608	Aug. 15, 2005	Aug. 15, 2006
Desai, Shantanu 100% LIGO I 100% AdLIGO 0% Postdoc	Center for Gravitational Wave Physics, Pennsylvania State University, 104 Davey Laboratory, PMB 16, PA 16802	shantanu@gravity.psu.edu	814-863-6775 Fax: 814-863-9608	Aug. 15, 2005	Aug. 15, 2006
McNabb, John 100% LIGO I 100% AdLIGO 0% Postdoc	Center for Gravitational Wave Physics, Pennsylvania State University, 104 Davey Laboratory, PMB 39, PA 16802	mcnabb@gravity.psu.edu	814-863-9596 Fax: 814-863-9608	Aug. 15, 2005	Aug. 15, 2006
Thorne, Keith 100% LIGO I 100% AdLIGO 0% Postdoc	Center for Gravitational Wave Physics, Pennsylvania State University, 104 Davey Laboratory, PMB 74, PA 16802	thorne@gravity.psu.edu	814-863-9596 Fax: 814-863-9608	Aug. 15, 2005	Aug. 15, 2006
Rakhmanov, Malik 100% LIGO I 100% AdLIGO 0% Postdoc	LIGO Hanford Observatory	malik@gravity.psu.edu	814-863-6773 Fax: 814-863-9608	Aug. 15, 2005	Aug. 15, 2006
Stuver, Amber 100% LIGO I 100% AdLIGO 0% %	Center for Gravitational Wave Physics, Pennsylvania State University, 104 Davey Laboratory, PMB 175, PA 16802	stuver@psu.edu	814-865-3719 Fax: 814-863-9608	Aug. 15, 2005	Aug. 15, 2006
Grad. Student Summerscales, Tiffany 100% LIGO I 100% AdLIGO 0% Grad. Student	Center for Gravitational Wave Physics, Pennsylvania State University, 104 Davey Laboratory, PMB 233, PA 16802	tzk101@psu.edu	814-865-3719 Fax: 814-863-9608	Aug. 15, 2005	Aug. 15, 2006
Yunes, Nicolas 50% LIGO I 50% AdLIGO 0% Grad. student	Center for Gravitational Physics and Geometry, Pennsylvania State University, 104 Davey Laboratory, PA 16802	yunes@gravity.psu.edu	814-865-7976 Fax: 814-863-9608	Aug. 15, 2005	Aug. 15, 2006
Lin, Tina 100% LIGO I 100% AdLIGO 0% Undergrad	Center for Gravitational Wave Physics, 104 Davey Laboratory, University Park PA 16802	Tul111@PSU.Edu	814-863-9605 Fax: 814-863-9608	Aug. 15, 2005	Aug. 15, 2006
Argawala, Vijay 10% LIGO I 10% AdLIGO 0% Staff	229K Computer Building, University Park, PA 16802	v2a@psu.edu	814-865-2162 Fax: 814-863-7049	Aug. 15, 2005	Aug. 15, 2006

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Aug. 15,
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Jeff 20% LIGO I 20% AdLIGO 0%	214F Computer Building, University Park, PA 16802	nucci@psu.edu	814-865-5333 Fax: 814-863- 7049	Aug. 15, 2005	Aug. 15, 2006
Staff Ramsunder, Murali					
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Staff					

Barry Barish
LIGO Laboratory Director

Lee Samuel Finn
PSURG Principal Investigator

Peter Saulson
LSC Spokesperson