Attachment OPS to the

Memorandum of Understanding (LIGO-M 050315 -00-M)

between the

Hobart and William Smith LIGO Group (HWSLG)

and the

Laser Interferometer Gravitational Wave Observatory (LIGO)

August 15, 2006

This Attachment OPS to the Memorandum of Understanding LIGO-M 050315 -00-M defines the role of the Hobart and William Smith LIGO Group as a Member of the LIGO Scientific Collaboration (LSC) in the areas of detector commissioning, detector characterization, and operations support in the initial LIGO interferometers. The period of performance for the activities in this Attachment is from August 15, 2006 to August 15, 2007.

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 Laboratroy and the LSC.

2. During the period August 15, 2006 to August 15, 2007, the members of HWSLG will participate in the initial LIGO detector research program in the following areas:

b) Detector Characterization

The HWSLG PI has written two DMT monitors, BicoViewer and BicoMon, that are used to detect bilinear processes, which includes upconversion noise, frequency noise, and phase noise. BicoViewer is a stand-alone, GUI-based, interactive monitor that lets the user look for bicoherence between data channels as evidence of a bilinear process. BicoMon performs the same calculation, but the calculation is performed in background on a set channel list. This activity is coordinated within the upconversion detector characterization subgroup. As the IFO sensitivity has reached a level where upconversion noise is being observed, these monitor should be used in diagnosing these noise sources.

The HWSLG will continue the maintenance and continued upgrade of these monitors. We have been able to performs two minor upgrades in the past year and expect that rate going forward. Given the long list of recommended new features, the HWSLG would welcome assistance from other members of the LSC interested in developing, testing, and using these monitors.

Recently the University of Maryland group has contacted us with interest in using bicoherence to look for gravity wave signals. Both inspiral and burst source should produce strong bicoherence signals. They have also expressed interest in getting involved in using bicoherence for detector characterization. I have begun discussions with them and hope to recruit them to the effort.

As the thermal noise problems for Advanced LIGO and Intermediate LIGO reach resolution, I would like to devote half of my research time to detector characterization. However, given the deadlines for the thermal noise research, I don't expect that I will be able to reallocate my time during the next year.

c) Detector Operations

The HWSLG is pleased to continue to serve its share of science monitor shifts and any other proportioned obligations necessary to keep the detector operating well. During S5 that obligation is in the form of SciMon shifts. However after S5, during the likely upgrade to Intermediate LIGO, we expect that obligation will be in the form of assisting in the installation and commissioning work for the upgrade.

d) 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 **HWSLG** 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.

c) Not Applicable

4. Coordination and Reporting -

HWSLG 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 LIGO Laboratory Commissioning Leader, Item 2b) will be carried out within the Detector Characterization Working Group of the LSC, and Item 2c) will be carried out in coordination with the LHO {or LLO} Site Head. 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

Steven Penn
Principal Investigator
Hobart and William Smith LIGO Group

Peter Saulson
LSC Spokesperson

Attachment OPT to the

Memorandum of Understanding (LIGO-M 040074 -00-M)

between the

Hobart and William Smith LIGO Group (HWSLG)

and the

Laser Interferometer Gravitational Wave Observatory (LIGO)

August 15, 2006

This Attachment OPT to the Memorandum of Understanding LIGO-M 040074 -00-M defines the role of the Hobart and William Smith LIGO Group as a Member of the LIGO Scientific Collaboration (LSC) and a member of the Optics Development Group (ODG). The period of performance for the activities in this Attachment is from August 15, 2006 to August 15, 2007.

1. Optics Development Group - 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 Attachments define the roles and responsibilities of groups in this development group.

2. During the period August 15, 2006 to August 15, 2007, the members of HWSLG will participate in ODG in the following areas:

a) Optics Characterization

The HWSLG is involved in a series of experiments to determine the optimal annealing cycle for Advanced LIGO optics. The goal of these experiments is to anneal each optics so that its mechanical loss is on or near the mimimum loss surface (as described in Penn et al., http://arxiv.org/abs/gr-qc/0507097) but not to alter the optical characteristics in the process. These experiments will be performed on a set of optics that are logarithmically-spaced in size between previously measured small optics and Advanced LIGO optics. Both the mechanical loss and the cooling rate of the annealing process will depend on the size of the optic. The set of optics were ordered last summer from Heraeus. They have now arrived at Caltech where they are being characterized. At HWS the vacuum chamber has been fitted with a single wire loop suspension and the vacuum annealing oven has been upgraded with a turbo pump and a residual gas analyzer. We expect delivery of the optics from Caltech at any time. These measurements will require 1–1.5 years depending on the number of annealing cycles required to optimize the process. Each annealing cycle can require two weeks or more for large optics.

The HWSLG is continuing its efforts to determine the minimal mechanical loss in fused silica. Previously we had developed a model of the loss that depended on frequency and on the volume-to-surface ratio. However that model lacked measurements in the region of low frequency and large V/S, the regime in which Advanced LIGO optics reside. We seek to directly measure the the loss in this region by measuring the loss in a large cantilever rod. In March 2005, we ordered this cantilever sample from Heraeus. One year later the sample arrived. But the surface was damaged and not prepared as requested. In addition there was no confirmation that the sample was annealed as specified. We are now in the process of having the sample replaced and reannealed. I suspect that this process will require a few months. Everything that Heraeus does requires a few months. Our hope is that this sample will fill in the gap in data in our model and confirm the low loss that we expect for Advanced LIGO optics.

b) 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 **HWSLG** 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.

c) LIGO will provide and optically characterize the set of optics that will be used in the annealing experiment. These optics have already been purchased and are in the process of being characterized.

4. Coordination and Reporting -

HWSLG 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 Optics Development 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:

Jay Marx
LIGO Laboratory Director

Steven Penn
Principal Investigator
Hobart and William Smith LIGO Group

Peter Saulson
LSC Spokesperson

Attachment OUT to the

Memorandum of Understanding (LIGO-M 050315 -00-M)

between the

Hobart and William Smith LIGO Group (HWSLG)

and the

Laser Interferometer Gravitational Wave Observatory (LIGO)

August 15, 2006

This Attachment OUT to the Memorandum of Understanding LIGO-M 050315 -00-M defines the role of the Hobart and William Smith LIGO Group as a Member of the LIGO Scientific Collaboration (LSC) in support of Educational and Outreach to the broader community. The period of performance for the activities in this Attachment is from August 15, 2006 to August 15, 2007.

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. MOU Attachments define the roles and responsibilities of groups in this development group.

2. During the period August 15, 2006 to August 15, 2007, the members of HWSLG will participate in Education and Outreach in the following areas:

b) Other Contributions

HWSLG has a continuing relationship with Geneva High School (Geneva, NY) in support of its class "AP Physics C and LIGO" taught by Mr. Greg Baker. This class uses LIGO as an example in teaching many of the concept needed for the AP Physics C exam. A recent update to this program has been the donation of two small teaching interferometers to Mr. Baker's classroom. We have also equipt two data analysis computers for the students to use in detector characterization research. This student research will be supervised by Mr. Baker and the HWSLG PI. This student research, which was originally scheduled to begin in Fall 2005, was delayed until Fall 2006 because of changes in the schedule of Mr. Baker and the HWSLG PI. Mr. Baker was required to assume additional administrative duties at the high school which was a significant time constrint. In addition, the HWSLG PI was on research leave for the 2005-06 academic year. Thus it was decided to delay this work by one year.

The HWSLG PI is on the executive committee of the APS Topical Group on Gravity and through this group advocates for public outreach efforts. The TGG's main outreach effort is its speaker bureau which matches gravity researchers with institutions requesting speakers.

Finally, the PI gives 1-2 public talks on LIGO each year .

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 **HWSLG** 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.

c) Not Applicable

4. Coordination and Reporting -

HWSLG 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 with the LIGO Observatories Educational and Outreach Leaders. 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

Steven Penn
Principal Investigator
Hobart and William Smith LIGO Group

Peter Saulson
LSC Spokesperson

Attachment SUS to the

Memorandum of Understanding (LIGO-M 050315 -00-M)

between the

Hobart and William Smith LIGO Group (HWSLG)

and the

Laser Interferometer Gravitational Wave Observatory (LIGO)

August 15, 2006

This Attachment OUT to the Memorandum of Understanding LIGO-M 050315 -00-M defines the role of the Hobart and William Smith LIGO Group as a Member of the LIGO Scientific Collaboration (LSC) and a member of the Isolation/ Suspension/Thermal Noise Development Group (ISTNDG). The period of performance for the activities in this Attachment is from August 15, 2006 to August 15, 2007.

1. Isolation/Suspension/Thermal Noise Development Group - The Isolation/Suspension/Thermal Noise Development Group (ISTNDG) 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 Attachments define the roles and responsibilities of groups in this development group.

2. During the period August 15, 2006 to August 15, 2007, the members of HWSLG will participate in ISTNDG in the following areas:

a) Coating Losses

The HWSLG plans to continue its longstanding role in the Coating Program. Our facility acts as a second test facility, along with MIT, for thin coating samples and is the primary lab for testing the effects of annealing on coating loss. We work in close coordination with the MIT Coating group.

The Coating Program is very important to the success of Advanced LIGO since it is the coating thermal noise that is the limiting noise source in the minimum of the Advanced LIGO noise curve. The goal of our research is to develop a coating in which the thermal noise will be less than the quantum noise from the laser. The intial goal of the Coating Program was to understand the source of the noise in the current LIGO coatings. We discovered that the loss was primarily in the high index, tantala layers rather than the low index, silica layers (see Penn, et al., Classical and Quantum Gravity 20 (2003) 2917-2928). While the proportion of loss ascribed to those two materials has changed slightly due to the direct measurement of the Young's modulus by Sheila Rowan, the essential conclusion stands. Thus our research has focused on finding a high index coating material with low mechanical loss. We have explored using other high index dielectrics instead of tantala, and doping the tantala in order to lower its loss. At present the best candidate coating is tantala doped with titanium.

Our work with CSIRO has shown that we can reduce the mechanical loss in titania coatings by doping them with silica. The new coating is stable, but does not have lower thermal noise since the process also lowers the refractive index requiring thicker coatings. This result suggests that we might be able to use other low index dielectrics, such as alumina, as stable dopants, and that we might be able to have coatings with two dopants. Some of the coatings being considered are tantala doped with silica and titania, tantala doped with alumina and titania, and titania doped with alumina and silica. In addition, a cobalt-oxide and silica coating was found to have a very low mechanical loss, but its optical loss was unacceptably high. We are considering doping the cobalt layer to see if the optical loss can be lowered without ruining the mechanical loss.

One major difficulty in understanding coating loss is in understanding the physical parameters of the coating layer, which can differ significantly from the bulk material values. While visiting MIT, the HWS PI initiated a program with Prof. Krystyn van Vliet of the MIT Mechanical Engineering department. Prof. van Vliet uses nanoindenting to measure coating parameters. She is currently in the process of measuring various tantala coatings so that we can compare her results to measurements performed at Glasgow.

Finally, we have shown that a high temperature anneal of a silica-alumina coating resulted in a significantly lower mechanical loss. Unfortunately the loss in that coating was still unacceptably high. Currently, the coating manufacturers anneal our coatings at the highest temperature that the coating can withstand. However, we are planning to test if we can lower the loss by performing an annealing with a very slow cooldown.

c) Other Contributions

At present Initial LIGO appears to be limited in the 40-100 Hz band by an as-yet undetermined noise source. This noise has an f^-3 dependence similar to suspension thermal noise. In Fall 2005, Gregg Harry and I began a study of the suspension thermal noise in Initial LIGO. We performed free and tensioned wire measurements to determine the inherent loss in the wire material. We also set-up a large optic suspension at MIT using a spare Pathfinder optic in order to measure the loss in the full suspension. We found that while the internal friction of the wire was about a factor two lower than previous measurments, but the loss in the full suspension was a factor 10 higher than the internal loss. Moreover the loss in the suspension was shown to vary with clamp condition. These results indicate that Inital LIGO's wire loop suspension contains excess noise, most likely from rubbing friction, and that this suspension thermal noise could make a major contribution to the excess noise in Initial LIGO. We are currently investigating alternative wire clamping methods in order to better understand and reduce this noise. Our goal is to understand this excess noise and if possible find a means for reducing it. If feasible, we would hope to implement this suspension upgrade in Intermediate LIGO.

The LIGO-Virgo Thermal Noise meeting: LIGO and Virgo have been working to develop a full, formal collaboration. Thusfar, the expression of that collaboration have been almost entirely within the realm of data analysis. I was of the opinion that there should also be close collaboration in the technical areas as well. Therefore I proposed the idea to Benoit Mours that there be a joint LIGO-Virgo meeting on thermal noise. The prupose of the meeting is to familiarize the attendees with the current research being performed in both collaborations, to discuss areas of possible collaboration, and to avenue of research in preparation for the next generation of detectors. Researchers in both collaborations have supported the idea of the meeting. The meeting will occur on October 7 at the Virgo observatory.

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 **HWSLG** 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.

c) Not Applicable

4. Coordination and Reporting -

HWSLG 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 Isolation/Suspension/Thermal Noise Development 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:

Jay Marx
LIGO Laboratory Director

Steven Penn
Principal Investigator
Hobart and William Smith LIGO Group

Peter Saulson
LSC Spokesperson

Attachment Number Z to the Memorandum of Understanding (LIGO-M **050315** -00-M) between the **HWS LIGO Group** (**HWSLG**) and the Laser Interferometer Gravitational Wave Observatory (LIGO) Laboratory

This Attachment to the Memorandum of Understanding LIGO-M **050315** -00-M lists the coordinates of members of the **HWS LIGO Group** 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, 2006 to August 15, 2007. This period may be modified by agreement to a revision of this Attachment. This list may be extended by agreement to a revision of this Attachment.

Principal Investigator

First Name: **Steven** Last Name: **Penn**

Affiliation: **Hobart and William Smith Colleges**

Address: **3172 Scandling Center**

City: **Geneva** State: **NY** Zip Code: **14456**

Country: **United States** Primary Email: **penn@hws.edu**

Job Title: **Assistant Professor** Secondary Email: **penn@mac.com**

Phone Number: **315-383-0069** Fax Number: **315-781-3806**

Begin Date: **Aug 15, 2006** End Date: **Aug 15, 2007**

Research FTE: **33** % LIGO FTE: **25** % AdvLIGO FTE: **75** %

Author on LSC papers: ☒ LSC Council Delegate? ☒

Member #10

☐ Select this box if the contact information of this member is the same as that of the Principal Investigator.

First Name: Last Name:

Affiliation:

Address:

City: State: Zip Code:

Country: Primary Email:

Job Title: Secondary Email:

Phone Number: Fax Number:

Begin Date: End Date:

Research FTE % LIGO FTE % AdvLIGO FTE %

Author on LSC papers: ☐ LSC Council Delegate? ☐

Authorship:

Penn

Scientific Collaboration Council Delegate(s):

Penn

Approved:

Jay Marx
LIGO Laboratory Director

Steven Penn
Principal Investigator
HWS LIGO Group

Peter Saulson
LSC Spokesperson