

Memorandum of Understanding (LIGO-M050242-00-M)
between the
Inter-University Centre for Astronomy and Astrophysics (IUCAA)
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 Inter-University Centre for Astronomy and Astrophysics Group (IUCAA) 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 IUCAA Group will be a member group of the LIGO Scientific Collaboration.

1. The Inter University Centre for Astronomy & Astrophysics (IUCAA) group consists of Prof. Sanjeev Dhurandhar who will serve as the Principal Investigator for research in LIGO, and the rest of the group consists of Dr. Tarun Souradeep (Asst. Prof.) and typically one or two graduate students. The focus of the work done by the IUCAA group under this understanding will be on the data analysis of targeted stochastic gravitational wave background (SGWB) search towards obtaining the SGWB map of the sky. For this purpose several techniques available in other fields of astronomy will be explored and eventually the group proposes to come up with a viable scheme.
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 IUCAA 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. 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.
 5. 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.
 6. Attachments to this MOU will be prepared annually to define the specific activities and responsibilities of the IUCAA Group and to define any resources to be provided by the LIGO Laboratory to the IUCAA Group in support of those activities.
 7. IUCAA 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.

8. 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.
9. The membership list of the IUCAA group will be updated at least every six months. ABC 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 IUCAA Group Principal Investigator is responsible for timely notification to the Directorate and to the computing committee so access may be revoked.
10. 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.
11. 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 IUCAA Group using LIGO Laboratory resources, 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 IUCAA Group or first actually reduced to practice at LIGO facilities solely by member of the IUCAA Group shall be owned by the Inter 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 or first actually reduced to practice by both members of the IUCAA Group and LIGO Laboratory staff shall be jointly owned by the Inter University and Caltech/MIT 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 IUCAA Group under this Attachment will be in accordance with the policies of Inter University.

12. This MOU supersedes the previous MOU between the LIGO Laboratory and the IUCAA group (LIGO-M000234-00) 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

Sanjeev Dhurandhar
Principal Investigator
Inter-University Centre for Astron. & Astrophysics

Peter Saulson
LSC Spokesperson

Attachment DAT to the
Memorandum of Understanding (LIGO-M050242-00-M)
between the
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August 15, 2005

This Attachment DAT to the Memorandum of Understanding LIGO-M050242-00-M defines the role of the Inter-University Centre for Astronomy and Astrophysics Group (IUCAA) 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 IUCAA Gravitational Wave Data Analysis Group will focus on the following two tasks:
 - a) The detection and mapping of the anisotropy in stochastic GW background bears strong semblance to the analysis of the cosmic microwave background (CMB) anisotropy and polarization which is also a stochastic field statistically described in terms of its correlation properties. The first goal of the IUCAA group will be to identify the key features that would allow us to adapt appropriate techniques from CMB analysis.
 - b) The raw sky map of the GW background is the signal convolved with antennae pattern. The IUCAA group will explore and compare the various image reconstruction techniques for the application to the the GW background. The first step is to compute the kernel analytically and study its properties and structure. We will also compute it numerically and check whether these results agree with the ones so far obtained. The structure will be investigated with the help of angular basis functions. Unraveling the structure is extremely important from the point of deciding the appropriate inversion technique. There are a suite of such methods developed in allied fields such as radio astronomy, CMB etc. A promising method is the maximum entropy method which gives the most likely distribution of intensity consistent with the available data. The eventual goal of the IUCAA group will be to identify and develop an efficient method to reconstruct the true sky map.
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 IUCAA 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 – IUCAA Group 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 LSC Stochastic 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

Sanjeev Dhurandhar
IUCAA Principal Investigator

Peter Saulson
LSC Spokesperson

Peter Fritschel
LSC Stochastic Search Group Leader

Albert Lazzarini
LIGO Laboratory Data and Computing
Group Leader

**Attachment Number Z to the
Memorandum of Understanding (LIGO-M050242-00-M)
between the
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and the
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August 15, 2005**

This Attachment to the Memorandum of Understanding LIGO-M050242-00-M lists the coordinates of the IUCAA members 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.

Name	Address	E-Mail	Phone Nos.	Begin Date	End Date
Dhurandhar Sanjeev 40% LIGO I 40 AdLIGO 0 Faculty	Inter-University Centre for Astronomy and Astrophysics Postbag 4, Ganeshkhind Pune - 411 007 India	sanjeev@ iucaa.ernet.in	91-20-25604-224 Fax: 91-20-25604699	Aug. 15, 2005	Aug. 15, 2006
Sanjit Mitra 70% LIGO I 70 AdLIGO 0 Grad. Student	Inter-University Centre for Astronomy and Astrophysics Postbag 4, Ganeshkhind Pune - 411 007 India	sanjit@ iucaa.ernet.in	91-20-25604-215 Fax: 91-20-25604699	Aug. 15, 2005	Aug. 15, 2006

Scientific Collaboration Council Delegate: Sanjeev Dhurandhar

Approved:

Barry Barish
LIGO Laboratory Director

Sanjeev Dhurandhar
IUCAA Principal Investigator

Peter Saulson
LSC Spokesperson