QUARTERLY REPORT
NSF COOPERATIVE AGREEMENT NO. PHY-9210038
THE CONSTRUCTION, OPERATION, AND SUPPORTING RESEARCH AND DEVELOPMENT OF A LASER INTERFEROMETER GRAVITATIONAL-WAVE OBSERVATORY

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I. INTRODUCTION

This report summarizes the Laser Interferometer Gravitational-Wave Observatory (LIGO) Project activities from September through November 1993. It includes technical accomplishments, project status, and a summary of interactions between the LIGO Project and the rest of the scientific community.

II. TECHNICAL ACCOMPLISHMENTS

The technical work of the Caltech and MIT science groups and the engineering team located at Caltech includes:

- LIGO development, including sites, facility design and development of the initial interferometers.
- Prototype laboratory activities aimed at improved understanding of interferometer noise sources or at development of key interferometer techniques.

A. LIGO DEVELOPMENT

1. Sites

Livingston Parish, Louisiana. Louisiana State University (LSU) reports that the terms of a purchase agreement with the principal landowner (Cavenham) have been resolved. In addition, all issues regarding the acquisition of the second, smaller parcel of land have been resolved and the transfer is reported to be complete.

Site investigation work continues to be on hold, awaiting clearing of the forested area by Cavenham.

LIGO engineers and management met with engineers from Transcontinental Gas Pipe Line Company about technical details regarding the LIGO facility crossing their underground pipelines. They have agreed that the crossing is technically feasible, but we have some concerns about their estimated costs for implementation. Details are discussed in a separate letter to NSF on this topic.

Hanford, Washington. The DOE/NSF land use permit and MOU were signed, and we authorized funding to DOE for services in support of site planning.

The engineering design for rough grading of the site was completed and reviewed, and an RFP was issued for this initial construction activity. Five proposals were received in response to the RFP and are being evaluated. The proposed subcontract is expected to be forwarded to NSF for approval in early December. Construction will be initiated upon NSF approval of this subcontract and the previously submitted Environmental Assessment, and NSF issuance of the Finding of No Significant Impact.

2. Industrial Design Subcontracts

Chicago Bridge and Iron, Inc. (CBI) is developing the design and planning the qualification testing for the LIGO beam tube modules. CBI has conducted a large number of significant trade studies and laboratory tests, including having a 20 ft length of 4 ft diam spiral welded tube (.125 in wall thickness) manufactured (by a producer different from the two previously tried by us) to evaluate weld procedures, in preparation for the upcoming Preliminary Design Review (scheduled to be held November 30 – December 1, 1993).

3. LIGO Beam Tube Investigations

The air bake procedure to reduce hydrogen outgassing in the LIGO beam tube wall material, developed and adopted by LIGO, has been tested and verified by the VIRGO project.

A measurement program has been initiated to evaluate the effects of cleaning procedures on the outgassing of hydrocarbons. Both surface analysis and outgassing rate measurements of prepared air baked stainless steel samples will be carried out.

B. PROTOTYPE ACTIVITIES

1. 40-Meter Interferometer

The shakedown of the Mark II prototype has been completed. This process included fine tuning of electronics and operating parameters (such as centering of the light beams on the test masses), and standard tests for sensitivity to noise on the light or in the control electronics.

The servosystems for orientation control and damping of the test masses have been characterized, and found not to contribute strongly to the interferometer noise if the laser light is well centered on the test masses. Similar tests of the beam splitter controls are underway. Characterization of the Mark II seismic isolation has begun. A significant improvement in interferometer noise is already evident between 30–100 Hz, due to the enhanced isolation from the new vibration isolation stacks. Construction activities in the vicinity of the 40-m laboratory have hampered the interferometer research effort.

2. Suspended-Mirror Mode Cleaner

Initial testing of the mirror control servomechanisms for the suspended-mirror mode cleaner has begun. Excessive rms motion of the mirrors was measured, caused by insufficient damping of resonances in the vibration isolators. Experiments indicate that substitution of Viton springs instead of the RTV silicone rubber springs now used will reduce this motion to acceptable levels.

3. Stationary Interferometer

The goal of stationary interferometer research has been to select the modulation and optical topology scheme to be used in the initial LIGO interferometer.

The data and modeling associated with the two stationary interferometer research efforts were assembled and presented to the LIGO science team on September 30. Based on the results of this research, the project adopted the recommendation for the initial LIGO modulation and optical topology. In brief, this topology uses an asymmetry in the interferometer with a fore-modulation to develop the gravitational wave signal, and a combination of signals from the main and one additional input frequency of light to sense the additional degrees of freedom.

Work is continuing on the stationary interferometers to answer some remaining questions about the modulation system, and to complete two PhD theses associated with this research. An ongoing program of modeling of the recommended scheme is coordinated with the planning of future experimental tests of the scheme.

4. Interferometer Alignment

This research is directed to providing a system for alignment of the LIGO initial interferometer. A systems approach to the general problem of interferometer alignment (angular alignment, beam centering, bootstrap to the aligned state) has been outlined. The initial priority is to establish a set of functional requirements for the system, to be followed with a recommendation for a complete system for detailed study and test.

The semi-analytical model of alignment signals available in a coupled cavity system has been completed. A comparison of the model predictions and the data collected from an experimental setup of a stationary double cavity shows good quantitative agreement. The experimental work will be transferred to the stationary interferometer used for the modulation and topology research. The basic semi-analytical model for the complete recycled interferometer has been finished and is undergoing tests.

Work has continued on a demonstration of automated alignment of a suspended cavity. The suspended mirrors are now being installed in the 5-m baseline vacuum system and vacuum preparations are underway. The engineering of a prototype RF phase-front detector head is started.

5. Suspension Development

Preparations have begun for installing monolithic test masses (masses in which the mirror surfaces have been polished and coated directly onto the test mass substrate) into the 40-meter interferometer. A sample monolithic test mass was suspended which exhibited suspension and test mass Q values comparable to those specified for the initial LIGO interferometers. Final optical testing of the monolithic test masses prior to installation is now in progress.

6. Optics Testing and Development

An apparatus for making transmission maps of mirrors has been completed. This apparatus will be used for testing the homogeneity of mirror coatings; information from such tests will be shared with the mirror coating manufacturer to improve mirror coatings.

7. Phase Noise Demonstration

This research is designed to develop and demonstrate the technology for the shot-noise limited interferometer fringe readout using the 5-m facility at MIT; planning started in this quarter. A draft experimental plan has been developed. The optical design and modulation scheme have been completed. Conceptual designs for work on the vacuum system and space changes to the laboratory are underway.

Auxiliary experiments which support this research are underway. A test of the spatial uniformity of photodiodes has been refined to the level of a 0.05% rms measurement noise, and preliminary data indicate that the large scale variations observed (about 0.15% rms) are acceptable. Measurements of the optical distortion in Pockels phase modulators, due to power dissipated by the applied RF field, are starting to yield results.

Contact with Barry Controls has been established to explore the possibility of incorporating an active anti-seismic system in the 5-m interferometer, with possible participation in an early prototype test of their system. This system also has potential application to the initial LIGO interferometer.

III. PROJECT STATUS

A. Schedule

The schedule status of the project is summarized using the significant milestones identified in the Project Management Plan. Table 1 gives a summary of current and near-term milestones and their status.

Table 1

SIGNIFICANT MILESTONES

Milestone	Baseline Date	Completed Date	Expected Date	Comment
Past-Due From Prior Report				
No Past-Due Milestones				
Due During Reporting Quarter				
Select Interferometer Optical Topology	10/01/93	9/30/93		Completed
Initiate Site Development at WA site (Contract Award Date)	10/14/93		1/10/94	Depends on NSF approval of EA and FONSI, and award and approval of subcontract
Upcoming				
Release Vacuum Equipment RFP	12/10/93		—	Rescheduling in progress
Select Building Design Contractor	1/04/94		—	Rescheduling in progress
Beam Tube Final Design Review	1//24/94		3/10/94	Delay of beam tube contract start resulted in schedule slip
Initiate Site Development at LA Site	5/26/94		—	Will be delayed; to be rescheduled once site acquisition date is known

B. Financial Status

Cumulative funding and obligations are given in the following table:

Table 2

Cooperative Agreement No. PHY-9210038 Financial Status as of 10/1/93 ($M)	
Cumulative Funding to date	23,105.9K
Cumulative Obligations to date:	
WBS 1.1 Site Plans	85.5K
1.2 Building Design	15.7
1.5 Beam Tube Design	1301.2
1.8 Site Investigations	636.8
4.1 Management and Administration	1424.7
4.2 Technical Staff	4965.3
4.3 Travel	253.5
4.4 R&D Equipment	1796.8
4.5 In-house Operations Support	1170.6
TOTAL	11,649.7K

C. Programmatic Issues

A list of programmatic issues involving LIGO and NSF is given in Table 3.

Table 3

PROGRAMMATIC ISSUES - CALTECH / NSF RESPONSIBILITIES

Issue	Responsible	Due Date	Status / Comment
Appoint External Advisory Committee	LIGO	11/01/92	Draft charter and membership list submitted to NSF on 10/21/93; awaiting NSF response
LIGO FY 1993 Funding	NSF	12/01/92	Authorization received 9/01/93; $20M frozen by NSF pending acceptance of Management Plan
Submit Management Plan to NSF	LIGO	9/15/93	Completed 9/22/93
Completion of DOE/NSF land use permit and MOU for WA site	NSF	10/14/93	Completed
Approval of EA and FONSI for WA site	NSF	10/14/93	Expected 12/93
Approval of Management Plan	NSF	—	

D. Staffing / Personnel Changes

Dr. Volker Schmidt has joined the project as head of the control and data system (CDS) effort. He most recently completed a similar system for the RFX project, a nuclear fusion research facility at Padua. Dr. Schmidt's arrival allows us to proceed with recruitment of several engineering personnel related to the CDS.

Dr. Edwin Goldwasser (University of Illinois) accepted a half-time appointment as a Distinguished Scholar at Caltech and will be associated with the project. He will provide assistance to project management and scientific staff in a broad range of areas.

Dr. Seiji Kawamura has rejoined the project as a staff scientist. He has spent the past year as a member of the gravitational-wave group headed by Professor Kawashima at the University of Tokyo. Prior to that, he had spent three years with the LIGO project.

The following table compares the actual current LIGO staff with the staffing goal for this period given in the Project Management Plan.

Category	Management Plan Goals	Actual
Scientists	15	15.5
Engineers	12	11
Graduate Students	9	10
Technicians	6	5
Administration	5	5

IV. INTERACTIONS WITH SCIENTIFIC COMMUNITY

A paper ("Mirror Orientation Noise in a Fabry-Perot Interferometer Gravitational-Wave Detector" by S. Kawamura and M. Zucker) was accepted for publication in *Applied Optics.* Two papers were published in *Reviews of Scientific Instruments* ("A Sensitive Interferometric Accelerometer," by M. Stephens, *Rev. Sci. Instrum. 64*, **9**, September 1993, and "Mechanical Loss in Fibers for Low Noise Pendulums," by Joseph Kovalik and Peter R. Saulson, *Rev. Sci Instrum. 64*, **10**, October 1993).

Stan Whitcomb presented the Physics Department Colloquium at Michigan State University of November 9.

F. Raab presented an invited plenary talk on LIGO to open the 6th Annual Meeting of the Laser and Electro Optics Society meeting in San Jose, CA, on November 15. He also visited Stanford University, November 17, for discussions of laser and interferometer development with R. Byer and collaborators.

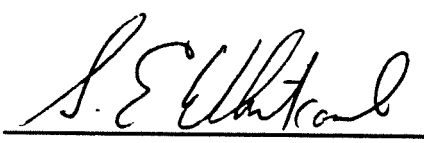
Fred Raab presented a Physics Colloquium at Washington State University, Pullman, WA, on November 30.

Visitors to LIGO during this quarter included:

- Jesper Munch (University of Adelaide), October 1, for discussions of possible collaborative research in the areas of lasers and nonlinear optics;

- Mark Notcutt (University of Western Australia, Perth), October 13 – November 12, to work with LIGO team members on 40-meter interferometer and to gain experience which will be useful in developing an interferometer at UWA;
- R. Byer (Stanford University), October 22, for discussions of collaborative efforts;
- John Sandeman (Australian National University, Canberra), November 4–8, to discuss the organization of Australian research in laser interferometer gravitational-wave detection and possible areas and mechanisms for collaboration with LIGO;
- Hans Bachor (Australian National University, Canberra), November 8–11, for discussions of possible collaborative research in the areas of interferometry and optical modeling;
- Ju Li (University of Western Australia, Perth), November 15–26, for consultations concerning design of LIGO vacuum chambers to ensure that they are compatible with low frequency vibration isolator concepts being developed at UWA;
- Georg Rupschus (Physikalisch-Technische Bundesanstalt, Berlin), November 24, to discuss his group's results studying gas bursts from ion pumps and their possible applicability to LIGO.

Pasadena, December 2, 1993



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