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March 1, 1994

Dr. David Berley
Physics Division
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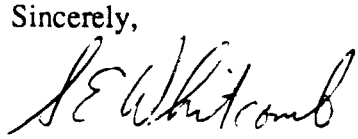
4201 Wilson Boulevard
Arlington, VA 22230

Dear David,

Enclosed are the original and four copies of the LIGO Project Quarterly Report covering the period from December 1993 through February 1994.

Sincerely,



Stanley E. Whitcomb
Acting Director

cc: L. Allen
W. Althouse
B. Barish
E. Freise
C. Peck
F. Raab
R. Vogt
R. Weiss
File –2

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

B. Barish, Principal Investigator
S. E. Whitcomb, Acting Director
W. E. Althouse, Chief Engineer

March 1, 1994

I. INTRODUCTION

This report summarizes the Laser Interferometer Gravitational-Wave Observatory (LIGO) Project activities from December 1993 through February 1994. 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 reports that the land transfer is imminent. The original land owner (Cavenham) has harvested the tree crop, leaving hardwood trees and "slashing" (broken branches and other debris from the harvesting operation). Site investigation work continues to be on hold, awaiting the completion of land clearing so that access can be obtained.

Hanford, Washington. NSF has issued the Finding of No Significant Impact (FONSI) for the Hanford site which allows construction to be initiated.

The evaluation of the five proposals for the rough grading was completed and a contractor was selected. The selected subcontract was submitted to NSF for approval but the initiation of construction has been delayed pending NSF's approval of the subcontract. Two additional subcontract modifications (to the engineering firms which performed the design work and the

geotechnical investigations) have been completed which will provide the day-to-day engineering supervision and quality assurance for the rough grading contractor. Awarding these modifications are on hold pending the resolution of the rough grading contract.

2. Industrial Design Subcontracts

The Preliminary Design Review (PDR) for the beam tube module being developed by Chicago Bridge and Iron, Inc. (CBI), was conducted on November 30 – December 1. The review board, which included a number of independent experts in addition to LIGO project members, issued its report including its recommendations to the LIGO Project Director. The disposition of the recommendations is being documented and critical items are being implemented.

CBI is proceeding with the final design of the beam tube and a Final Design Review is scheduled for April 1994.

3. LIGO Beam Tube Investigations

As a result of the Beam Tube Module PDR, the possibility of welding with filler wire is being investigated. CBI welded a number of samples with filler wire which was heat treated and cleaned prior to welding. Hydrogen outgassing measurements were conducted and compared to non-welded samples. The data indicate that the use of cleaned and baked weld filler wire will be acceptable. Tests are underway to determine if weld filler wire without special treatment (i.e., unbaked) is also acceptable.

B. PROTOTYPE ACTIVITIES

1. 40-Meter Interferometer

Research efforts were disrupted by a large earthquake which occurred in the Northern San Fernando Valley on January 17, at 4:31 am PST, registering 6.6 on the Richter scale. Previous efforts to design earthquake safety features into the interferometer helped to minimize damage to the interferometer; improved safety upgrades are being made, based on new information learned from this event. Repairs to the interferometer and completion of a mode cleaner cavity replacement (which was in progress when the earthquake struck) were completed in about three weeks.

Characterization of the new seismic isolation stacks installed in the Mark II prototype has been completed. The measured and predicted performance are in good agreement. Replacement of the mode cleaner cavity (which had become contaminated in handling during the Mark II rebuild) now allows operation at optical power levels comparable to those used previously in the Mark I prototype. Except for isolated resonances, the noise is now below 10^{-18} m/$\sqrt{\text{Hz}}$ at frequencies from 300 Hz to 2000 Hz, and seismic noise is negligible above 100 Hz. Various potential noise sources are being reassessed following these changes; this will be followed by installation of monolithic test masses, the first major configuration change to the Mark II interferometer.

2. Suspended-Mirror Mode Cleaner

The vibration isolation stacks for the suspended-mirror mode cleaner were rebuilt in an effort to reduce excessive mirror motion associated with resonances in the previous isolator. A novel design, using a mixture of RTV silicone rubber and Fluorel springs, was used to obtain a five-fold reduction in mirror motion. Testing of the mirror control servomechanisms has resumed.

3. Interferometer Alignment

The research is directed to providing a system for alignment of the LIGO initial interferometer. Significant progress has been made in generating requirements for the alignment system. The semi-analytical model has produced a set of maximum angles of misalignment allowed in order to maintain the interferometer sensitivity at an acceptable level. The next step in the analysis is to determine the sensitivity required of the alignment detectors. The experimental verification of these results will be made on the MIT stationary interferometer, which is being prepared for this new task. The engineering of a prototype RF phase-front detector head has advanced. One channel of a 5-element detector has been breadboarded, and the design is now being transferred to PC boards for tests of a complete 5-channel prototype.

4. Suspension Development

Final preparations for installing monolithic test masses into the 40-meter prototype are nearing completion. The new test mass configuration will exhibit Q-values for the various mechanical resonances that are compatible with thermal noise goals for the initial LIGO interferometers; thermal noise from some low Q internal modes of the test masses currently used in the prototype (which may be limiting its sensitivity at frequencies near 500 Hz) will be greatly reduced by this change.

5. Optics Testing and Development

Analytic and numerical modeling of the large aperture optics continued this quarter as input to the optical pathfinder process. Specifications for the tolerable wave front distortions were established and tested numerically in the Fourier Transform propagation code in complete interferometer configurations. Data on the wavefront distortions of a calibration flat used in the AXAF X-ray satellite program, kindly provided to the LIGO project by Hughes Danbury, were extended to high spatial frequency. The characteristics of the polished surface of this mirror have been found to be better than the requirements of the initial LIGO interferometer by a factor of 5 or more.

6. Phase Noise Demonstration

This research is designed to develop and demonstrate the technology for the shot-noise limited interferometer fringe readout using the 5-meter facility at MIT. Experimental and fabrication planning has gone through several iterations. Vendors and engineering subcontractors for the fabrication phase have been identified. Space changes to the laboratory, underwritten by MIT, have been detailed and pending final review by MIT, should get underway in March. A design review of the project can take place early in the next quarter.

Auxiliary experiments have continued. One of the consequences of the interferometer configuration which we have chosen for the LIGO is that higher phase modulation frequencies will be required. Measurements show that the planned modulation frequencies and depths can be obtained using existing modulators in matched pairs to cancel first-order heating effects.

A cooperative arrangement has been agreed on with Barry Controls (Brighton, Massachusetts) to perform tests of an active anti-seismic system in the 5–meter interferometer lab. An engineering prototype of their system will be tested at MIT by both Barry and MIT personnel for its applicability to both the 5-meter phase noise research and the full LIGO. The tests will be performed with a LIGO prototype passive stack as the load, and measurements similar to those which were used to verify the performance of the stack will be repeated. To this end, needed vacuum modifications to the 5-meter installation have begun, and the tests are scheduled to take place in the coming quarter.

III. PROJECT STATUS

A. Schedule

Table 1 shows the schedule status of the project compared with the significant milestones established in the Project Management Plan.

Table 1
SIGNIFICANT MILESTONES

Milestone	Baseline Date	Completed Date	Expected Date	Comment
Past-Due From Prior Report				
Initiate Site Development at WA site	10/14/93		3/20/94	Depends on NSF approval of subcontract
Due During Reporting Quarter				
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		4/26-27/94	Delay of beam tube contract start resulted in schedule slip
Upcoming				
Initiate Site Development at LA Site	5/26/94		—	Will be delayed due to delays in site acquisition

B. Financial Status

Cumulative funding and obligations are given in the following table.

Table 2
CUMULATIVE FUNDING AND OBLIGATIONS

Cooperative Agreement No. PHY-9210038 Financial Status as of 12/1/93 ($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	641.4
4.1 Management and Administration	1529.6
4.2 Technical Staff	5518.6
4.3 Travel	311.1
4.4 R&D Equipment	1873.2
4.5 In-house Operations Support	1327.6
TOTAL	12,603.9K

Future progress reports will include, in addition to augmented versions of above table, new graphs which display planned and actual obligations for each of the four WBS level 2 elements. The plot for WBS 4., which contains most obligations incurred to date, is included below. The next report will contain all four plots.

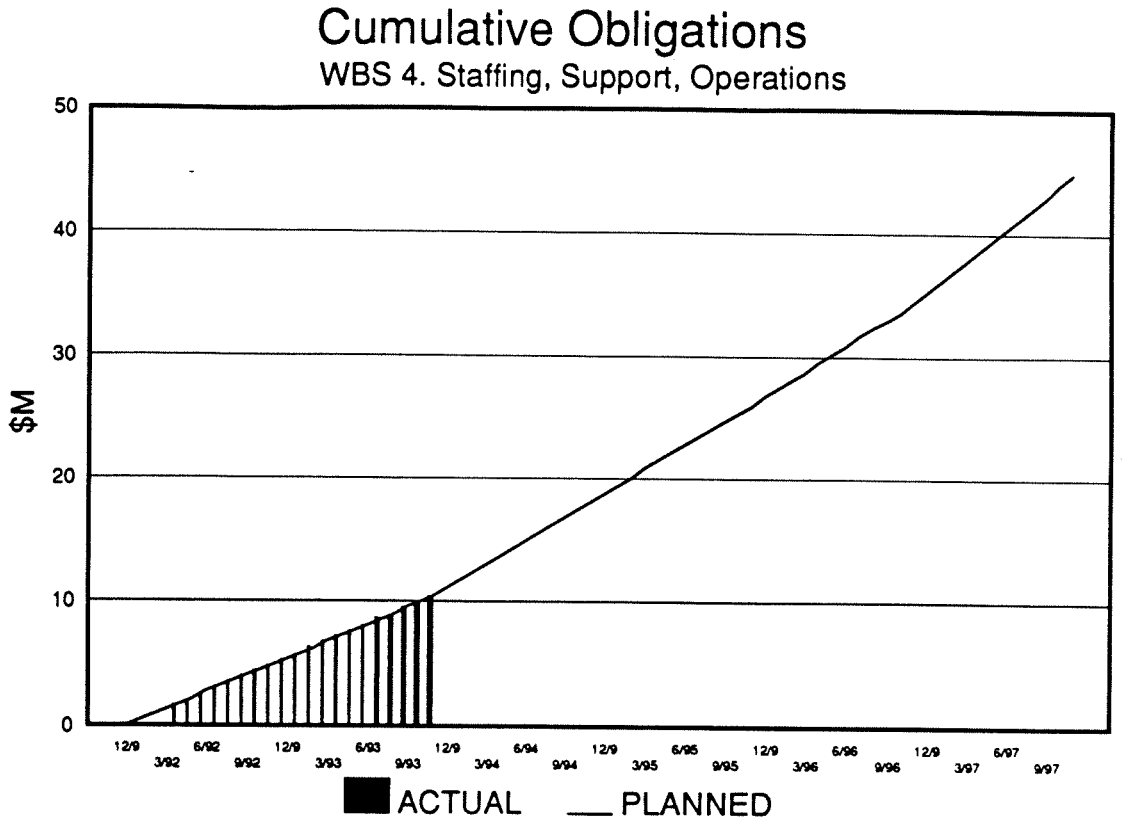


Figure 1 Cumulative obligations for WBS 4., showing present baseline planned (line) obligations from 12/1/92 through 11/30/97 and actual (bars) obligations by month through November 1993, the most recent data available.

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	Charter and proposed membership approved by NSF 1/18/94
LIGO FY 1993 Funding	NSF	12/01/92	Authorization received 9/01/93; $20M frozen by NSF pending acceptance of Management Plan
Approval of EA and FONSI for WA site	NSF	10/14/93	Completed 12/93
Conduct Project Cost Review	NSF-LIGO	—	To be scheduled

D. Staffing / Personnel Changes

Rolf Bork and Jay Heefner have accepted offers to join the project as software engineering specialist and electronics engineering specialist, respectively, as part of the newly formed control and data systems group. Both Rolf and Jay come to us from the controls department of the Superconducting Supercollider (SSC) Accelerator Division.

Boude Moore retired as vacuum engineering specialist on January 7.

John Worden has joined the project as vacuum engineering specialist. John was Vacuum Section Leader in the SSC Accelerator Division and was the lead engineer responsible for design and construction of major parts of the SSC.

Barry Barish (professor of physics at Caltech) has been appointed as LIGO Principal Investigator. Stan Whitcomb has been appointed Acting Director while a permanent reorganization of the management is formulated.

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	17	17
Engineers	12	11
Graduate Students	9	10
Technicians	6	5
Administration	6	5

IV. INTERACTIONS WITH SCIENTIFIC COMMUNITY

An international workshop on "Thermal Noise in Laser Interferometer Gravitational-Wave Detectors" was held at Caltech on January 4 and 5. This was the first gathering of experts in this research area, organized by Fred Raab and Peter Saulson in an effort to forge individual group efforts into a cohesive research community. More than 20 participants (not counting LIGO staff) from the United Kingdom, France, Germany, Italy, Russia, Japan and the United States attended the workshop.

LIGO staff participated in a workshop on gravitational waves from coalescing compact binaries held at Caltech January 6-8. This workshop was intended to strengthen ties between the theoretical and experimental communities working toward the study of gravitational waves.

Stan Whitcomb gave an invited talk on the LIGO and VIRGO projects at the Cornelius Lanczos Centenary Conference on December 17 at North Carolina State University.

Stan Whitcomb presented an invited talk on LIGO to the High Energy Astrophysics Division of the American Astronomical Society at their meeting in Crystal City, Virginia, on January 14.

Fred Raab presented a research seminar on LIGO at the Center for Astrophysics and Space Sciences, University of California at San Diego on January 25.

Rai Weiss gave a physics department colloquium on Interferometric Gravitational-Wave Detection at the University of Vermont at Burlington on January 26.

Fred Raab presented a physics colloquium at Caltech on thermal noise on February 3.

A paper ("Measured Limits to Contamination of Optical Surfaces by Elastomers in Vacuum" by A. Abramovici, T. Lyons, and F. Raab) was submitted for publication in *Applied Optics*.

David Shoemaker visited the VIRGO Project in Orsay on December 21 and 29 to discuss optical models under development by the two groups and to compare results.

Visitors to LIGO during this quarter included:

- Ke Sun (Stanford University) visited the MIT laboratory November 23-26 to discuss phase noise measurements being planned at Stanford with Nd:YAG lasers.
- Professor Bernard Schutz visited LIGO in January with two other members of his group (David Nicholson and Justin Shuttleworth) to discuss collaboration in the areas of data acquisition and analysis. David and Justin remained for a period of two weeks.
- Shang Sung (University of New Mexico) visited on January 26-27 to discuss her theoretical work on interferometer noise.
- Professor Ken Ueda and one of his students (Mr. Uehara) visited the LIGO group at Caltech on February 10-11 to discuss their work on developing lasers for the Japanese gravitational-wave effort. Dr. Riu Takahashi (ISAS) visited the same week (February 7-11) to learn about the 40–meter interferometer.
- Alex Farinas (Stanford University) visited the LIGO labs at Caltech on February 11 to discuss his work with stabilized YAG lasers and LIGO laser requirements.
- Sam Finn (Northwestern University) visited LIGO and the theoretical astrophysics group at Caltech from February 21-March 3 to discuss source calculations and data analysis techniques.

A special session of contributed talks on LIGO has been organized for the upcoming American Physical Society meeting, to be held during April in Crystal City, Virginia. The special session, organized in cooperation with the Topical Group on Instrumentation and Measurement Science, will present the basic scientific and technological principles behind LIGO. In addition there will be contributed talks by LIGO graduate students, presenting their work on interferometer development and thermal noise.

Pasadena, March 1, 1994

S. Whitcomb, Acting Director