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Date: June 27, 2003
Refer to: LIGO-L030107-00-P

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National Science Foundation
4201 Wilson Boulevard
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Subject: LIGO Construction Project Quarterly Progress Report, LIGO-M030127-00-P

Reference: NSF Award No. PHY-9210038

Dear Ms. Klein:

Four copies of the LIGO Construction Project Quarterly Progress Report providing status information for the fiscal quarter ending February 2003 are enclosed in accordance with the requirements of the award referenced above. Please forward three (3) copies to Dr. Thomas Lucatorto.

Sincerely,

Philip E. Lindquist
LIGO Project Controls Manager

Concurrence for Caltech:

____________________________
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# LASER INTERFEROMETER GRAVITATIONAL-WAVE OBSERVATORY
# (LIGO)

CALIFORNIA INSTITUTE OF TECHNOLOGY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

| Document Type *Quarterly Progress Report* | LIGO-M030127-00-P | June 25, 2003 |
|---|---|---|

## LIGO Construction Project Quarterly Progress Report (February 2003)

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# LIGO Construction Project Quarterly Progress Report
# February 2003

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# 1. INTRODUCTION

This Quarterly Progress Report is submitted under NSF Cooperative Agreement PHY-9210038[1]. The report summarizes the progress and status of the Laser Interferometer Gravitational-Wave Observatory (LIGO) Construction Project for the fiscal quarter ending February 2003.

Facility construction, including the vacuum systems, is complete with the exception of very minor items related to final completion of the Laboratory Building in Hanford and the Staging and Storage Building in Livingston. We have installed the Detectors, and we are commissioning. The original completion date for the Cooperative Agreement was September 30, 2001. We have requested and been granted a no-cost extension through June 2003 to finish commissioning as well as to complete project scope that was deferred to manage contingency and risk.

The construction effort is 99 percent complete. The detectors are operating although additional commissioning will be required to achieve the sensitivity goals in the science requirements document (SRD). Science runs are providing data, which is being analyzed by the LIGO Scientific Collaboration (LSC), and we are preparing papers for publication. These are exciting times for LIGO and the gravitational-wave community.

This will be the last Quarterly Progress Report. A Final Report will be submitted after completion in June 2003.

# 2. FACILITIES

We have completed the construction of the vacuum systems, beam tubes, and the initial complement of buildings. Construction of a Laboratory building at Hanford, and the Storage and Staging building at Livingston, are nearing completion.

## 2.1. Livingston Storage and Staging Building

The new Storage and Staging building at Livingston is complete. The construction contract is being closed out.

## 2.2. Hanford Laboratory Building

The construction of the Laboratory building is complete. The construction contract will be closed upon completion of a punch list. Landscaping, parking, furnishing of the laboratory area, sunshade awnings, and a second set of glass doors remain. We have moved into the building.

## 2.3. Safety

An audit team has conducted laser safety audits of various Caltech LIGO facilities where lasers are operated. Additionally, we completed and distributed a revised update of the LIGO Laser Safety Program (LIGO-M960001) document.

[1] Cooperative Agreement No PHY-9210038 between the National Science Foundation, Washington, D.C. 20550 and the California Institute of Technology, Pasadena, CA 91125, May 1992

A safety audit of the 40M laboratory was completed. This LIGO facility has established and is practicing a good safety program including good housekeeping.

# 3. DETECTOR

The Detector Group is focused on commissioning and operating the interferometers. We continue to work on reducing noise and improving duty cycle. We are refining the design based on our growing operational experience. A very successful science run (S1) was conducted at the end of August 2002 continuing into September. Data recorded during S1 is being analyzed by working groups in the LIGO Scientific Collaboration (LSC), and papers are being prepared for publication. A second science run (S2) began February 14, 2003 and will continue through mid-April. The sensitivity of the detectors has been improved by a factor of ten over that achieved in S1 although we still have a factor of ten to go to reach the goals in the science requirements document (SRD).

## 3.1. Science Runs

Our mission is to achieve the scientific reach intended for LIGO and, with the LSC, to accomplish the science. With these goals, we have planned an initial progression of three science runs, interleaving interferometer development and improvement with increased scientific reach for each run. The three consecutive runs will provide a baseline for LIGO Data Analysis System (LDAS) development, detector modeling and diagnosis, as well as interferometer commissioning, modification, and revision. All three science runs are the joint responsibility of the Laboratory and the LSC.

LIGO initiated its first science run (S1) August 23, 2002. Data was recorded over 17 days (408 hours), some of it in coincidence with our GEO Project associates. During S1, the most sensitive detector (the Livingston four-kilometer interferometer) approached a strain sensitivity of $10^{-21}$ $(1/\sqrt{Hz})$. The "in-lock" statistics for S1 are summarized in Table 1.

**Table 1: Summary of "In-lock" Statistics for the First Science Run**

| | Duty Cycle (percent) | Total Locked Time (hours) |
|---|---|---|
| H1 (Hanford 4km) | 57.6 | 235 |
| H2 (Hanford 2km) | 73.1 | 298 |
| L1 (Livingston 4km) | 41.7 | 170 |
| L1 & H1 | 28.4 | 116 |
| L1 & H2 | 32.1 | 131 |
| H1 & H2 | 46.1 | 188 |
| Triple Coincidence | 23.4 | 96 |

## 3.2. Commissioning

**Hanford Four-kilometer (H1):** The primary focus has been the wave front sensing systems. A number of other improvements have been incorporated into the optical-lever and interferometer control loops. H1 continues to lock robustly and with improved performance.

**Hanford Two-kilometer (H2):** Efforts this quarter centered on the pre-stabilized laser controls.

**Livingston Four-kilometer (L1):** The main emphasis has been on the wave front sensing systems.

Since S1, the commissioning team has made impressive progress as illustrated in Figure 1. This plot shows the evolution of the sensitivity of the four-kilometer detector at Livingston. The curves represent the smallest signal that we could reliably discern as a function of the frequency. The green curve (September 2002) indicates the sensitivity during S1. We have achieved similar improvements in the sensitivities of the Hanford interferometers. The factor-of-ten improvement shown by the purple curve (January 2003) set the stage for our second science run (S2).

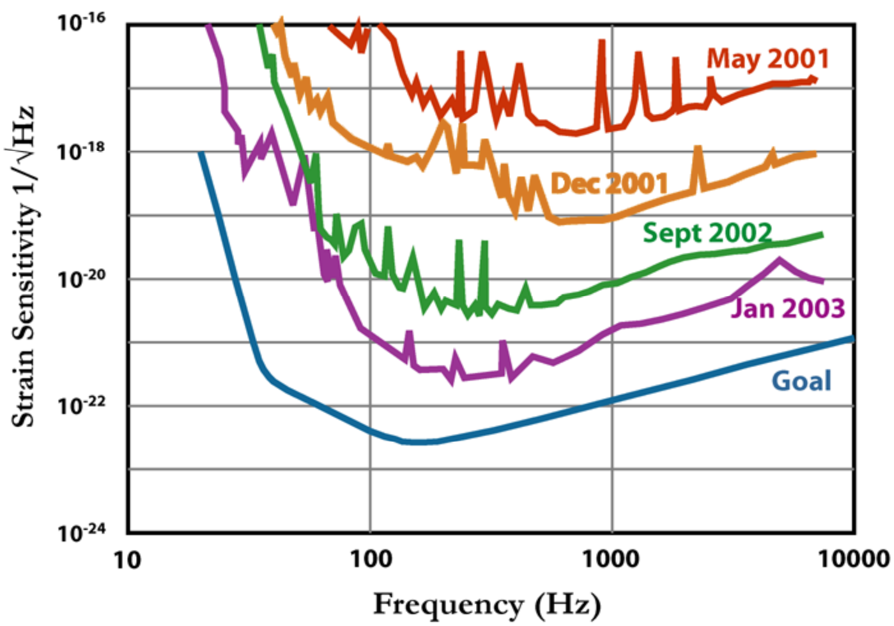


**Figure 1: Sensitivity History for Livingston, Louisiana Four-kilometer Interferometer**

**Engineering Run:** We successfully completed a ninth engineering run in late January. Its purpose was to test new systems in preparation for the second science run (S2).

**Second Science Run (S2):** S2 started on February 14 and will run through April 15. S2 will provide the first opportunity to see potential sources in other galaxies, most notably the Andromeda galaxy. The duty cycles achieved as of the end of the quarter are comparable to those experienced during S1 (67 percent for H1, 60 percent for H2, and 40 percent for L1). The longest "science" segment so far in a single interferometer is a record 66 hours (H1). Availability of the Livingston interferometer has been limited by daytime seismic noise sources caused by local human activities. However, the Livingston "reach" while locked has varied between 0.8

and 1.2 Mega parsecs for a binary neutron star inspiral event (1.4 solar masses). We still do not expect to catch a gravitational wave at these sensitivities, but we are pushing the scientific reach to limits never before achieved.

### 3.3. RFI/EMI Remediation

Studies of Radio-Frequency Interference (RFI) and Electromagnetic Interference (EMI) in the instruments indicate that we are suffering from contamination from the switching-mode power supplies used in the detector as well as cross-coupling from the digital electronics to the low-level analog electronics. We have changed some of the switching power supplies to linear power supplies and modified cabling and control system configurations and were successful in reducing the RFI/EMI in those subsystems. We have developed a comprehensive plan to address the contamination, which will be executed in stages starting shortly after the end of the S2 run.

### 3.4. Seismic Isolation Upgrade

An External Pre-Isolator (EPI) design effort was initiated in response to the need to provide better seismic isolation in the LIGO Livingston Observatory (LLO) environment. The goal is to accelerate the pre-isolation design effort already underway as part of Advanced LIGO seismic development. The Advanced LIGO EPI system, as originally conceived, employs a quiet hydraulic actuator. Since the hydraulic actuator entails considerable development risk, a commercial off-the-shelf electro-magnetic actuator was selected in a parallel effort. The EPI version using a hydraulic actuator is known as HEPI (Hydraulic EPI) and the EPI version using an electro-Magnetic actuator is known as MEPI (electro-Magnetic EPI). In the interim we have used the Fine Actuation System (FAS) for active damping of the seismic support structure with feedback from sensitive (GS-13) geophones placed on the crossbeams near the piers. This Piezo-electric EPI (or PEPI) controls in the x-direction (optical axis direction) and yaw (rotation about the vertical axis) degrees of freedom.

Although MEPI was originally planned as a fallback to be used only if the HEPI development encountered problems, we have since found that the costs for the HEPI system are considerably higher than for the MEPI system. There are also positive and negative factors for both systems.

Prototype Hydraulic External Pre-Isolation (HEPI) and Electro-Magnetic External Pre-Isolator (MEPI) have been installed in the LASTI test facility at MIT and are being evaluated. We plan to complete the testing, and to fabricate and install the pre-isolator at Livingston after the S2 run.

## 4. LIGO DATA ANALYSIS

The first science run (S1) provided our first opportunity to record data specifically targeting the search for gravitational waves. The sensitivity of the detectors, though short of our ultimate goal, was still better than any previous attempts using multiple interferometers in coincidence. New "upper limits" on the gravitational-wave flux were established, and preliminary results are being prepared for publication.

The LIGO Scientific Collaboration (LSC) is performing these analyses. The LSC is divided into four working groups, one each for: inspiral sources (e.g., compact binary inspiral), burst sources (e.g., supernovae, gamma ray bursts), periodic sources (e.g., pulsars), and cosmological signals (e.g., the stochastic background). Typically each group comprises approximately 25 physicists and is co-led by an experimentalist and a theorist. Draft pre-prints were sent to the collaboration in January 2003 and will be released for internal comment and for selected presentations in March.

We have released LDAS (LIGO Data Analysis System) version 0.6.0 software in preparation for the second science run. This code has been extensively tested to assure improved reliability. The failure rate has been reduced to between 0.1 percent and 3 percent depending on the computational performance of the platforms used to test. We are optimistic that the failure rate will be close to the 0.1 percent rate at the sites. This means that 999 jobs out of each 1000 will succeed.

## 5. LIGO SCIENTIFIC COLLABORATION (LSC)

The LIGO Laboratory is planning an LSC-wide outreach program. Outreach activities are a vital part of the LIGO Laboratory's mission and centralizing these efforts could only widen their scope. The idea is to coordinate and improve the quality of the program by assigning a person especially talented and qualified for the work. The program developed would then be available to all institutions in the LSC.

We have scheduled the next meeting of the LIGO Scientific Collaboration at Livingston, March 17-20, 2003.

# 6. PROJECT MANAGEMENT

All milestones identified in the LIGO Project Management Plan for Construction[2] have been completed.

## 6.1. Financial Status

Table 2 summarizes costs and commitments (encumbrances) as of the end of February 2003 and provides a comparison to budgets for both completed and open construction tasks.

**Table 2: Costs and Commitments vs. Budget as of the End of February 2003 ($K)**

| WBS | Description | Budget | Actual Costs (Feb 2003) | Open Encum-brances | Estimate-to-Complete | Total |
|---|---|---|---|---|---|---|
| **Completed Tasks** | | | | | | |
| 1.1.1 | Vacuum Equipment | 44,047 | 44,047 | | | 44,047 |
| 1.1.2 | Beam Tube | 47,004 | 47,004 | | | 47,004 |
| 1.1.3 | Beam Tube Enclosure | 19,338 | 19,338 | | | 19,338 |
| 1.1.4 | Civil Construction | 53,493 | 53,493 | | | 53,493 |
| 1.1.5 | Beam Tube Bake | 5,570 | 5,570 | | | 5,570 |
| 1.3.1 | Lab Operations | 6,291 | 6,291 | | | 6,291 |
| 1.3.2 | Research and Development | 15,860 | 15,860 | | | 15,860 |
| 1.4.1 | Project Management | 14,561 | 14,561 | | | 14,561 |
| 1.4.2 | Support Services | 819 | 819 | | | 819 |
| 1.4.3 | Document Control | 830 | 830 | | | 830 |
| 1.4.4 | Office Operations | 3,845 | 3,845 | | | 3,845 |
| **Subtotal Completed Tasks** | | **211,659** | **211,659** | | | **211,659** |
| **WBS** | **Description** | **Budget** | **Actual Costs (Feb 2003)** | **Open Encum-brances** | **Estimate-to-Complete** | **Total** |
| **Open Tasks** | | | | | | |
| 1.1.4 | Livingston Construction | 2,719 | 2,592 | 52 | 85 | 2,729 |
| 1.1.4 | Hanford Building | 3,085 | 2,966 | 25 | 94 | 3,085 |
| 1.2 | Detector | 59,415 | 58,751 | 157 | 537 | 59,445 |
| 1.4 | Data Analysis System | 15,398 | 12,885 | 614 | 1658 | 15,157 |
| | Contingency | (176) | | | 23 | 23 |
| **Total** | | **292,100** | **288,853** | **848** | **2,399** | **292,100** |

Funds remaining to be encumbered and paid total $2.4 million.

[2] Project Management Plan, Revision C, LIGO-M950001-C-M submitted to the NSF November 1997.

We requested and received a no-cost extension to the Cooperative Agreement to June 30, 2003. This will be sufficient to complete the construction work discussed below. Our current focus is to manage the remaining funds and risk.

## 6.2. Performance Reporting

Figure 2 shows the time phased budget, earned value, and actual costs through the end of February 2003. The construction effort is 99 percent complete.

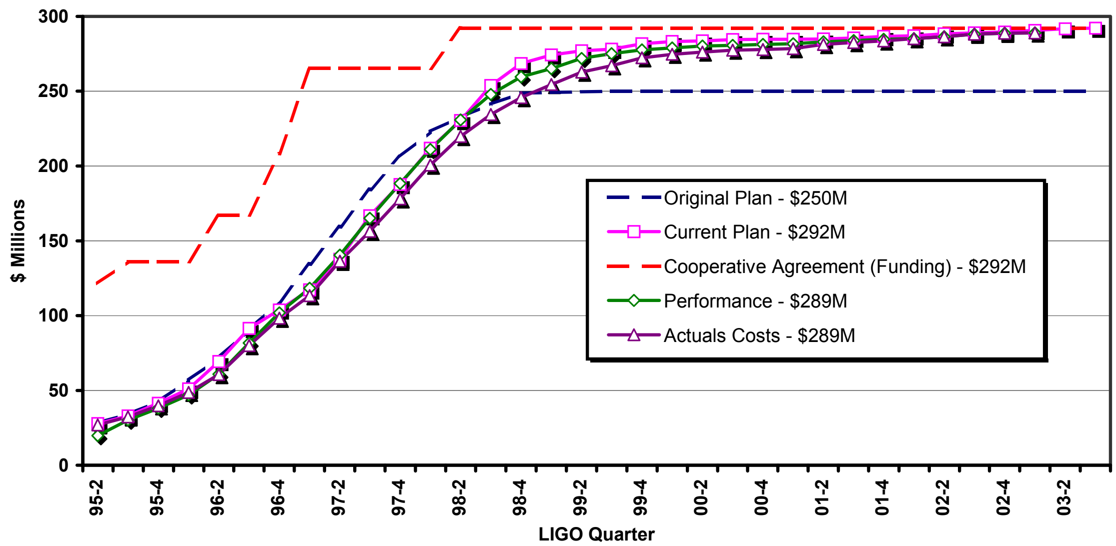


**Figure 2: Time-phased Budget, Earned Value, and Actual Costs for LIGO Construction Project (End of February 2003)**

**Vacuum Equipment (WBS 1.1.1).** All work is complete.

**Beam Tube (WBS 1.1.2).** All work is complete.

**Beam Tube Enclosures (WBS 1.1.3).** All work is complete.

**Civil Construction (WBS 1.1.4).** The contract to build a Laboratory Building at Hanford was completed during the fourth quarter. The Storage and Staging Building at Livingston is complete. Only very minor expenses not covered under the building contracts but relating to the building environment remain.

**Beam Tube Bake (WBS 1.1.5).** All work is complete.

**Detector (WBS 1.2).** The Detector is the largest task remaining to be completed, although of a total budget of $59,415,293 we have accrued and committed a total of $58,817,758. We continue to adjust priorities to optimize progress towards the science runs. The second science run began on February 14.

**Research and Development (WBS 1.3).** All LIGO Construction Related Research and Development effort is complete.

**Project Office (WBS 1.4).** All LIGO Project Office activities are complete with the exception of the procurement of computer hardware associated with the LIGO data analysis and computing systems. This represents most of the $2.4 million remaining to be spent. These procurements were delayed pending NSF approval of our procurement plan and also to achieve the most favorable performance per dollar ratio. The NSF has approved our plan, and procurements will be completed by June 2003.

## 6.3. Change Control and Contingency Analysis

The following construction project change request was approved this quarter. The total budget baseline is now $292,276,516 leaving a negative management contingency of $176,516. We project under runs in other accounts (Data Analysis, see Table 2) that will offset the negative contingency.

**Table 3: Change Requests Approved during First Quarter FY 2003**

| Change Request | Description | Submitted | Amount |
|---|---|---|---|
| **CR-030001** | WBS 1.1.4, Completion of the Hanford Laboratory Facilities | January 3, 2003 | $180,000 |