Quarterly Progress Report

(LIGO Fiscal Quarter Ending August 2001)

The Construction, Operation and Supporting Research and Development of a Laser Interferometer Gravitational-Wave Observatory (LIGO)

NSF Cooperative Agreement No. PHY-9210038

LIGO-M010259-00-P

Quarterly Progress Report

(End of August 2001)

THE CONSTRUCTION, OPERATION AND SUPPORTING RESEARCH AND DEVELOPMENT OF A LASER INTERFEROMETER GRAVITATIONAL-WAVE OBSERVATORY (LIGO)
NSF COOPERATIVE AGREEMENT No. PHY-9210038

LIGO-M010259-00-P

CALIFORNIA INSTITUTE OF TECHNOLOGY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

1.0 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) Project for the LIGO fiscal quarter ending August 2001.

Facility construction, including the vacuum system, is complete. All Beam Tube modules have completed vacuum bake, and we are installing and commissioning the detectors. The project continues to make excellent progress and is 97.4 percent complete as of the end of August 2001[2].

2.0 Vacuum Equipment

All Process Systems International (PSI) field activities are complete. All scheduled payment milestones are complete, and the PSI contract is closed out.

3.0 Beam Tube

All Beam Tube modules have been accepted, and all contract work is complete.

4.0 Beam Tube Enclosures

Washington Beam Tube Enclosure. Construction activity is complete. The contracts for the fabrication and installation of the Beam Tube Enclosure are closed.

---

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.
2. Percentage completion is calculated by dividing the budget for work completed by the total budget (BCWP/BCWS). The allocation of budget tends to hold down the percent complete by increasing the BCWS. Recent allocations of contingency by the LIGO Change Control Board to restore scope originally removed to manage program risks have retarded the reported percent complete.

Louisiana Beam Tube Enclosure. Fabrication and installation of all enclosure segments are complete. The contractor has finished all construction activities along both arms and the contract is closed.

5.0 Civil Construction

Washington Civil Construction. Construction activities for the facilities are complete. This includes completion of the Staging and Storage Building. An architect/engineering firm, NTD Architects of Glendora, CA, has been selected to design an additional office and laboratory building including an auditorium and other facilities for outreach activities. No additional Construction funds will be required. (Bids for this building were opened on September 26, 2001, with the low bid in the amount of $2,436,000 submitted by Cravenly Construction Company of Kennewick, WA. This compares favorably to our estimate of $2,841,022. We hope to be able to award this contract by the mid-October.)

Louisiana Civil Construction. Construction of the facilities is complete and the contracts are closed. We issued a contract during the first quarter to Brunt Construction Company of Independence, LA for the construction of the Staging and Storage Building. Work is in progress.

6.0 Beam Tube Bakeout

We completed the bake of all four Beam Tube modules at Hanford during 1999 and finished the final module at the Livingston site in 2000.

7.0 Detector

The Detector group is focusing on the installation and commissioning at the observatories. IAt the same time we are revising the design based on commissioning experience. Installation is nearing completion, with re-work after initial commissioning a continuing important activity.

7.1 Installation and Commissioning Progress Overview

The installation highlights for the past quarter are:

- After recovery from the Olympia earthquake, the Hanford two-kilometer interferometer is operating again in the full-recycled Fabry-Perot/Michelson configuration. The input power was increased from 100 mWatt to 1 Watt.
- We completed installation of the Hanford four-kilometer interferometer and verified the alignment.
- We accelerated and completed the replacement of the suspension sensor for the Livingston four-kilometer interferometer (originally planned for late summer). The anticipated improvement in performance was realized. We verified the realignment of the optics, and commissioning has resumed.
- The fifth engineering run (August 3-6) was the first to involve a full recycled Fabry-Perot/Michelson interferometer.

Continuing seismic studies at the Livingston Observatory reveal a strong diurnal variation, apparently from a large number of ground vibration sources. The level today is significantly higher than was seen in early site surveys and may be a consequence of continued growth in the surrounding community. Simple calculations indicate that the present suspension controllers cannot reliably hold the interferometer in lock in this environment (at least during the most active portions of the day). In the short term the drive capability of the suspension controllers at Livingston is being increased; for the longer term a team is studying the various possibilities for coping with this excess excitation.

7.2 Lasers and Optics

7.2.1 Pre-Stabilized Laser

We regularly use the pre-stabilized Lasers in all three interferometers. Incremental improvements and updates to the servo systems, based on commissioning experience at both observatories, are being applied to all lasers to bring them to a uniform design and level of performance. We are installing acoustic shielding on both four-kilometer interferometers to prevent room noise from affecting the laser frequency.

We tested a prototype intensity stabilization servo at Hanford on the two-kilometer interferometer, and it meets the requirements for stabilization prior to the mode cleaner, the so-called "inner loop." We are fabricating a unit with the standard EPICS[3] interfaces, and we will test it in the planned final configuration, in which a second "outer" stabilization loop is closed using a sensor located after the mode cleaner.

7.2.2 Input Optics

This quarter, we replaced the local sensors for all of the suspensions of the Livingston interferometer optics to reduce their sensitivity to stray Nd:YAG laser light. Before this rework, it was impossible to increase the laser power at the input to the mode cleaner beyond a few hundred mWatts without seeing the influence of cross-coupling as an increase in the optics angular motion. With the rework, the Livingston mode cleaner operates without difficulty up the full input laser power currently available.

The mode cleaners on all three interferometers are now fully operational and supporting other commissioning activities. They are key in understanding pre-stabilized laser performance and the continuing efforts to improve their performance. We are currently tuning the servo parameters to obtain optimal performance (chiefly the maximum suppression of laser frequency noise by the pre-stabilized laser/mode cleaner combination).

7.2.3 Core Optics Components

We completed the installation of the last end test mass for the Hanford four-kilometer interferometer this quarter. All core optics for the three interferometers have been characterized, delivered to

3. EPICS, Experimental Physics and Industrial Control System, a set of software tools and applications used worldwide to develop distributed real-time control systems for scientific instruments such as a particle accelerators, telescopes and other large scientific experiments. (See http://www.aps.anl.gov/epics/.)

the sites, and installed. Some core optics with minor defects have been sent to our polisher for rework so they can serve as spares.

7.2.4 Core Optics Support

Installation and alignment of all core optics support components have been completed concurrent with the installation of the final end test mass for the Hanford four-kilometer interferometer.

7.3 Isolation

7.3.1 Seismic Isolation System

We completed the in-vacuum seismic isolation system installation last year. This quarter at Hanford we started the installation and test of the control electronics for the fine actuator system used to off-load the correction for the tidal motion from the suspension actuators.

The seismic noise level at the Livingston site, particularly at the Y-arm end station, has been found to be higher than original surveys indicated and possibly growing with time. The seismic noise is characterized by impulsive noise in the 1 - 3 Hz band. The increase in this frequency band is clearly related to human activity (higher during working hours and lower on Sunday). Unfortunately this elevated noise coincides with isolation stack resonances that amplify the motion and cause unacceptably large rms excursions, which so far has precluded interferometer lock during the day.

We have assembled a team to investigate ways to mitigate this motion. In the meantime, we are modifying the suspension controllers to have a greater range, though this comes with some penalty in noise performance (See next section.) The motion of the seismic isolation platform must be reduced by about a factor of 10 in the frequency band from 1-3 Hz to keep the suspension drive circuit from compromising the interferometer noise performance.

Several ideas are being explored to provide increased seismic isolation as a retrofit to the initial LIGO seismic isolation system:

- A six degree-of-freedom hydraulic pre-isolation system being developed by the LIGO Scientific Collaboration (LSC) for Advanced LIGO Detectors,
- The existing Seismic Piezo-based Fine Actuator modified to operate beyond its current bandwidth,
- Tuned Mass Dampers added to the isolation stack to decrease the modal amplification, and
- Advanced vibration isolation solutions from industry.

The most promising approach appears to be the hydraulic pre-isolator. This actuator is external to the vacuum system, would replace the current coarse actuator system, and would not require rework of in-vacuum components. We are preparing the LASTI Beam Splitter Chamber (BSC) to be used to install and test a pre-isolator system during Spring 2002. We plan to complete the R&D, test, and production of the hydraulic pre-isolator system for installation at Livingston during the fourth quarter of 2002. The horizontal isolation performance for the hydraulic pre-isolator in the Stanford test stand is shown in Figure 1; the factor of ten suppression at several Hz would bring the motion to a satisfactory level at Livingston.

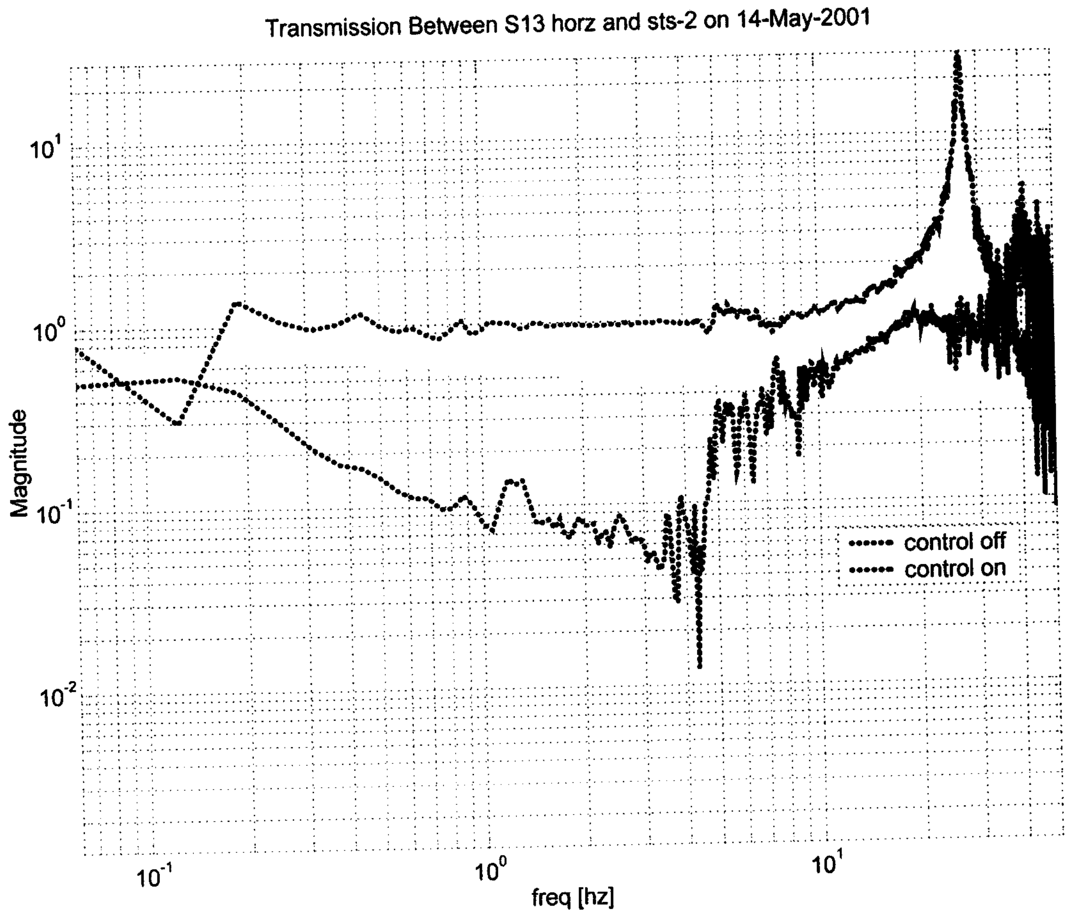

FIGURE 1. The horizontal isolation performance for the hydraulic pre-isolator in the Stanford test stand.

7.3.2 Suspensions

New digital suspension controllers have been installed and tested on the Hanford four-kilometer interferometer. These controllers allow frequency dependent matrices relating either the sensors or external inputs to the drive forces on the mirrors. This will be important for reducing the cross-coupling between the angle and translation feedback signals as we approach our overall design sensitivity. The initial tests with the new controllers indicate that they function correctly, and fabrication for the other interferometers is underway.

Near the end of the first month of testing, the digital suspensions suffered a previously unseen failure mode; the input analog-to-digital converter (ADC) lost synchronization, causing the controllers to drive the mirrors into oscillation. Repeated contact with the earthquake stops caused a static charge buildup that misaligned the input optics. We vented the vertex system to fix the misalignments and to make other small adjustments. Fortunately, it was relatively easy to implement a “watchdog” function on an independent processor, which monitors the motions of the mirrors and turns off the controllers in the event of oscillations.

During this quarter, the local suspension sensors previously installed on the Hanford interferometers were installed on the Livingston interferometer; these sensors eliminate the sensitivity to scattered laser light. As noted above, initial tests on the mode cleaner optics with the new sensors show that they perform well and solve the coupling problem. A number of the small optics were re-suspended to address problems identified during the early commissioning; in particular, the mechanical Q of some of the suspended optic pendulum motions had been anomalously low. Rubbing due to excess wire length is the most probable cause, and a rigorous inspection process was instituted to prevent further instances.

As an interim measure to fight the higher-than-expected seismic noise at Livingston, we are increasing the current drive amplifier capacity for the voice coil actuation on the optics to handle the larger required range. This modification will increase the electronics noise above a level acceptable to meet final science goals, but will permit continued commissioning at Livingston. In addition to the modifications to increase the drive capability, we are adding a circuit to monitor rms current to prevent the coils from overheating in vacuum.

7.3.3 Control and Data Systems (CDS)

The Control and Data Systems (electronics and software) group continues to make essential contributions during installation and commissioning of the subsystems, as well as during system level testing. The Hanford data acquisition system has been upgraded to accommodate the full data stream (over 6 Mb per second and over 6000 channels). After some tuning, it is now operating reliably.

We enhanced the code for the digital suspension systems to add digital excitation and readout test points; this required the addition of another processor to handle the computational load. This quarter we also focused on accelerating the computations for the digital length control servo system. Use of the locking code on the Livingston four-kilometer interferometer highlighted the need for robust handling of internal test points.

The length and alignment control electronics have been delivered and installed on the four-kilometer interferometer at Hanford. Attention has now turned to incremental improvements as the various systems are commissioned, as well as assuring that there are adequate spares to support both sites.

Another emphasis has been to upgrade the operating system to the most recent release of Sun Solaris; this is necessary to interface correctly to the LIGO Data Analysis System (LDAS) code. We then intend to "freeze" all code to this operating system version until necessity dictates otherwise.

7.4 Physics Environment Monitoring System

The Physics Environment Monitoring system is now functional and in regular use. Trend data (e.g., seismic activity) are regularly compiled and reviewed for anomalies or correlations with interferometer data. Verification and calibration of signals is an on-going task at both sites.

7.5 Global Diagnostics System

The Global Diagnostics tools, working together with the CDS data acquisition system, have become the key tool used in the commissioning of the interferometers. Enhancements to these tools continue to improve their utility.

The Data Monitoring Tool, designed to pace the full data rate while scanning for signatures of problems and optimizing the instrument, continues to run routinely at both sites. The Data Monitoring Tool will also serve a key role in the data analysis pipeline, providing "vetoes." Further development and testing of the code has been motivated as a result of the Upper Limit Data Analysis effort.

7.6 Interferometer Sensing and Control

Most interferometer sensing and control activities are reported in conjunction with the interferometer commissioning (described further below). At Hanford, the length and alignment sensors for the four-kilometer interferometer were set up on their optical tables and moved into position for integration with the interferometer. The locking electronics were delivered to the site and installed. Cabling and checkout is in progress. We continue to commission the wave front sensing alignment system on the two-kilometer interferometer. At Livingston, the cabling of the wave front alignment sensors was completed, and checkout of their operation is beginning.

7.7 System Level Commissioning/Testing

Commissioning activity was significant at both observatories this quarter.

Following completion of earthquake repairs at Hanford last quarter, the focus has been on the two-kilometer interferometer. We were able to re-align the interferometer and supporting optics. We successfully operated the mode cleaner at six Watts input power, but decided to operate the interferometer at one Watt input power until we gain operating experience with the protection circuits that protect the photodetectors from exposure to damaging light intensities during loss-of-lock events. These circuits have been commissioned on most of the interferometer outputs and are generally operating normally.

We tested the lock acquisition program at the higher power, and after re-measuring various parameters, locked the two-kilometer interferometer. The recycling gain of the two-kilometer interferometer reached about 25, compared with the 15 that had been observed in earlier commissioning. We attribute this improvement to some combination of mirror cleaning during the earthquake repairs, improved alignment stability due to the improved suspension sensors, and improved absolute alignment due to partial implementation of the wavefront sensing alignment system.

The noise level returned to the level observed prior to the earthquake. We believe frequency noise to be a significant contributor, and one of the main activities has been tailoring servo loops to minimize it. We redesigned the mode cleaner servo to improve its performance and tested it on the two-kilometer interferometer. We installed the common mode servo (the servo which feeds back from the average arm length to control the laser frequency). This servo uses three different feedback paths and requires careful adjustment to achieve stable operation. Initial tuning was accomplished using a single arm cavity, and at the end of the quarter we are ready to test on the full interferometer.

Commissioning on the Livingston interferometer was limited most of this quarter while we replaced the suspension sensors. Once completed, we then re-aligned, and started again the process of locking the interferometer. An important early result is that we measured the internal mode Q's of the end test masses and found them to be within the required range. Preliminary measurements prior to vent, which had indicated very low Q's, were apparently incorrect.

The arms of the Hanford four-kilometer interferometer were opened to the vertex optics for the first time this quarter, and the initial alignment was easily within the range of the suspension controllers. During the early part of the quarter we characterized and commissioned the pre-stabilized laser and mode cleaner.

We conducted the E5 Engineering Run this quarter. The Hanford two-kilometer interferometer was operated in the full-recycled Fabry-Perot Michelson configuration, with approximately 50 percent locked time, which we consider good performance at this stage of commissioning. At Livingston, the laser mode cleaner and the Physics Environment Monitoring system were operated. A number of LIGO Scientific Collaboration visitors and many staff members participated. We ran numerous Data Monitoring Tool (DMT) processes and produced useful information about the detector operation.

7.8 Work planned next quarter:

During the next quarter we plan to:

- lock the full Hanford four-kilometer interferometer and continue commissioning activities,
- upgrade the suspension controllers for the two-kilometer interferometer to the new digital servo design,
- increase the control authority in the Livingston suspension controllers to improve locking performance.

8.0 Data and Computing Group

8.1 Modeling

During this quarter the Modeling Group worked on the following:

- characterization and modeling of the Length Sensing and Control (LSXC) system electronics,
- improvements of the end-to-end noise model for the Hanford two-kilometer Interferometer,
- improvements of the mechanical systems model,
- refinements of the model of the frequency sensor system of the pre-stabilized laser,
- signal generators to simulate the time series of the strain from various signal sources.

A software tool for converting end-to-end data into frame format was released in June and is available at http://www.ligo.caltech.edu/~aivcere/Fbe/doc/html/index.html.

8.2 LIGO Data Analysis System (LDAS)

8.2.1 Software Systems

LDAS Software Releases. We again released three new versions of LDAS this quarter. The first, *ldas*-0.0.18 released June 22, 2001, fixed problems identified during the Inspiral Upper Limits Mock Data Challenge (MDC). The second, *ldas*-0.0.19, released July 19, fixed bugs and provided enhancements to support engineering run E5. Finally, *ldas*-0.0.20, released August 30, included the new *dataPipeline* functionality needed to support the Burst and Stochastic Upper Limits Mock Data Challenge at MIT in early September.

LDAS Engineering Runs. The LDAS group participated in one engineering run (E5) during this quarter. The components exercised included the *controlMonitorAPI* and the raw frame tape writing scripts. We enhanced the *controlMonitorAPI* to improve operator awareness of the status of data tape writing in response to requests after previous engineering runs. Operators expressed satisfaction with the improved visual queues for summary and health of the frame archival process and status of LDAS.

All E5 data has been archived in the High Performance Storage System (HPSS) at Caltech. An index is provided at http://www.cacr.caltech.edu/~dkozak/.

LDAS Boot Camp. We invited the members of the LIGO Scientific Collaboration (LSC) to attend a one week workshop focusing on the skills needed to develop code using LDAS and the LIGO/LSC Algorithm Library (LAL). This workshop, dubbed the LDAS "Boot Camp," was held at Caltech during the first week of June 2001. We also addressed development using the Diagnostic Monitoring Tool (DMT) in a parallel session. Approximately 25 LSC members attended.

LDAS Maintenance and Enhancements. New LDAS functionality has been motivated by lessons learned during Mock Data Challenges (the Burst and Stochastic Upper Limits MDCs are scheduled to be held in early September 2001.) Enhancements were also requested during the LDAS Boot Camp in June. Documentation has been updated to reflect suggestions by the LIGO Scientific Collaboration (LSC) and experience gained with each new installation.

8.2.2 Hardware Systems

We continue to archive all trend frames from both observatories as well as the full frames from the engineering runs. The current archive contains 18 Terabytes of data[4].

The phase I equipment for LDAS is in operation, comprising 28 Terabytes of disc storage, a 6000-slot tape silo, and Beowulf clusters for Hanford, Livingston, and MIT. We installed the complete LDAS system including a prototype 16 node Beowulf cluster at MIT this quarter.

At Livingston we investigated the BigBrother system administration network activity monitoring tool, which will be used to provide a measure of configuration control and can detect tampering with critical network system files. Our intent is to implement this solution elsewhere within the LIGO Laboratory once it is understood, documented, and reliable.

---

4. see http://www.srl.caltech.edu/personnel/sba/ligo/hpss.

8.2.3 Data Analysis Activities

Periodic Upper-Limits Working Group. The group has reduced from six to four the number of search algorithms to be implemented for the initial LIGO upper-limits run:

- Known pulsar--heterodyne narrow bandwidth,
- Known pulsar--coherent frequency domain,
- Wide area--hierarchical Hough transform,
- All sky--sum short power spectra.

Burst Upper-Limits Working Group. A major advance has been the definition of a new burst detection algorithm, similar to the excess power statistic, but appropriate for a uniform signal. The work is documented in LIGO publication LIGO-P010019-00-E currently being reviewed by the LIGO Scientific Collaboration (LSC). It will be applicable to searches for burst noise events in a Gaussian noise background and will be tested using data from the LIGO-Virgo exchange.

Stochastic Background Limits Working Group. We are publishing a paper that develops the concept of using a movable bar detector to modulate the stochastic background and thereby identify possible components of instrumental and environmental correlated noise that does not follow the quadrupolar antenna response expected from gravitational strain. In addition, we are investigating how to quantify possible long-term correlations from sites operating as part of a US power grid that imposes frequency stabilization. Data from earlier engineering runs have shown that there is possibly a low level of correlation that manifests itself as low narrowband FM around 60 Hz.

Network Data Analysis Activity. We continue to improve the experimental data exchange among LIGO sites, Caltech, and Virgo. We jointly maintain a Web site that provides a portal to the coincident databases: http://wwwcascina.virgo.infn.it/otherDetectors/NdasStatus.html or http://www.ligo.caltech.edu/~ndas/index.

Fast Chirp Transform (FCT). Since the Mock Data Challenge we have made several changes to the implementation of the FCT search code. The new changes enable the FCT to properly handle time-series data, instrument response, and noise power from the LIGO detectors. An improved event analyzer has been implemented to detect statistically significant events from the output of the FCT. A hierarchical algorithm has been designed and implemented to make the FCT search code more efficient. Comprehensive scientific verification of the improved FCT dynamically-loaded shared object is in progress.

Hierarchical Search Studies. In collaboration with VIRGO, we continued the development of a low computing cost technique, the Multi-Band Template Analysis (MBTA), for binary inspiral search. The first version of the code is being written at Annecy, France by the Virgo Lapp group. We expect to release it during the fall and then start measuring the cost saving relative to the conventional flat search approach.

In collaboration with IUCAA (Pune, India) we are also exploring an alternative, improved hierarchical search for inspiraling compact binaries. Because it is an extension of the original hierarchical search algorithm developed by Mohanty and Dhurandhar, and being implemented by the LSC

Upper Limits Inspiral Group, the new extension lends itself to direct application to the current approach. This procedure will reduce the overall computational cost since the parameter space can be searched more efficiently using the first stage as a trigger. We expect a factor of five to eight improvement in performance compared to the present hierarchical search implementation.

Grid Computing Research (GriPhyN Project). This quarter the LDAS group began prototyping a configuration that uses Grid Computing Technologies being promoted by the GriPhyN Project. These tools will provide a new standard of security for LDAS and its user community by integrating secure socket library (SSL) communications and certificate authentication. We plan to demonstrate a prototype using this hybrid at the Super Computing Conference this fall and will include GriPhyN Project participants from Caltech, the University of Wisconsin Milwaukee (UWM), and USC-ISI (the Information Sciences Institute of the University of Southern California).

ISI, Milwaukee, and Caltech groups have been collaborating extensively to devise and implement an end-to-end Virtual Data system for LIGO data, which we plan to demonstrate at the Super Computing 2001 convention in Denver in November. Globus[5] provides both security (see discussion above) and wide-area data distribution. Each installation of the LIGO Data Analysis System will communicate to the world only through two interfaces:

- a Globus job manager (also called a GRAM server), and
- a Globus data port (also called a GridFTP server).

A Request Manager module under construction at ISI receives Virtual Data requests, and decides which LDAS installation should complete the request, which data should be used as input, and where the output should go. Input data is moved to the local disk of a LDAS instance via the data port, the LDAS job is constructed and sent via the Globus gatekeeper, and the output moved from local disk to where it should be on the Grid. The request manager uses Condor[6] to schedule and execute these actions.

An XML-formatted virtual data request document, using the LIGO-LW (LIGO lightweight data) specification has been accepted by the collaboration, and tools have been built to both create requests from a client-side form on a web browser, and also to parse and implement requests on the request manager.

8.3 Laboratory Information Technologies Group

We are augmenting the Wide Area Network (WAN) at the Livingston Observatory by adding a second T1 line. This decision was predicated on usage statistics provided by Louisiana State University (LSU).

5. Globus--The Globus project is developing fundamental technologies needed to build computational grids. Grids are persistent environments that enable software applications to integrate instruments, displays, computational and information resources that are managed by diverse organizations in widespread locations. (http://www.globus.org/)
6. Condor--Condor works together with Globus software to provide the capability of submitting Condor jobs to remote computer systems. Globus software provides mechanisms to access and utilize remote resources. (http://www.cs.wisc.edu/condor/manual/v6.2/2_9Extending_your.html)

Hanford has upgraded a number of servers and installed a wireless network providing DHCP[7] services for visitors. Hanford network usage is also approaching the T1 bandwidth limit. LIGO is considering different options and will select the most cost-effective for increased bandwidth.

The LIGO Laboratory IT group is now using a web reporting system to record and track security issues such as viruses and network intrusions. After the recent spate of email virus attacks, we have instituted Laboratory-wide guidelines and procedures for the use of virus scan software. In addition, users have been educated concerning the need to be wary about downloaded files.

The sites have also been improving their network security. Each site has backup and restoration procedures in place, and we are exploring ways to efficiently backup local hard drives on the many independent PCs. Most of the critical PC workstations have backup systems implemented, and many users are now using CD RW devices to produce backups.

We used summer undergraduates to improve documentation and update the hardware and software inventory.

7. DHCP--Dynamic Host Configuration Protocol

9.0 Project Management

9.1 Project Milestones

The status of the project milestones identified in the Project Management Plan for the LIGO Facilities is summarized in Table 1. **All Facilities milestones have been completed.**

TABLE 1. Status of Significant Facility Milestones

Milestone Description	Project Management Plan Date[a]		Actual (A)/Projected (P) Completion Date	
	Washington	Louisiana	Washington	Louisiana
Initiate Site Development	03/94	08/95	03/94 (A)	06/95 (A)
Beam Tube Final Design Review	04/94		04/94 (A)	
Select A/E Contractor	11/94		11/94 (A)	
Complete Beam Tube Qualification Test	02/95		04/95 (A)	
Select Vacuum Equipment Contractor	03/95		07/95 (A)	
Complete Performance Measurement Baseline	04/95		04/95 (A)	
Initiate Beam Tube Fabrication	10/95		12/95(A)	
Initiate Slab Construction	10/95	01/97	02/96 (A)	01/97 (A)
Initiate Building Construction	06/96	01/97	07/96 (A)	01/97 (A)
Accept Tubes and Covers	03/98	03/99	03/98 (A)	10/98 (A)
Joint Occupancy	09/97	03/98	10/97 (A)	02/98 (A)
Beneficial Occupancy	03/98	09/98	03/98 (A)	12/98 (A)
Accept Vacuum Equipment	03/98	09/98	11/98 (A)	01/99 (A)
Initiate Facility Shakedown	03/98	03/99	11/98 (A)	01/99 (A)

a. Project Management Plan, Revision C, LIGO-M950001-C-M submitted to NSF November 1997.

Table 2 shows the actual and projected status of the significant Project Management Plan milestones for the Detector. Every effort has been made to prioritize critical-path tasks as required to support Detector installation. **The "Begin Coincidence Tests" milestone has been slipped to November 2001, because of the earthquake damage sustained in the Washington two-kilometer interferometer, efforts to mitigate higher-than-expected seismic noise in Livingston, and our decision to move forward the planned replacement of suspension sensors.**

TABLE 2. Status of Significant Detector Milestones

Milestone Description	Project Management Plan Date		Actual (A)/Projected (P) Completion Date	
	Washington	Louisiana	Washington	Louisiana
BSC Stack Final Design Review	04/98		08/98 (A)	
Core Optics Support Final Design Review	02/98		11/98 (A)	
HAM Seismic Isolation Final Design Review	04/98		06/98 (A)	
Core Optics Components Final Design Review	12/97		05/98 (A)	
Detector System Preliminary Design Review	12/97		10/98 (A)	
Input/Output Optics Final Design Review	04/98		03/98 (A)	
Pre-stabilized Laser (PSL) Final Design Review	08/98		03/99 (A)	
CDS Networking Systems Ready for Installation	04/98		03/98 (A)	
Alignment (Wavefront) Final Design Review	04/98		07/98 (A)	
CDS DAQ Final Design Review	04/98		05/98 (A)	
Length Sensing/Control Final Design Review	05/98		07/98 (A)	
Physics Environment Monitoring Final Design Review	06/98		10/97 (A)	
Initiate Interferometer Installation	07/98	01/99	07/98 (A)	01/99 (A)
Begin Coincidence Tests	12/00		11/01 (P)	

9.2 Financial Status

Table 3 on page 15 summarizes costs and commitments as of the end of August 2001.

TABLE 3. Costs and Commitments as of the End of August 2001

(all values are $Thousands)

WBS		Costs Thru Nov 1998	Costs LFY 1999	Costs LFY 2000	First Quarter LFY 2001	Second Quarter LFY 2001	Third Quarter LFY 2001	Cumulative	Open Encum-brances	Total Cost Plus Commitments
1.1.1	Vacuum Equipment	41,923	2,114	10	-	-	-	44,047	-	44,047
1.1.2	Beam Tube	46,251	753	-	-	-	-	47,004	-	47,004
1.1.3	Beam Tube Enclosure	19,418	153	(233)	-	-	-	19,338	-	19,338
1.1.4	Civil Construction	51,245	1,513	823	72	542	662	54,856	1,148	56,004
1.1.5	Beam Tube Bake	3,153	1,845	561	11	-	-	5,570	-	5,570
1.2	Detector	34,878	17,898	3,614	401	411	640	57,842	914	58,756
1.3	Research & Development	21,341	713	46	53	(2)	-	22,151	-	22,151
1.4	Project Management	27,562	1,525	845	75	1,669	161	31,838	190	32,028
7LIGO	Unassigned	20	13	(1)	-	-	-	32	-	32
TOTAL		245,791	26,527	5,665	612	2,620	1,463	282,679	2,252	284,930
Cumulative Actual Costs		245,791	272,318	277,983	278,595	281,215	282,679			
Open Commitments		16,422	7,078	1,378	3,000	2,748	2,252			
Total Costs plus Commitments		262,213	279,396	279,361	281,595	283,964	284,930			
NSF Funding - Construction		$ 265,089	$ 292,100	$ 292,100	$ 292,100	$ 292,100	$ 292,100			

Note: "Unassigned" costs have not been assigned to a specific LIGO Construction WBS but are continually reviewed to assure proper allocation.

9.3 Performance Status (Comparison to Project Baseline)

Figure 2 on page 18 is the Cost Schedule Status Report (CSSR) for the end of August 2001. The CSSR shows the time-phased budget to date, the earned value, and the actual costs through the end of the quarter for the NSF reporting levels of the Work Breakdown Structure. The schedule variance is equal to the difference between the budget-to-date and the earned value, and is a measure in dollars of the ahead (positive) or behind (negative) schedule position. The cost variance is equal to the difference between the earned value and the actual costs. In this case a negative result indicates an overrun. Figure 3 on page 19 shows the same information as a function of time for the top level LIGO Project.

Vacuum Equipment (WBS 1.1.1). All work is completed.

Beam Tube (WBS 1.1.2). The Beam Tubes are complete.

Beam Tube Enclosures (WBS 1.1.3). The contracts for both sites are complete.

Civil Construction (WBS 1.1.4). The original scope for Civil Construction has been completed. Additional scope has been budgeted for site improvements initially removed from the plan to conserve contingency. A contract has been issued for the Storage and Staging Building at Livingston and work is in progress. This contract is approximately two months behind schedule. A contract for an additional building at Hanford is being submitted to the NSF for review and approval.

Beam Tube Bake (WBS 1.1.5). The Beam Tube Bake has been completed. The underrun is due to favorable power rates.

Detector (WBS 1.2)

Washington Two-Kilometer Interferometer. We had completed installation of the two-kilometer interferometer and were well into the commissioning phase when an earthquake struck the Hanford facility at the end of February. We had locked the full recycled interferometer with both arms for periods up to an hour, and were working to improve the sensitivity. All repairs are completed now, and we have re-locked the interferometer and returned it to its previous performance. Sensitivity studies and improvements have the highest priorities.

Livingston Four-Kilometer Interferometer. We have installed all in-vacuum components including the suspended optics. We have completed an engineering run with the interferometer in the recombined mode. We have replaced the suspension sensors and have resumed commissioning activities.

Washington Four-Kilometer Interferometer. We have completed the installation of all in-vacuum components, and verified their correct alignment. The control systems for aligning the optics and locking the interferometer have been installed. The basic strategy has been one of staggered overlapping installation at both sites focusing on the two-kilometer interferometer at Hanford and the four-kilometer interferometer at Livingston. Installation and commissioning of the four-kilometer interferometer at Hanford has been deliberately delayed to make the best use of available resources as well as lessons learned during installation of the first two interferometers.

In spite of encouraging progress, the Detector continues to be behind schedule. Efforts to improve the schedule were set back by the Washington earthquake, and higher-than-expected seismic noise in Livingston. The net effect is that detector commissioning is about three months behind schedule. We continue to adjust priorities to optimize progress toward the Science Run.

Favorable Detector Cost Variance. A significant portion of the favorable cost variance in the Detector WBS is due to delays associated with processing and recording actual costs. As shown in Table 3, open commitments at the end of August totaled $913K.

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

Project Office (WBS 1.4). All LIGO I Project Office activities are complete with the exception of the procurement of computer hardware associated with the LIGO Data Analysis and Computing System (LDAS). These procurements were delayed pending NSF approval of our procurement plans, and also to achieve the most favorable performance per dollar ratio. The NSF approved the procurement plans early in March 2001, and the procurements are proceeding.

9.4 Change Control and Contingency Analysis

There were no change requests during the third quarter of FY 2001. The budget baseline for LIGO Construction remains at $291.6 million. This leaves a contingency (relative to the budget baseline) of $0.5 million. We are forecasting a $0.2M underrun relative to the budget baseline for the scope of work currently authorized so that the contingency relative to the estimate-at-completion is $0.7 million

9.5 Staffing

The LIGO staff currently numbers 163 (full time equivalent). Of these, 37 are contract employees. Ninety-nine LIGO staff are located at CIT including eight graduate students. 18.5 are located at MIT including five graduate students. Twenty-two are now located at the Hanford, Washington site, and 24 are assigned to Livingston, Louisiana. LIGO staff is partially paid by the LIGO Advanced Detector R&D Program, PHY-9801158.

LIGO Project
Cost Schedule Status Report (CSSR)
Period End Date: August 2001
(All values are $Thousands)

Reporting Level	Cumulative To Date					At Completion		
Work Breakdown Structure	Budgeted Cost of Work Scheduled (BCWS)	Budgeted Cost of Work Performed (BCWP)	Actual Cost of Work Performed (ACWP)	Schedule Variance (2-1)	Cost Variance (2-3)	Budget-at-Completion (BAC)	Estimate-at-Completion (EAC)	Variance-at-Completion (6-7)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1.1.1 Vacuum Equipment	43,970	43,970	44,047	-	(77)	43,970	44,047	(77)
1.1.2 Beam Tubes	46,967	46,967	47,004	-	(37)	46,967	47,004	(37)
1.1.3 Beam Tube Enclosure	19,338	19,338	19,338	-	-	19,338	19,338	-
1.1.4 Facility Design & Construction	55,288	54,856	54,856	(432)	-	58,501	58,501	-
1.1.5 Beam Tube Bake	5,695	5,695	5,570	-	125	5,695	5,570	125
1.2 Detector	59,530	59,130	57,842	(400)	1,288	59,530	59,359	171
1.3 Research & Development	22,089	22,089	22,151	-	(62)	22,089	22,151	(62)
1.4 Project Office	32,670	31,838	31,838	(832)	-	35,509	35,450	59
Subtotal	285,547	283,883	282,646	(1,664)	1,237	291,599	291,420	179
Contingency							680	(680)
Management Reserve						501		501
Total	285,547	283,883	282,646	(1,664)	1,237	292,100	292,100	-

FIGURE 2. Cost Schedule Status Report (CSSR) for the End of August 2001.

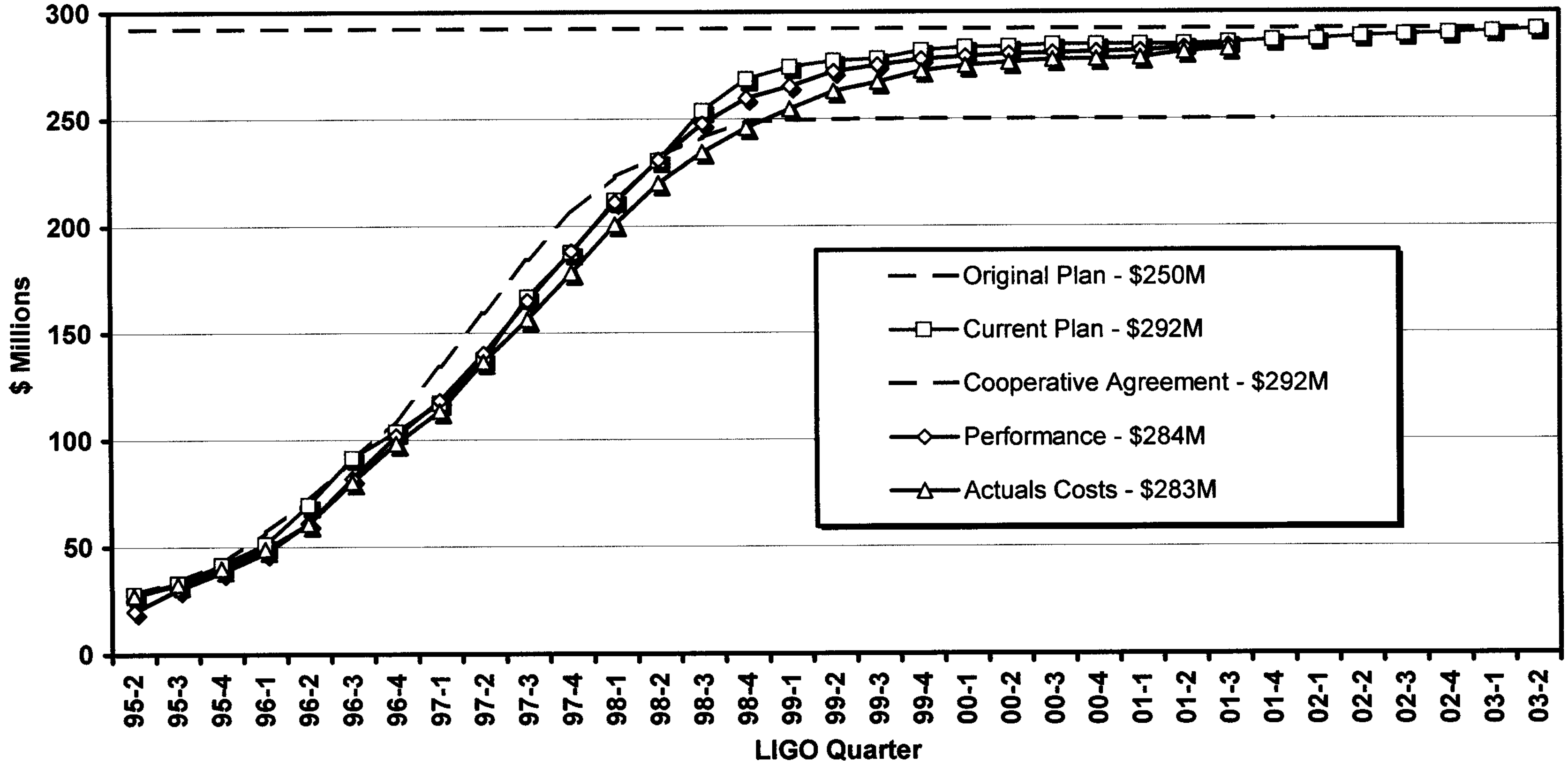

FIGURE 3. LIGO Construction Performance Summary as of the End of August 2001.