Quarterly Progress Report

(LIGO Fiscal Year Ending May 2000)

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

NSF Cooperative Agreement No. PHY-9210038

LIGO-M000192-00-P

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THE CONSTRUCTION, OPERATION AND SUPPORTING RESEARCH AND DEVELOPMENT OF A LASER INTERFEROMETER GRAVITATIONAL-WAVE OBSERVATORY (LIGO)

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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 May 2000.

Facility construction, including the vacuum system, is complete. At Hanford, all four Beam Tube modules have completed vacuum bake and we are in the process of completing the final bake at Livingston. Detector installation is in progress. The project continues to make excellent progress and is 98.2 percent complete as of the end of May 2000.

2.0 Vacuum Equipment

All Process Systems International (PSI) field activities were completed during the first quarter of the fiscal year. 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. Beam Tube module insulation and baking is discussed in Section 6.0.

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 pending the conclusion of litigation regarding charges by a subcontractor for sales taxes.

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[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.

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 the completion of the Staging and Storage Building. We are in the process of closing this contract.

Louisiana Civil Construction. Construction of the facilities is complete and the contracts are closed. We have awarded contracts for erosion control and landscaping, and for the design of a Staging and Storage Building. This work is in progress.

6.0 Beam Tube Bakeout

The bake of all four Beam Tube modules at Hanford, and three of the four modules at Livingston, is complete. The results of each vacuum bake have met or exceeded our goals. The bake of the final module has been completed and the data is being analyzed.

7.0 Detector

The Detector group is focusing on installation and commissioning at the observatories. Fabrication and design revisions based on commissioning experience are accomplished as parallel activities. We made significant progress this quarter.

7.1 Installation Progress Overview

Highlights for this quarter:

- Installation of the seismic isolation systems is complete at both observatories.
- We completed the installation of all in-vacuum components for the Hanford two-kilometer interferometer.
- We completed initial testing of the pre-stabilized laser at both observatories.
- We began installation of the four-kilometer core optics for the Livingston interferometer.
- We completed initial characterization of the Livingston mode cleaner-pre-stabilized laser system.
- We completed the Hanford two-kilometer one-arm Fabry-Perot testing.
- We performed the first LIGO engineering run, using the Hanford two-kilometer one-arm system.

Detector installation and commissioning are following the schedule shown below in Figure 1. The major commissioning activities this quarter were the single long arm cavity test on the two-kilometer interferometer at Hanford, and the combined pre-stabilized laser and mode cleaner commis-

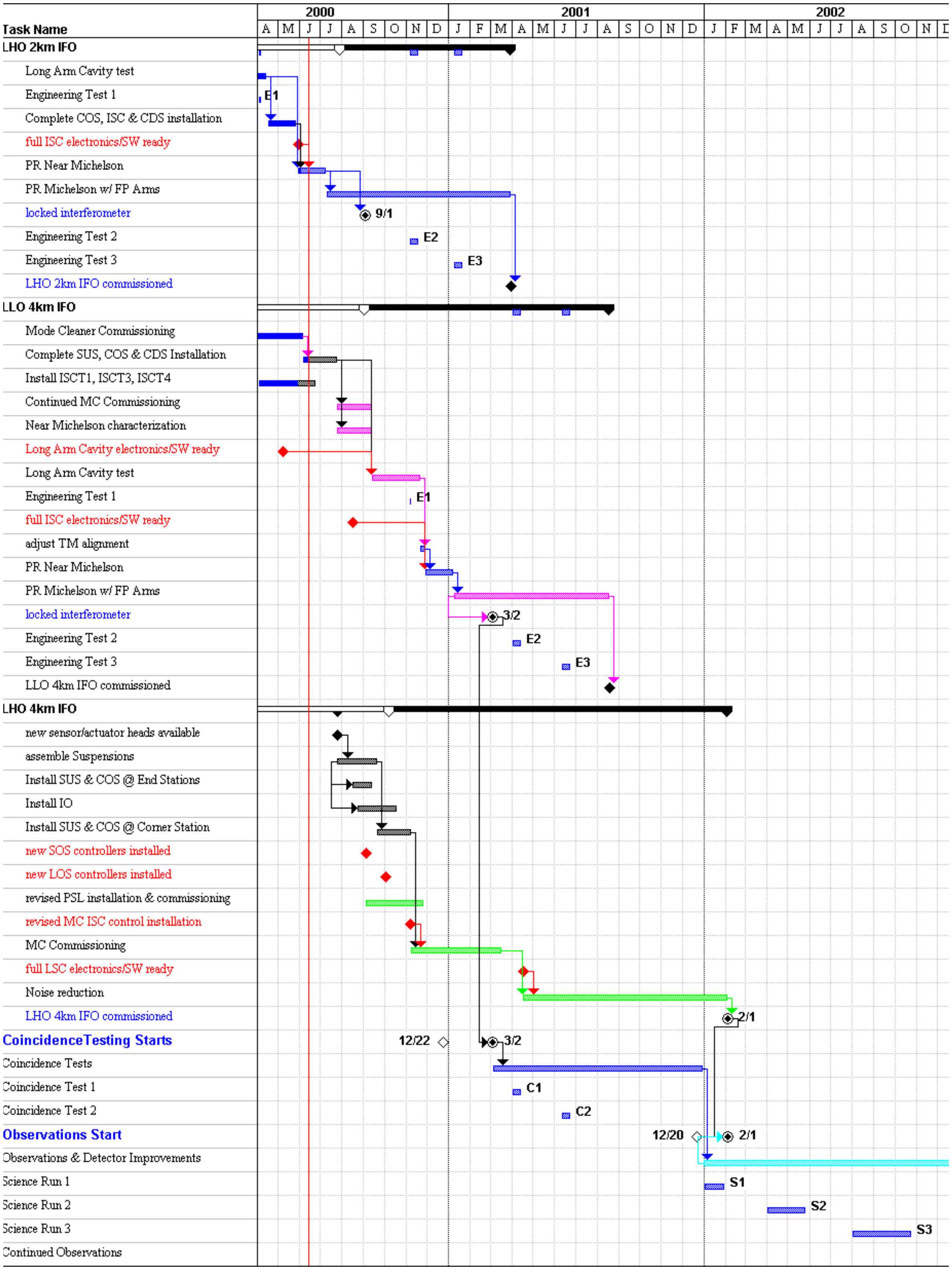

FIGURE 1. Overall Detector Installation Schedule.

sioning at Livingston. At quarter close, we are installing both systems: we are starting the installation of the main interferometer components for the Livingston interferometer, and completing the installation and alignment of installed components for the two-kilometer interferometer at Hanford. We are prepping the components for the Hanford four-kilometer interferometer to begin installation.

At Hanford, we have individually operated all cavities of the two-kilometer interferometer except for the recycling cavity. This includes both two-kilometer Fabry-Perot cavities and the short arm Michelson.

7.2 Lasers and Optics

Pre-Stabilized Laser (PSL). We regularly use both the Hanford two-kilometer and Livingston four-kilometer pre-stabilized lasers and have been incorporating incremental changes and improvements. Through the work at the observatories and on the campuses, we have achieved significant improvements in both the intensity and frequency noise. The intensity servo-control has been achieved through modulation of the current in the laser pump diodes. Changes in the current shunt have improved the actuator transfer function, allowing a better servo control.

We have conducted complementary studies of frequency noise at Hanford and Livingston and incorporated changes in the electronic and optical components as a result. Recent measurements at Hanford are shown in Figure 2. The upper curve is the frequency noise in this system as of January; the lower experimental curve is the recently measured noise, and the bottom-most curve is the performance requirement. The large improvement at high frequencies and between the peaks at lower frequencies comes from a re-ordering of filter and gain stages in the servo-control, and changes in the servo-control transfer function and demodulation phase adjustment. The low-frequency noise floor between peaks is better than our requirement; this indicates that the servo control has the required gain. At high frequencies, the factor two excess noise above requirements is under study, but believed to be due to the noise in the final voltage controlled oscillator and has a straightforward electrical solution. The majority of peaks in the spectrum are associated with mechanical resonances of the optical components and mounts, excited by acoustic pressure. We have identified the sources of the resonances (by selective excitation) and are in the process of replacing optical mounts with excessive sensitivity. We are also pursuing a reduction in the ambient acoustic noise by introducing acoustic shielding around the laser-input optics table and by modifying particular narrow band sources (e.g., the cooling fans in residual gas analyzers).

Input Optics. We studied the performance of the Livingston Observatory Input Optics this quarter. Following the model established at Hanford, the length, optical efficiency, and noise performance were investigated, various problems identified, and solutions crafted. Optically the system is satisfactory, and this phase of testing was completed. A lack of pointing stability will require changes in the optical suspensions (see Suspensions, below), and this will be done early next quarter.

At Hanford, the mode cleaner for the two-kilometer interferometer continues to be a key analytical tool for understanding the pre-stabilized laser.

Core Optics Components. We made a number of improvements in the metrology lab in preparation for measurements of the final interferometer core optics. We determined that the temperature

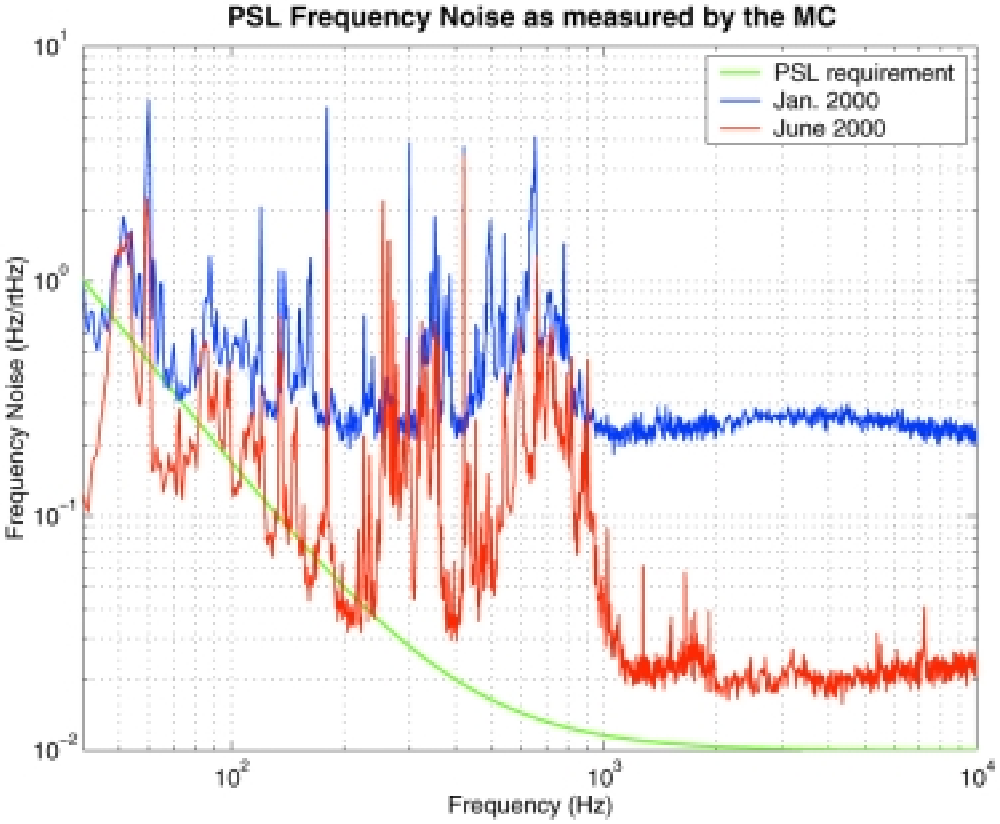

FIGURE 2. Laser frequency noise, two-kilometer interferometer at Hanford.

fluctuations in the lab are the principal limit to measurement repeatability and sensitivity and changed the heating/cooling system to provide better stability. We used the measurements of core optics made to date to improve the knowledge of the reference flat, augmented by a three-flat test. The objective is a more precise characterization of the optics for the Hanford four-kilometer interferometer. Measurements of previous optics were sufficient to show that the optics meet specifications. However, our goal is a detailed comparison of the optical performance with a model based on the metrology of the optics, and these improvements will support that.

We continued in-situ characterization of the optics at Hanford. As an example, the transmission of the two-kilometer recycling mirror was measured to be 2.81 percent ± 0.02. This is used in models for the optical performance and for trimming the servo control parameters. We began repolishing spares now that the main optics have been successfully installed at the observatories. Repolishing will provide matched sets for improved performance.

Core Optics Support. We completed the installation and alignment of the final core optics support components in the Hanford two-kilometer interferometer, and as the quarter ends installation at Livingston is underway.

7.3 Isolation

Seismic Isolation System. We completed the in-vacuum seismic isolation system installation at both sites for all interferometers on May 18, 2000. We also characterized the fine actuator (to be used to off-load the correction for tidal motion from the suspension actuators) and started the design and fabrication of components for that supplemental servo control.

Suspensions. We prepared the large optic suspensions for the Livingston interferometer this quarter. We continued the diagonalization of the sensor-actuator matrices and provided the results to the suspension controller redesign effort (see under Control and Data Systems, below).

Our efforts also focussed on the small optic suspensions for the Livingston mode cleaner. We observed excess beam jitter at the output of the Livingston mode cleaner relative to what was measured at Hanford. There is roughly an order of magnitude more motion, and it is more pronounced in yaw. A combination of detailed modeling and experiments on a spare suspension revealed the reason: the magnets which are used to correct for initial angle errors in the Livingston mode cleaner suspensions (but not the Hanford suspensions) cause strong perturbations to the mirror motion, so that the true normal modes are missing the symmetry of a correction-magnet-free suspension. Based upon this discovery, we have decided to eliminate the correction magnets from the small optic suspensions in the Livingston two-kilometer mode cleaner. This will require re-suspending two of the components at the next system vent (early next quarter) to reduce the initial offset, and the controllers will also be modified to permit larger dynamic range (while still meeting noise requirements).

7.4 Control and Data Systems (CDS)

The data acquisition system is operating in all buildings at Livingston, and continuous monitoring of environmental data, as well as interferometer parameters, is possible. Production of the data acquisition and controls hardware for the Livingston and Hanford four-kilometer interferometers is underway.

We completed the design and fabrication of the Hanford two-kilometer full length control system servo modules, and we are installing the modules for testing (described below under System Level Testing) in the two-kilometer interferometer.

As a result of the extensive experience gained at both Livingston and Hanford, we have decided to redesign the suspension controller system. The improvements will address a better understanding of the mechanical systems and their imperfections and correct for shortcomings in the local sensors. The core of the new controller will be digital, allowing more subtle coupling matrices between the sensors and the actuators (e.g., frequency-dependent terms). The sensors will be rebuilt using modulation-demodulation techniques to give a strong rejection of stray Nd:YAG light, which can confuse the local damping mechanisms. These new sensors can be employed with the existing suspensions (no incursion into the vacuum is needed) and will be incorporated and tested as the opportunity arises. The design and testing of prototypes and code is underway.

7.5 Physics Environment Monitoring System

The Physics Environment Monitoring system is now functional and in regular use. Trend data (e.g., dust, weather, and seismic activity) are measured continually and reviewed for anomalies or correlations with interferometer data.

7.6 Global Diagnostics System

We have refined the software tools, which are used regularly to support commissioning activities. A successful test of the Data Monitoring Tool, designed to keep up with the full data rate while scanning for problems and optimizing the instrument, was accomplished using an extended data set from the two-kilometer one-arm test.

7.7 Interferometer Sensing and Control

We are performing the initial alignment of the Livingston core optics. This follows successful completion of initial alignment at Hanford for the two-kilometer interferometer. We are pursuing the issue of short lifetimes for the optical lever laser diodes noted last quarter, both through a modified lowered power level for the present diodes and a search for a longer-lived diode for future installations and replacement. It appears preferable to use a shorter wavelength, and we are measuring the reflectivity of the core optics at the alternative frequency. In the interim, we have spares and commissioning can continue without interruption.

Sensing and control installation is in progress at Livingston. We have assembled most of the optical tables; the mode cleaner length and alignment controls are operational and were used during the commissioning activities.

At Hanford, we activated the alignment system for the two-kilometer one-arm test and confirmed the suitability and performance of the design. Successful operation was important for exploiting the one-arm configuration.

We successfully tested the prototype length controls for the full Hanford two-kilometer interferometer in the one-arm configuration, and the common-model length servo system is now in final design and production. Lock acquisition modeling and low-level real-time coding continues, and results are being checked against the "***e2e***" end-to-end simulation code.

7.8 System Level Commissioning/Testing

Commissioning activities were intense at both observatories this quarter. At Livingston, we concluded initial studies with the combined pre-stabilized laser and input optics subsystems; the results are discussed in the subsystem sections above. At Hanford, we focused on the completion of the two-kilometer arm cavity testing. The longest continuously "locked" period was 10 hours, allowing characterization of slow trends and high-resolution studies in the frequency domain.

One example of the results of this testing (See Figure 3) shows data during lock of the Hanford two-kilometer X-arm cavity March 3, 2000. The objective was to see how the six-to-eight second period microseism changes the length of the two-kilometer cavity by comparing the actual cavity length fluctuations, as indicated by the length control signal of the cavity servo, with the fluctuations measured by seismometers. The longer term goal is to use the seismometer signal to adjust the cavity length, via the stack fine actuators, and thereby reduce the length fluctuations at the microseism. To date the comparison has used only the minimal seismic information: the X-axis channel of the Laser and Vacuum Equipment Area (LVEA) and the X-arm mid-station seismometers. The comparison looks very encouraging; the coherence between the cavity length control signal and the difference of the two seismometers is good at the frequencies of interest (approximately 0.92 at the peak). The figure shows 200 seconds of the length control signal, the seismometer difference signal, and the residual difference between the two. The amplitudes match up well using only the specified calibration of the seismometers and the measured calibration of the length control signal. Based on this analysis we are developing a servo using this signal to control the fine actuator in the mid-station (at the end of the two-kilometer interferometer).

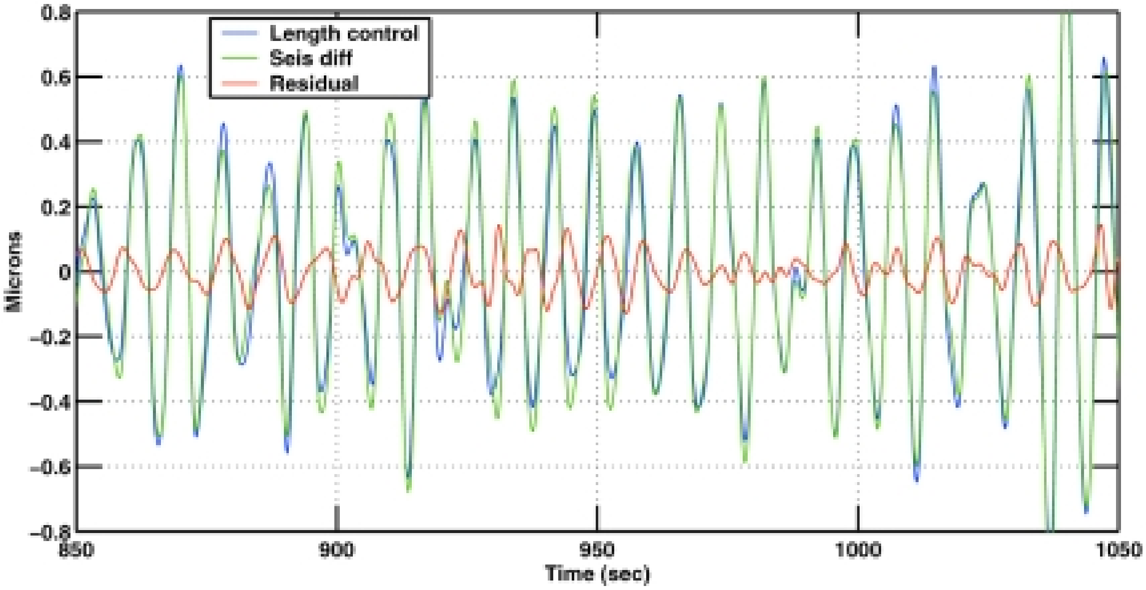

FIGURE 3. Time series showing the length control signal, the differential optic axis motion measured with seismometers at the ends of the two-kilometer cavity, and the difference (the smallest signal).

The one arm testing also provided important data about the performance of the optics. Measurements of the arm cavity storage time and reflectivity proved that the reflectivity and losses of the individual test mass mirrors meet specifications. Based on the analysis of optical matching data, we plan to change the position of one mirror of the input coupling optics by nine millimeters which should improve coupling to the two-kilometer arm cavity from approximately 96 percent to approximately 98 percent.

We accomplished the first of the Engineering Runs this quarter using the single two-kilometer arm being commissioned at Hanford. This data should be quite useful in detector characterization studies, both in understanding the single arm's behavior and in exercising algorithms now being developed. Several LIGO Scientific Collaboration (LSC) researchers came to the Hanford Observatory to participate in the data run, which started at 15:00 on Monday, April 3, 2000 and ended Tuesday, April 4 at noon. The computer storing a reduced data set hung up in the middle of the night resulting in the loss of about two hours of data. The remaining 19 hours generally exhibited good locking behavior with typical locked periods in the range of 30 to 120 minutes. The exercise provided significant experience and knowledge about the system.

A typical use of this data is in the search for transients. Clearly, this is important not only now to help characterize the instrument, but also for the future development and testing of algorithms to scan the data from the complete operating interferometer. The complete data sets for 11 channels taken during the April 3-4 run were processed and searched for correlated transients. The analysis required approximately 90 hours on the Sun 450 computer at Hanford. The strongest bursts appear to be periodic narrow-band signals with discrete frequencies at 55, 57, and 70 Hz lasting approximately 150 seconds and occurring every 900 seconds. These bursts are observed in the corner station seismometer and in the cavity control signal. They are likely produced by some mechanical equipment, and we are searching for the source using portable accelerometers and instrumentation. In addition, we saw bursts with well-defined frequencies monotonically decreasing from approximately 110 Hz to about 50 Hz over 80 seconds. These bursts are strong in the mid-station seismometer and somewhat weaker in the corner station seismometer and cavity control signal. There are at least 22 of these bursts in the 22 hour data record, and they occur only during daytime, i.e., between 6am and 9pm. At least 13 of them are visible in the cavity control signal. The source appears to be Doppler-shifted vibrations from airplanes. There is numerical agreement for jets flying above five kilometers in altitude at approximately 700 kilometers per hour, and FAA records support the coincidence in timing of airplanes with the bursts.

Work planned next quarter

Next quarter we plan to:

- complete the commissioning of the Hanford power-recycled near-mirror Michelson interferometer,
- complete installation for the Livingston interferometer,
- start the commissioning of the Livingston power-recycled near-mirror Michelson interferometer, and
- start the installation of the suspensions, the core optics components and support, and the input optics for the Hanford four-kilometer interferometer.

8.0 Data and Computing Group

8.1 Modeling and Simulation

8.1.1 Lock Acquisition Study

We completed the baseline redesign for LIGO lock acquisition and delivered the code to the Control and Data System (CDS) group for implementation. The design assumes that laser frequency noise can be reduced further than the presently measured value. It is based on a simulation using a single mode model of the field (TEM_{00}). We are investigating the effect of angular misalignment of the mirrors for the Michelson locking case. Preliminary results indicate that a misalignment of the order of 0.1 μradians can be accommodated. During this study, the source code of the Michelson summation cavity was debugged and improved to increase accuracy and to simulate the field noise properly. Simulating the full LIGO interferometer with higher order modes requires a much longer computation. We are exploring the possibility of using faster processors including the Alpha chip.

8.1.2 Simulation Engine

We updated the simulation source code to use ANSI C++ standard template library tools, such as the vector data type, instead of custom tools, like block objects, which were designed in-house. As a result we have realized a decrease in computation times of between 50 and 80 percent depending on the configurations being simulated.

We also revised the digital filter implementation. The new algorithm is based on the second order '***matlab***' algorithm, and the filter calculation uses the same code as the CDS. The whole calculation from psiir.m[2] to the CDS filter is now reproduced in the end-to-end (***e2e***) digital filter. A benefit is that one digital filter may contain many zeros and poles with different magnitudes. In the old implementation, either quadruple precision or several cascaded digital filters were needed. The new implementation still switches automatically to quadruple precision internally for the simulation of thermal noise with very small time steps.

8.1.3 Modeling of Mechanical Systems

We have completed the interface definition between the Mechanical Simulation Engine (MSE) component and end-to-end model. We have also addressed other details, including the structure of automake and autoconfig, the graphical user's interface (GUI) for assigning very complicated settings of a MSE-based primitive, and the treatment of global variables, such as temperature. The final integration is ongoing, and the fully integrated code will be completed in June.

In addition to this flexible mechanical model, we have developed a fixed configuration mechanical primitive to simulate the LIGO single-suspension 3D masses. The model simulates a system composed of two suspension wires and one cylindrical mass and can be used for fast simulations. The length sensing and control (LSC) and alignment sensing and control (ASC) systems can be fully simulated using this model.

LIGO and VIRGO[3] have also made significant collaborative progress in data analysis and simulation. For example, the mechanical model developed primarily for LIGO can also be used by VIRGO. Other specific efforts will be discussed and defined in attachments to the Memorandum of Understanding (MOU) for the LIGO-VIRGO collaboration.

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[2] pziir.m is a ***matlab*** code file written by Peter Fritschel. When a device is characterized by zeros and poles and must be emulated on a computer, we use this pziir.m (pole-zero-infinite-impulse-response) code to convert those zeros and poles to a set of numbers which can be embedded in the CDS code (which uses its own code to do the infinite-impulse-response filtering). The term "uses a digital filter" is not quite unique in its meaning, and until now, the end-to-end model had its own implementation of a digital filter. But, to make the simulation as close as possible to the real world, we adopted pziir.m and the CDS calculation. But the end-to-end model does not interface to ***matlab***, so the code has been rewritten in C++ and the same functionality has been embedded in the model.

[3] Italian-French Laser Interferometer Collaboration.

8.1.4 Thermal Noise

Thermal noise will be implemented within the MSE. To improve simulation speed, a model based on a digital filter has been implemented in the end-to-end model.

8.1.5 Graphical User's Interface (GUI)

We have released a new version of ***alfi***, the GUI front-end for the end-to-end model. A screen snapshot is provided in Figure 4. Two new features introduced this version greatly improve its capabilities. The first is a tree view of box structures. As shown in Figure 4, a tree view window looks and behaves like a browser of the file system. Instead of files and folders, however, the view shows the simulation primitives and boxes (macro objects). In the tree view window, the content of a box can be expanded ([-] at the node) or collapsed ([+] at the node). This enables navigating and editing complex systems. A second new feature is the support of multiple directories. Until now, the GUI could handle only the box files in the same directory where ***alfi*** was started.

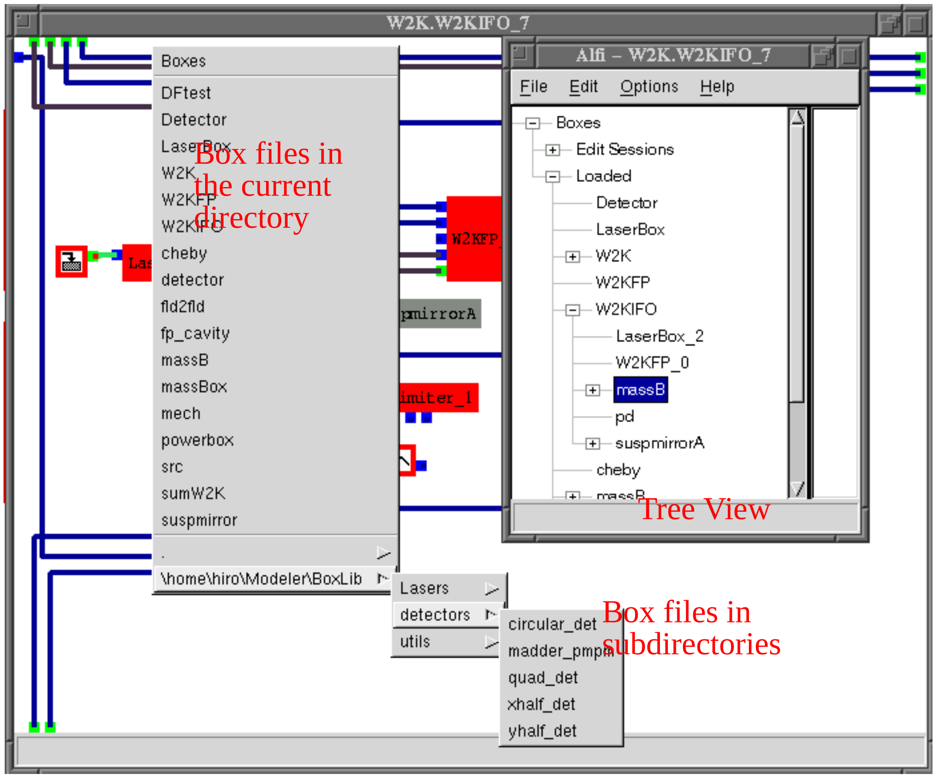


FIGURE 4. *alfi* Screen.

8.2 LIGO Data Analysis System (LDAS)

8.2.1 LIGO/VIRGO C++ Frame Class Library (FrameCPP)

We completed the C++ I/O class library for the newest 4.0 Frame specification this quarter. The additional functionality to support a table of contents for the frame file along with other enhancements have improved the performance of the higher level FrameAPI (Application Programmer's Interface) significantly. Figure 5 demonstrates the levels of improvements realized relative to the previous frame file specification and software configuration (top and bottom bars). In each case shown, a full frame is ingested from disk into the FrameAPI. Based on the content of the user request, various channel subsets are extracted and translated into the Internal Light Weight Data (***ilwd***) format. For extracting large numbers of channels, performance is roughly three times faster. This can easily support five full (one second) frames of data being read into LDAS per second. For cases involving only a few channels of data per request, improvements are roughly 25 times better than previous LDAS code.

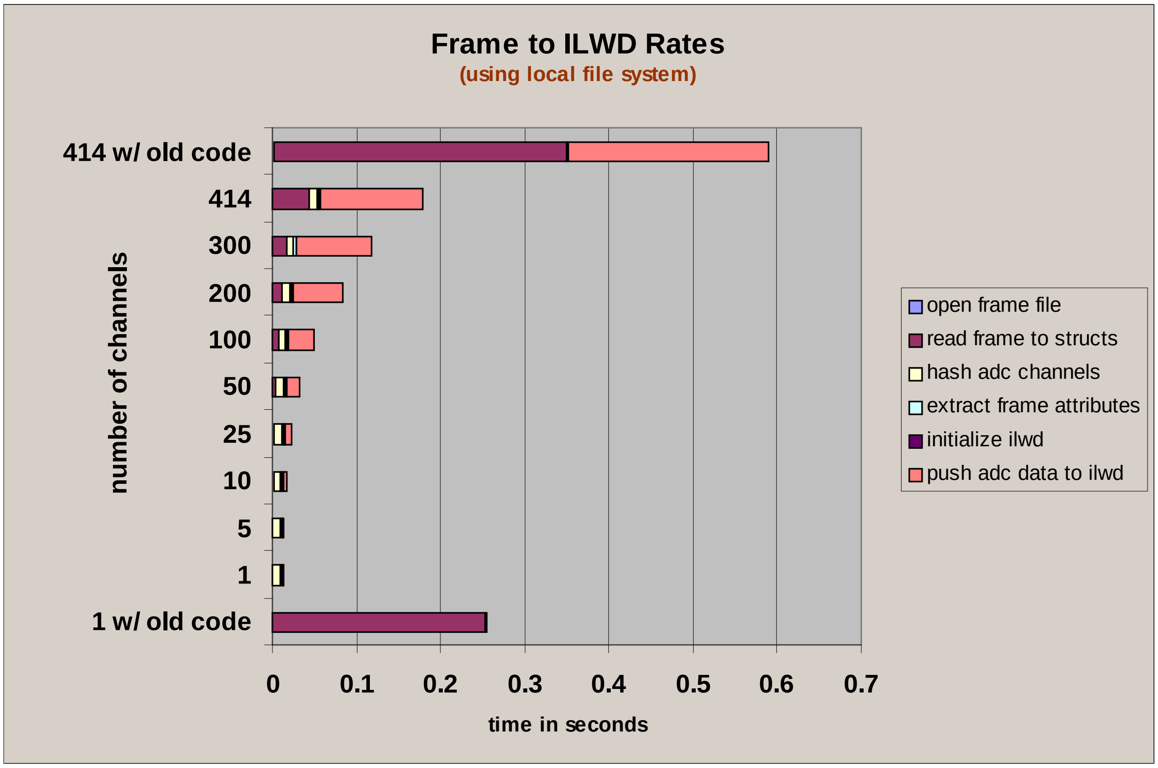


FIGURE 5. Internal Light Weight Data (*ilwd*) conversion times for LIGO/Virgo Frames using the new Version 4.0 FrameCPP I/O library.

8.2.2 The wrapperAPI and Other Parallel Computing Components of LDAS

We invested tremendous effort in the design and implementation of the Message Passing Interface (MPI) based wrapperAPI. This LDAS API is responsible for the calculations required to run the algorithms used in the search strategies in parallel on the LDAS massive cluster of computers (BEOWULF). The API receives data and control messages from the LDAS system, passes these data to the complement of nodes running the parallel code, gathers the results, and submits the results back to LDAS for inclusion in the LDAS database. LDAS staff is working closely with members of the LIGO Scientific Collaboration (LSC) from the University of Wisconsin at Milwaukee (UWM) to develop a test case using dynamically loaded shared objects of UWM design within the framework of the LDAS wrapperAPI. Preliminary tests indicate that the required functionality of the wrapperAPI is now in place and future verification and validation tests will be used to tune the wrapperAPI and dynamically-loaded shared-object designs. Once the wrapperAPI is fully functional it will be integrated into an LDAS/LSC Mock Data Challenge. See Figure 6 below.

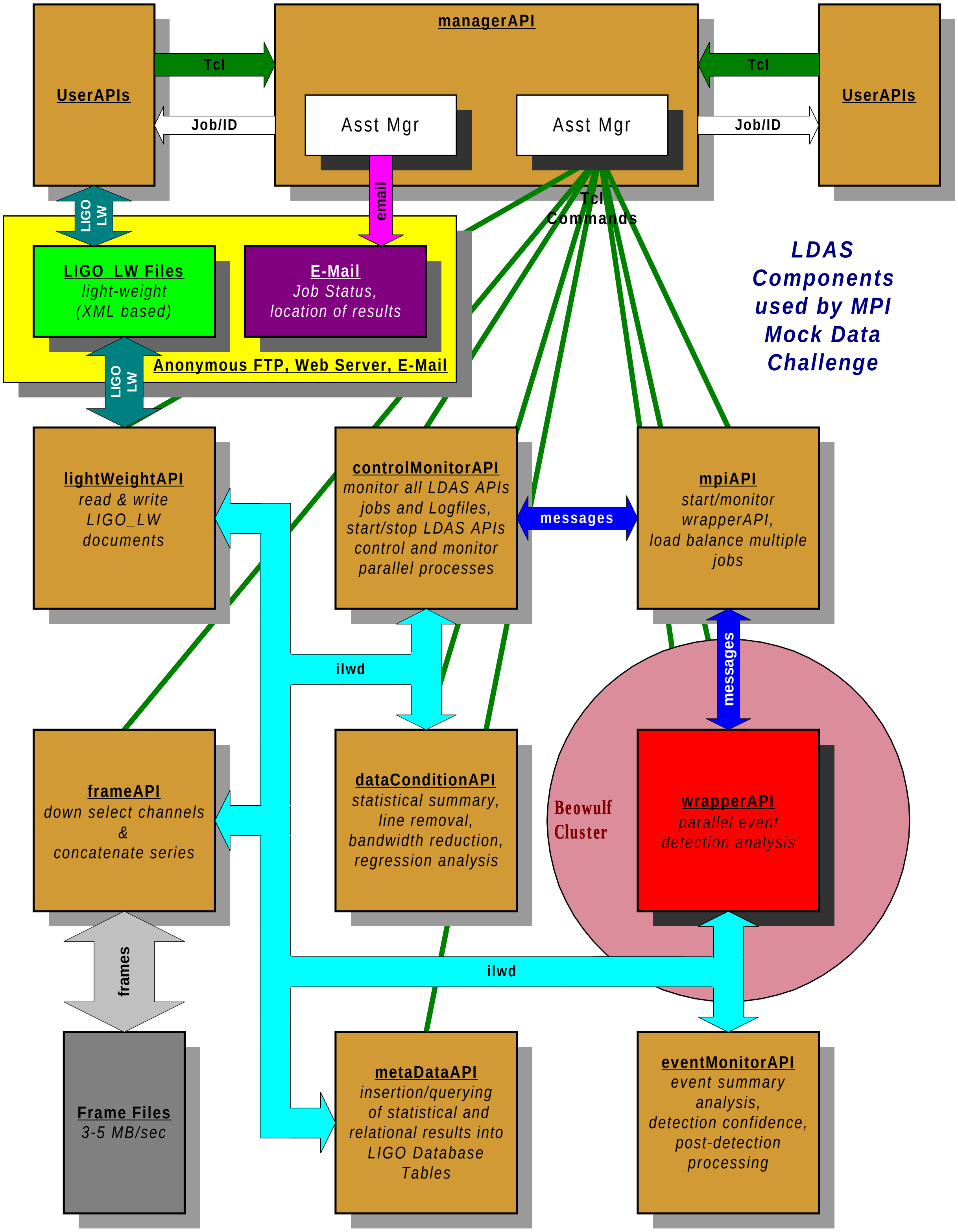


FIGURE 6. The LDAS components and data flow to be tested in the parallel mock data challenge at the end of the year.

8.2.3 The Pre-parallel Processing dataConditionAPI

Members of the LDAS group have also been working with a widely distributed group from the LIGO Scientific Collaboration (LSC) to develop the dataConditionAPI. This API prepares the data for the parallel computing wrapperAPI. It is also responsible for producing statistical summaries of data sets and for reduced data sets such as current best estimates for gravitational strain. The working group has included the California Institute of Technology, Pennsylvania State University, the University of Texas at Brownsville, and the Australia National University at Canberra. Software development has been entirely in C++ with a strong object-oriented paradigm. The goals of the working group are to have a subset of the dataConditionAPI baseline requirements implemented and ready for the first LDAS/LSC Mock Data Challenge next quarter. Currently, the dataConditionAPI functionality includes:

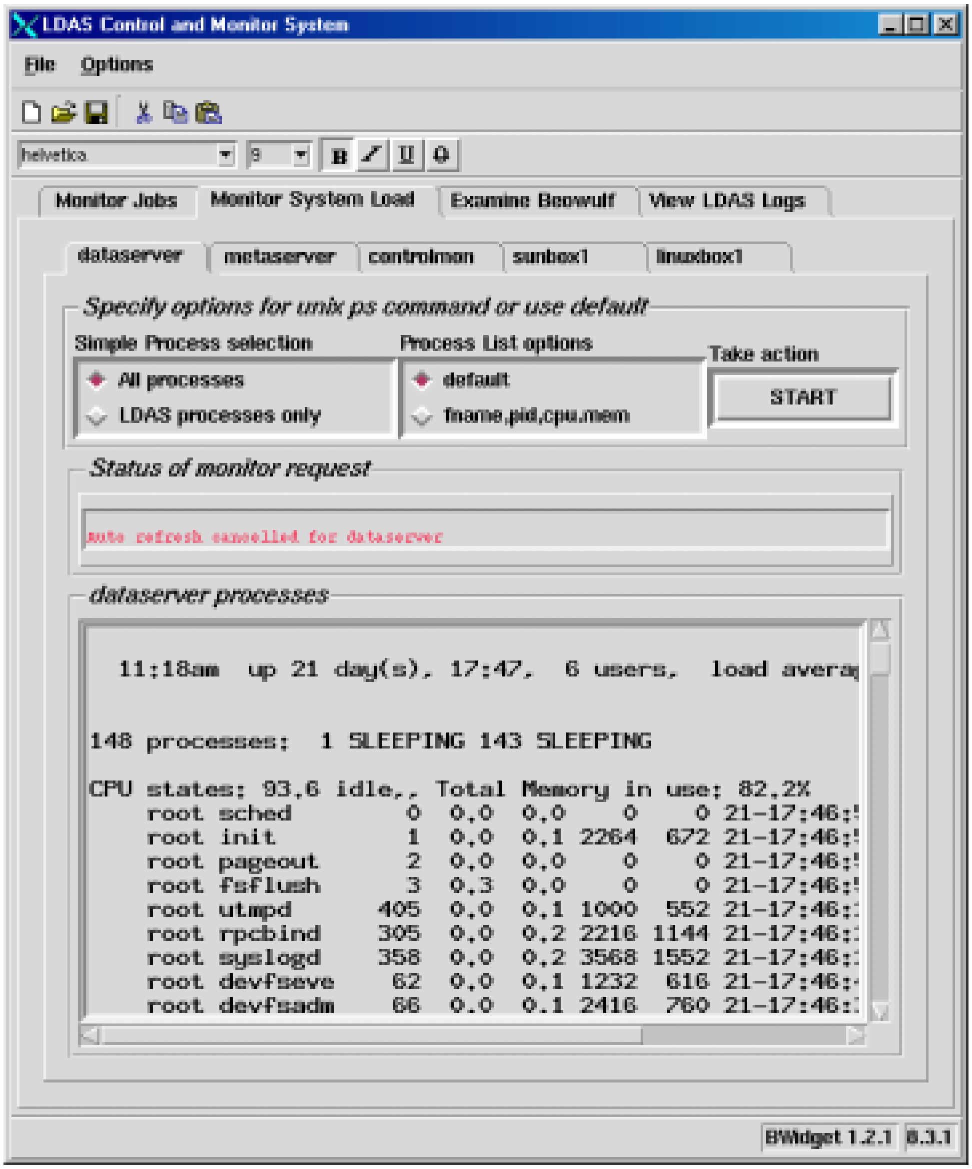
- Mixer Classes - used to heterodyne data to different frequencies,
- Statistics Classes - used to statistically characterize data sets in the dataCondtionAPI,
- Power Spectral Estimators and Window Classes - used to estimate power spectra,
- Fourier Analysis Classes - used to efficiently carry out Fast Fourier Transforms,
- Data Classes - used to share time and frequency data between algorithms.

The dataConditionAPI is a heavily threaded application, intended to be executed on a quad-Pentium III platform. We are implementing additional C++ object classes to chain sequences of algorithms, to support collecting intermediate results (in addition to the final result), and to direct each result to a unique destination.

8.2.4 The LDAS controlMonitorAPI

We began the development of this Applications Programmer Interface (API) last quarter. Its primary purpose is to monitor and control the state of all LDAS software and hardware from a Graphical User Interface (GUI). The design calls for two components. The first is a server which polls the LDAS system and executes user commands. The second is the GUI client with which users interact. Communication with the server component is through a socket. This permits multiple clients and enables monitoring of the health and status of the LDAS system from any Unix computer on the LDAS network supporting the TCL/TK package. Separation of the API into a server and client allows us to implement the server strictly using TCL. The TCL interpreter is much more efficient and is also safer for developing threaded applications without the TK widgets. Figure 7 shows an example client-side controlMonitorAPI as it is used to monitor remote processes around the LDAS system. Users may select a particular remote host to monitor, and they may request periodic updates on that system’s load. Future enhancements will include color coding LDAS components and the ability to sort and select process subsets.

The controlMonitorAPI currently has GUI interfaces for monitoring the API logs, the processes currently running, and the status of the DB2 database. Future functionality will include the ability to control LDAS APIs, configure job queues on the parallel computing cluster, and rearrange the priorities of jobs running on LDAS. The user will also be able to request the LDAS managerAPI to cleanly shutdown and restart various components of the LDAS system and to purge exhausted system resources.



auto refresh cancelled for dataserver

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  11:18am  up 21 day(s), 17:47,  6 users,  load avera

148 processes:  1 SLEEPING 143 SLEEPING

CPU states: 93.6 idle,, Total Memory in use: 82.2%
    root sched        0  0.0  0.0    0    0 21-17:46:
    root init         1  0.0  0.1 2264  672 21-17:46:
    root pageout      2  0.0  0.0    0    0 21-17:46:
    root fsflush      3  0.3  0.0    0    0 21-17:46:
    root utmpd      405  0.0  0.1 1000  552 21-17:46:
    root rpcbind    305  0.0  0.2 2216 1144 21-17:46:
    root syslogd    358  0.0  0.2 3568 1552 21-17:46:
    root devfseve    62  0.0  0.1 1232  616 21-17:46:
    root devfsadm    66  0.0  0.1 2416  760 21-17:46:
```

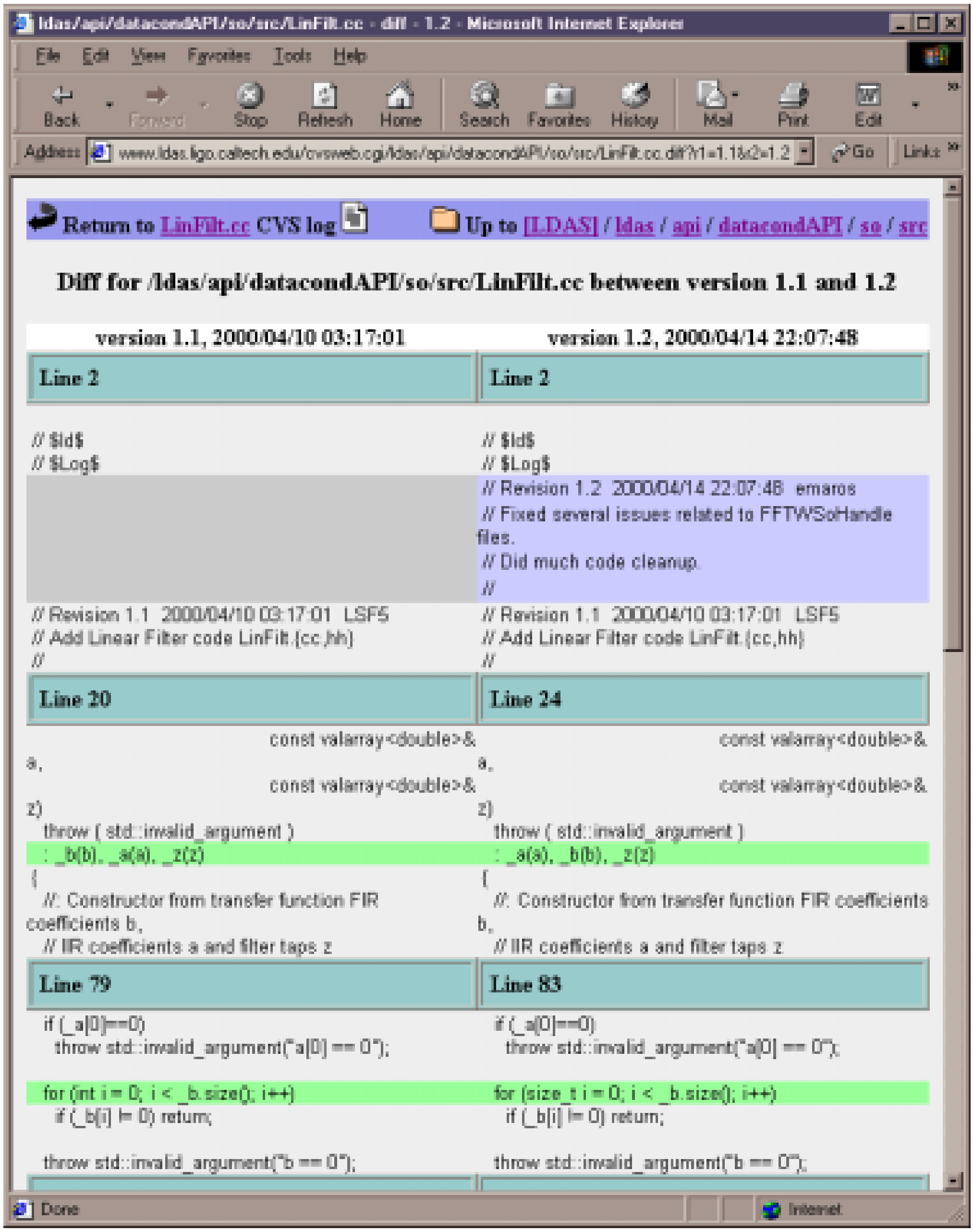
FIGURE 7. User Interface to the controlMonitorAPI client used to request system resource loads on components throughout the LDAS system.

8.2.5 LDAS Software System Reliability and Robustness

We have improved the reliability of the LDAS system significantly during the last quarter. We have cleaned up the ILWD data transmissions via sockets and implemented new methods for monitoring the status of a data transmission between two LDAS APIs. All significant API memory leaks have been identified and fixed. We complemented this with a set of memory usage throttles added to the managerAPI which will safely shutdown and restart any LDAS API that exceeds a predetermined memory usages size. We also replaced memory management utilities with the ***dlmalloc*** package from the public domain. LDAS can now safely handle much larger data objects than were possible using the standard Unix memory management tools. This ***dlmalloc*** package also allows Unix processes to return memory to the system without restarting the process. This feature is highly advantageous on the LDAS data server gateway where several LDAS APIs compete for system memory resources.

8.2.6 Greater Accessibility to LDAS Source Code over the Web

The LDAS CVS[4] repository is now accessible over the web. Figure 8 illustrates some of the features of the web interface to the repository for comparing different versions of software.



Address: www.ldas.ligo.caltech.edu/cvsweb.cgi/ldas/api/datacondAPI/so/src/LinFilt.cc.diff?r1=1.1&r2=1.2

Return to LinFilt.cc CVS log Up to [LDAS] / ldas / api / datacondAPI / so / src

Diff for /ldas/api/datacondAPI/so/src/LinFilt.cc between version 1.1 and 1.2

version 1.1, 2000/04/10 03:17:01

Line 2

```
// $Id$
// $Log$
// Revision 1.1  2000/04/10 03:17:01  LSF5
// Add Linear Filter code LinFilt.{cc,hh}
//
```

Line 20

```
                              const valarray<double>&
a,
                              const valarray<double>&
z)
  throw ( std::invalid_argument )
  : _b(b), _a(a), _z(z)
{
  //: Constructor from transfer function FIR
coefficients b,
  // IIR coefficients a and filter taps z
```

Line 79

```
  if (_a[0]==0)
    throw std::invalid_argument("a[0] == 0");

  for (int i = 0; i < _b.size(); i++)
    if (_b[i] != 0) return;

  throw std::invalid_argument("b == 0");
```

version 1.2, 2000/04/14 22:07:48

Line 2

```
// $Id$
// $Log$
// Revision 1.2  2000/04/14 22:07:48  emaros
// Fixed several issues related to FFTWSoHandle
files.
// Did much code cleanup.
//
// Revision 1.1  2000/04/10 03:17:01  LSF5
// Add Linear Filter code LinFilt.{cc,hh}
//
```

Line 24

```
                              const valarray<double>&
a,
                              const valarray<double>&
z)
  throw ( std::invalid_argument )
  : _a(a), _b(b), _z(z)
{
  //: Constructor from transfer function FIR coefficients
b,
  // IIR coefficients a and filter taps z
```

Line 83

```
  if (_a[0]==0)
    throw std::invalid_argument("a[0] == 0");

  for (size_t i = 0; i < _b.size(); i++)
    if (_b[i] != 0) return;

  throw std::invalid_argument("b == 0");
```

FIGURE 8. Web visible LDAS CVS repository showing differences in source code between two sequential releases.

---

[4] CVS is a Version Control System.

This web tool has been tremendously useful for the distributed development of LDAS software by the various working groups collaborating around the world. It has also been a helpful training tool providing new developers with examples of coding standards and styles.

8.2.7 LDAS Support of the First Engineering Run

On April 3 and 4 LIGO conducted the first engineering data run using one arm of the Hanford two-kilometer interferometer. LDAS staff was on hand to participate in the control room activities. The data collected during the run in Frames using the Diagnostic Monitoring Tool (DMT) was later processed to produce triggers which were ingested into the LDAS DB2 database tables for diagnostic triggers. Roughly 2400 triggers were added to the tables. We have used this interface between the DMT and the database during several subsequent passes through the Frame data to validate and verify the functionality of the DMT and the LDAS system.

We are developing an extremely stable version of the software that can be used during future engineering runs. The goal is a version of LDAS in which the managerAPI, lightweightAPI, frameAPI, and metadataAPI work reliably with the DMT and the ***guild*** graphical user interface to the LIGO database. Other goals are to eliminate all memory leaks and to optimize threads and socket communications for support of multi-day engineering runs.

8.2.8 LDAS Relational Database

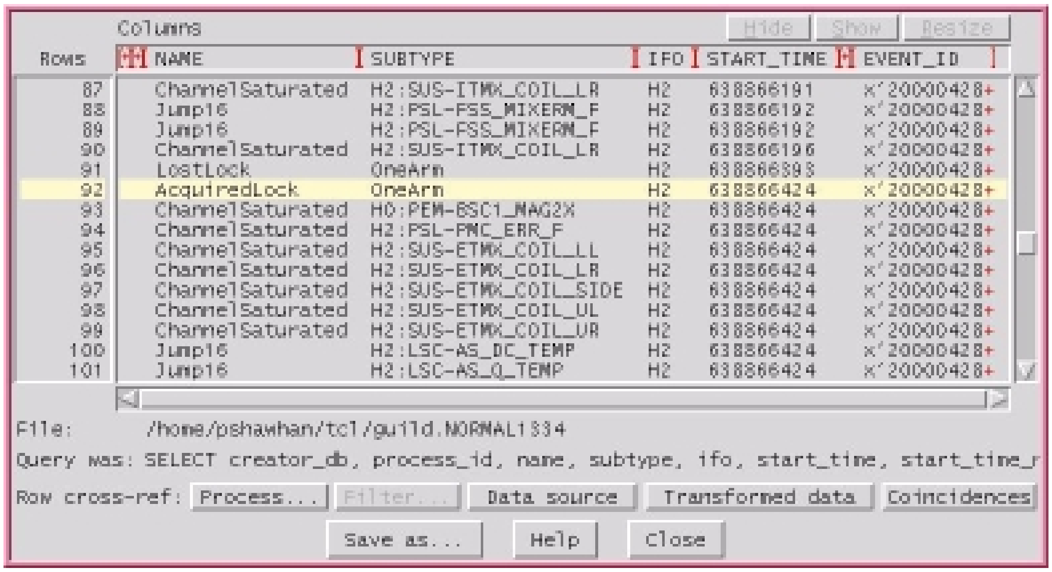
We use the LDAS relational database to store “metadata” about the state of the LIGO detectors, a catalog of the raw data collected, summary information about the performance of the detectors and environmental conditions, lists of various types of astrophysical event candidates found in the data, and a record of diagnostic triggers. During this quarter, we instantiated a complete draft design for the database table definitions (described in LIGO-T990101-02-E) on the LDAS database servers at Caltech and at the interferometer sites. Initially, we used simulated database records to test the self-consistency of the design and to measure the functionality and performance of the hardware and interface software for data insertion and retrieval. Following these system tests, we developed code for the Data Monitoring Tool library to generate diagnostic triggers, cast them into the proper “LIGO lightweight” XML format, and automatically insert them into the database. This was successfully tested using actual data from the engineering data run.

8.2.9 User Interface to LDAS (“*guild*”)[5]

We improved the graphical user’s interface to the LIGO database in various ways. We added new query options and developed code to allow the user to save table data in different formats. We implemented a socket-based method for receiving job status information from the LDAS managerAPI allowing multiple simultaneous queries. A “beta” version of ***guild*** is now in use by a limited number of people; distribution to the rest of the LIGO Scientific Collaboration (LSC) is planned for late June. Refer to Figure 9 for the ***guild*** display.

---

[5] *guild*: Graphical User’s Interface to the LIGO Database.



Rows	NAME	SUBTYPE	IFO	START_TIME	EVENT_ID
87	ChannelSaturated	H2:SUS-ITMX_COIL_LR	H2	638866191	x'20000428+
88	Jump16	H2:PSL-FSS_MIXERM_F	H2	638866192	x'20000428+
89	Jump16	H2:PSL-FSS_MIXERM_F	H2	638866192	x'20000428+
90	ChannelSaturated	H2:SUS-ITMX_COIL_LR	H2	638866196	x'20000428+
91	LostLock	OneArm	H2	638866393	x'20000428+
92	AcquiredLock	OneArm	H2	638866424	x'20000428+
93	ChannelSaturated	H0:PEM-BSC1_MAG2X	H2	638866424	x'20000428+
94	ChannelSaturated	H2:PSL-PMC_ERR_F	H2	638866424	x'20000428+
95	ChannelSaturated	H2:SUS-ETMX_COIL_LL	H2	638866424	x'20000428+
96	ChannelSaturated	H2:SUS-ETMX_COIL_LR	H2	638866424	x'20000428+
97	ChannelSaturated	H2:SUS-ETMX_COIL_SIDE	H2	638866424	x'20000428+
98	ChannelSaturated	H2:SUS-ETMX_COIL_UL	H2	638866424	x'20000428+
99	ChannelSaturated	H2:SUS-ETMX_COIL_UR	H2	638866424	x'20000428+
100	Jump16	H2:LSC-AS_DC_TEMP	H2	638866424	x'20000428+
101	Jump16	H2:LSC-AS_Q_TEMP	H2	638866424	x'20000428+

```
File:      /home/pshawhan/tcl/guild.NORMAL1334
Query was: SELECT creator_db, process_id, name, subtype, ifo, start_time, start_time_r
```

FIGURE 9. *guild* display of database query return.

8.2.10 LDAS Hardware

The NSF conducted its annual review of the LIGO Project May 9-11, 2000. LIGO presented the hardware procurement plan for the LDAS hardware. Following an iteration to provided more detailed information, a revised plan was submitted to the NSF for a quick turn-around review early in the next quarter. During this process we developed a detailed procurement schedule for each site to coordinate personnel and resources for the intense period of hardware installation anticipated over the next 24 months.

8.3 General Computing Infrastructure

We continue to monitor network traffic to and from the observatories. We conducted a number of tests to ensure that the conclusions derived from performance data provided by the Pacific Northwest National Laboratory (PNNL) are accurate. A number of procedures need to be arranged at both locations so that these performance data are more widely accessible. Basically, to-date monthly averages for daily use corresponds to approximately 10 percent of the T1 bandwidth to the Hanford Observatory. Peak use easily maximizes the available bandwidth. Typically such heavy traffic occurs at night and is caused mainly by data and software mirroring from and to Caltech.

In anticipation of increased bandwidth demands, we have been exploring options to expand beyond the current T1 links at both observatories. The long term plan is to evolve to OC3 (155 Mbps) for both sites.

We have identified additional usable computer room space in the Caltech Synchrotron mezzanine area, which will be used to install the LIGO LDAS computer cluster and data servers.

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 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 March 2001.

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.

9.2 Financial Status

Table 3 on page 21 summarizes costs and commitments as of the end of May 2000.

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		03/01 (P)	

9.3 Performance Status (Comparison to Project Baseline)

Figure 10 on page 23 is the Cost Schedule Status Report (CSSR) for the end of May 2000. 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 WBS. The schedule variance is equal to the difference between the budget-to-date and the earned value, and represents a “dollar” measure 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 11 on page 24 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 Tube is complete. All Beam Tube installation was successfully completed ahead of schedule.

TABLE 3. Costs and Commitments as of the end of May 2000

(all values are $Thousands)

WBS		*Costs Thru Nov 1997*	*Costs LFY 1998*	*Costs LFY 1999*	*First Quarter LFY 00*	*Second Quarter LFY 00*	*Cumulative*	*Open Encumbrances*	*Total Cost Plus Commitments*
1.1.1	**Vacuum Equipment**	30,517	11,406	2,114	10	1	44,047	-	44,047
1.1.2	**Beam Tube**	32,978	13,273	753	-	-	47,004	-	47,004
1.1.3	**Beam Tube Enclosure**	13,274	6,145	153	-	(392)	19,180	-	19,180
1.1.4	**Civil Construction**	44,681	6,563	1,513	313	192	53,261	495	53,756
1.1.5	**Beam Tube Bake**	75	3,078	1,845	178	233	5,410	229	5,639
1.2	**Detector**	14,340	20,537	17,898	1,619	1,156	55,549	1,922	57,472
1.3	**Research & Development**	19,681	1,661	713	33	13	22,100	57	22,158
1.4	**Project Management**	22,649	4,914	1,527	343	261	29,694	57	29,751
7LIGO	**Unassigned**	1	18	13	-	-	32	1	33
TOTAL		178,196	67,594	26,529	2,495	1,464	276,278	2,762	279,040
Cumulative Actual Costs		178,196	245,790	272,320	274,813	276,277			
Open Commitments		62,510	16,422	7,078	4,726	2,761			
Total Costs plus Commitments		240,706	262,213	279,398	279,539	279,038			
NSF Funding - Construction		*$ 265,089*	*$ 291,900*	*$ 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.

Beam Tube Enclosures (WBS 1.1.3). The contract for the Hanford site is complete. Contract closeout is pending resolution of litigation regarding state tax issues. The contract for Livingston is complete.

Civil Construction (WBS 1.1.4). The original scope for Civil Construction has been completed. Additional scope has been budgeted for site improvements that were initially removed from the scope to conserve contingency. These include erosion control, signage at both sites, and the initial design effort for a staging and storage building at Livingston.

Beam Tube Bake (WBS 1.1.5). The unfavorable schedule variance is due to a delayed start of the first bake while awaiting completion of repairs to gate valves on the Beam Tube ports (manufactured by VAT, delivered by Chicago Bridge and Iron, and repaired by VAT under warranty). Seven of eight Beam Tube modules have been successfully vacuum baked. We shut down the power supplies for the last bake on May 21, 2000, and post bake measurements are in progress. The favorable cost variance is due to the normal lag in the payment of invoices.

Detector (WBS 1.2). Washington Two Kilometer Interferometer--Installation of the Seismic Isolation System is complete. The laser system is installed and operational. We have installed and aligned all suspended optics. All of the output optics are in place. The data acquisition and global diagnostics systems are installed. We have also installed most of the servo control electronics and sensors and expect to install the balance by July 2000. The laser locks to the Mode Cleaner routinely and robustly. The vertex Michelson has been locked. In addition we have locked each of the two-kilometer arm cavities for periods up to ten hours. A 24-hour Engineering Data Run was successfully completed.

Livingston Four Kilometer Interferometer--We have installed the seismic isolation system, the laser system is installed and operational, and we have assembled all suspended optics. We have installed and aligned the input optics. The mode cleaner has been installed, locked to the laser and characterized. We have installed the data acquisition and global diagnostics systems. We expect to complete the balance of the installation by October 2000.

Washington Four Kilometer Interferometer--We have installed the seismic isolation system and the data acquisition and global diagnostics systems (shared with the two kilometer interferometer) are in place. The basic strategy has been 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 on the first two interferometers.

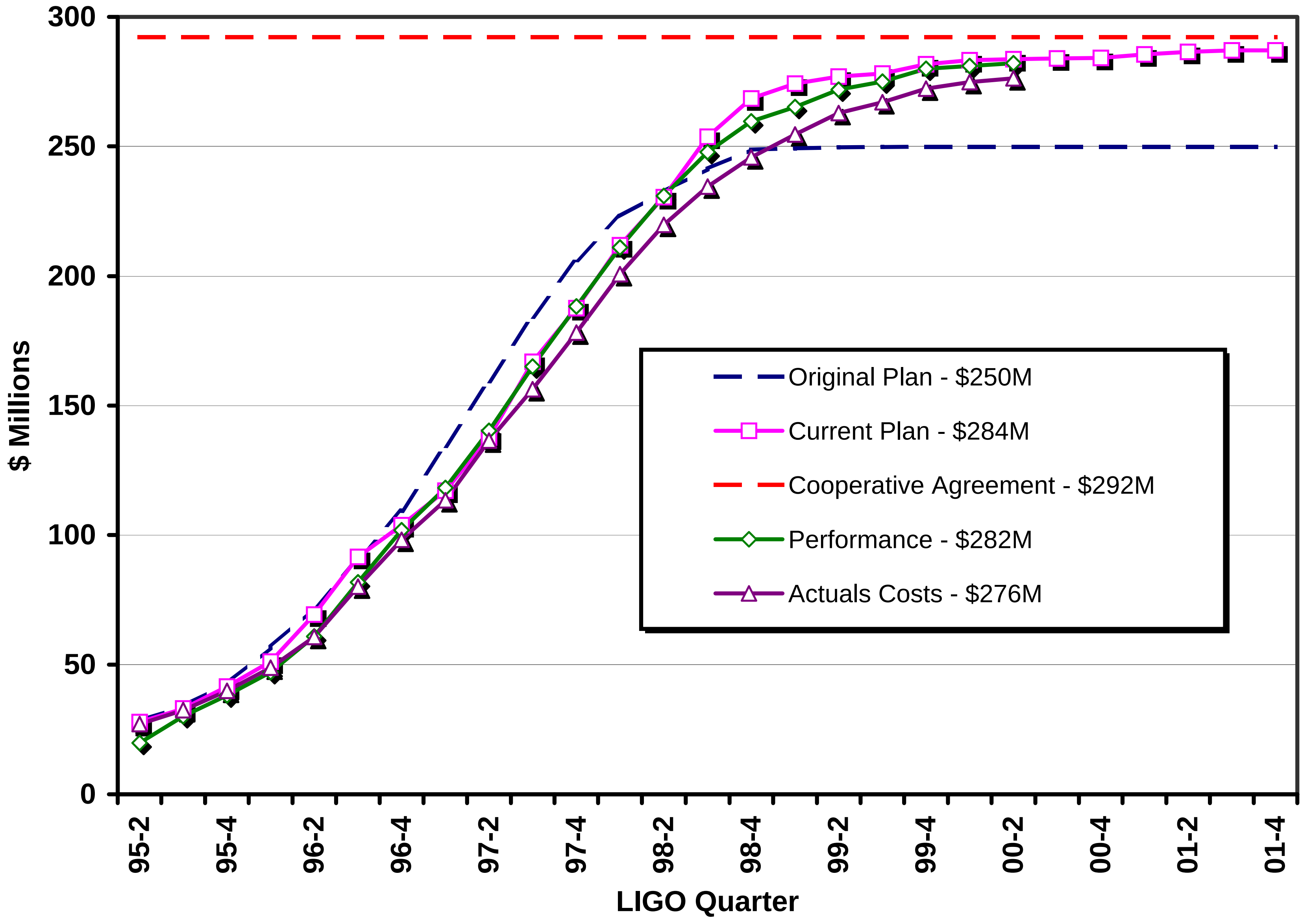
In spite of impressive progress, the Detector continues to be behind schedule. There have been a number of minor delays, including start-up problems with the production of seismic isolation components; adhesion problems for the magnet/stand-off assembly for the optics; handling and fixture problems for the completed suspension assemblies; loss of critical-path Fluorel components in a tornado in Oklahoma; a decision to re-bake the seismic stack springs to mitigate water outgassing; and a number of secondary (non-critical path) delays. The cumulative effect is that detector commissioning is approximately three months behind schedule. We continue to adjust priorities to assure that critical milestones are met.

FIGURE 10. Cost Schedule Status Report (CSSR) for the End of May 2000.

LIGO Project
Cost Schedule Status Report (CSSR)
Period End Date: May 2000
(All values are $Thousands)

Reporting Level	Cumulative To Date					At Completion		
Work Breakdown Structure	Budgeted Cost of Work Scheduled (BCWS) (1)	Budgeted Cost of Work Performed (BCWP) (2)	Actual Cost of Work Performed (ACWP) (3)	Schedule Variance (2-1) (4)	Cost Variance (2-3) (5)	Budget-at-Completion (BAC) (6)	Estimate-at-Completion (EAC) (7)	Variance-at-Completion (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	19,790	19,790	19,180	-	610	19,790	19,338	452
1.1.4 Facility Design & Construction	53,446	53,580	53,261	134	319	53,703	53,703	-
1.1.5 Beam Tube Bake	5,695	5,446	5,410	(249)	36	5,695	5,695	-
1.2 Detector	60,037	58,762	55,549	(1,275)	3,213	60,037	59,200	837
1.3 Research & Development	22,089	22,089	22,100	-	(11)	22,089	22,100	(11)
1.4 Project Office	31,677	31,677	29,694	-	1,983	35,293	35,293	-
Subtotal	283,671	282,281	276,245	(1,390)	6,036	287,544	286,380	1,164
Contingency						-	5,720	(5,720)
Management Reserve						4,556	-	4,556
Total	283,671	282,281	276,245	(1,390)	6,036	292,100	292,100	-

FIGURE 11. LIGO Construction Performance Summary as of the End of May 2000.



A significant portion of the favorable cost variance is due to normal delays associated with the recording actual costs.

Research and Development (WBS 1.3). All LIGO I 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 materials and labor associated with LIGO Data Analysis and Computing. There is a significant amount of computer hardware remaining to be purchased. These procurements have been delayed to maximize the performance per dollar ratio.

9.4 Change Control and Contingency Analysis

The following three change requests were approved during the quarter. As a result the budget baseline for LIGO Construction was increased by $52,500 to $287,544,000. This leaves a contingency (relative to the budget baseline) of $4,556,000. We are forecasting a $931,000 underrun relative to the budget baseline so that the contingency relative to the estimate-at-completion is $5,487,000.

TABLE 4. LIGO Construction Change Control Board Activity During Quarter

CR Number	WBS	Description	Amount
CR-000001	1.1.4	Cattle Fence along Livingston Access Road	34,500
CR-000002	1.4	Closeout of Selected Project Office Accounts	(192,000)
CR-000003	1.1.4	Slope Stabilization along Y Arm at Livingston	210,000
		Total	52,500

9.5 Staffing

The LIGO staff currently numbers 135 (full time equivalent). Of these, 23 are contract employees. Eighty-two LIGO staff are located at CIT including seven graduate students. Sixteen are located at MIT including five graduate students. Twenty-one are now located at the Hanford, Washington site, and 16 are assigned to Livingston, Louisiana. LIGO staff is partially paid by the LIGO Advanced Detector R&D Program, PHY-9801158.