LASER INTERFEROMETER GRAVITATIONAL-WAVE OBSERVATORY (LIGO)

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A. PROJECT SUMMARY

The Laser Interferometer Gravitational-Wave Observatory (LIGO) detectors use laser interferometry to measure the distortions of space-time between free masses to directly detect passing gravitational-waves. The objective is to open the field of gravitational-wave astrophysics.

Scientists, engineers and staff at the California Institute of Technology (Caltech) and the Massachusetts Institute of Technology (MIT) are installing and commissioning the LIGO detectors. Caltech has primary responsibility for the project under the terms of a Cooperative Agreement[1] with the National Science Foundation (NSF). LIGO is a national facility for gravitational-wave research, providing opportunities for the broader scientific community to participate in detector development, observations, and data analysis. LIGO welcomes the participation of outside scientists in these endeavors.

The LIGO Scientific Collaboration (LSC) is the organization comprising the scientific community. This includes Caltech and MIT scientists and engineers responsible for data analysis, advanced R&D and the development of advanced subsystems for LIGO. This Collaboration will exploit the initial detector and is pursuing the development of second-generation detectors. The LSC has its own management structure with shared participation in its governance, and corresponding obligations and privileges. The initial LIGO comprises one three-interferometer detector system. The sites allow for expansion of the facility to a multiple-detector configuration.

This work plan covers the second year LIGO Operations (LIGO FY 2003) activities associated with commissioning the initial detector and commencement of long-term scientific observations, and the research and development for the second generation of detectors. The LIGO funding year begins on October 1 and ends September 30.

LIGO is requesting $33 million for the twelve months beginning October 1, 2002. Of this total, $29 million is for operations of the current facility and $4 million is for Research and Development.

This work plan and the total budget of $160 million requested over five years are consistent with NSF Cooperative Agreement No. PHY-0107417 issued during February 2002.

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C. PROJECT DESCRIPTION

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C.1. Work Accomplished During FY 2002

C.1.1. LIGO Hanford Observatory

Commissioning work continued during FY 2002. We have established power-recycled operation with the Hanford four-kilometer interferometer, the first interferometer to incorporate a fully digital control topology. Engineering runs 6, 7 and 8 were conducted to test both interferometers. The most significant of these runs was E7, during which the interferometers were operated in coincidence with the Livingston Observatory, with GEO-600 (British-German Gravity Wave Experiment), and with ALLEGRO, the cryogenic resonant bar detector at Louisiana State University (LSU). This run also tested the newly constructed on-site Beowulf data analysis system. We made steady progress improving the two-kilometer interferometer sensitivity, achieving noise equivalent strain sensitivity better than $10^{-20}/\sqrt{Hz}$. Both interferometers will participate in the first Science Run (S1) in August/September 2002. More details can be found below in the discussion on commissioning. We completed the last phase of facilities construction, providing laboratory, office and meeting space. We have hired additional staff required as we approach twenty-four-hour-per-day, seven-day-a-week operation.

C.1.1.1. Educational Outreach – Hanford

LIGO Hanford Observatory has contributed to the expansion of high-school science education by directly involving students in LIGO research. This year approximately 70 students from Gladstone High School (in northwest Oregon) worked on LIGO-related projects throughout the academic year. On May 28, 2002, students from grades 9-12 described their contributions to LIGO research to a packed audience of community members at Gladstone High School. (See story at http://www.ligo.caltech.edu/LIGO_web/0205news/0205han.html - Article_1 for additional details.)

In the summer, a high-school teacher and a middle-school teacher held visiting appointments at the observatory, helping us to develop in-classroom and informal educational resources. This work has been disseminated using the "teachers corner" web pages (http://www.ligo-wa.caltech.edu/teachers_corner/teachers.html) at LIGO Hanford Observatory. A special emphasis was put on science and math lesson plans in both high-school and middle-school versions, that not only include plans, activities and worksheets, but also the web pages (http://www.ligo-wa.caltech.edu/teachers_corner/lessons.html) highlight lesson-plan alignment to the state education standards for Oregon and Washington.

The observatory hosted five undergraduate research students through the REU/SURF program this summer. Eric Adelberger (University of Washington) gave the LIGO Public Lecture this summer, entitled "How Many Dimensions Are There to the Universe?," to an enthusiastic audience of approximately 225 people, ranging in age from pre-teens to retirees. Approximately 600 visitors toured the observatory this year.

C.1.2. LIGO Livingston Observatory

The four-kilometer laser interferometer in Livingston readily locks in a power-recycled configuration. The duty cycle is limited by higher than anticipated 1-3 Hz ground motion due to man-made activity such as tree harvesting, road noise, and train traffic. The interferometer locks robustly when the ground velocity is below about 0.5-microns/sec rms in the 1-3 Hz range. This environment occurs at night. Sensitivity improvements have enhanced the noise performance of the interferometer by nearly three orders of magnitude above 100 Hz in the past year. More details can be found below in the discussion of commissioning.

Engineering data runs, some coordinated with the Hanford Observatory, and one which included simultaneous operation with the ALLEGRO and the GEO-600 interferometer, have tested our ability to operate around the clock, collect and process data, and coordinate activities between sites. We have developed a staff of trained operators able to start up and maintain the operation of the interferometer. We continue to strengthen the operational training of the Livingston Observatory staff in anticipation of continuous operation over extended periods.

The staging building at the Livingston site has been modified to include an auditorium, office space, and additional lab space for support of interferometer operations. This work is fully complete except for punch list items.

C.1.2.1. Educational Outreach -- Livingston

LIGO Livingston Observatory has been the site for a Research Experiences for Undergraduates (REU) program each summer for the last three years. This year, we are hosting 17 undergraduate and graduate students who are participating in REU and graduate programs at Caltech, MIT, Louisiana State University, Southern University, University of Texas at Brownsville, and Stanford University.

We have established contacts with local school districts through the Louisiana Science Teachers' Association; the NSF supported state systemic initiative; the Delta Rural Systemic Initiative; and various teacher forums. More than 200 teachers have visited the Livingston Observatory during the summer through an Eisenhower grant program in the Livingston Parish schools, and more than 2000 students visit the site each year as part of school field trips. We have developed hands-on science activities and lessons that are offered to students when they visit. Many classes have painted murals on the beam tube enclosures as a souvenir of their visits. More than 100 murals now decorate the Y-arm of the interferometer. We developed a Research Experiences for Teachers (RET) program during the summers of 2001 and 2002. In collaboration with these teachers, we have developed LIGO related lesson plans that coordinate with state science benchmarks.

In collaboration with Louisiana State University (LSU), LIGO supported a proposal by Professor Gregory Guzik to the state of Louisiana Technology Innovation Fund to procure and install a sixteen-inch optical telescope that can be remotely accessed via the Internet. LIGO agreed to provide an enclosure for the telescope and Internet access in support of this proposal. This telescope has been delivered. We are now engaging an architect to design an attractive, utilitarian facility that will enhance the ability to conduct educational outreach activities at Livingston.

C.1.2.2. Safety

Installation of the Livingston Safety system is complete. Safety training and regular safety meetings are in progress**.** Both observatories now have card controller laser interlock safety systems on line. This includes restricted area access control.

C.1.3. Technical and Engineering Support

During the past year the Technical and Engineering Support Group focused on completing the installation of detector components and supporting commissioning activities. The accomplishments of this group are reported in the discussion of commissioning and the Advanced R&D below.

Figure 1. More than 100 school classes and youth groups have painted murals on the beam tube enclosure at the Livingston Observatory.

C.1.4. Detector Support

The Detector Group is commissioning and operating the interferometers in preparation for the first Science Run (S1). The commissioning work reported here is effort shared between the Detector group, the Technical and Engineering Support group, MIT LIGO staff, the Observatory staff, and our LIGO Scientific Collaboration partners. We continue to concentrate on reducing noise and improving the duty cycle. We are refining the design based on our growing operational experience.

By the end of July 2002 we achieved strain sensitivity better than has been achieved with any previous broadband detector, and on two interferometers, the two-kilometer interferometer at Hanford and the four-kilometer interferometer at Livingston. This was the case over the entire gravitational-wave band from 100Hz to higher frequencies. Two interferometers at separated sites support coincidence techniques for the gravitational-wave searches.

C.1.4.1. Engineering Runs

A very successful engineering run (E7) was conducted at the end of December continuing into January. The run started on December 28, 2001, and data collection was completed January 15, 2002. Lock statistics for the run are summarized in Table 1.

Table 1: Interferometer Lock Statistics for E7 Engineering Run.

Single Interferometer Statistics		**Hours**	**Duty Cycle (Percent)**
L1	Total Locked Time	284	71
	Locked Time for Periods Longer than 15 Minutes	249	62
H1	Total Locked Time	294	72
	Locked Time for Periods Longer than 15 Minutes	231	57
H2	Total Locked Time	214	53
	Locked Time for Periods Longer than 15 Minutes	157	39
Three Interferometer Coincidence Statistics			
	Total Locked Time	140	35
	Locked Time for Periods Longer than 15 Minutes	72	18

The Livingston four-kilometer interferometer (L1) was operated at a sensitivity of 2.5 x 10^{-19} strain/√(Hz) or better from 250 to 3000 Hz and 8 x 10^{-20} strain/√(Hz) between 400 to 1000 Hz. The combined duty cycle with the two-kilometer at Hanford, which has comparable sensitivity, was about 40 percent. The overlap is primarily at night when the seismic conditions at Livingston are relatively quiet. Combined observations with the bar detector at Louisiana State University (LSU) began on Wednesday, January 9. Concurrently, GEO-600 operated a power-recycled Michelson. These coincidence runs may set new observational limits on the gravitational-wave strengths incident on the Earth, although they do not yet test theorists' predictions of signal strengths.

At the end of the first quarter we were able to operate the two-kilometer interferometer for extended periods up to a record-setting lock of 14 hours and 45 minutes with five watts of laser input power to the mode cleaner and with the common mode servo running.

The E8 Engineering Run (E8) was conducted in early June 2002. This brief run, held only at Hanford, served to exercise extended running procedures.

Analysis of engineering run data and continued interferometer commissioning and modification, based partly on the E7 experience, are in progress. We are currently preparing for the first Science Run (S1) scheduled to start in August 2002.

C.1.4.2. Commissioning the Two-kilometer Interferometer at Hanford

Building upon the enhanced robustness of the interferometer we have been able to remove protective attenuators before the photo detectors, resulting in higher photocurrents and a smaller relative contribution from photo detector amplifiers, and thus achieved an overall improved sensitivity. Locking is generally robust even at high light levels. With approximately an order of magnitude less light attenuation, we have four to five times better displacement sensitivity at frequencies above 500 Hz and another factor of four to five in margin above the photo detector noise.

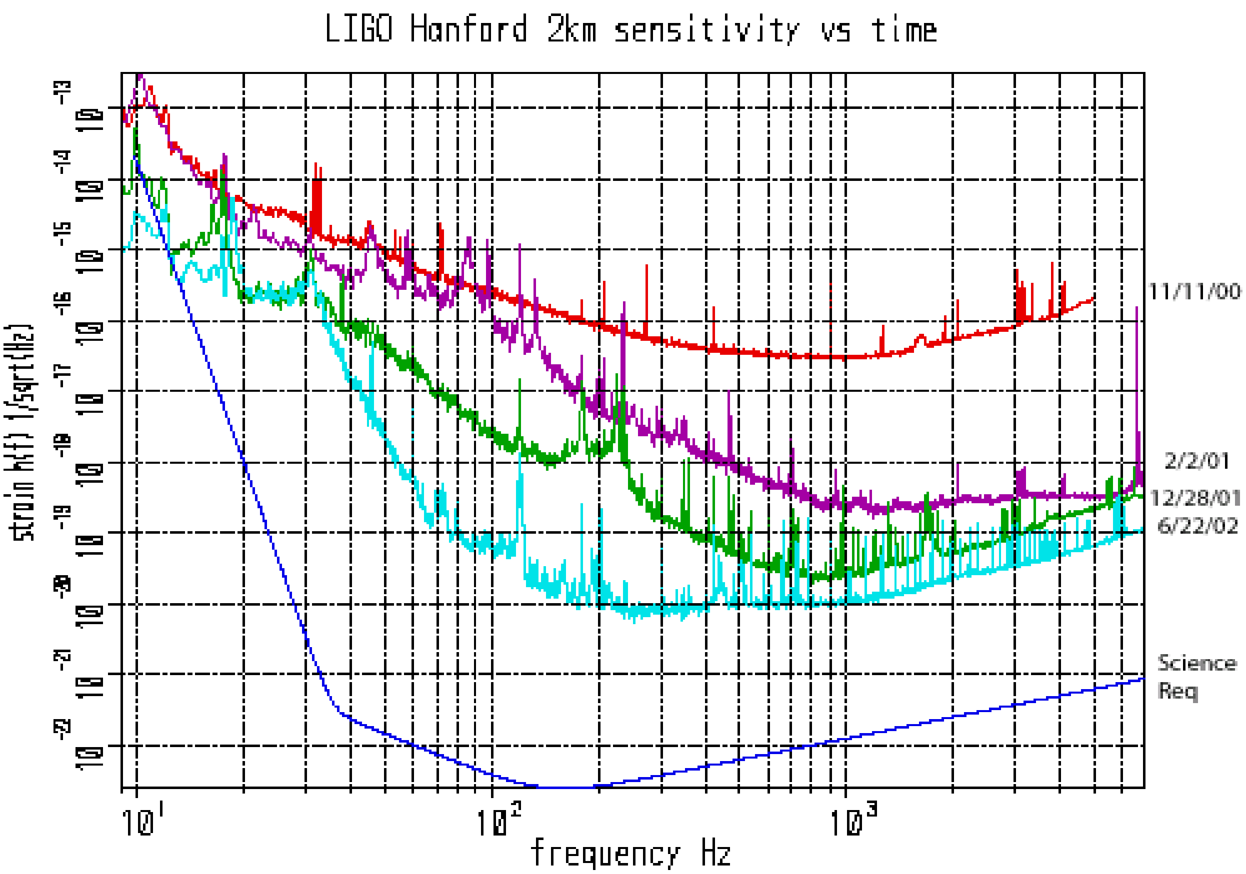


Figure 2. Evolution of the Hanford two-kilometer interferometer sensitivity.

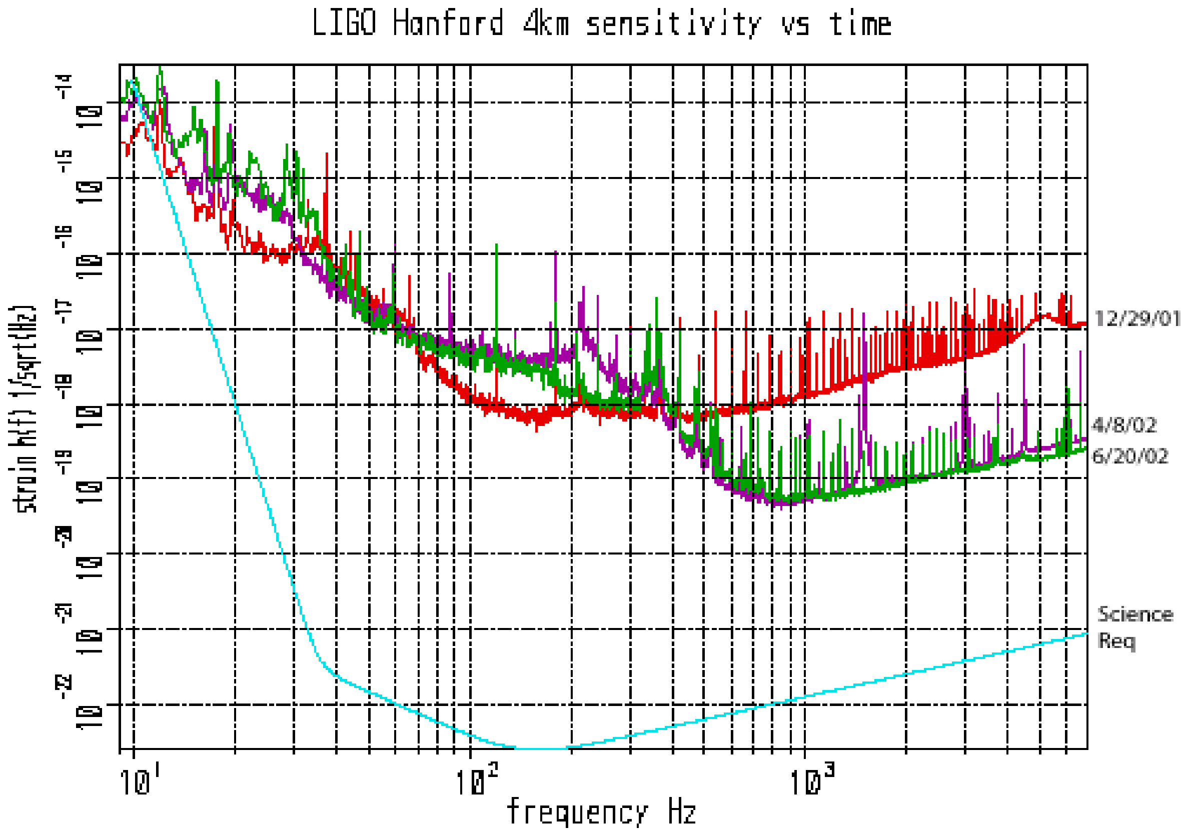


Figure 3: Evolution of the Hanford four-kilometer interferometer sensitivity.

We implemented a new configuration for the common mode servo that coordinates the control signals to the test mass common mode motion, the mode cleaner length, and the pre-stabilized laser frequency. The interferometer locked easily in common mode and held for nine hours. We used improved filtering capability to insert resonant gain stages and to quiet a number of control loops. These changes have dramatically improved interferometer behavior.

We implemented new Length Sensing and Control (LSC) hardware and software. The ability to dynamically add filtering is an important new feature aiding in noise investigations.

C.1.4.3. Commissioning the Four-kilometer Interferometer at Hanford

The four-kilometer interferometer at Hanford continues as a pathfinder for the digital controls environment. These developments will be reproduced on the other interferometers once the techniques have been proven. The commissioning team focused on implementing software changes, optimizing operating parameters, and making subsystem adjustments and improvements in preparation for the first Science Run (S1). We also implemented subsystem enhancements to improve interferometer locking. Significant progress was made in characterizing and tuning the hardware and software for the digital suspension controllers. We continued our one-arm investigations to better understand frequency noise in the light beam and saturation effects in the control signals. Single-arm locks have been obtained on both arms, with sufficient stability on the ‘x-arm’ for a preliminary single-arm measurement of the frequency noise.

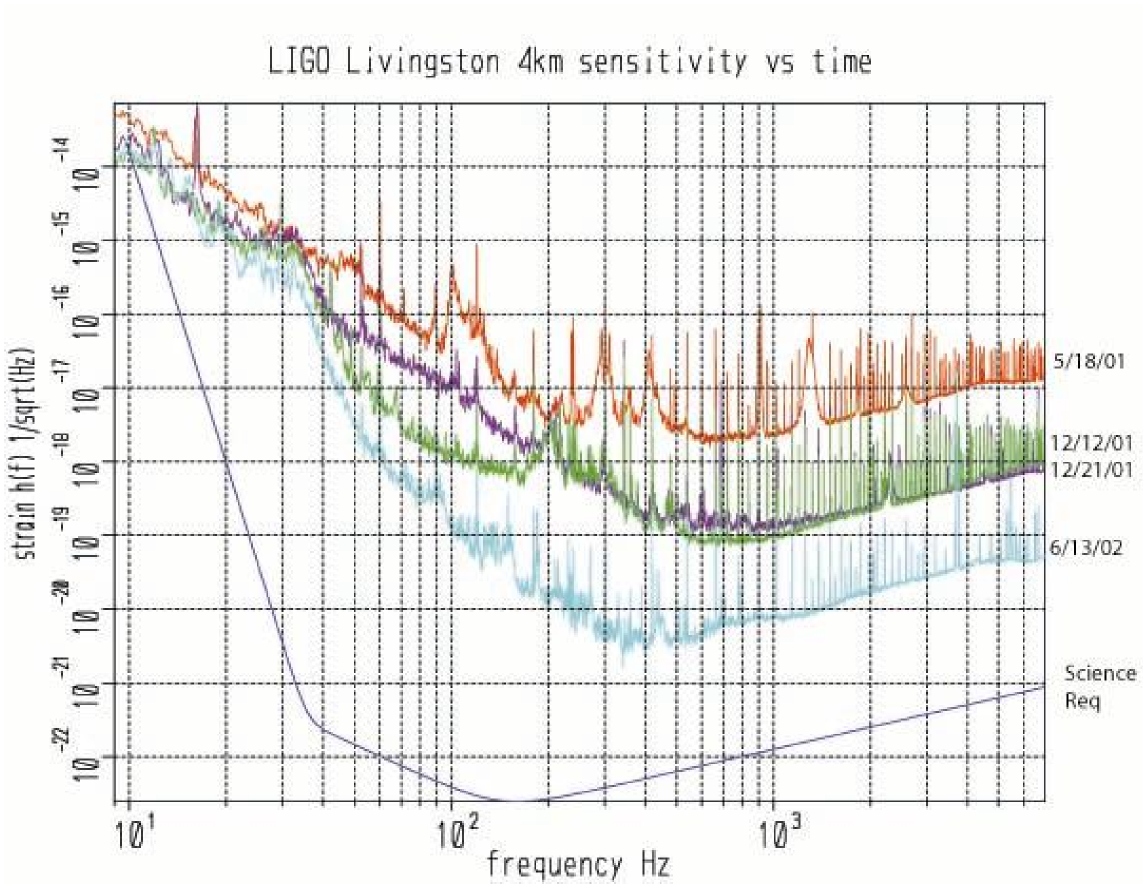


Figure 4. Evolution of the LIGO Livingston four-kilometer interferometer sensitivity.

Testing of the fully digital common-mode servo amplifier is in progress. We implemented filters that significantly improve frequency noise. We developed improved optical levers on the end mirrors, using a digital control system, and found that they work extremely well.

C.1.4.4. Commissioning the Four-kilometer Interferometer at Livingston

The interferometer exhibited reasonably short acquisition times, and when seismic noise is light, as at night, robust operation. The strain sensitivity since the Engineering Run E7 has improved by almost a factor of three at frequencies above 700 Hz. We are working on further improvements by operating the recycled interferometer at higher power and delivering more light to the photo detectors.

We incorporated several critical interferometer features. We implemented significantly improved Length Sensing and Control (LSC) software. We modified the mode cleaner board to reduce the crossover frequency. We tuned the micro-seismic feed-forward system to enhance suppression of the six-second period seismic disturbance. We tuned the common mode servo. We are implementing a new intensity stabilization servo. We continued identifying and measuring noise sources. We improved the robustness of the recycled lock.

To address the excess low-frequency seismic motion in the near term, we added low-noise seismometers and a flexible digital control system to the existing ”fine actuators” implemented on the end test masses. Motion at the seismic supports is sensed, and control signals fed back to the fine actuators to reduce motion in the band from 1 to 10 Hz. The amplitudes of the key stack modes at 1.2 and 2.1 Hz, which are responsible for most of the excess motion, were reduced by a factor of seven, allowing increased duty cycle and improved stability.

We developed software to be used in the control room to make time domain studies of the signals. We can now make histograms of band pass limited signals for many of the interferometer and Physical Environment Monitoring (PEM) System signals.

We are addressing Electro-magnetic Interference (EMI) and Radio Frequency Interference (RFI) through a series of incremental changes in inter- and intra-rack wiring practice. The use of shielded ribbon cables in the Alignment Sensing and Control (ASC) System has led to a reduction of high-frequency ”hash,” which can appear in the base band through accidental rectification by low-level low-frequency-bandwidth amplifiers.

We modified hardware and software to allow optical lever damping as well as wave front sensing. Furthermore, it is now possible to adjust filter coefficients in the ASC signal chain while the ASC is running.

C.1.4.5. Seismic Isolation Upgrade

We are designing and building prototypes of a pre-isolator system targeting the excess seismic noise at Livingston. Our plan is to implement this much-improved low-frequency isolation after the S2 run. The goal is stable operation of the interferometer during the daytime hours when seismic activity caused by human activity is excessive. Stanford University has transferred their basic conceptual design for the hydraulic portion of the system to the LIGO-LSC collaboration for continued development. Preliminary designs for the Hydraulic External Pre-Isolator (HEPI) and Electro-Magnetic External Pre-Isolator (MEPI) prototypes are complete, and the final design is being developed. As noted above, we installed and tested Piezoelectric External Pre-Isolation (PEPI), an interim measure to improve performance and duty cycle at Livingston, in the End Test Mass (ETM) chambers. We placed orders to equip the Input Test Mass (ITM) chambers with PEPI as well, and intend to install them before the S1 run.

C.1.5. Data and Computing Group

C.1.5.1. Modeling and Simulation

During FY 2002 we:

- developed the second generation LIGO simulation package, ***SimLIGO***;
- developed the second generation of the graphical user front end for the simulation package.

Development of the time-domain simulation framework is almost complete. During FY 2002 the major focus has been to improve the simulation, so as to reproduce the fine structure of LIGO interferometer output. Improvements were based on discussions with and priorities set by the Detector Group. We developed a second-generation LIGO simulation package, named ***SimLIGO***, which incorporates many new features, including the digital electronics and 3-D mirror motion. The tool can be used to simulate the major noise sources currently limiting interferometer performance. A new version of the graphical front-end of the simulation software, ***alfi,*** has been developed using JAVA. The new features and improved stability are both excellent. The older version of ***alfi*** will soon be retired.

A research program has begun in collaboration with Professor Yoshida from Southeastern Louisiana University, which has several goals: to engage undergraduate students who will be able to work with the LIGO simulation group by providing useful input measurements, such as the seismic motion at the Livingston site, and by running simulation under the guidance of the LIGO simulation group; and outreach, where the time-domain simulation software can provide a valuable virtual experiment environment to learn about physical optics as part of their physics education. We schedule teleconferences on a regular basis, and an SLU student is participating in the Summer Undergraduate Research Fellowship (SURF) program this summer.

C.1.5.2. LIGO Data Analysis System (LDAS) Software Systems.

During FY 2002, the LIGO Data Analysis System (LDAS) group worked closely with the LIGO Scientific Collaboration (LSC) to develop the functionality to perform the various types of analyses planned by the Upper Limits Groups for the E7 Upper Limits Engineering Run. This effort was highly successful as evidenced by the fact that all four upper limits groups made extensive use of LDAS both during the engineering run as well as during the subsequent months of analysis. Data were collected over two and a half weeks. We released a subsequent version of LDAS after the engineering run. This was the first development release of LDAS with functional code in place for all major components. We have continued to develop the software in preparation for the first science run. This primarily involved various performance enhancements, implementation of new interfaces, extending the basic math and signal processing, adding the capability to handle the creation of RDS (reduced data set) frames, and other improvements for managing user requests. In addition, we modified the job request interface to include encryption, and all usernames and passwords were reset using a new secure web based service.

Hardware Systems. SunFire880 servers where installed in all of the LDAS systems to operate as the main data servers with high-speed access to the disk cache.

All LDAS servers at the observatories where upgraded to Gigabit Ethernet network connectivity. A new 50-μm-fiber network was installed at Caltech to provide Gigabit network speeds for both Ethernet and Fiber Channel between the various LDAS systems in different buildings. This process is being replicated at the two observatories. The Storage Area Network (SAN) at the observatories was upgraded to a shared mode so that both the Control and Data System (CDS) and LDAS servers can access all of the storage space directly. It is no longer necessary to copy the raw data from one file system to another to transfer data from CDS to LDAS.

The computational clusters were upgraded for the first Science Run (S1) to 48 and 64 2-GHz P4 Linux machines at the Livingston Observatory and the Hanford Observatory respectively. The old 16-node Engineering Run clusters where transferred to MIT and CIT for integration into existing LDAS systems.

We archived all Engineering Run data at Caltech in the LIGO data archive running HPSS (High Performance Storage System). The current archive contains 39 Terabytes. However, we continue to evaluate the suitability of SAM-QFS (a SUN Storage and Archive Management System) as an alternative mass storage system to HPSS. Important reasons to consider this change are: simplicity, reliability, the ability to do move media between systems without data replication, sufficiently low licensing fees to allow for the possibility of running at the observatories as well as Caltech, disaster recovery, metadata performance, and minimizing the number of vendors supporting LDAS. We began testing at Caltech at the end of April, and initial indicators are all favorable for switching to SAM-QFS.

C.1.5.3. LIGO Computing Infrastructure

General Computing activities during the past year included updates of hardware for users, for file servers, and also addition of significantly more powerful general-purpose scientific computing capability. The LIGO CIT LAN backbone has been upgraded from the older ATM network to gigabit Ethernet. A new web server was added that is devoted exclusively to LIGO Scientific Collaboration (LSC) web sites. We acquired the domain name, ***ligo.org***, for this server. A draft of a LIGO Laboratory-wide computer security plan was developed. The Laboratory Directorship is reviewing it. An acceptable computer usage policy was written and incorporated into the LIGO Laboratory Policy Manual that is provided to employees.

C.1.6. Campus Research Facilities

C.1.6.1. 40-Meter Laboratory

LIGO operates a 40-Meter prototype gravitational-wave interferometer on the Caltech campus. To prototype the Advanced LIGO optical configuration and controls, and study its performance, a fully instrumented suspended-mass interferometer is needed. The 40-Meter facility is dedicated to this task.

Progress during FY 2002. We held an internal Conceptual Design Review for the 40-Meter Dual Recycling project early in FY 2002. At that time, detailed conceptual designs were presented (with accompanying documentation) for the overall project, the tentative optical configuration and control scheme, the optical layout, all sensing table instrumentation, core suspended optics, mechanical suspensions, digital suspension controllers, and auxiliary optics (stray light control, initial alignment system, optical levers, video monitoring, etc), laboratory infrastructure and vacuum systems, environmental monitoring, data acquisition, computing and networking. Progress on key components was reviewed. The schedule of milestones was presented and discussed. The review committee was satisfied with the design and the progress, and a few specific concerns were addressed.

As of July 2002, we are on schedule. In particular, the following components and subsystems are implemented:

- The laboratory building has been expanded and upgraded, providing room for electronics racks, optical tables, controls consoles, etc.

- We have augmented the existing vacuum envelope with a new output optic chamber with seismic stack, a 13 meter mode cleaner beam tube, and a small chamber and seismic stack for the end mode cleaner suspended optic (MC2). We have also installed new IRcoated optical ports, new flexible in-vacuum cables, new welded vacuum electrical feed-through connections, and new cameras and mounts for viewing the beam on the in-vacuum suspended optics.

- We installed a commercial active seismic pre-isolation system (STACIS) on all four test mass chambers. This system is now in continuous use. We installed, commissioned, and characterized initial-LIGO pre-stabilized laser, data acquisition, and EPICS slow control systems, which are now used continually.

- The optics and suspensions for the 13-meter mode cleaner were fabricated. We hung, tested, and installed the three suspended optics into the vacuum envelope. We designed, fabricated, and installed digital suspension controllers for the mode cleaner. We installed mode cleaner length and frequency control servo electronics, and optical sensing trains and beam tubes, by late May 2002. We aligned the mode cleaner, and observed first fringes in June 2002. As of July 2002, we are tuning the mode cleaner lock acquisition, and characterizing the mode cleaner performance. Summer Undergraduate Research Fellowship (SURF) students are making major contributions to this effort.

- We procured polished core optics for the main dual recycled interferometer, and coating of all pieces (including spares) is in progress as of July 2002. The mechanical suspensions for the remaining seven optical elements for the main dual recycled interferometer have been designed, fabricated, cleaned, and baked.

Thus, we can report considerable progress in the fabrication and commissioning of a full dual-recycled interferometer with LIGO-engineered controls. The work that remains to complete the fabrication and begin the experiments in dual recycling configuration response, lock acquisition, and control, is described in section C.2.6.2.

C.1.6.2. MIT Facilities (LASTI)

The principal undertaking in the LIGO Advanced System Test Interferometer (LASTI) facility in FY02 was the preparation and initial measurements to support the development of the pre-isolator for the Livingston Observatory. We installed an initial LIGO seismic isolation system in the BSC (Test Mass) vacuum chamber and characterized the matrix of transfer functions. We also prepared for the installation of a prototype pre-isolator in a HAM (Auxiliary Optics) vacuum chamber. As the year closes, we are installing the first pre-isolator prototype components. This process permits full-scale testing of LIGO hardware without disruption at the observatories.

LASTI also was the development platform for improved Pre-Stabilized Laser (PSL) servo controls for the initial LIGO system. In particular, we tested an approach for increased bandwidth for the Frequency Stabilization Servo (FSS) on the LASTI PSL, and the approach is being considered for the observatories.

C.1.6.3. Advanced R&D

This year we initiated or continued a broad range of research and development to support the Advanced LIGO concept. This effort is very strongly collaborative, and the progress described below is often the result of collaborations with other institutions in the LIGO Scientific Collaboration (LSC). Highlights this year include:

- Seismic Isolation: The seismic isolation team focused on the pre-isolator development for initial LIGO described above. A second-generation active isolation system prototype was designed by the LSC team and fabricated by the LIGO Laboratory. It is currently being commissioned at the Stanford Engineering Test facility. This technology demonstrator will be used to (a) inform the development of the full-scale LASTI seismic systems for the HAM and BSC chambers, which will be developed this coming fiscal year and (b) serve as a controls test bed for the active isolation systems.

- Suspensions: Characterization of the prototype quadruple test mass suspension started at the GEO-600 (British-German Gravity Wave Experiment) Glasgow facility and continued at MIT. All principal modes were identified in models developed at Caltech and Glasgow. An analysis of the thermal noise of tapered fused silica fibers at Caltech showed that this is an attractive alternative to ribbons, being easier to fabricate; some first samples have been fabricated for tests. We have nearly completed the design of the first prototype auxiliary optics suspensions, and we are now fabricating some components.

- Optics: We made progress in producing and characterizing sapphire as the preferred test mass material for Advanced LIGO. Industrial partners fabricated full-sized boules; annealing processes were refined in collaboration with Stanford, resulting in reductions in the absorption of 1-micron laser light. Industrial partners successfully pursued approaches to compensating for inhomogeneity, while at the same time manufacturers were able to produce material with improved homogeneity. The Thermal Noise Interferometer (TNI) research at Caltech produced its first preliminary results with fused silica test masses, and noise hunting and reduction is underway.

- Optical Coatings: We pursued a strong LSC/LIGO Laboratory program this year to identify the magnitude and source of coating mechanical losses (which lead to thermal noise); we concluded that the high-index tantalum material, rather than the low-index material or interfaces, is responsible. We are now pursuing alternative coating materials with several vendors. Optical coatings with acceptable optical absorptions (sub-ppm) have been demonstrated.

- Lasers and input optics: The program to develop 200 W lasers sources continued at Adelaide, Stanford, and Hannover. Up to 70 W have been produced. We reviewed the Input Optics Design Requirements prepared by the University of Florida, and the group was given approval to proceed to the preliminary design.

- Systems and Interferometer Sensing and Control: We refined the baseline design and conducted a System Design Requirements Review. A number of subsystem requirements and trade studies were concluded. We initiated a study of the data readout approach for the signal-recycled interferometer. The preliminary result is that the DC readout (in contrast to the traditional RF-modulation technique) appears to take advantage of the coupling that exists in a signal-recycled interferometer between the shot-noise fluctuations and the photon pressure on the test masses. We have also been working with industry to develop a low noise Digital-to-Analog Converter (DAC). Test results on the first prototypes should be available before the end of this year.

C.1.7. LIGO Scientific Collaboration (LSC)

The LIGO Scientific Collaboration (LSC) is a forum for organizing technical and scientific research in LIGO. Its mission is to insure equal scientific opportunity for individual participants and institutions by organizing research, publications, and all other scientific activities. It includes scientists from the LIGO Laboratory as well as collaborating institutions. The organization is separate from the LIGO Laboratory, with its own leadership and governance, but reports to the Laboratory Directorate for final approval of its research program, technical projects, observational physics publications, and talks announcing new observations and physics results.

The March 2002 LSC meeting was held at the Livingston Observatory. In conjunction, Louisiana State University (LSU) hosted a symposium. Numerical relativists with an interest in coupling to LIGO and LISA made presentations and participated throughout the LSC meeting. There was interest in collaborating with LIGO-LSC to formulate plans for useful activities by the Numerical relativists in support of LIGO observational programs and to guide theoretical research.

The LIGO Hanford, Washington Observatory will host the next meeting of the LIGO Scientific Collaboration, August 19 - 22, 2002.

C.2. Work Planned for FY 2003

C.2.1. The Hanford Observatory

The effort on science runs and commissioning activities will be equal in FY 2003. Intensive efforts to identify and reduce sources of noise will, as a goal, extend the volume of space-time searched for gravitational-waves by an order of magnitude with each science run. LIGO will implement incremental improvements to both hardware and software. We expect to engage in science runs approximately one half of the year. This will require augmentation of the resident science and engineering staff to support a more advanced phase of commissioning and the higher demands for data, network and computing services, and technical liaison with the LIGO Scientific Collaboration. We will continue to provide outreach to schools and the general public as funding and manpower allows.

C.2.2. The Livingston Observatory

We will implement the remaining wave front sensor angular control loops, which control the power recycling mirror degrees of freedom and the mode cleaner.

We will revise the layout of the symmetric port optical table to facilitate the addition of a second RF photodiode. This will accommodate further increases in the output light intensity, which will become possible with the addition of the remaining wave front sensor control loops.

We will continue to investigate the length sensing and control servo electronics since interferometer performance is limited by electronic noise in these systems.

We will implement seismic isolation systems on all of the Beam Splitter Chambers (BSCs). This will provide active compensation for ground, and it is anticipated that this will increase the duty factor at Livingston to make 24 hour per day operation possible.

C.2.3. Technical and Engineering Support

The Technical and Engineering support group is an intrinsic part of the effort to commission the interferometers, and to enable and execute the Advanced R&D program. These activities are described below

C.2.4. Detector Support

The coming year will see a shift of focus from commissioning to running the instruments as detectors. LIGO has prepared a detailed plan for the commissioning activities between science runs, taking into consideration the advances in sensitivity and duty cycle that we expect. We have ordered the commissioning activities to optimize the expected benefits in the time available and to coordinate the complementary activities, which can be simultaneously pursued. Some highlights of commissioning activities this year include:

- Installation and shakedown of the seismic pre-isolator at Livingston; installation of the PEPI fine-actuator based attenuator at Hanford.
- Completion of commissioning of the wave front sensing system for automated alignment of all interferometers.
- Duplication of the digital suspension systems, currently installed in the Hanford four-kilometer interferometer, to the Hanford two-kilometer interferometer and the Livingston four-kilometer interferometer.
- Installation and commissioning of the photon strain calibrator on all interferometers.
- Modifications of the electronics and wiring infrastructure to reduce identified sources of interference due to self-generated noise (digital ”hash,” mains pickup, analog-to-digital and digital-to-analog conversion limitations, etc.)
- Continued improvements in the software for real-time control, user interface, and on-line diagnostics.

C.2.4.1. Science Runs

Our mission is to achieve the scientific reach planned for the LIGO interferometer system and to exploit the system, with the LIGO Scientific Collaboration (LSC), to accomplish the astrophysics. Given these goals, we have planned a progression of three Science Runs with ever-increasing scientific reach. All three Science Runs will be the joint responsibility of the Laboratory and the LSC. The first, S1, will begin at the end of August 2002. The timing for S1 is driven by lessons learned from Engineering Runs conducted to date, the readiness of the hardware, and the remaining high priority interferometer installation and rework tasks.

The goals for S1 are a two-site coincidence with all three interferometers running, and an achieved scientific reach (volume searched multiplied by the observation time in coincidence) an order of magnitude better than that achieved in the E7 run. At least one interferometer at each site should be operated in the full-recycled configuration. The S2 run will have a goal of at least an order of magnitude improvement in scientific reach beyond S1, and will follow the completion of the analysis of S1 data.

S2 will complete upper limit running and the orientation of the LIGO-LSC scientific and operations staff. We believe that S1 and S2 running experience should lead to new publishable limits, well beyond what has been previously observed.

S3, scheduled to start in the middle of 2003, will be a true search for gravitational waves with astrophysical significance.

The plan for scientific operation of the LIGO interferometers provides a clear structure for the work involved, interleaving interferometer development and improvement with progressively more ambitious science goals. The three consecutive Science Runs also provide a baseline for LIGO Data Analysis System (LDAS) development, detector modeling and diagnosis, as well as interferometer commissioning, modification, and revision.

C.2.5. Data and Computing Group

C.2.5.1. Modeling and Simulation

The primary activity this period will be the continued application of the simulation models to support the commissioning of LIGO. Several physics elements will be included in the simulation code, for example, incorporating the measured phase maps of mirrors.

The simulation group will support the commissioning team as new problems are addressed by performing simulations analyses to better understand LIGO performance. Many noise sources can only be simulated in the time domain simulation, for example, bi-linear couplings and nonlinear (up-conversion) effects. These non-trivial noise sources must be calculated to identify quantitatively the ultimate performance impact.

The collaboration with Professor Yashida and Southeastern Louisiana University (SLU) will continue. We will assist Professor Yoshida in developing a grant proposal to the NSF for his collaborative R&D with the simulation group. We will incorporate the latest physical environment measurements, which SLU will be performing for LIGO, into the simulation environment.

C.2.5.2. LIGO Data Analysis System (LDAS)

Software Systems. During FY 2003 the LIGO Data Analysis System will continue to work closely with key members of the LIGO Scientific Collaboration to assure that LIGO data is successfully analyzed and that all necessary functionality is in place to support new analysis models as needs expand from primarily performing upper limit studies to include detection strategies. A key task to be carried out in FY 2003 is to integrate the new version 5 international frame specification into the ***frameCPP*** C++ I/O library and integrate support for the new elements of this specification into the ***frameAPI***. We will also profile the overall performance of LDAS, and based on the data collected, we will optimize to improve processing speed. This will include increased threading in each component of LDAS. We will add authentication and security features to LDAS as we integrate Globus Security Interfaces that have been adopted by ***grid*** projects. We expect to migrate from beta releases of the software to the first full release late in FY 2003.

Hardware Systems. We will upgrade the data conditioning servers in all LDAS systems to support the science runs. Based on experience during initial science runs, additional memory and processors will be purchased for any other servers that are limiting job processing. All Linux machines will be upgraded to RedHat7.3 and Sun machines to Solaris 9.

We will move the LDAS systems at the observatories to the new facility buildings and a 50-μm-fiber network will be used to connect to the necessary Control and Data System (CDS) computers. We will install a dedicated Firewall and Virtual Private Network (VPN) server between each LDAS system and all other networks. This will provide additional security, flexibility in load-balancing LDAS services across multiple servers, and allow federation and replication between LDAS database servers in different LDAS locations.

We will purchase the full-scale science run Beowulf clusters. There will be approximately 600 nodes, e.g., 100 per interferometer at each observatory plus 100 per interferometer in the central Caltech system.

We will make a final decision on high performance storage systems (HPSS) versus SAM-QFS, and we will purchase approximately 12 Fiber Channel tape drives to support writing to tape at the observatories and for the central archive at Caltech. The Storage Area Network (SAN) will be upgraded at the observatories and at Caltech to support multiple writers (currently only one server is allowed to write data), provide ports for CDS and General Computing data access, and to upgrade critical systems to two Gigabit/s. An initial 20 Terabyte disk cache system will be built at Caltech to cache all of the S1 science run data in front of the tape archive.

C.2.5.3. LIGO General Computing Infrastructure

During FY 2003 General Computing will upgrade the overall network performance at the observatories to reflect last year's upgrades at Caltech.

C.2.6. Campus Research Facilities

C.2.6.1. 40-Meter Laboratory

We will complete the fabrication of an Advanced LIGO-design dual-recycled Fabry-Perot Michelson interferometer at the 40-Meter laboratory in FY 2003. We plan to assemble, hang, and install the seven core suspended optics; and install and test the digital suspension controllers. We will also fabricate and install all remaining optical sensing and auxiliary equipment on the existing enclosed optical tables, and fabricate and install the length and alignment sensing and control systems.

We plan to have all these systems installed, and begin commissioning by Summer 2003. First experiments in dual recycled configuration response, lock acquisition, and control are planned for Summer 2003 and are expected to require at least a year. We expect that LIGO Scientific Collaboration members, as well as students, will participate in this most interesting phase of the project.

C.2.6.2. MIT Campus Facilities (LASTI)

Activities to support the development of the pre-isolator for the Livingston Observatory will dominate LASTI installation during the first quarter of the year. Both BSC (test mass) and HAM (auxiliary optics) versions will be tried, and with two actuator types. We will test modifications of the design as they are identified, and plan to have a design in production for installation at

Livingston shortly after the S2 science run. Teams from Stanford, Louisiana State University, and Caltech will join the MIT staff for this work.

Once the installation is available, an in-vacuum test of prototypes of the suspensions destined for the HAM vacuum chamber will be made. These are the recycling mirror and mode-cleaner mirror suspensions, which are triple pendulum designs much like the GEO-600 suspensions. This will involve tests of the installation tooling and procedures, and actuator and damping performance testing of the suspensions *per se*. Teams from Caltech, Stanford, and GEO Glasgow will work with the MIT staff in this stage of the research.

Parallel work in the LASTI Lab will continue throughout the year. We will use the Quad "rough" pendulum to explore hierarchical actuation techniques, and the pre-stabilized laser will serve as a test bed for servo-system improvements for initial LIGO. We will be preparing for the arrival of the first Advanced LIGO HAM active seismic isolation system, planned for mid-2003. This will require developing the data acquisition system, and electrical and mechanical interfaces.

C.2.6.3. Advanced R&D

We plan significant progress for the Advanced LIGO subsystems in FY 2003. To briefly summarize:

- Seismic Isolation: We will exploit the Engineering Test Facility prototype at Stanford to enable the design of the LASTI HAM prototype. Once basic design information is extracted, work will continue to develop operational software. The LASTI HAM prototype will be fabricated, and shipped to MIT for installation. Testing should start in FY 2003.

- Optics: The down selection between sapphire and fused silica will occur early in the fiscal year, followed by fabrication of pathfinder optics, which are destined for the LASTI tests. We will continue development of material properties, and the research into optical coatings for low optical and mechanical loss. We will design and build a prototype of the thermal compensator system for delivery to the ACIGA (Australian Consortium for Gravitational Astronomy) Gingin test facility, and will support those tests.

- Suspensions: We will test the auxiliary suspensions (mode cleaner, recycling mirrors), and the resulting design refinements will support the Preliminary Design Review early in the fiscal year. We will continue, in parallel, the design of the test mass suspensions and the test of actuator hierarchies on the existing prototype. We will also refine the control systems and develop electrostatic and photon actuators.

- Laser and Input Optics: We will select the approach, currently being explored by groups in Adelaide, Stanford, and Hannover, for the 200 Watt laser source early in the year. This enables the preliminary design of the laser in FY 2003. We will complete the preliminary design phase for the Input Optics mid-year, and will fabricate modulators and isolators compatible with the elevated power levels in Advanced LIGO. These will be sent to the ACIGA Gingin facility for testing.

- Systems and Sensing/Control: The systems group will continue to identify requirements for the subsystems and help in the design and review process. We will perform tabletop experiments on techniques for strain readout in parallel with calculations and modeling to refine our measurement system design and to extract the highest sensitivity from the signal-recycled interferometer topology.

C.2.7. LIGO Scientific Collaboration (LSC)

LIGO will continue to work within the LIGO Scientific Collaboration as the forum for organizing the technical and scientific research. Appendix A lists the Memoranda of Understanding that have been established with members of the LSC (http://www.ligo.org/mou/mou.html).

C.3. Actual Costs, Staffing, Organization

C.3.1. FY 2002 Actual Costs

Table 2 summarizes the costs and commitments as of the end of August 2002 for Operations and for R&D. Advanced R&D was previously paid under a separate grant, NSF-PHY9801158. The last period of performance under this grant was September 1, 2001 through August 30, 2002. Due to the considerable overlap between the grant and this cooperative agreement, the switch to the cooperative agreement for R&D effort was delayed. However, we are currently 100 percent charged against the cooperative agreement.

Table 2. Actual Costs and Commitments as of End of August 2002.

	Actual Costs (End of August 2002)	Open Encumbrances	Total Costs And Commitments	FY2002 Funding
Operations	18,925,593	4,181,866	23,107,459	24,000,000
R&D	1,043,448	669,640	1,713,088	4,000,000
Total	19,969,041	4,851,506	24,820,547	28,000,000

C.3.2. Staffing

Table 3 summarizes the proposed Full Time Equivalent (FTE) Staffing levels at the various sites and provides a comparison with staffing levels as of the end of August 2002. The proposed increase represents primarily staffing for full 24-7 operations at the sites.

Table 3. Proposed Staffing Levels Compared with Current (end of August 2002) Staffing

Line	Description	Caltech	Hanford	Livingston (incl CAP)	MIT	Total	Current (End of Aug)
A	Senior Personnel	0.9			1.2	2.1	2.1
B1	Post Doctoral	12.5	3.0	4.5	8.3	28.3	16.5
B2	Other Professionals	35.9	26.5	21.0	4.0	87.4	85.1
B3	Graduate Students	7.0			7.0	14.0	10.0
B4	Undergraduates	2.5			2.0	4.5	3.1
B5	Clerical/Secretarial	4.7	1.5	1.0	1.0	8.2	7.7
G5	Contract	26.0		1.9		27.9	30.0
Total		**89.5**	**31.0**	**28.4**	**23.5**	**172.4**	**154.5**

C.3.3. Organization

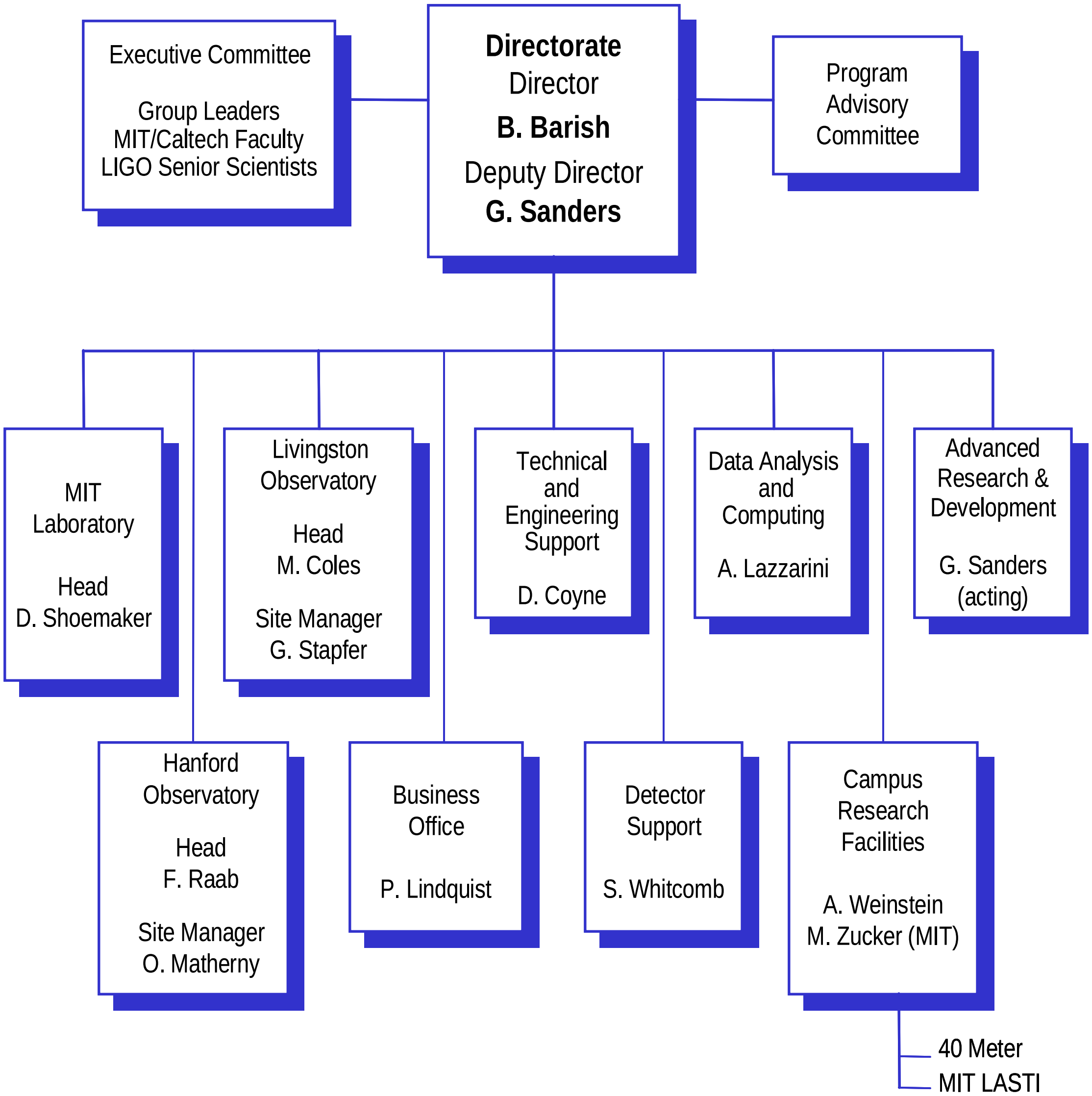
There are no significant differences between the current LIGO organization and the organization chart provided in the Proposal and in the Laboratory Charter.[2] Minor differences include the reorganization of the Administrative Support function within the Business Office and the identification of G. Sanders as the acting head of the Advanced Research and Development effort (See Figure 5.)

C.4. Meetings

Meetings scheduled in FY 2003 include:

- NSF Review – October 23-25, 2002 at MIT
- Program Advisory Committee (PAC) – December 5-6, 2002 at Livingston
- LIGO Scientific Collaboration (LSC) -- March 17-20, 2003 at Livingston Observatory
- Program Advisory Committee (PAC) – to be determined (May, June timeframe)
- LIGO Scientific Collaboration (LSC) – August 18-21, 2003 at GEO

Figure 5. LIGO Organization Chart



D. REFERENCES

[1]NSF Cooperative Agreement No. PHY-0107417, Amendment No. 001 “Laser Interferometer Gravitational Wave Observatory LIGO”, October 1, 2001 – September 30, 2006

[2]The LIGO Laboratory Charter (2002 - 2006), LIGO-M010213-01-M, October 2001, (http://www.ligo.caltech.edu/LIGO_web/ligolab/charter.html)

F. PROPOSAL BUDGET AND JUSTIFICATION

F.1. Summary

The total funding request for LIGO Operations for FY 2002 through 2006 is $160.0 million (NSF Proposal 0107417). The proposed period of performance is October 1, 2001 through September 30, 2006.

The effort covered by this request includes LIGO Operations as well as Research and Development on key Advanced Detector technologies. The period of performance is FY 2003 beginning October 1, 2002 and ending September 30, 2003. The total requested is $33 million consistent with NSF Proposal 0107417 submitted September 2001.

F.2. MIT Funding

LIGO activity is ongoing at four separate sites: Caltech, MIT, the Hanford Observatory, and the Livingston Observatory. A staff of 23.5 scientists, engineers, graduate students, undergraduates, and support staff are located at MIT. This proposal for $160 million includes the effort at all four sites. However, in this Proposal Budget and Justification the MIT effort is identified as a subcontract, and the MIT budget appears as a single entry in the G5 Subawards line. The separate MIT Proposal Budget attached details the budget allocation within this subcontract.

F.3. Proposal Budgets

The Proposal Budgets for FY2003 Operations, Advanced R&D, and Totals are attached. The following definitions and overhead rates apply:

Table 4. LIGO FY 2003 Proposal Budget Location Codes

CAP	Capital Facilities, Caltech Owned	Caltech Approved Rates for Capital Facilities, 0 Percent
CIT	California Institute of Technology	Caltech Approved On-Campus Rates, 58 Percent
HAN	Hanford Observatory	Caltech Approved Off-Campus Rates, 26 Percent
LIV	Livingston Observatory	Caltech Approved Off Campus Rates, 26 Percent
MIT	Massachusetts Institute of Technology	MIT Approved Rates

Table 5. LIGO FY 2003 Proposal Budget Line Definitions

Line A	Senior Personnel
Line B1	Post Doctoral Associates
Line B2	Other Professionals
Line B3	Graduate Students
Line B4	Undergraduate Students
Line B5	Secretarial/Clerical
Line C	Fringe Benefits
Line D	Equipment (> $5000)
Line E1	Travel—Domestic
Line E2	Travel—Foreign
Line F1	Participant Costs--Stipends
Line F2	Participant Costs—Travel
Line F4	Participant Costs—Other
Line G1	Other Direct Costs—Materials and Supplies (Including Equipment < $5000)
Line G5	Other Direct Costs—Subawards
Line G6	Other Direct Costs—Other (GRA Benefits)
Line I	Indirect Costs

Table 6. LIGO FY 2003 Proposal Budget for Operations

	CAP		CIT		HAN		LIV		MIT		Total	
Line	FY 2003 Proposed FTEs	FY 2003 Proposed Amount	FY 2003 Proposed FTEs	FY 2003 Proposed Amount	FY 2003 Proposed FTEs	FY 2003 Proposed Amount	FY 2003 Proposed FTEs	FY 2003 Proposed Amount	FY 2003 Proposed FTEs	FY 2003 Proposed Amount	FY 2003 Proposed FTEs	FY 2003 Proposed Amount
A	-	-	0.93	181,125	-	-	-	-	-	-	0.93	181,125
B1	0.50	20,000	11.00	489,814	3.00	128,806	4.00	199,450	-	-	18.50	838,070
B2	3.00	228,500	33.56	2,953,958	26.50	1,641,032	18.00	1,176,108	-	-	81.06	5,999,598
B3	-	-	4.00	81,636	-	-	-	-	-	-	4.00	81,636
B4	-	-	2.50	60,420	-	-	-	-	-	-	2.50	60,420
B5	-	-	4.65	209,347	1.50	59,600	1.00	31,200	-	-	7.15	300,147
C	-	62,125	-	958,561	-	457,360	-	351,689	-	-	-	1,829,735
D	-	-	-	1,841,080	-	170,070	-	187,664	-	-	-	2,198,814
E1	-	79,800	-	355,060	-	309,575	-	190,550	-	-	-	934,985
E2	-	-	-	78,650	-	-	-	-	-	-	-	78,650
F1	-	-	-	-	-	4,635	-	-	-	-	-	4,635
F2	-	-	-	-	-	-	-	-	-	-	-	-
F4	-	-	-	-	-	57,508	-	-	-	-	-	57,508
G1	-	8,583	-	1,324,372	-	807,618	-	681,655	-	-	-	2,822,228
G5	1.00	85,176	25.00	3,437,113	-	1,051,115	0.92	1,281,074	12.58	2,244,407.00	39.50	8,098,884
G6	-	-	-	48,982	-	-	-	-	-	-	-	48,982
I	-	-	-	3,881,907	-	885,707	-	696,970	-	-	-	5,464,584
Total	**4.50**	**484,184**	**81.64**	**15,902,024**	**31.00**	**5,573,026**	**23.92**	**4,796,360**	**12.58**	**2,244,407**	**153.65**	**29,000,000**

Table 7. LIGO FY 2003 Proposal Budget for Research and Development

	CAP		CIT		HAN		LIV		MIT		Total	
Line	FY 2003 Proposed FTEs	FY 2003 Proposed Amount	FY 2003 Proposed FTEs	FY 2003 Proposed Amount	FY 2003 Proposed FTEs	FY 2003 Proposed Amount	FY 2003 Proposed FTEs	FY 2003 Proposed Amount	FY 2003 Proposed FTEs	FY 2003 Proposed Amount	FY 2003 Proposed FTEs	FY 2003 Proposed Amount
A	-	-	-	-	-	-	-	-	-	-	-	-
B1	-	-	1.50	66,435	-	-	-	-	-	-	1.50	66,435
B2	-	-	2.33	206,280	-	-	-	-	-	-	2.33	206,280
B3	-	-	3.00	62,731	-	-	-	-	-	-	3.00	62,731
B4	-	-	-	-	-	-	-	-	-	-	-	-
B5	-	-	-	-	-	-	-	-	-	-	-	-
C	-	-	-	68,179	-	-	-	-	-	-	-	68,179
D	-	-	-	1,341,740	-	-	-	-	-	-	-	1,341,740
E1	-	-	-	28,000	-	-	-	-	-	-	-	28,000
E2	-	-	-	18,800	-	-	-	-	-	-	-	18,800
F1	-	-	-	20,000	-	-	-	-	-	-	-	20,000
F2	-	-	-	20,000	-	-	-	-	-	-	-	20,000
F4	-	-	-	-	-	-	-	-	-	-	-	-
G1	-	-	-	184,281	-	-	-	-	-	-	-	184,281
G5	-	-	1.00	474,423	-	-	-	-	10.92	1,103,363.00	11.92	1,577,786
G6	-	-	-	37,639	-	-	-	-	-	-	-	37,639
I	-	-	-	368,129	-	-	-	-	-	-	-	368,129
Total	**0.00**	**0**	**7.83**	**2,896,637**	**0.00**	**0**	**0.00**	**0**	**10.92**	**1,103,363**	**18.75**	**4,000,000**

Table 8. LIGO FY 2003 Proposal Budget Total

	CAP		CIT		HAN		LIV		MIT		Total	
Line	FY 2003 Proposed FTEs	FY 2003 Proposed Amount	FY 2003 Proposed FTEs	FY 2003 Proposed Amount	FY 2003 Proposed FTEs	FY 2003 Proposed Amount	FY 2003 Proposed FTEs	FY 2003 Proposed Amount	FY 2003 Proposed FTEs	FY 2003 Proposed Amount	FY 2003 Proposed FTEs	FY 2003 Proposed Amount
A	-	-	0.93	181,125	-	-	-	-	-	-	0.93	181,125
B1	0.50	20,000	12.50	556,249	3.00	128,806	4.00	199,450	-	-	20.00	904,505
B2	3.00	228,500	35.89	3,160,238	26.50	1,641,032	18.00	1,176,108	-	-	83.39	6,205,878
B3	-	-	7.00	144,367	-	-	-	-	-	-	7.00	144,367
B4	-	-	2.50	60,420	-	-	-	-	-	-	2.50	60,420
B5	-	-	4.65	209,347	1.50	59,600	1.00	31,200	-	-	7.15	300,147
C	-	62,125	-	1,026,740	-	457,360	-	351,689	-	-	-	1,897,914
D	-	-	-	3,182,820	-	170,070	-	187,664	-	-	-	3,540,554
E1	-	79,800	-	383,060	-	309,575	-	190,550	-	-	-	962,985
E2	-	-	-	97,450	-	-	-	-	-	-	-	97,450
F1	-	-	-	20,000	-	4,635	-	-	-	-	-	24,635
F2	-	-	-	20,000	-	-	-	-	-	-	-	20,000
F4	-	-	-	-	-	57,508	-	-	-	-	-	57,508
G1	-	8,583	-	1,508,653	-	807,618	-	681,655	-	-	-	3,006,509
G5	1.00	85,176	26.00	3,911,536	-	1,051,115	0.92	1,281,074	23.50	3,347,770.00	51.42	9,676,670
G6	-	-	-	86,620	-	-	-	-	-	-	-	86,620
I	-	-	-	4,250,036	-	885,707	-	696,970	-	-	-	5,832,713
Total	**4.50**	**484,184**	**89.47**	**18,798,661**	**31.00**	**5,573,026**	**23.92**	**4,796,360**	**23.50**	**3,347,770**	**172.39**	**33,000,000**

F.3.1. Line A - Senior Personnel

In accordance with Institute Policy, individual senior personnel salary data are furnished under separate cover to the NSF.

Location	Description	Name	FTEs [1] Charged to LIGO	FTEs Assigned to LIGO	Calendar Months
Caltech	Laboratory Director, Professor of Physics—Caltech	B. Barish	0.33	0.50	4
Caltech	Deputy Laboratory Director	G. Sanders	0.60	1.00	7
MIT	MIT Professor Emeritus	R. Weiss	0.17[2]	1.00	2
MIT	MIT Group Head, MIT Subcontract Principal Investigator	D. Shoemaker	1.00[3]	1.00	12
	Total		2.10	3.50	25

F.3.2. Line B--Salaries and Wages

Actual salaries have been used when available to calculate direct costs.

F.3.3. Line C—Fringe Benefits

Staff Benefits Rate as of October 1, 2001excluding Undergraduate and Graduate Student Salaries: 25 percent.

[1] FTE—Full Time Equivalent

[2] Covered within the MIT Subaward.

[3] Covered within the MIT Subaward

F.3.4. Line D—Equipment

Location	WBS	Description	FY 2003 Proposed Amount	Funds Source
CIT	1.1.2	Components for Seismic Remediation	758,000	OPS
CIT	1.1.2	OC3 Interface	50,000	OPS
CIT	1.1.2	Components for Microseismic Feedforward to Fine Actuators	30,000	OPS
CIT	1.1.2	Operations Equipment Reserve	38,121	OPS
CIT	1.3	Technical and Engineering Support Equipment	85,000	OPS
CIT	1.4	Detector Support Equipment	51,750	OPS
CIT	1.5.1	LDAS Maintenance Equipment	62,456	OPS
CIT	1.5.3	General Computing Equipment	100,000	OPS
CIT	1.6.1	40-Meter Facility Equipment	100,000	OPS
HAN	2.1	Hanford Site Office Equipment	51,500	OPS
HAN	2.2	Hanford Fafilities Maintenance Equipment	18,540	OPS
HAN	2.5	Hanford Data Analysis and Computing Equipment	72,100	OPS
HAN	2.12	Hanford LDAS Maintenance Equipment	27,930	OPS
LIV	3.1	Livingston Site Office Equipment	51,500	OPS
LIV	3.3	Livingston Vacuum Equipment	41,200	OPS
LIV	3.5	Livingston Data Analysis and Computing Equipment	25,750	OPS
LIV	3.6	Livingston Electronics Shop	20,600	OPS
LIV	3.8	Installation and Commissioning Support Equipment	30,900	OPS
LIV	3.12	Livingston LDAS Maintenance Equipment	17,714	OPS
CIT	5.4	Core Optics, Metrology, and Sapphire Development	565,753	OPS
CIT	1.1.3	Equipment Reserve (R&D)	36,162	ARD
CIT	5.2	Thermal Noise Interferometer	8,000	ARD
CIT	5.3	Advanced Stabilized Lasers	14,006	ARD
CIT	5.8	Seismic Isolation Systems	82,815	ARD
CIT	5.10	Advanced Suspensions	1,040,757	ARD
CIT	5.11	Low Frequency Noise Suppression	60,000	ARD
CIT	5.14	100 Watt Laser (Quote 2002-0117)	100,000	ARD
		Total	**3,540,554**	

F.3.5. Line F--Participant Costs

Funds will support participation by visitors in the Research and Development efforts in the 40-Meter facility and the Low Frequency Sensitivity Improvement program. Funds also support participation in the LIGO Outreach program.

F.3.6. Line G5—Other Direct Costs, Subawards

Caltech applies overhead against the first $25,000 of a subcontract. New planned subcontract amounts falling within the first $25,000 include:

LOC	WBS	Description	FY 2003 Proposed Amount
HAN	2.10	Educational Consultant Costs	2,575
LIV	3.2	Site Facility Maintenance Contracts	50,000

The on-campus overhead rate is 58 percent on the first $25,000. The off-campus overhead rate is 26 percent on the first $25,000. No overhead is applied for contacts continued from the previous year if the total contract amount has exceeded $25,000.

F.3.7. Line G6—Other Direct Costs, Other (GRA Benefits)

Graduate Research Assistantship Benefits— Institute Policy is to provide each graduate student employee who meets a required average workweek with full tuition and fees. A portion of this cost is requested as a benefit (exempt from indirect costs) equivalent to 60 percent of the graduate research assistant stipend effective October 1, 1999. This rate is applicable to all federal grants and contracts, and all other awards that provide full indirect cost recovery. The GRA Tuition Remission Benefit for all non-federal awards (gifts, grants, contracts) that do not provide full overhead is 80% of GRA salary.

F.3.8. Line I--Indirect Costs

Indirect Cost Rate Agreement Agency and Date: Office of Naval Research, 8/31/00 (rates in effect at time of proposal in September 2001)

On-Campus Overhead Rate: 58.0 percent MTDC.
Off-Campus Overhead Rate: 26.0 percent.
Excludes Equipment, JPL Work Orders (when work is performed at JPL), Subcontract amounts in excess of $25,000, and GRA Benefits.

F.3.9. Computation of Overhead for Caltech Fabricated Capital Facilities

A separate account has been established for the Seismic Development Facility at Livingston. These facilities are required to support the LIGO Scientific Collaboration and Advanced Research and Development planned in support of the Advanced LIGO configuration. Caltech does not apply overhead for Capital Facilities costs.

APPENDIX A.

LIGO Scientific Collaboration (LSC) Memoranda of Understanding

LIGO Scientific Collaboration (LSC) Memoranda of Understanding

Last updated on September 4, 2002

LSC Members | LSC Non-Members

ey to Lettered Attachments
A LIGO I
B Isolation/Suspension/Thermal Noise
C Lasers/Optics
D Advanced Detector Configurations
E Advanced Data Analysis
Z Working Group Members

LSC Members

Institution	Attachments	Reports
Australian Consortium for Interferometric Gravitational Astronomy (ACIGA)		
	Aug 15, 2001 A B C D Z	Aug 15, 2001
	Feb 15, 2002 A B C D Z	Feb 15, 2002
Caltech Center for Advanced Computing Research (CACR)		
	Feb 15, 2001 A Z	Aug 15, 1999
		Feb 15, 2000

Institution	Attachments	Reports
Caltech Relativity Theory Group (CaRT)		
	Aug 15, 2001 A D Z	Aug 15, 2001
	Feb 15, 2002 A D Z	Feb 15, 2002
Caltech Experimental Gravitational-Physics Group (CEGG)		
	Aug 15, 2001 A B Z	Aug 15, 2000
	Feb 15, 2002 A B Z	Aug 15, 2002
California State University Dominguez Hills Elementary Particles and Relativity Group		
	Aug 15, 2001 A Z	Feb 15, 2001
	Feb 15, 2002 A Z	Aug 15, 2001
Carleton College Relativity Group (CCRG)		
	Aug 15, 2001 A Z	Feb 15, 2002
	Feb 15, 2002 A Z	Aug 15, 2002
Fermi National Accelerator Laboratory (Fermilab)		
	Mar 07, 2001 A Z	
	Aug 15, 2001 A Z	

Institution	Attachments	Reports
University of Florida Physics Department LIGO Group (UF-LIGO)		
	Aug 15, 2001 A C D Z	Aug'00-Feb'01
	Feb 15, 2002 A C D Z	Feb'01-Feb'02
German/British Collaboration for the Detection of Gravitational Waves (GEO 600)		
	Aug 15, 2001 A B C D Z	Feb'01-Feb'02
	Feb 15, 2002 A B C D Z	Feb-Aug'02
Goddard Gravitational Wave Astrophysics Group (GGWAG)		
	Aug 15, 2001 A C D Z	Feb 15, 2002
India Inter-University Centre for Astronomy and Astrophysics (IUCAA)		
	Aug 15, 2001 A Z	Aug 15, 2001
	Feb 15, 2002 A Z	Feb 15, 2002
Institute of Applied Physics (IAP) Russian Academy of Sciences at Nizhny Novgorod		
	Feb 15, 2001 C Z	Feb 15, 2001
	Feb 15, 2002 C Z	Aug 15, 2001

Institution	Attachments	Reports
Japan NAOJ-TAMA Group		
	Aug 15, 2001 D Z	Feb 15, 2002
	Feb 15, 2002 D Z	Aug 15, 2002
Louisiana State University Experimental Relativity Group (ERG)		
	Feb 15, 2000 A B Z	Feb 15, 2000
	Aug 15, 2000 A B Z	Aug 15, 2000
Relativity and Astrophysics Group of Louisiana Tech University		
	Nov 01, 2001 A Z	Feb 15, 2001
	Feb 15, 2002 A Z	Feb 15, 2002
Loyola University Experimental Gravitation Group (LUEGG)		
	Aug 15, 2001 MOU A Z	Feb 15, 2002
	Feb 15, 2002 A Z	Aug 15, 2002
University of Michigan Gravity Wave Group (MGWG)		
	Feb 15, 2000 2 A Z	Aug 15, 2000
	Aug 15, 2000 A Z	Feb 15, 2001

Institution	Attachments	Reports
Moscow State University Relativity Group (MSURG)		
	Aug 15, 2001 B D Z	Jan-Dec 2001
	Feb 15, 2002 B D Z	Jan-Jun 2002
Northwestern University Gravitational Wave Astrophysics Group (NUGWAG)		
	Aug 15, 2001 A Z	
	Feb 15, 2002 Z	
University of Oregon Experimental Relativity Group (UOERG)		
	Aug 15, 2001 A Z	Aug 15, 2001
	Feb 15, 2002 A Z	Feb 15, 2002
Pennsylvania State University Experimental Relativity Group (ERG)		
	Aug 15, 2001 A B Z	Aug 15, 2001
	Feb 15, 2002 A D Z	Feb 15, 2002
Salish Kootenai College Astrophysics Group (SKCAG)		
	Feb 01, 2002 MOU	
	Feb 15, 2002 A Z	

Institution	Attachments	Reports
Southeastern Louisiana University Department of Chemistry and Physics (DCP/SLU)		
	Dec 01, 1999 MOU	Feb 15, 2002
	Feb 15, 2002 A Z	
Southern University and A&M College Baton Rouge, LA (SUBR) Department of Physics		
	Feb 1, 2001 C Z	Feb 15, 2001
	Aug 15, 2001 C Z	Feb 15, 2002
Stanford Advanced Gravitational Wave Interferometry Group		
	Aug 15, 2001 B C D Z	Aug 15, 2001 B C D
	Feb 15, 2002 A B C D Z	Feb 15, 2002 B C D
Syracuse University Experimental Relativity Group (SUERG)		
	Aug 15, 2001 A B Z	Aug 15, 2001
	Feb 15, 2002 A B Z	Feb 15, 2002
University of Texas at Brownsville Relativity Group (UTBRG)		
	Aug 15, 2001 A Z	Aug 15, 2001
	Feb 15, 2002 A Z	Aug'01-Feb'02

Institution	Attachments	Reports
University of Wisconsin-Milwaukee Relativity Group (UWMRG)		
	Feb 15, 2001 A Z	Aug 15, 2001
	Aug 15, 2001 A Z	Aug'01-Aug'02
Washington State University Relativity Group (WSURG)		
	Feb 15, 2002 MOU A Z	

LSC Non-Members

Institution	Attachments
California Extremely Large Telescope (CELT) Project	
	Apr 15, 2002 MOU
Chinese Academy of Sciences Shanghai Institute of Optics and Fine Mechanics (SIOM)	
	Jan 01, 1999 1
	May 15, 2002 2
Collaboration of the Russian Research Institutes (CRRI)	
	Mar 14, 2000 1
	Feb 15, 2002 1
Institut National des Sciences Appliquees (INSA) de Lyon, France	
	Jan 04, 2000 1
	Apr 24, 2002 2

Institution	Attachments
Dipartimento di Astronomia e Scienza dello Spazio dell'Universita' degli Studi di Firenze, Italia	
	Aug 29, 2000 MOU
European Gravitational Observatory (EGO)	
	Jun 1, 2001 MOU
	Jun 1, 2001 1
Instituto di Fisica dell'Universita' degli Studi di Urbino, Italia	
	Aug 29, 2000 MOU
TAMA Project, Japan	
	Jun 23, 2000 5
	Feb 15, 2001 D Z
University of Tokyo, Japan Department of Physics	
	Jun 01, 1999 MOU
	Jun 01, 1999 1

Institution	Attachments	
VIRGO Project		
	Jun 01, 1999 3	
	Sep 15, 2000 2	

APPENDIX B.

MIT Proposal for FY 2003 Participation in LIGO

The original signed MIT Proposal including budget allocations to various tasks is on file at Caltech.

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
CENTER FOR SPACE RESEARCH

From: David Shoemaker, NW17-161
Phone: 617 253 6411
Date: 1 August 2002

Proposal for MIT LIGO participation, FY 2003

The gravitational research group at MIT is fully integrated into the LIGO Laboratory and together with Caltech and Observatory scientists carry out laboratory functions to:

- provide scientific guidance to the LIGO Laboratory,
- perform research leading to the initial LIGO detector,
- perform research leading to future enhancements of the detectors,
- fulfill responsibilities in the construction, installation, testing and operation of the LIGO detectors and facilities,
- fulfill responsibilities for the data analysis,
- represent the project to the scientific community.

The LIGO group at MIT consists of a three faculty members (Weiss (emeritus), Katsavounidis, Mavalvala) 3 scientists (Fritschel, Shoemaker, Zucker), 5 postdocs/term scientists, 2 engineers, 7 graduate students, several undergraduate students, 2 technical personnel, and administrative support. The plan for calls for a roughly constant group size as funded by the subcontract from Caltech.

Specific activities of the MIT group for 2003 consist of:

- Continued responsibility for the commissioning/operation of the initial LIGO detector subsystems to:
  a) sense and hold the separation of the interferometer mirrors and develop the gravitational wave output signal,
  b) sense and hold the interferometer alignment
- Support for all subsystems through a significant site presence
- Responsibility for an R&D program to support the initial and advanced detector, which in this year includes research on
  a) suspension and isolation systems for advanced interferometers,
  b) work on thermal lens compensation
  c) development of strain readout systems
- Support to the direction and management of the detector program across the LIGO project
- Scientific support to the LIGO systems integration and modeling program
- Providing planning, managerial, administrative, and computing support to the Lab (MIT and elsewhere)

General indications of the foci of effort are given in this document. A breakdown of the planned equipment purchases is given in the attached budget. We are continuing the commissioning of the interferometer components at the LIGO sites (Hanford, Washington; Livingston, Louisiana), and thus a significant amount of travel (funded through the Caltech-operated LIGO Sites) is foreseen for some members of the group. The development of the LIGO Advanced Systems Test Interferometer (LASTI) continues as the primary focus of the experimental work.

It is anticipated that other sources of support (NSF, NASA) will be sought for specific activities in Data Analysis and Instrument Science; this would support activities beyond the scope of LIGO Lab work of our new faculty members.

I. Detector Design, Fabrication, Installation, and Commissioning

A) Interferometer Sensing and Control

The MIT group carries the responsibility for the Interferometer Sensing and Control Task Leadership. This involves coordination of tasks at both MIT and Caltech and the Hanford and Livingston observatories, in both research and implementation. Mike Zucker leads this task group.

The Detector Alignment Sensing/Control System, or ASC, is one of the principal subsystems of the LIGO detector for which MIT carries the responsibility. This system serves to determine and maintain the correct alignment during operation, as well as providing a means to bring the interferometer into initial alignment. The Detector Length Sensing/Control System, or LSC, is a second principal subsystem of the LIGO detector for which MIT carries the responsibility. This system serves to determine and maintain the correct lengths of the interferometer during operation, as well as providing a means to bring the interferometer into the initial operational state. Activities in include integration, and testing at Hanford and Livingston, with continuing incremental improvements.

B) Commissioning Leadership

The MIT group plays a strong role in the commissioning of the interferometers at Hanford and Livingston. Weiss and Fritschel are co-leaders of the commissioning effort to bring the system to the design sensitivity, and Zucker leads the effort to revamp the electronics infrastructure. Extensive presence at the sites as well as work on the MIT campus is required to carry out this responsibility. Weiss is off-campus at the Livingston site, where he is the lead commissioner; one or more graduate students will be stationed there for their research.

II. Operations Research and Development

A) **Laboratory operations**: The operating funds to maintain the laboratory, purchase capital equipment, and the funds for R&D-related travel fall in the following categories:

- Scientific travel to workshops and internal meetings
- Laboratory supplies (consumables)
- Small laboratory equipment
- Capital laboratory equipment
- Equipment maintenance
- Technical manpower to maintain the infrastructure

III. Advanced Research and Development

A) **LIGO Advanced System Test Interferometer:** The LASTI serves as a community-wide basis for research. It is the focus for testing of the mechanical systems for the next generation interferometers, and many visitors will be spending time at MIT to exploit it over the coming years. Some limited funds to support completion of the infrastructure cover scientific, limited engineering, and technical manpower, and materials and supplies for fabricated equipment. Specific activities in FY03 are the completion of work on the seismic pre-isolator for the Livingston remedial effort, testing of the initial Advanced LIGO suspension designs for the HAM vacuum system, and preparation for the tests of the Advanced LIGO HAM seismic isolation system.

B) **R&D Stochastic Noise research:** This research addresses the limits to interferometer sensitivity due to unintended physical motions of the test masses. Examples are thermal noise, seismic noise, coupling to external electric or magnetic fields, and stress-release mechanisms in the suspension fibers. The long-term goal is to develop, test, and qualify a next-generation approach to suspensions, isolation, and the associated control systems for LIGO. Specific activities in FY03 are the exploration of actuator hierarchies for the triple and quad suspensions, studies of the coating and substrate mechanical losses. In this context, Gregg Harry is responsible for the Lab-wide optical coating program.

C) **R&D Active Optics Thermal Compensation:** This work seeks to develop and demonstrate means to correct for the thermal lens due to substrate and coating absorption. Tabletop and in-vacuum measurements will continue. Specific activities in FY03 are developing a complete scaled prototype of a compensator for delivery to the ACIGA Gingin facility, and support of the tests performed on that prototype. David Ottaway will lead this effort.

D) **R&D Advanced LIGO ISC development:** This research is targeted at developing the readout system for Advanced LIGO. The leadership of the Interferometer Sensing and Control subsystem is carried at MIT, and specific activities in FY03 will be analytical and numerical studies of the performance of various approaches, and tests of schemes in simple table-top optical setups.

IV. Data Analysis and Observational Planning

Diagnostics and Signals: Strategies for detection, coding of algorithms, and work with the engineering data are foci of the Data Analysis group. Activities for include the extension of the MIT Beowulf cluster, development of veto techniques for the un-modeled Burst waveform signal searches, development of the Event Tool used to combine the Veto and Strain analysis code outputs, and most importantly the scientific interpretation of the resulting event analysis. should see the first publication of upper limits to gravitational wave flux from the LIGO Scientific Collaboration, with the MIT analysis group playing a significant role.

V. Project support

A) **Project management:** The MIT group contributes to the project management through management roles (D. Shoemaker is MIT LIGO group leader, and Weiss, Mavalvala, Shoemaker, and Katsavounidis serve on the LIGO Executive Council). In addition, MIT staff support the project management in conferences and community outreach and in project-wide reviews (for example, NSF reviews).

B) **System Integration:** R. Weiss is the cognizant scientist for the project System Integration effort. This involves establishing and refining the System Specifications, studying interface issues, and working on specific problems in the Detector or Facilities as needed.

C) **Administration:** This covers the costs of administrative and secretarial support, local documentation control, and running the offices. Funds to support these activities cover office supplies, copiers, telephones, data connections and manpower.

D) **General computing:** This covers the costs of supporting the general computing environment. Hardware and software purchases, are included in this category, as well as manpower for installation, maintenance, and upgrading of hard- and software.

VI. Planned Equipment purchases

The table below sketches out the equipment purchases (apart from Fabricated Equipment activities) associated with the FY03 research activities.

Account	Item	Cost, k$
63047	real-time control system	41
	spectrum analyzer	27
	oscilloscopes (5)	25
	power supplies (10)	10
	TOTAL	103
63043	spectrum analyzer	27
	oscilloscopes (3)	10
	power supplies (6)	6
	TOTAL	43
63051	workstations (5)	25
	printers (2)	10
	laptop systems (2)	8
	TOTAL	43

SUMMARY PROPOSAL BUDGET

YEAR 1

FOR NSF USE ONLY		
PROPOSAL NO.	DURATION (months)	
	Proposed	Granted
AWARD NO.		

ORGANIZATION
Massachusetts Institute of Technology

PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR
David H Shoemaker

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-mos. CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. David H Shoemaker - Principal Investigator	12.00	0.00	0.00	$ 132,355	$
2. Erotokritos Katsavounidis - Professor	0.00	0.00	2.00	14,878	
3. Nergis Mavalvala - Professor	0.00	0.00	2.00	14,878	
4. Rainer Weiss - Professor	0.00	0.00	2.00	32,716	
5.					
6. (0) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	0	
7. (4) TOTAL SENIOR PERSONNEL (1 - 6)	12.00	0.00	6.00	194,827	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (4) POST DOCTORAL ASSOCIATES	48.00	0.00	0.00	189,006	
2. (0) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	96.00	0.00	0.00	622,895	
3. (0) GRADUATE STUDENTS				0	
4. (8) UNDERGRADUATE STUDENTS				163,520	
5. (1) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				36,874	
6. (2) OTHER				138,909	
TOTAL SALARIES AND WAGES (A + B)				1,346,031	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				313,584	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				1,659,615	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.) See Attached $ 289,520					
TOTAL EQUIPMENT				289,520	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				55,000	
2. FOREIGN				15,000	
F. PARTICIPANT SUPPORT COSTS 1. STIPENDS $ 0 2. TRAVEL 0 3. SUBSISTENCE 0 4. OTHER 0					
TOTAL NUMBER OF PARTICIPANTS (0) TOTAL PARTICIPANT COSTS				0	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				131,840	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				0	
3. CONSULTANT SERVICES				0	
4. COMPUTER SERVICES				27,810	
5. SUBAWARDS				0	
6. OTHER				117,572	
TOTAL OTHER DIRECT COSTS				277,222	
H. TOTAL DIRECT COSTS (A THROUGH G)				2,296,357	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE) F&A (Off) (Rate: 10.0000, Base: 115691) (Cont. on Comments Page)					
TOTAL INDIRECT COSTS (F&A)				1,051,415	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				3,347,772	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.C.6.j.)				0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ 3,347,772	$

M. COST SHARING PROPOSED LEVEL $ 0 AGREED LEVEL IF DIFFERENT $

PI/PD NAME
David H Shoemaker

ORG. REP. NAME*

FOR NSF USE ONLY		
INDIRECT COST RATE VERIFICATION		
Date Checked	Date Of Rate Sheet	Initials - ORG

 *ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET

SUMMARY PROPOSAL BUDGET COMMENTS - Year 1

**** I- Indirect Costs**
F&A (On) (Rate: 63.0000, Base 1650549)

SUMMARY PROPOSAL BUDGET

Cumulative

ORGANIZATION **Massachusetts Institute of Technology**				FOR NSF USE ONLY PROPOSAL NO.	DURATION (months) Proposed / Granted
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR **David H Shoemaker**				AWARD NO.	

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-mos. CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. David H Shoemaker - Principal Investigator	12.00	0.00	0.00	$ 132,355	$
2. Erotokritos Katsavounidis - Professor	0.00	0.00	2.00	14,878	
3. Nergis Mavalvala - Professor	0.00	0.00	2.00	14,878	
4. Rainer Weiss - Professor	0.00	0.00	2.00	32,716	
5.					
6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	0	
7. (4) TOTAL SENIOR PERSONNEL (1 - 6)	12.00	0.00	6.00	194,827	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (4) POST DOCTORAL ASSOCIATES	48.00	0.00	0.00	189,006	
2. (0) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	96.00	0.00	0.00	622,895	
3. (0) GRADUATE STUDENTS				0	
4. (8) UNDERGRADUATE STUDENTS				163,520	
5. (1) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				36,874	
6. (2) OTHER				138,909	
TOTAL SALARIES AND WAGES (A + B)				1,346,031	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				313,584	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				1,659,615	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.) $ 289,520					
TOTAL EQUIPMENT				289,520	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				55,000	
2. FOREIGN				15,000	
F. PARTICIPANT SUPPORT COSTS 1. STIPENDS $ 0 2. TRAVEL 0 3. SUBSISTENCE 0 4. OTHER 0					
TOTAL NUMBER OF PARTICIPANTS (0) TOTAL PARTICIPANT COSTS				0	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				131,840	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				0	
3. CONSULTANT SERVICES				0	
4. COMPUTER SERVICES				27,810	
5. SUBAWARDS				0	
6. OTHER				117,572	
TOTAL OTHER DIRECT COSTS				277,222	
H. TOTAL DIRECT COSTS (A THROUGH G)				2,296,357	
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K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.C.6.j.)				0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ 3,347,772	$

M. COST SHARING PROPOSED LEVEL $ 0 AGREED LEVEL IF DIFFERENT $

PI/PD NAME **David H Shoemaker**	FOR NSF USE ONLY INDIRECT COST RATE VERIFICATION		
ORG. REP. NAME*	Date Checked	Date Of Rate Sheet	Initials - ORG

C ***ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET**