LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY
- LIGO -
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Planning Proposal for LIGO SST Program

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This is an internal working note
of the LIGO Project.

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1 PROJECT SUMMARY

The LIGO Laboratory, a joint venture of the California Institute of Technology (Caltech) and the Massachusetts Institute of Technology (MIT) supported by NSF Cooperative Agreement PHY921038, is constructing and operating gravitational-wave observatories[1] in Washington and Louisiana as national facilities within an international network of gravitational-wave detectors. The quest for gravitational waves involves pushing the art of experimental physics to the edge of modern technology. Monumental laser interferometers, that measure 4-km on a side but are limited in their precision only by the fundamental laws of thermodynamics and quantum mechanics, will seek to uncover a universe hidden from our electromagnetic senses. Even as we perfect these detectors, we want to make this exciting science accessible to America's high schools as part of a broader LIGO outreach program[2]. We request this planning grant to develop the LIGO Scientist/Student/Teacher (SST) program, which will engage teams of scientists, high-school students and their teachers in the transfer of research from LIGO to high schools and their school districts.

In this program a teacher becomes familiar with a long-term LIGO research task in a first summer internship and begins introducing this work into his teaching. The second summer, the teacher returns with three students, who have completed 11th grade studies, for intensive summer research. In this summer this "leadership team" develops the necessary leadership, science and mentoring skills and a project management plan for leading the research effort as it returns to their high school for the follwoing academic year. The following summer, the teacher returns to LIGO with a new "leadership team" of students and begins another year of research at the high school. Our intent is for research to become a permanent feature of physics education at the high school with broad student participation. We request funding to run two LIGO-SST teams for two years[3] to test aspects of this program and to develop plans and resources for expanding this program.

We believe that LIGO has unique resources for developing SST into a national program. LIGO science is a first-class, interdisciplinary effort that cuts across physics, mathematics, engineering and astronomy, offering a rich mixture of research opportunities. LIGO is an NSF Research Experiences for Undergraduates (REU) site and thereby offers synergy between teacher/student teams and undergraduate researchers during the summer. Teachers can discover how young undergraduates are taught to do research, better enabling them to prepare their students; high-school students benefit from exposure to college-aged and more advanced researchers; REU students and the high school "leadership-team" students are given opportunities to learn valuable leadership and mentoring skills. LIGO has a national presence with observatories under common management in both Washington and Louisiana, and LIGO has developed an international set of collaborating institutions, known as the LIGO Science Collaboration, comprised of more than 250 scientists in twelve states across the U.S.[4], in addition to research consortia in Europe, Asia and Australia. This provides a natural platform for expanding this program to the national level and beyond.

Our effort builds on a similar program, developed at Pacific Northwest National Laboratory (PNNL) and funded by the NSF (grant ESI 97-312334). The nascent LIGO-SST effort will gain from its close proximity to the PNNL facility (15-minutes by car), sharing expertise and services (teacher development workshops, project evaluation and administration, etc.) with PNNL and Associated Western Universities (AWU). LIGO-SST will effectively complement the local PNNL program, adding several new dimensions: introducing projects in physics and related fields of physical science, especially data analysis; extending opportunities to teachers without prior

research experience; emphasizing broad student participation; and regionalizing the program beyond Washington state, with an eye toward national access to research opportunities.

2 PROJECT DESCRIPTION

2.1. NEED ADDRESSED BY LIGO-SST PROGRAM

Science is a process, not just a collection of facts, principles and algorithms. The typical classroom science experience focuses on the latter with few mechanisms to expose students to the process of science. We eventually reap the bitter harvest of this neglect through public misunderstanding of the nature of science and public disdain when scientific debates reach the news media. *This project addresses the need to bring to our secondary schools insights into the true nature of scientific and technical processes.* Accomplished science teachers at the high school level may have excellent scholastic underpinnings in the science they teach but most have not had research experience. Without this experience, teachers can communicate the "what" of science but they are challenged in trying to communicate the "how" of science. The need exists (1) for science teachers to have an intimate knowledge of scientific process, that can only be obtained first-hand, (2) for students to gain experience with the tools, teamwork and methods practiced by scientists and technology professionals to augment scholastic activities in the classroom, and (3) for school districts to have a base of teachers with the capability to manage and mentor research efforts within the school district.

2.2. SST Program Objective and Goals

The objective of LIGO-SST is to involve teams of high-school teachers and students in actual research projects with observatory scientists and engineers. *We are aiming at broad student involvement, with a goal of exposing the average science student to research.* This goal can only be accomplished by bringing research into the high-school classroom. Each research project starts within the environment of the observatory and then moves to the school and the classroom. Over the course of this project, the team develops first-hand insights into the process of scientific research; the teacher develops research mentoring and management skills as well as acquiring valuable experience to enrich inquiry-based classroom experiences; the students build valuable leadership and teaming skills and the school develops a real-world window into the professional world of science, engineering and mathematics. These research experiences provide:

- relevant educational opportunities as envisaged in the School-To-Work Opportunities Act, by allowing students to explore professional career opportunities
- support for state educational reform efforts which call for certification of mastery in essential areas and career pathways for 11th and 12th grade students
- support for standards-based science and technology education by providing students with the knowledge and skill necessary to understand and use scientific concepts and principles, to conduct scientific investigations individually and cooperatively, to hone their communication and presentation skills, and to understand the connection between science and the real world.

Students also acquire new purpose and motivation by seeing both how their scholastic learning is incorporated in actual practice and what career paths are available in these areas. The net effect is to make education more relevant, both for future careers in science and for lifelong learning. The teacher, who will invest several years of effort in this endeavor is rewarded with first-hand research and management skills that can greatly strengthen his teaching role in the school and the district. The schools, which are requested to make a substantial "buy-in" investment to support the research, establish a base for maintaining research-based course offerings for their curricula and gain highly trained teachers, who become effective at leading and managing a research effort. This can be a strong mechanism for flowing down experience with the “how” of science to other grade levels in the district. The schools can also reap significant opportunities for integrated learning across disciplines, since the research experience involves significant interactions with mathematics, technology, technical reading, writing and presentation skills. Finally, the observatory obtains real research results and develops resources that will provide for future research, personnel recruitment and outreach possibilities.

2.3. SST Program Implementation

The Scientist/Student/Teacher program was originally designed by the University and Secondary Education Programs group (USEP) at Pacific Northwest National Laboratory (PNNL) to involve high school teachers and students into research in a long-lasting and effective manner. SST provides a multi-year experience for a cadre comprised of a teacher and students who will establish a research center at their high school that produces real research results for the collaborating laboratory. This is a serious endeavor that requires a multi-year commitment of time on the part of the teacher and sponsoring scientist and a significant buy-in by the administration of the high school.

We propose extending the SST model to LIGO Hanford Observatory. LIGO has committed funds (approximately $24K drawn from reserved operating funds) for a pilot program that began in Summer 1999, but LIGO needs additional funding to continue the program in future years. We envisage two years of funding to firmly establish the program and to build plans and resources to expand it. LIGO pilot funds allowed two SST teams to be formed in 1999 that will work with the observatory’s Physics Environment Monitoring system to produce research results for LIGO. Research will be conducted at the observatory over an eight-week period during the summer, followed by research conducted at the participating high schools throughout the academic years. One day per week of the eight-week period will be devoted to training and planning workshops, conducted by PNNL, to prepare the teams to effectively transfer the research to the classroom[5].

We are emphasizing broad student participation in our program. Exposing a student or teacher to research by residency at university or national research laboratories is expensive enough - typically $3-4K per participant - to preclude involving large numbers of participants. A far more affordable proposition is to expose students to research in the setting of the high school. For example, our pilot program this year will expend $24K this year. But we were already able to actively engage two teachers and 31 students in LIGO research with real deliverables. Note that we will get another semester of involvement for no additional outlays this year.

We envision seven steps that must be mastered and replicated to implement this program:

1. Develop “leadership” teams, each comprised of a teacher and three students who will lead the research effort at the high school.
2. Develop a Project Management Plan for research integration into the high school, written by the leadership team.
3. Develop research tools and expertise as well as leadership and mentoring skills to facilitate the research transfer to the school.
4. Develop broad student involvement with a goal of familiarizing the typical science student with research.
5. Develop natural integration paths with students and teachers in other grade levels and other disciplines.

6. Develop broad community support for the program with a goal to bring research-based curricula to other schools in the district and to establish district-level funding for long-term continuation of the research programs.
7. Develop a plan and resources to extend the program nationally.

We have accomplished significant progress on the first four steps and we have made a start on steps 5 and 6. We need more experience to evaluate how to get good results consistently, to make further progress on integration and community support and to develop a firm strategy and resources for expansion.

Our general plan for spinning off research projects to high schools and accomplishing the goals is given below. Details of how we have proceeded in the pilot program can be seen in Section 3, *Results From Prior NSF Support*.

A local high school teacher, Norman Graham, who teaches physics and AP physics courses at Kamiakin High School in Kennewick, WA but had no previous research experience, has interned at Hanford in summer, 1999. He will form a team that will use seismic monitoring equipment to isolate and analyze seismic events and seismic spectra (in a frequency band from 0.5 to 50 Hz) created by human activity in the land and communities surrounding LIGO Hanford Observatory[7]. They will look for signals related to traffic patterns, railroad activity, dam operations and river flows, military exercises, nuclear waste remediation activities, etc. During Summer 1999, Mr. Graham became acclimated to the research environment and began work with LIGO staff to develop tools (hardware and software) for carrying out research in future years. During the 1999-2000 academic year Mr. Graham will recruit a three-member "leadership team" of 11th-year students to return in Summer 2000 to continue pursuing this project at the observatory, provided this project becomes funded by NSF. Starting in Autumn 2000, the project will move to Kamiakin High School[6]. Mr. Graham and Kamiakin High School have agreed to make a three-year commitment to this program.

A second teacher, Dale Ingram from Gladstone High School, near Portland, Oregon, was recruited for the pilot with an eye toward expanding SST regionally throughout the Pacific Northwest and eventually throughout the U.S. He has a background teaching both chemistry and physics courses. Taking advantage of Mr. Ingram's prior research experience, his team started at the 2nd-year level in the program, with Mr. Ingram recruiting a team of three 11th-year high-school students to participate in Summer 1999. Mr. Ingram and these students are the "leadership team" responsible for establishing the research program as part of physics classes at Gladstone High School, making the research program available to a much larger audience of students. This team has begun and will continue to analyze motion of the LIGO observatory buildings at frequencies below 0.5 Hz[8]. This low frequency band will be dominated by geophysical effects and physical details of the LHO site. We expect the data from seismometers and tiltmeters to show significant effects due to earth tides, microseismic waves generated by ocean-wave activity, thermal expansion effects of the ground and responses to rainfall and solar irradiation. Working with LHO staff, the team has become familiar with the research equipment and has developed on-site software and web-based tools to support their research activities back at the high school. Portland is approximately a 3.5 hour drive from LHO, close enough to arrange visits without undue difficulty but far enough to approximate limitations that could be encountered operating a similar program at greater distance. Based on extensive experience within LIGO with working groups whose members collaborate effectively from thousands of miles away, we believe that appropriate use of the internet and web-based tools can transform our experience with this team into a model that has national applicability. Mr. Ingram and Gladstone High School have agreed to make a two-year commitment to this program, recruiting new 11th-year students for Summer 2000 and the following academic year, provided NSF funds the program.

Table 1. Plan for SST Team Selection and Activities

Grant Year	*Period Funded*	*Slot 1 Activity*	*Slot 2 Activity*
Pilot	Summer 1999	Kamiakin Teacher	Gladstone Team 1
	Academic 99-00	Recruit Kamiakin Team 1	Research @ Gladstone
Year 1	Summer 2000	Kamiakin Team 1	Gladstone Team 2
	Academic 00-01	Research @ Kamiakin	Research @ Gladstone
Year 2	Summer 2001	Kamiakin Team 2	New School A Teacher
	Academic 01-02	Research @ Kamiakin	Recruit School A Team

We propose to expand the program to a third team in Summer 2001 as NSF funding from this proposal ceases for the Gladstone team. We propose to award this slot based on a competitive application process covering the Pacific Northwest. On a similar time scale, we anticipate being joined in nationalizing this effort by a proposed program of similar nature hosted by LIGO Livingston Observatory, covering the Gulf region and the Southern U.S.

These projects have been selected for synergy among the different working teams, transferability of the research experience to the high schools and maximum gain to observatory staff who work with these teams. Having two teams with different levels of experience in the program at any time provides additional support for the less experienced teacher while the more senior teacher gains experience in mentoring less-experienced professional colleagues. Topics have been chosen so that the teams will be working with close but separate goals and using similar but complementary techniques. In addition a SURF/REU student, who has just finished his freshman year at Caltech, was recruited to build an earth-tide model for the LIGO Hanford site that will be used eventually by the Gladstone team to analyze data. Such arrangements allow SST students to work with a successful college student, senior enough to be a good role model but close enough in age to be accessible. Effectively the scientists, the SST teams and SURF/REU student formed a larger research group with the observatory - a pattern we would like to emulate in future years. As in our pilot, the research tasks will be complementary to other research by LIGO collaborators. In the two pilot projects, we expect researchers at Caltech, MIT, University of Oregon, Louisiana State University, Louisiana Technical University and Pennsylvania State University will be in close communication as the research progresses. This allows our program to put special emphasis on presentation skills with frequent seminars on related research topics and frequent reporting of results. We will also place special emphasis on the importance of developing good mentoring skills which are essential both to successful transfer of experience to the school and to career development by the students and teachers involved.

The research techniques developed and used by the teams will have general applicability, bringing important skills to the school that can find many other applications. Researchers will learn first-hand the importance of teamwork and coordination in the performance of technically challenging research tasks and the role of collegial scientific debate in ensuring the validity and robustness of scientific conclusions. Teams will gain skills in using the internet and teleconferencing to break down spatial separations between researchers and facilities. Students will exercise library research, writing and presentation skills. They will acquire expertise in the areas of statistics, data analysis and computation which are the foundation of effective scientific analysis across all fields of science. We expect these lessons to be replicated throughout the school district by personal interactions, improved lesson plans and the development of many of the research tools as a consequence of making the school a research site.

Observatory staff participation is possible using NSF research money because the products of this research for the observatory are real. (Cost sharing estimates include: approximately $24K of

Cost-Sharing Contributions ($K)			
Year	***Requested SST Funds***	***LIGO Operations Contribution***	***Contribution by Schools***
Pilot		41.8	8.8
1	44.3	18.0	17.0
2	31.0	16.8	8.5
Equipment		5.0	
Totals	*75.3*	*81.6*	*34.3*

operating funds for the pilot; in-kind contributions of $9K/yr of supervisory time and summer supplies for a full team and $7.8K/yr for a teacher only; high school contributions of $5K/yr in matching funds to support team research at the school; additional “in-kind” cost sharing in the form of access to computer equipment and technical personnel is estimated at $3.5K/yr per school, based on experience with Gladstone High School.) Data on man-made sources of noise near the LIGO site are important for dealing with local land-use issues to protect the viability of a significant infrastructure investment (> $120 million at Hanford) by the NSF. Local government agencies are tasked with developing lands adjacent to LHO to optimize employment, income and cultural opportunities as the DOE role at Hanford wanes, in a manner that does not endanger assets already in place such as LIGO. The Kamiakin High School team’s data will be important input into future planning decisions and will guide observatory management in ways to mitigate activities already in place that could affect the sensitivity of detectors at this site. Data on earth tides and other low-frequency seismic displacements and tilts will be used to develop feedforward adjustment of the seismic isolation in LIGO’s interferometers. Successful implementation of this scheme promises to reduce demands on LIGO control systems and improve performance. Collaboration with the existing PNNL-SST program brings tremendous resources and strength to this LIGO-based effort at low cost. Associated Western Universities (AWU), a partner in the PNNL program, will provide administrative services for the LIGO-SST program, handling teachers stipends, insurance matters, etc. Research transfer will be facilitated by special meetings on Fridays of each week of the summer program where the teams, PNNL-USEP staff and Washington education specialists will develop comprehensive plans to transfer research experiences into improved instructional practices in the classroom. PNNL staff have extensive experience in promoting such transfer from many years of experience in the U.S. D.O.E.’s Teacher Research Associates Program. SST teams will return to their schools with explicit plans for transfer of the research experiences into the classrooms.

2.4. Evaluation

The LIGO-SST program will share evaluation resources (at incremental cost) and procedures with the PNNL-SST program, which includes both formative and summative evaluation. An annual report of progress will be provided to NSF. This will include project management information that will be used to strengthen the project in future years. Pre-assignment evaluations will occur before each summer research team begins their designated assignments. Continuous monitoring will occur during the progress of each research assignment. Evaluation of the quality of research assignments will be made by studying the responses from a variety of resources including scientists, students, teachers, school administrators, etc.

Dr. Ann Davis from the Northwest Regional Education Laboratory[9] in Portland, Oregon will assess the classrooms of the scientist/student/teacher research teams before and after the summer research experiences to identify changed classroom practices in each school. Our pilot teams are already being included for assessment with the PNNL teams for 1999. Assessment in the classrooms of each research team will continue throughout the project, with special emphasis regarding the actual practice of research activities in the classroom after the summer assignments.

2.5. Dissemination

Information illustrating this project will be disseminated through publications targeted at educators (such as the Science Teacher), through coauthored technical publications with observatory staff and through dissemination in special reports at meetings of the LIGO Science Collaboration and the Topical Group on Gravitation within the American Physical Society. Teachers involved in the program will be encouraged to present reports on their work to their colleagues at regional, state and/or national meetings as such opportunities arise. A valuable tool in this effort will be presentations on this program to workshops conducted through teleconferencing facilities, such as Washington's K-20 network. Information on the LIGO-SST program will be fully shared with the PNNL-SST program and disseminated to the appropriate state offices that cover public instruction for the schools in question. LIGO-SST web pages will be linked to the LIGO web pages and to the web pages of the associated high schools. The 1999 LIGO-SST program was featured in a LIGO newsletter article [10] and a student member of the Gladstone "leadership team" from Summer 1999 has lead other students in development of a Gladstone High School LIGO-SST web page[11] for disseminating results on this program.

2.6. Educational Consultation

Evaluators of the LIGO-SST preproposal to NSF-ESIE in April, 1999 identified that Barish and Raab do not have educational credentials for dealing with high-school students, although they have extensive experience mentoring university graduate and undergraduate students. So far in the pilot, Raab and the high school teachers involved have been able to achieve good results with the students. However, expansion of this pilot to a national program will involve inclusion of many more mentoring scientists and many more teacher-student teams. To optimize results as we expand the program we believe it is wise to follow the advice of the preproposal evaluators and add an educational consulting capacity to our original plan.

We have included $2500/yr to pay such educational consulting services over the three years of funding requested here. A first priority will be to establish a mentoring workshop for scientists at

LIGO and to expand mentoring training for the teachers and students. We will also ask for help in designing follow-up activities, for strengthening our connections to the educational community and for help in planning a competitive selection process for future teacher recruitment. As the competitive selection process moves from the planning to execution, we will rely on educators to help in evaluating applications. By this process at LIGO Hanford Observatory we hope to perfect a method that we can use nationwide.

LIGO plans to broaden its educational outreach program by quantitative growth in the LIGO-SST program and by increasing outreach scope to cover all levels of education from primary through secondary and on to undergraduate and graduate student training. This will eventually require the full-time effort of a person with strong educational credentials. In this proposal we have included a modest educator role to keep costs in line with the modest size of the program. We have established a Memorandum of Understanding (MOU) with Pacific Northwest National Laboratory's University Science and Education Programs group to share resources and to optimize the effectiveness of programs at both institutions. Royace Aikins and Jeff Estes of PNNL-USEP have been generous with their ideas and encouragement and we look forward to continued association with them. We have also established a cooperative working relationship with Dr. Marilynn Baker, Superintendent and her staff at Educational Service District (ESD) 123 in Southeastern Washington, working on a joint project for development of interactive science education programming to be carried by the K20 teleconferencing network available to area schools. We hope these efforts will help us to identify people and cost-effective cooperative arrangements within the education community that can grow with us as our outreach efforts grow.

3 RESULTS FROM PRIOR NSF SUPPORT

LIGO has completed its physical facilities. An inauguration for the two LIGO observatories was held on November 12, 1999 and interferometer installation is well under way at both sites. LIGO Hanford Observatory has hosted a number of graduate students from Caltech, MIT, University of Florida, and the University of Oregon. Through the Caltech REU center we have hosted seven REU students at Hanford since our facilities were completed in November, 1997. LIGO Hanford Observatory is currently conducting a pilot LIGO-SST program using approximately $24K in reserve operating funds. In summer 1999, a team from Gladstone High School (Gladstone, OR) and a single teacher from Kamiakin High School (Kennewick, WA) were resident at LIGO Hanford Observatory. The Gladstone team consisted of Mr. Dale Ingram, who teaches Chemistry and Physics, and three students who had just completed their junior year at Gladstone. The Kamiakin High School teacher was Mr. Norm Graham, who teaches advanced Physics courses. Mr. Ingram came with some familiarity with research from a previous internship at Pacific Northwest National Laboratory in Richland, WA. Mr. Graham had no previous exposure to scientific research. Given Mr. Ingram's prior experience, we decided to have him bring students to LIGO for the first summer. This allowed us to implement in the pilot our vision for research-inexperienced teachers to learn from observing a fully formed "leadership team" in action.

We obtained signed letters of commitment from the teachers and signed letters of commitment from the school administrations, pledging multiple-year commitment by all parties (provided LIGO is successful in obtaining funding for future years) and matching funds from the schools for the duration of the projects.

The Gladstone team's mission was threefold: (1) to immerse themselves in a research problem; (2) to develop a plan for incorporating this research into the curriculum at Gladstone and for sustaining the research throughout the academic year; and (3) to develop the necessary tools to allow them to conduct this research from Gladstone in an efficient manner. Graham's mission was also threefold: (1) to immerse himself in the research; (2) to develop a plan for incorporating this research into his teaching; and (3) to obtain a critical perspective from interactions with the Gladstone team that would help him choose future student team members who would return with him the following summer. For eight weeks the team worked Monday through Thursday on research at LIGO; on Friday of each week, the team met with 10 other similar teams for workshops at Pacific Northwest National Laboratory (PNNL) under the supervision of education specialists, Jeff Estes and Royace Aiken. These Friday workshops concentrated on team-building and research management issues, culminating in development of a project management plan for moving the research to the high school. At the end of summer, both teams presented their work in a poster session held at Batelle Auditorium on the PNNL campus.

Fred Raab organized the Gladstone team, the single Kamiakin teacher and an REU student (Eric Morgansen, who just completed Freshman studies at Caltech) into a research group attacking issues concerning the seismic background at the LIGO Hanford site. The Gladstone team focused on arm-length stability on times longer than 1 second. That summer the work would focus on the 6-sec microseism, but later they would expand their effort to include analysis of earth tides and outdoor temperature cycles. Eric Morgansen constructed an earth-tide model - a computer program for predicting earth tides from the sun and moon - and a computer program that would allow data from LIGO observations to be used to adjust parameters in the earth-tide model. Norm Graham focused on evaluating man-made sources of seismic background that would later be the centerpiece of investigation for his future team.

The methodology employed by Raab was to quickly move the team members away from the “passive” paradigm of classroom learning to the “active” modus operandi of real scientific investigation, where each member alternates between the roles of leader and learner. Once the initial safety orientations were completed, Raab and the team spent a few hours familiarizing themselves with each other and the tasks at hand, and then each team member was assigned a problem to work with the deliverable of giving a presentation to the group within the following week. One student was to learn enough about the UNIX operating system to prepare a single-page primer that would allow team members to safely navigate in UNIX. Another would write, compile and execute a C program to plot successive approximations to a square wave on a string using Fourier Series. Another would do an evaluation of sources of information on the microseism that LIGO had previously used. The group met daily for approximately one hour in the mornings from Monday through Thursday to report results on open projects, to strategize their next moves and to make new assignments.

Progress was steady and good. By midsummer, the teams had a rudimentary understanding of seismic measurements and the basic statistical tools of data analysis. Increasingly, Raab turned over moderation of the assessment meetings to Ingram to allow him to exercise management over the research enterprise. By the end of summer, deliverables were starting to come in. The Gladstone team delivered a “real-time” program running in the LIGO control room that analyzed and compressed data from a single seismometer in the corner station and loaded results every fifteen minutes to a web page that was accessible via internet from their high school. Ingram was ready to manage day-to-day research activity at the high school and he had the team's management plan in his pocket. The students had enough research experience to serve as leaders in the expanded effort that would be pursued at Gladstone. Graham had acquired some research “seasoning” and delivered an evaluation of the seismic background created by foot traffic in the corner station, which would be useful in considerations for siting an optical metrology lab at the observatory. He had a plan for augmenting his teaching through a connection with this research and ideas for recruiting students for next summer's effort. Morgansen delivered his software for predicting and analyzing earth tides, which will be used to assess data from the 2-km arm cavity test at Hanford this winter and will later be used by the Gladstone team to analyze LIGO data to understand the earth-tide background.

By design, the Gladstone effort is today the most advanced and is working the problem of pursuing research (and research-based education) in a high-school setting with broad participation. Today the Gladstone students are seniors in Ingram's research-based physics course at Gladstone High. Ingram is using LIGO as a backdrop for discussing physics concepts (like wave phenomena) and has 31 students split into subgoups working projects, either directly related to deliverables to LIGO or deliverables to Gladstone associated with the LIGO program. Last summer's student interns lead some of the key groups. There is a computers and software group, a data analysis group, a seismic study group, an instrumentation group, a web development group and a physic demo group. The software group has modified the “real-time” effort to include data from seismometers in the midstations as well as the corner stations. The analysis group has identified strong impulsive signals in the microseism band associated with large earthquakes and the Gladstone/LIGO team has found and fixed a software bug that caused excess fluctuations in the microseism data. Several computers (donated to Gladstone under a grant from Intel) have been made available to the physics class for this effort. The students are loading LINUX on one of the machines so they can install GRASP (Gravitational-wave Research And Simulation Package) and other LIGO-developed tools that run under UNIX. The web development group is setting up a Gladstone-LIGO-SST home page for posting data analysis reports. The instrumentation group is building a home-made seismometer to familiarize students with basic operating principles and to demonstrate how human activities within the school affect the vibration background. (LIGO is interested in a similar device for demonstration purposes in its visitors area.) Recently the demo group tried simulating an impulse response in a “Jello” mock-up of the corner station floor and demonstrated that life is harder than it looks. Progress is monitored by teleconferences between the Gladstone Physics class and Raab every two weeks where written reports are reviewed, progress is assessed and new directions are plotted. The class is being introduced to the standards of critical science writing and a “peer review” system is being established in the class. Members of the Gladstone school district visited LIGO during the summer to evaluate the effort and Ingram and students have made a presentation to the school board since the program moved research activity to Gladstone. The work at Gladstone was also featured in an article in the Gladstone community newspaper. This increasing support in the community will hopefully provide the momentum to keep this particular seed growing even after NSF support of this group ceases.

In summary, we have conducted a pilot outreach program to introduce real, product-oriented, research based on LIGO into the high school science curriculum. We are assessing many aspects associated with building this effort into a national program that can be pursued through the national reach of the LIGO Laboratory and eventually the LIGO Science Collaboration. So far this year, we have gained “live” exposure to the issues of developing a high-school research team with broad student participation, packaging a real research commitment with real deliverables that can be accomplished by such a team, enlisting the support and backing of the school administration and managing such a research effort across state boundaries during the academic year.

4 BUDGET

Requested additional funding from NSF:

Year 1			
Stipends for 2 teachers	8,240		
Stipend for 6 students	9,888		
Gladstone Teacher housing allowance	1,030		
Gladstone Students housing allowance	1,854		
Matching research support at 2 schools	10,000		
Travel allowance (for Gladstone team)	800		
Insurance	200		
Evaluation Costs	2,000		
Travel (dissemination related)	1,500		
Educational Consultant Costs	2,500		
Subtotal Direct Costs		*38,012*	
*Overhead charges**		*6,272*	
Year 1 Total Costs		*44,284*	
Year 2			
Stipends for 2 teachers	8,487		
Stipend for 3 students	5,092		
School A Teacher housing allowance	1,061		
Matching research support at 1 school	5,000		
Travel allowance (for New Team A)	800		
Insurance	200		
Evaluation Costs	2,000		
Travel (dissemination related)	1,500		
Educational Consultant Costs	2,500		
Subtotal Direct Costs		*26,640*	
*Overhead charges**		*4,396*	
Year 2 Total Costs		*31,036*	
Total Direct Costs			**64,652**
Total Indirect Costs*			**10,668**
Grand Total			**75,320**

*AWU Rate = 16.5%

5 REFERENCES CITED

1. Gravitational waves, first hypothesized in 1916 by Einstein as part of the theory of General Relativity, are propagating distortions in the fabric of space and time produced when star-sized chunks of matter undergo violent acceleration. Phenomena that we can imagine generating these waves are collisions of black holes or neutron stars, the rapid spin-down of neutron stars or the rotation of neutron stars with small deformations, supernovae and the big bang itself.
2. A draft document discussing a broader vision for LIGO outreach can be found on the web at http://www.ligo-wa.caltech.edu/~fjr/outreach/vision.pdf.
3. LIGO began operating a pilot LIGO-SST program using reserve operating funds in summer, 1999. A fully formed SST team from Gladstone High School in Gladstone, OR was resident at LIGO last summer beginning a (hopefully) multiple-year commitment to analyzing seismic data for LIGO. The team has now successfully transferred its research to the high school, where it is the inquiry-based cornerstone of a Physics class for 31 students. Students are actively pursuing the creation of real research products supervised by their teacher under a management plan drawn by the summer leadership team. Research progress is monitored by LIGO scientists in the form of weekly reports and in biweekly teleconferences. A teacher from a local (Kennewick, WA) school also participated last summer and will be ready to recruit a full SST team for next summer. Both the teachers and their administrations have signed commitments to make adequate resources available to support this work.
4. The specific states currently represented in the LIGO Science Collaboration include: California Colorado, Florida, Louisiana, Massachusetts, Michigan, New York, Oregon, Pennsylvania, Texas, Washington and Wisconsin.
5. A description of the Friday workshop series for Summer, 1999 is available at http://www.ligo-wa.caltech.edu/~fjr/outreach/SST_Friday_menu.pdf
6. A description of the planned Kamiakin High School research is available on the web at http://www.ligo-wa.caltech.edu/cultural_noise.html
7. It is our intent that LIGO will typically form new teams in this manner: (1) by bringing in a single teacher without research experience to work in association with a more experienced team for one summer; (2) to have this teacher recruit a team from his school's junior class for residency at LIGO the following summer; and (3) for that expanded team to bring the research program back to the high school and thereafter be an experienced team.
8. A description of the planned Gladstone High School research is available on the web at http://www.ligo-wa.caltech.edu/arm_stabilization.html
9. Information about Northwest Regional Education Laboratory is available from the web in PDF format at http://www.ligo-wa.caltech.edu/~fjr/outreach/NWREL_qual.pdf
10. The LIGO Newsletter article of the 1999 LIGO-SST program can be obtained at http://www.ligo-wa.caltech.edu/news/9907han/9907han.html
11. The newly minted Gladstone High School Physics/LIGO-SST web page is viewable at http://www.ghs.gladstone.k12.or.us/~physics. This page will carry research results and stories on the progress of the Gladstone LIGO-SST effort.

6 VITAE

Barry Barish (Principal Investigator): Barry Barish received his BA in Physics from U.C. Berkeley in 1957. He also did his graduate studies in Berkeley and received his Ph.D. in Experimental High Energy Physics in 1963. Barry Barish came to Caltech directly from Berkeley in 1963 where he has pursued high energy physics as a researcher and a faculty member. Barry Barish was named the Maxine and Ronald Linde Professor of Physics in 1991.

Barry Barish conducted experiments at Fermilab using high energy neutrinos that were important in demonstrating the quark substructure of the nucleon. These experiments were also among the first to observe the weak neutral current which was vital in establishing the validity of Electroweak Unification theories of Glashow, Salam, and Weinberg. Over the past decade, Barry Barish has led an ambitious effort to search for the magnetic monopole predicted in theories of Grand Unification. A large experiment (MACRO) to make this search is being conducted underground below the Gran Sasso mountain in Italy. Barish also served as co-spokesman of a large international collaboration to develop the GEM detector, one of two major detectors that were planned for the Supercollider. In 1994, Barry Barish became the Principal Investigator of the Laser Interferometer Gravitational-Wave Observatory (LIGO) project. Professor Barish became Director of the LIGO Laboratory in 1997 and was instrumental in the establishment of the LIGO Science Collaboration. Internationally, he is regarded as a leader in the field of elementary particle physics, is often an invited speaker at international conferences, and serves on many important international committees.

Frederick J. Raab (Co-PI): Fred Raab received his B.S. in Physics from Manhattan College in New York in 1973. He did his graduate studies at S.U.N.Y., Stony Brook and received his Ph.D. in Experimental Atomic Physics in 1980. From 1980 to 1988, he was a member of the research faculty at the University of Washington, where he developed a number of precision experiments to test fundamental symmetries using atoms as a sensitive probe of the underlying physics. This led to a number of strong bounds on violations of time-reversal symmetry and local Lorentz invariance. During this time he also became involved in torsion-balance experiments to provide stringent tests of the equivalence principle over a range of distances from centimeters to one astronomical unit. In 1988 he joined Caltech as Assistant Professor of Physics and coauthored the LIGO Construction Proposal. His research with his graduate students and scientific collaborators at Caltech has led to key developments that appear in the LIGO-1 optical control configuration and mirror suspensions. He was named Head of LIGO Hanford Observatory in 1997.

Raab's interest in education began with his work as a laboratory assistant at Manhattan College, where he co-developed an introductory optics laboratory and participated in a summer laboratory training program for teachers from secondary schools in the greater New York metropolitan area. He has gainfully employed dozens of student workers in his research laboratories, and mentored undergraduates, graduate students and professional engineers in a variety of research endeavors, from REU projects to Ph.D. dissertations. As Head of LIGO Hanford Observatory, he has networked with professionals in the local education community to develop plans for an extensive outreach effort in gravitational physics (see www.ligo-wa.caltech.edu/~fjr/vision.pdf). He actively directs the day-to-day activities of resident observatory staff and resources, which allows him to ensure laboratory commitment to successful completion of the research endeavors of this proposal.