The LSC White Paper on Education and Public Outreach

Goals, Status and Plans, Priorities (2011 edition)

Public Version

EPO group of the LSC[1]

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Introduction

1 Overview

This document is the second edition of the White Paper on Education and Public Outreach (EPO) of the LIGO Scientific Collaboration (LSC). It describes the goals, status, and plans of the EPO working group of the LSC, an international network of scientists interested in public outreach. This document is revised and updated every year in the spring, and is finalized by early summer. In the spirit of other LSC white papers, the purpose of this document is to:

- Coordinate the EPO activities of the LSC;
- Exploit EPO resources and synergies among the work carried out in the LSC;
- Limit unnecessary duplication of EPO efforts and waste of resources;
- Prioritize EPO objectives.

This is the public version of the LVC internal document T1100319.

2 Executive Summary

During the next five years, we expect Advanced LIGO to become operational, and then to detect the first gravitational waves (GW). These initial detections are expected to generate a tremendous amount of public interest in all things LIGO - its discoveries, science, technologies and scientists. The main goal of the LIGO EPO group is to use the excitement of LIGO's potential discoveries to engage the wider community beyond GW scientists, motivating students and increasing the scientific literacy of the general public. We are especially interested in developing opportunities to help alleviate socio-economic disparities, focusing on improving the access and quality of education for under-represented groups in the Science, Technology, Engineering and Mathematics (STEM) fields. The LIGO EPO group also is intended to function as an interface between our specialized field and the population in general, bringing the excitement of LIGO science at a more general level to the broadest possible audience. In order to function effectively with audiences including students, teachers, and the general public, the EPO group is using many different approaches including: informal education through traveling exhibits, on-line social networks and web activities, traditional speaking engagements, development of curriculum for use in formal education, educator training, and internships.

The LIGO EPO group's goal for human resource development is long term: through our efforts, we hope to increase the number of motivated educators, potential research scientists, and well- trained science students.

Sources of funding used to support LIGO EPO efforts are pursued by individual EPO member groups. Although most funding is derived from NSF grants, there are also some opportunities for funding from other agencies, especially outside the USA.

Our EPO efforts involve participating in conferences relevant to more than the gravitational wave physics community. In the future, LIGO EPO plans to increase its presence at national conferences of astrophysicists, under-represented physicists, physical science educators, and science education researchers.

The member institutions of the LIGO EPO effort are geographically dispersed due to the dispersed nature of the LIGO Scientific Collaboration. This gives the LIGO EPO program a worldwide reach, with EPO members resident in and representing many different states and countries.

Outreach has been a part of the LIGO project since the completion of site construction. The level of outreach has steadily increased from early good will development to serious programs reaching tens of thousands of people in the general public. In addition to the work done via the LIGO laboratory, the LIGO Scientific Collaboration (LSC) has formalized its outreach efforts and formed a dedicated working group that has a complementary and far-reaching impact beyond the laboratory sites. Outreach has been on the agenda of gravitational-wave related science since the birth of the observatories, and this effort continues to grow.

The LIGO Livingston site was the first observatory to receive funding in 2004 from the National Science Foundation. This initiative, the Science Education Center(SEC), had several key partners:

Southern University, the Exploratorium, Louisiana Systemic Initiative Program and Louisiana GEAR UP. The purpose of this initiative was to have a positive impact on education on the areas surrounding the observatory. The SEC has worked to make its positive effects felt as far from the observatory site as possible in many different parishes: reaching a few hundred teachers, hosting several thousand visitors to the facility, and going into the community and hosting dozens of activities impacting hundreds that may not be able to go to the observatory. The SEC at LIGO Livingston, continues to expand its collaborative science education efforts past the initial partners. The SEC has involved Tulane University, and the Baton Rouge Area Foundation (BRAF). As the SEC matures, it continues to help raise the scientific literacy in Louisiana. It also has been working through its partners to understand how the general public learns about science with the intent to better educate the public in the future. The work of the SEC has seen a saturation in the public school system interest for teacher development, but by striving to remain fresh and engaging, the loss of teacher development participants and outreach audience has been small compared to the large impacts made by the SEC. The SEC will need continued steady management to ensure a place for itself in the education landscape of Louisiana.

The LIGO Hanford observatory is also actively engaged in outreach. At Hanford, the initial personnel dedicated to outreach were brought on board in 2004; since then the numbers of education and outreach staff have slowly continued to grow. This growth is reflected in the growing impact that the Hanford observatory is making in its local community. Funding for the efforts at Hanford have primarily come from the Federal Department of Education. The target audience and goals at Hanford are very similar to those at Livingston. The notable difference is the absence of a dedicated Exploratorium style exhibit hall at Hanford. The demographics of Hanford's audience are also remarkably different, with more than half of the audience being of Hispanic and Native American ethnicity. The Hanford site has had over ten thousand interactions with members of the public. These interactions include site visits, and more importantly, teacher development activities. To increase the observatory's impacts, docents have begun to become involved in site activities. The ability of the Hanford outreach activities to stay successful relies on growing the amount of current external support and finding sources of long-term support to aid with outreach to the minority communities served by the Hanford site.

The activities of the LSC EPO group are varied and wide-ranging. Each activity represents a different approach to engage the general community in which LIGO's large-scale science lives. Internet outreach through social networking services like Facebook and Twitter are useful places to disseminate information to a technologically savvy audience. To help combat Internet misinformation, innocent or otherwise, members of the EPO group participate in an activity called the "Blog Squad" in which LSC EPO members rapidly respond to any incorrect comments encountered on publicly accessible websites. Additionally, the Internet is used to host a public website (`http://www.ligo.org`) that has general descriptions of LIGO science and technology, as well as links to the laboratories, and interactive games and multi-media experiences.

The LSC EPO group has developed exhibits that aim to replicate the experience of a visitor to a LIGO site by squeezing many demonstrations and interactive activities representing LIGO science into two traveling exhibits with footprints of 200 sq. ft. and 1000 sq. ft., respectively. These exhibits offer demonstrations showcasing the astronomy and physics of gravitational wave detection. They contain simple physics demonstrations, models of detector systems, and electronic games to entertain visitors of all ages. In addition, the large exhibit is a blend of physics with art through the inclusion of a custom-designed interacting lighting display by a renowned New York artist. The exhibits have been booked at venues ranging from the World Science Festival and the Adler Planetarium to small museums and universities throughout the United States.

The EPO group also partners with other groups doing outreach. For example information about the science of LIGO has been integrated into the NASA sponsored "Space Place" on-line comics and interview resources, and into NASA's Epo's Chronicles weekly webcomic. At the intersection of data analysis and outreach, the LSC EPO effort has also had references linked into publicly available computing applications so that members of the public can contribute to the search for gravitational waves (Einstein@home).

In addition to reaching out the general community, various member groups of the LSC EPO also work at engaging current undergraduate and beginning graduate students. This engagement is designed to stir interest in gravitational wave physics. There are many activities aimed at this particular target group, including NSF-sponsored research experience for undergraduates (REU). The REU program is intended to introduce students to the practical aspects of research. In addition to the REU program, there is a summer workshop led by a member of the LSC EPO group at the University of Texas, Brownsville. This two-week long summer workshop introduces students to data analysis methods, the physics of gravitation and many other aspects of cutting-edge gravitational wave research. The main goal of recruiting at this level by the EPO group is to bring students into the collaboration and increase the number of potential gravitational-wave scientists capable of pursuing the type of research done by LIGO and related science projects.

The LSC EPO group is composed of an international collection of independent education and outreach efforts. The EPO group is like a cooperative, where information and ideas on effective EPO activities are shared. This sharing promotes higher quality programs for each of the individual groups in the LSC EPO group. The mission of the LSC EPO group is vast in scope, but the existence of this association is key to managing all the individual education and outreach activities in the gravitational wave astronomy community, specifically the part of the community where LIGO is playing a key role. Although it is challenging for the LSC EPO group to try to coordinate the diverse and disparate efforts carried out by the collaboration's individual groups, we are already seeing many successes in the outreach programs, and in our inter-collaborative individual group communications and idea sharing.

3 LIGO and LSC: Fact sheet

The Laser Interferometer Gravitational-Wave Observatory (LIGO) is a facility dedicated to the detection of cosmic gravitational waves and the measurement of these waves for scientific research. It consists of two widely separated installations within the United States, at Hanford, Wash., and Livingston, La., operated in unison as a single observatory. This observatory is available for use by the world scientific community, and is a vital member in a developing global network of gravitational wave observatories which includes the German-British detector GEO 600 and the French-Italian-Dutch detector Virgo. LIGO is funded by the National Science Foundation (NSF) and operated by the California Institute of Technology and the Massachusetts Institute of Technology. It is the largest single enterprise undertaken by NSF, with capital investments of over $500 million and operating costs of more than $30 million/year.

The LIGO Scientific Collaboration consists of 845 scientists, approximately 500 full time equivalents, from more than 70 institutions worldwide (May 2011 data). Since April 2007 the LSC and the Virgo Collaboration have been operating their instruments as a network and the analysis of the data of the two detectors is carried out jointly. The LIGO-Virgo Collaboration (LVC) has interactions with the numerical relativity community and established formal external collaboration with wide-field optical follow-up telescopes.

As of May 2011, the LSC comprises of 50 research groups and 28 affiliated laboratories with members from 18 U.S. states: Arizona, California, Florida, Illinois, Louisiana, Maryland, Massachusetts, Michigan, Minnesota, Mississippi, Montana, New Hampshire, New York, Oregon, Pennsylvania, Texas, Washington, Wisconsin, and from 15 countries: Australia, Canada, China, Germany, India, Italy, Japan, Korea, Hungary, Poland, Spain, Sweden, Russia, UK, USA. While the great majority of the LSC groups are engaged in outreach at some level, 24 of them and have expressely signed a MOU with an outreach attachment.

The demographics of the LSC are illustrated in Fig. 3.1 (May 2007 data). (More recent demographic data are being collected by the LSC and will be released soon.) In 2007, women and minorities[1] made up 15% and 6% of the LSC, respectively. While some increase in women and minority participation in the LSC is expected, the percentage of female and minority scientists in the LSC is likely not to be representative of the U.S. population demographics, but instead reflects the percentages of female and minority physicists and engineers. The LSC roster and additional general information of interest for the LSC can be found at `https://www.lsc-group.phys.uwm.edu/twiki/bin/view/LSC/WebHome`.

[1] Hispanic, African American, Native American, US-based institutions only

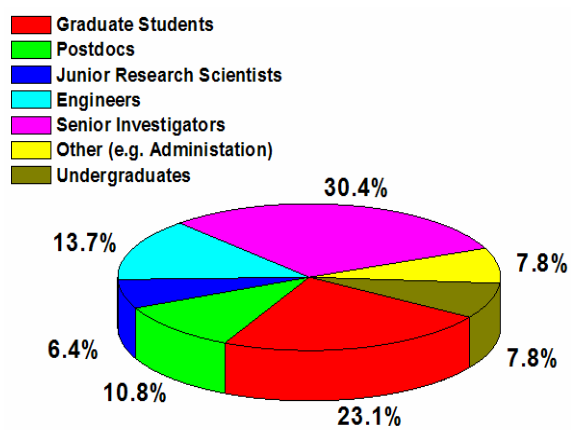

Figure 3.1: Demographics of the LSC as of May 2007 (From www.ligo.org).

4 Outreach Goals of the LSC

The goal of the LSC is the detection of gravitational waves from cataclysmic astrophysical sources. Direct measurement of gravitational waves will open up a revolutionary new window on the Universe, which will probe some of the most violent and energetic phenomena in the cosmos - from black holes and supernovae to the Big Bang itself.

As a frontier physics effort, a core mission of the LSC is to harness the excitement and enthusiasm generated by gravitational wave research to inspire and educate students and the general public in astronomy and fundamental science, thus raising standards of science literacy and education. LSC's researchers and students believe that the opportunity to discover the beauty of the cosmos should not be limited by age, culture or abode. The LSC EPO working group aims to communicate the vision and benefits of gravitational wave detection to the public at large throughout the world. By combining different ideas and approaches across participating institutions, the LSC EPO network is able to create outreach programs which are far more effective than they would be if LSC member institutions worked independently. The outreach goals of the LSC include:

- Improving science literacy in the general population;
- Increasing participation in science, especially among under-represented and underserved groups;
- Helping to reduce existing disparities in the access to educational resources;
- Advocating the intellectual and social / socio-economic benefits of careers in science;
- Recruiting future generations of scientists and engineers, to our own collaboration and to the wider scientific community;
- Providing and coordinating resources for the design and delivery of outreach and education activities by others within the collaboration;
- Improving understanding by the citizenry of frontier science and large scientific projects.

LSC outreach initiatives aim to inform the public not only about the science of gravitational waves and the activities of LIGO and other partner detectors, but also about science in general. LIGO outreach introduces non-scientists to multi-messenger astronomy, high-energy physics, cosmology, laser technology, material science, computing facilities and data acquisition. The cornerstones of this program are:

- The scientific endeavor of the LSC is motivated by the same desire for exploration, curiosity about the unknown and awe of nature that have inspired and motivated humankind throughout millennia of history.

- A new view of the distant Universe will be studied by non-electromagnetic means through the detection of gravitational waves. Mapping the gravitational-wave sky will provide an understanding of the Universe in a way that electromagnetic observations cannot. As a new field of astrophysics it is quite likely that gravitational wave observations will uncover new classes of sources not anticipated in our current thinking.
- Giant, new non-conventional "telescopes" are needed to detect the gravitational-wave spectrum. The cutting-edge technology of these telescopes, called interferometers, is pushing back the frontiers of many scientific fields. A remarkable combination of technological innovations in vacuum technology, precision lasers, measuring techniques, and advanced optical and mechanical systems is required to observe gravitational waves.

LSC's outreach programs use different ways to communicate these concepts to the public in formal and informal settings:

- Events at the observatory outreach centers, on-site tours and visits;
- Public events and lectures, projects in local communities;
- Development of printed materials, hand-outs;
- Development of internet-based activities, games, multimedia;
- Use of new social media, Twitter, Facebook;
- Formal education projects, classroom lessons, curriculum development;
- After-school programs, classroom visits;
- Professional development of teachers, graduate students and post-docs;
- Interdisciplinary activities, science and art events;,
- Diversity programs;
- Participation at conferences, science fairs, and exhibits.

These programs offer great potential for public education and outreach at all levels and external funding is continuously sought to realize them.

Target audiences for these activities are school-age children and their families, college students, young adults, teachers and science professionals, and more generally "informal learners", who may have some general awareness of astronomy and its long and rich cultural heritage. Increasing the awareness of current scientific research in the youngest segments of the citizenry is particularly important to achieve the four goals of the "Rising Above the Gathering Storm" report:

- Increase the talent pool in all the participating nations by improving science education;
- Strengthen the participating nations' commitment to fundamental research;
- Educate, recruit, and retain top students and scientists;
- Ensure the leading role of the participating nations in innovation and scientific research.

Figure 4.1: An example of interdisciplinary science and art public event: Andrea Centazzo performing *Einstein's Cosmic Messengers* at the University of Mississippi's Nutt Auditorium on February 5th, 2009.

Acknowledging that this audience is traditionally a difficult one to attract, LSC outreach efforts continuously explore new opportunities to promote science among adolescents and young people.

LSC's outreach programs also contribute to human resource development in science by providing opportunities for the mentoring of post-docs, graduate and undergraduate students in the field of gravitational physics and science in general. An important component of LSC outreach programs is training students to become the next generation of science educators. Through participation in outreach projects, junior researchers and students have the opportunity to engage with the public and improve their teaching skills.

Figure 4.2: Outreach as human resource development: LSC graduate student Marcelo Ponce (Rochester Institute of Technology) helping a "budding scientist" to play the Black Hole Hunter game at the 2009 World Science Festival.

5 Funding Sources

The National Science Foundation is the primary funder for LIGO construction. It has programs within the Education and Human Resources division that are relevant to LIGO EPO efforts, including:

- Informal Science Education (ISE) (NSF 11-546) Posted May 12, 2011: http://www.nsf.gov/publications/pub_summ.jsp?ods_key=nsf11546
- Integrative Graduate Education and Research Traineeship Program (NSF 11-533) Posted March 10, 2011: http://www.nsf.gov/publications/pub_summ.jsp?ods_key=nsf11533
- Research Experiences for Undergraduates (NSF 09-598) Full Proposal: July 23, 2009: http://www.nsf.gov/publications/pub_summ.jsp?WT.z_pims_id=5517&ods_key=nsf09598
- Innovative Technology Experiences for Students and Teachers (ITEST) (NSF 11-525) Posted: January 25, 2011: http://www.nsf.gov/publications/pub_summ.jsp?ods_key=nsf11525

The Foundation Center maintains a list of all RFPs currently listed by private organizations. To see the list of Science and Technology grant opportunities, go to http://foundationcenter.org/pnd/rfp/cat_science_technology.jhtml.

Google has a philanthropic branch, which offers small grants for various STEM-related purposes, including the "Google RISE Awards:" http://www.google.com/diversity/rise/index.html. For the complete list of Google Philanthropic activities, see http://www.google.org/googlers.html

In the UK there are various funding sources which support Education and Public Outreach efforts in the field of gravitational waves. The Science and Technology Facilities Council (STFC), which is the primary source of funding for UK gravitational wave research supports an extensive Science in Society program that funds a range of activities. These include a Small Awards Scheme (for amounts of about 10K to 15K GBP) which has a funding call twice per year, in April and October, for individual outreach projects to be carried out by University staff or students working alone or in collaboration with e.g., local schools, museums or science centres; a Large Awards Scheme (for amounts of up to about 100K GBP) which has a single funding call per year and a two-level application process. Large Award projects are usually much grander in scope and are often based around consortia of academics, educators and sicence communicators – generally seeking to reach a wide range of demographics and ages and across a range of science topics. The STFC also operates a Science in Society Fellowship program that permits applicants (who are normally research active academics with an established track record in outreach and public engagement) to seek to 'buy out' a significant fraction of their teaching and administrative responsibilities in order that they can undertake a more concentrated and substantive program of outreach work. Current information about all of STFC's Science in Society funding schemes can be found at their website: http://www.stfc.ac.uk/.

Additional UK funding schemes for outreach are operated by the following organisations (information can be found easily on their websites):

- The Royal Society, http://www.royalsociety.org
- The Royal Society of Edinburgh, http://www.royalsoced.org.uk
- The Institute of Physics, http://www.iop.org
- The Royal Astronomical Society, http://www.ras.org.uk
- The British Science Association, http://www.britishscienceassociation.org/web/
- The Nuffield Foundation, http://www.nuffieldfoundation.org/

Although the amounts for which one may apply are often modest, some of the schemes are not too heavily over-subscribed. Several of the funding bodies (e.g., the Nuffield Foundation, the Royal Society of Edinburgh and the Royal Astronomical Society) operate schemes which can support undergraduate vacation projects of 6 to 10 weeks; these projects could be undertaken, for example, by a student from the US or other country outside of the UK.

6 List of conferences of interest for LSC EPO

Conference	Location and dates	Web site	Audience
AAPT Summer	Omaha NE, 7/30-8/3/2011	www.aapt.org	Teachers, students
AAPT Winter	Ontario CA, 2/4-8/2012	www.aapt.org	Teachers, students
AAS (219th)	Austin TX, 1/8-12/2012	aas.org/meetings	Scientists, students
ACUMG	Houston TX, 05/21/2011	www.acumg.org	University museums
AISES 2011	Minneapolis MN, 11/10-12/2011	www.aises.org	Sci-eng, students
AISES 2012	Anchorage AK, 11/1-3/2012	www.aises.org	Sci-eng, students
APS March 2012	Boston MA, 2/27-3/2/2012	www.aps.org	Scientists, students
APS April 2012	Atlanta GA, 4/28-5/1/2012	www.aps.org	Scientists, students
APS March 2013	Baltimore MD, 3/18-22/2013	www.aps.org	Scientists, students
APS April 2013	Denver CO, 4/13-16/2013	www.aps.org	Scientists, students
CAL-APS	Menlo Park CA, 11/11-12/2011	www.aps.org/units/cal	Scientists, students
4CS-APS	Tucson AZ, 10/21-22/2011	www.aps.org/units/4cs	Scientists, students
NYSS-APS	Oneonta NY, 10/7-8/2011	www.aps.org/units/nyss	Scientists, students
NWS-APS	Corvallis OR, 10/20-22/2011	www.aps.org/units/nws	Scientists, students
OS-APS	Muncie, IN, 10/14-15/2011	www.aps.org/units/osaps	Scientists, students
SES-APS	Blacksburg VA, 10/19-22/2011	www.aps.org/units/sesaps	Scientists, students
TS-APS	Commerce TX, 10/6-8/2011	www.aps.org/units/tsaps	Scientists, students
ASP 2011	Baltimore MD, 7/31-8/3/2011	www.astrosociety.org	Outreach

(Table continues next page)

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Conference	Location and dates	Web site	Audience
ASTC 2011	Baltimore, MD, 10/15-18/2011	`www.astc.org/conference/future.htm`	Exhibit developers
ASTC 2012	Columbus, OH, 10/13-16/2012	`www.astc.org/conference/future.htm`	Exhibit developers
CSTA 2011	Pasadena, CA, 10/21-23/2011	`www.cascience.org`	K12 teachers
NAA 2012	Dallas, TX, 4/2-4/2012	`www.naaweb.org`	Afterschool education providers
NSBP/NSHP	Canceled 2011, 2012	`www.nsbp.org`	Scientists, students
NSBE (38th)	Pittsburgh PA, 3/28-4/2/2012	`www.nsbe.org/Events.aspx`	Engineers, students
NSTA Regional 2011	New Orleans, LA, 11/8-12/2011	`www.nsta.org/conferences`	K12 teachers
NSTA Regional 2011	Seattle, WA, 12/8-10/2011	`www.nsta.org/conferences`	K12 teachers
NSTA National 2012	Indianapolis IN, 3/29-4/1/2012	`www.nsta.org`	K12 teachers
SACNAS 2011	San Jose CA, 10/27-30/2011	`www.sacnas.org`	Scientists, students
SACNAS 2012	Seattle WA, 10/11-14/2012	`www.sacnas.org`	Scientists, students
SHPE	Anaheim CA, 10/26-30/2011	`conference.shpe.org`	Scientists, students
UATP	Lincoln NE, 7/27-30/2011	`sites.google.com/site/betterphysics`	Scientists, teachers

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Conference	Location and dates	Web site	Audience
UK Nat. Science & Eng. Week	UK, 3/9-18/2012	`www.britishscienceassociation.org/web/NSEW`	Scientists, students
UK RAS Nat. Astron. Meeting	Manchester, 3/27-30/2012	`www.jodrellbank.manchester.ac.uk/meetings/nam2012`	Scientists, students
Royal Society Summer Science Exhibition	London, 7/2012	`http://royalsociety.org/How-to-exhibit/`	Outreach

7 Participating institutions with outreach MOU

As of May 2010, 24 LSC groups have signed outreach MOU attachments, a net increase of 4 groups compared to 2009. The groups are:

- Australian Consortium for Interferometric Gravitational Astronomy [ACIGA] PI: David Mcclelland.[1]
- Andrews University [Andrews] PI: Tiffany Summerscales
- Caltech Relativity Group [CaRT] PI: Yanbei Chen
- Columbia Experimental Gravity Group [Columbia] PI: Szabolcs Marka
- Eotvos University [Eotvos] PI: Zsolt Frei
- German/British Collaboration [GEO] for the Detection of Gravitational Waves [GEO600] PI: Karsten Danzmann[2]
- Hobart & William Smith Colleges LIGO Group [HobartWilliamSmith] PI: Steven Penn
- Korean Gravitational-Wave Group [KGWG] PI: Hyung-mok Lee
- Experimental Relativity Group of the Louisiana State University [LSU] PI: Gabriela Gonzalez
- Northwestern University Gravitational Wave Astrophysics Group [Northwestern] PI: Vassiliki Kalogera
- Pennsylvania State University Relativity Group [PennState] PI: Ben Owen
- Rochester Institute of Technology [RIT] PI: John Whelan
- San Jose State University [SanJoseState] PI: Peter Beyersdorf
- Southern University and A&M College [SouthernU] PI: Stephen Mcguire
- Stanford Advanced Gravitational Wave Interferometry Group [Stanford] PI: Robert Byer
- Syracuse University Experimental Relativity Group [Syracuse] PI: Duncan Brown

[1] Starting 2011 the ACIGA group will submit separate MOUs for each institutions.
[2] Starting 2011 the GEO group will submit separate MOUs for each institutions.

- Trinity University Group [Trinity] PI: Dennis Ugolini
- University of Florida LIGO Group [UFlorida] PI: David Reitze
- Maryland Gravitational-Wave Group [UMaryland] PI: Alessandra Buonanno
- Michigan Gravitational Wave Group [UMichigan] PI: Keith Riles
- University of Mississippi [UMiss] PI: Marco Cavaglià
- University of Oregon Experimental Relativity Group [UOregon] PI: Jim Brau
- University of Texas at Brownsville Relativity Group [UTBrownsville] PI: Mario Diaz
- University of Wisconsin at Milwaukee [UWM] PI: Patrick Brady

II

Education and Public Outreach of LIGO Laboratory

8 Overview

LIGO Laboratory began implementing public outreach programs at Livingston and Hanford after the completion of construction in 1998. The sites provided tours of the facilities and summer teacher internships from the outset as the Observatory Heads built relationships with institutions and outreach interests near the sites. After twelve years of steady growth in the breadth of outreach activities and in the strength of regional partnerships, LIGO's site-based programs will reach more than 20,000 people in 2011. Each site aims to thoughtfully serve the large underrepresented populations that reside in the nearby counties/parishes. LIGO Livingston's Science Education Center (SEC) now serves as a premier science education destination in the Louisiana region, offering dozens of compelling hands-on physics exhibits and hosting a growing variety of innovative science programs for students, teachers and the general public.

Staff (5.5 FTE) are responsible for LIGO Lab outreach at the Observatory sites. The Hanford and Livingston outreach teams coordinate the involvement of technical staff members and LSC visitors in public activities. The vast majority of Hanford and Livingston outreach contacts are face-to-face, but the number of virtual contacts per year continues to increase through the use of EVO, Skype and similar platforms. Caltech's LIGO group continues to increase its volume of interactions with Pasadena area schools through the efforts of LIGO Caltech scientists, postdocs and graduate students.

The birth of the LSC-EPO Working Group in 2008 has strengthened the Lab's outreach portfolio. LSC-EPO provides a mechanism for Lab personnel to participate in national and international gravitational wave outreach projects. The Lab outreach team brings resources from the sites to bear on these projects as needed. Technical and outreach staff in the Lab collaborate with members of LSC-EPO in promoting LIGO to the public and to diverse student groups through participation in conferences and exhibitions. Activity also flows into the Lab through LSC-EPO as personnel at LSC sites are able to connect their local constituents with education resources that are available through the Observatories.

9 LIGO Livingston Observatory and the LIGO Science Education Center

9.1 Past and Current Activities

In 2004, a successful proposal to the NSF authored by a partnership of LIGO, Southern University at Baton Rouge (SUBR), the Exploratorium, and the Louisiana Systemic Initiative Program and Louisiana GEAR UP resulted in the construction of the 10,000 sq. ft. Science Education Center (SEC) at the Livingston site. The SEC currently houses over 50 Exploratorium-style exhibits that focus on the science themes of LIGO. Auditorium and classroom space near the exhibit hall amplifies the educational value of the facility, allowing the staff to delve into topics in more depth. Three LLO outreach staff members operate the SEC with assistance from undergraduate SUBR docents and LLO staff. The Exploratorium continues to partner with the SEC on exhibit training and teacher professional development. The SEC has become a key destination for school field trips and K-12 teacher professional development activities in central Louisiana and beyond, serving 5136 school children (K-12) with field trips during the academic year. The SEC has trained 506 K-12 teachers through contacts during teacher workshops.

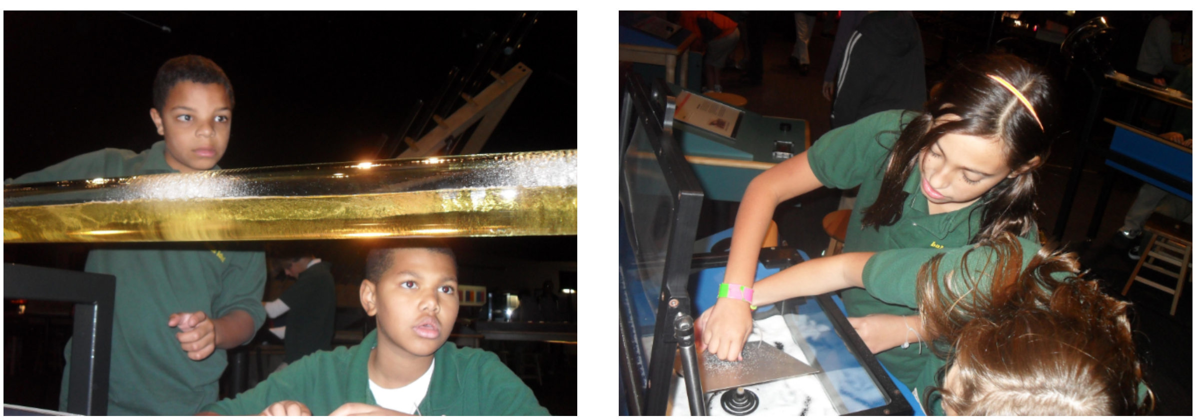
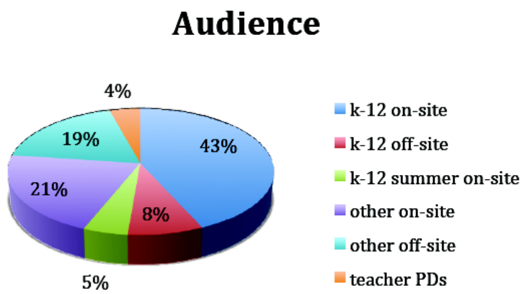
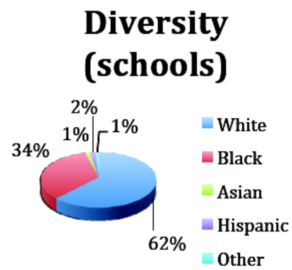


Figure 9.1: Students explore wave properties through exhibits at the SEC.

Since its inception, the SEC has seen an increase in LLO's on-site outreach attendance from 1100 on-site visitors in 2004 to 8223 on-site visitors during the past year. The SEC reached a total of 11503 contacts from June 2010-May 2011 (8223 on-site, 3280 off-site) through 200 programs and activities. Additionally, the SEC staff exhibited at the Louisiana Science and Teachers Association teacher conference and delivered four professional national presentations.





As shown in the accompanying graphs, the majority of current contacts are with students on-site. LLO continues to strategize new means of engaging the general public and teachers.

9.2 Needs and Future Plans

The SEC has transitioned to a regional collaboration headed by the Baton Rouge Area Foundation (BRAF), that involves Tulane University as well as all of the original SEC partners. BRAF provides an institutional umbrella under which the collaboration can continue to grow and mature. Future plans include growth in the scope and depth of the SEC's programming with an eye towards innovation as the SEC staff continues to expand the reach of the facility, reaches out to the general public more effectively and leverages the facility's potential as a unique tool for enhancing the public's science literacy and the level of interest in LIGO's pioneering research. One aspect of this mission includes the effort to involve students and teachers from several local school districts in a continuum of repeated LIGO-based experiences over a span of years. The intention of this concentrated effort is to ramp up students' understanding of STEM professions in an authentic context, while evaluating the longitudinal effectiveness of the outreach efforts.

Figure 9.2: Fifth grade teachers investigate waves.

From 2004 until 2010 the SEC saw a small but steady decline in teachers attending professional development opportunities with the SEC. During this past year the number of teachers involved in professional development with the SEC started to level off and then increase. In the future the SEC will need to retain the ability to involve LIGO in new and innovative outreach work as it becomes available while at the same time serving our core audiences and ensuring that the longitudinal outreach efforts are effectively managed.

10 LIGO Hanford Observatory

10.1 Past and Current Activities

Along with LIGO Livingston, LIGO Hanford (LHO) hired a full-time outreach coordinator in 2004. In the absence of an outreach facility similar to the SEC, this single FTE served the Observatory through the close of 2009, at which time a second outreach professional joined the LHO staff. Outreach activities at Hanford are similar to those at Livingston in flavor and intent, although balanced differently due to contrasts in local demographics and site facilities. LHO offers 18 interactive exhibits to support school field trips and family-oriented outreach at the site. Outreach staff members and summer teacher interns have developed a number of portable hands-on items for use in schools and community venues. LIGO's participation in NSF's Interactions in Understanding the Universe program (I2U2) has yielded a Web-based interface for the analysis of LIGO seismometer data. The interface and its companion Web site provide a platform for student research projects in school settings.

In 2011 LHO will participate in roughly 11,500 outreach contacts, nearly 3600 of which will be visitors to the Observatory for school field trips, public tours and public events. The balance will come from off-site interactions at schools, at school-based family events and at community exhibitions and festivals. Teacher professional development activities remain a key component of LIGO Lab outreach. In 2011, LHO and several K-12 and higher education partner institutions will complete a five-year Math Science Partnership program that will have served over 120 elementary and middle school teachers from two nearby high-needs school districts with high quality, sustained instruction related to the teaching of scientific inquiry.

10.2 Needs and Future Plans

Early in 2011, LHO learned that NSF had decided that it could not fund LIGO's 2009 proposal for a SEC-like science center at Hanford. LIGO remains committed to exploring ways of developing a Hanford center. Going forward, LHO management and outreach staff must make provision for the growth of the on-site outreach program in the face of space constraints that limit the number of new exhibits and the volume of new programming that can be implemented. More space will become available as Advanced LIGO construction moves towards completion.

Perpetual shortfalls in the Washington State budget continue to tighten the funding that Washington schools can apply to activities such as field trips and teacher professional development activities, a circumstance that will require LHO to pursue new and innovative strategies for attracting K-12 students, their families and their teachers to the Observatory.

Of paramount importance in the years between 2011 and 2015 will be the story of Advanced LIGO construction. LHO outreach staff members must provide a consistent flow of information, images and video that will keep the public apprised of the big picture and the technical details of the advanced detectors. These aLIGO resources must remain broadly accessible on Lab and LSC Web sites and in newly emerging media. Visitors to the site should see Initial LIGO artifacts and Advanced LIGO print materials throughout the facility.

III

Education and Public Outreach of the LSC

11 Current EPO activities of the LSC

11.1 Social Networking

Why is the LSC interested in social networking?

Social networks are simply the relationships or connections that tie individuals together. With the advent of the internet and electronic communications, social networks have grown from relationships within one's own local community to relationships with individuals from across the globe and those with whom we may have little personal contact. Also the term *social network* itself is now commonly used to describe activities related to a number of internet-based communication platforms. This expansion of the reach of social networks has evolved the character of relationships into two main categories: strong and weak [33]. A strong connection is one in which an individual has repeated contact and interaction with an individual. Because of the time and attention that a strong connection requires, an individual can only maintain a limited number of these connections. A weak connection is one with which an individual has limited interaction and may know only within relatively impersonal or distant contexts (e.g., the real estate agent who sold you your house or a schoolmate that you haven't seen or spoken to in years).

The LSC-EPO program is interested in exploiting the ability of social networks to make current LSC science and news accessible to members of the public as well as to the members of the growing gravitational wave collaborations. To that end, the LSC-EPO program has established channels on the popular social networking sites Facebook (`www.facebook.com`) and Twitter (`www.twitter.com`) for outreach purposes. The current LSC social networking state (with current status, etc.) is displayed on the LIGO homepage under the heading of students/teachers/public → LIGO on Social Networking at `http://www.ligo.org/students_teachers_public/social.php` [20]

Blogs (we**b logs**) are also a popular way for individuals to discuss their thoughts on the happenings of their lives or other current events. The LSC-EPO program as also established a subgroup called the 'Blog Squad' who monitors a certain number of blogs and brings to the group's attention blogs that are propagating inaccurate information so that a polite response from LSC-EPO can be issued. Individual LSC members may also have their own blogs that discuss their work on LIGO Science. While these blogs cannot be portrayed as official statements of the LSC, they can be a powerful outreach tool.

Facebook

Facebook is a social networking site where a user creates a profile of information about themselves. The user may be a person or a group. Once the profile is complete, the user may disseminate information to their 'friends' (other users who have established a connection with the account) through the use of the status update. When users log on, they are taken to a default home page that displays

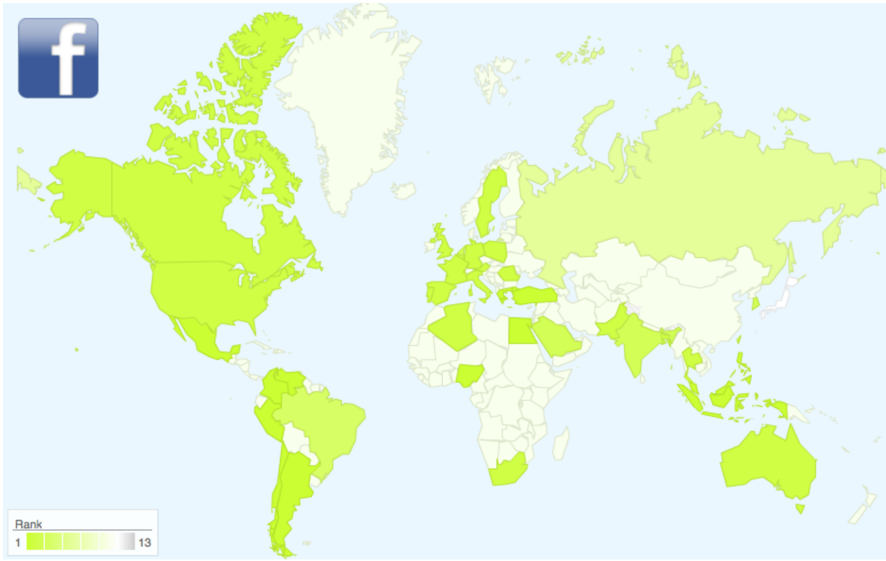


Figure 11.1: International ranking of Facebook compared to other social networking sites, based on the number of page views. Image by `http://www.appappeal.com`, based on data taken by www.alexa.com on May 4, 2011.

status updates and news from their 'friends.' Other utilities, known as apps, can be added to the page to do everything from play interactive games with their friends to track what books a user is reading. Facebook has been ranked the #1 social networking site in many surveys, reviews and analyses of user numbers. It currently has more than 500 million active users worldwide [32] and a world map of social networks shows that Facebook has by far the largest international reach of a single vendor/application [30].

Twitter

Twitter is a social networking site that can also be considered a micro-blogging site that allows users to send and read messages known as tweets. Tweets are text based messages that are strictly limited to 140 characters which are displayed on the user's profile page and to their followers (users with a connection to the account and analogous to 'friends' on Facebook). The limitation on the number of characters that can be displayed was initially determined so that tweets could be sent as SMS (Short Message Service) messages, such as cell phone text messages, or other external applications.

Twitter does not release all information on the number of users, however, their latest update (14 March 2011) states that each week the site sends 1 billion messages [35]. Independent estimates show that the number of active users is much lower than on other networking sites, for example Nico Schoonderwoerd estimate s the number of active users to be 30-40 million [34]. However Twitter is probably the best known micro-blogging platform and especially popular for distributing facts and information. Julie Letierce et. al. believe that 'Twitter has this potential to help the erosion of boundaries between researchers and a broader audience.' [31].

LIGO's social networking for the public at large

LIGO's social networking for the public at large is the main priority for the LSC-EPO program's internet-based outreach efforts. Because of this, interactions with the public in this manner are classified as a weak connection.

Facebook

The LIGO outreach user name on Facebook is 'LIGO Scientific Collaboration' and may be accessed at `http://www.facebook.com/ligo.collaboration`. (N.B. There is also a group on Facebook [a group is a special kind of account which has special settings to display content like what kind of group this is and who may join the group] with the same name that is not overseen by the LSC-EPO program.) To date (20 May 2011), we are 'friends' with 188 individuals many (but not all) of whom are already members of the collaboration. Periodically, the status is set to display a relevant bit of information that may be of interest to the public and pictures related to LIGO are linked to the profile by 'friends' tagging (or identifying) that the LIGO Scientific Collaboration is being discussed or is in a posted picture.

Twitter

The LIGO outreach user name on Twitter is 'LIGO' and may be accessed at `http://twitter.com/ligo`. To date (20 May 2011), we are being followed by 268 users many of whom are not already members of the collaboration. During the last months the number of users has constantly grown with an average increase of 1 per day. Tweets are posted to this account on the order of one to two per day and contain news and information from the collaboration as well as science-related highlights from outside the LSC.

LIGO's social networking for the LVC community

LIGO's social networking for the LVC community is an auxiliary opportunity for LSC-EPO program's internet-based outreach efforts. Because of this, interactions with the collaboration in this manner are classified as a strong connection.

Facebook

Since the LIGO EPO account on Facebook is 'friends' with many members of the collaboration, this medium also serves as a social networking opportunity for the LVC community. A LIGO network, a label that is attached to your profile that requires verification to prove that you are a member, has also been established for the LVC community to serve as a means to identifying one another within this forum and to serve as identification to the public that a user is a member of the collaboration. To take advantage of this, a user must modify their settings and specify that they would like to join the 'LIGO' (the quotes are not part of the network name) network and verify this by entering their `@ligo.org` email address. A confirmation email is then sent to that email with a link to click to complete the verification process.

11.2 Blogs

11.2.1 Blog Squad

A subset of the EPO group has taken on the task of periodically monitoring blogs that feature discussions on science or other blogs where LIGO may be discussed. The EPO group also receives notifications from the collaboration when a blog inaccurately portrays the science being conducted by the collaboration. It is an accepted practice not to respond to those blogs that are irrationally critical of science in general (or a 'crackpot' blog) since there are many such blogs in existence and attention from LIGO may simply encourage such discussions.

When a blog entry is noted that should be responded to, the Blog Squad uses a standard statement that summarizes LIGO science and can be used for most purposes with slight modification:

> "LIGO (funded by the National Science Foundation), as well as other worldwide gravitational wave projects, is actively engaged in a scientific endeavor to search for the gravitational waves predicted by Einstein's general theory of relativity. We look for gravitational waves from a variety of astrophysical sources, such as coalescing binary neutron stars and black holes. The nature of the gravitational waves is such that a detectable gravitational wave coming from a galactic or extra-galactic source requires an immense amount of energy (over one trillion, trillion gigatons of TNT). It is highly unlikely that detectable gravitational wave amplitudes could be produced from anything other than massive and large-scale astrophysical processes.
>
> Your Name
> Your Institution
> LIGO Scientific Collaboration"

The Blog Squad maintains a list of blogs that are monitored periodically along with the template response on the EPO wiki at `https://wiki.ligo.org/EPO/BlogSquad`. All LSC members are strongly encouraged to join the Blog squad.

11.2.2 Personal Blogs

Individual members may also compose their own blogs which may or may not discuss their work in the collaboration. If the blog does discuss LIGO science, it can be a powerful tool for public outreach. Such blogs should have a disclaimer prominently displayed stating that the views and opinions expressed within the blog are those of the individual and not necessarily those of the LSC.

One such blog is the *Living LIGO* blog (`http://www.livingligo.org`) by Amber Stuver (also associated with the twitter account livingligo [11]). This blog focuses on the day-to-day aspects of being a LIGO scientist with the outreach goal of humanizing the search for gravitational waves. This blog also proved to be an effective outlet of news as shown by the coverage of the "Big Dog" blind injection of 16 September 2010. The day after the event was revealed to be a blind injection (15 March 2011), *Living LIGO* posted a story about it and explained why scientists were excited and the utility of doing blind tests[10]. This story was then picked up by multiple internet outlets including Discover Magazine's *Cosmic Variance* blog [1] and the The Discovery Channel's news site [6]. Since this story was published on *Living LIGO*, it has received over 2385 hits (as of 20 May 2011). N.B. Approval from the LSC Spokesperson and the P&P Committee was attained before this story was published (unreviewed).

Other members of the LSC are encouraged to create blogs with outreach focuses or to incorporate outreach directed posts into their existing blogs.

11.3 Astronomy's New Messengers: An exhibit for the general public

One of the current major outreach efforts of the LSC is the *Astronomy's New Messengers: Listening to the Universe with Gravitational Waves* project, consisting of two public exhibitions on gravitational waves and LIGO [5] which are touring colleges, universities, museums and other public institutions throughout the United States. The two exhibitions have footprints of 200 sq. ft. ($\sim$ 18.6 m^2.) and 1000 sq. ft.($\sim$ 93 m^2) The portable 200 sq. ft. version premiered at the Street Fest of the 2009 World Science Festival in New York City, June 2009. The extended 1000 sq. ft. exhibit was presented at the 2010 World Science Festival, alongside a signature event on the theme of gravitational-wave astronomy featuring science journalist Marcia Bartusiak, physicists Andrea Lommen, Kip Thorne and Ray Weiss, and astronomer Laura Danly. *Astronomy's New Messengers* is a project funded by the National Science Foundation [22] through grant NSF-0852870 [23] from the Informal Science Education program, the EPSCOR program, and the Office of Multidisciplinary Activities (Program Manager: Kathleen V. McCloud, PHY Division of Physics, MPS Directorate for Mathematical & Physical Sciences). The project is managed by M. Cavaglià (Mississippi) with M. Hendry (Glasgow), S. Márka (Columbia), David Reitze (Florida) and Keith Riles (Michigan) serving as co-PIs. *Astronomy's New Messengers* was designed and realized by Lee H. Skolnick Architecture + Design Partnership [26], a multi-disciplinary firm of architects, designers, and educators providing award-winning architecture and exhibit design services. Leni Schwendinger Light Projects [19], a NYC-based art studio which specializes in creating lighting environments for architectural and public spaces all over the world, designed and realized the artistic component of the 2010 exhibit. Members of the EPO working group, staff, graduate students and postdocs from various LSC institutions contributed to concept development, the exhibit's ancillary activities, and management.

Learning objectives and target audience

The learning objectives of *Astronomy's New Messengers* are to increase interest in, and understanding of, gravitational-wave astronomy and LIGO science. The target audience of the exhibits is an adolescent and young adult population of students, college age visitors, and informal learners. To attract this difficult audience, the exhibits include possibilities for age-appropriate self exploration and messages that allow visitors to first discover their own excitement in the material, and then delve deeper into its complexity. To maximize the impact of the exhibit, and achieve these goals, the design of *Astronomy's New Messengers* reproduces the physics and technology of the actual LIGO instruments in an eye-catching and entertaining way.

Design of the portable exhibit

The floorplan and elevation of the portable exhibit are shown in Figures 11.2 and 11.3, respectively. The exhibit's introductory area presents a general overview of the LIGO detectors and their science, while inviting visitors to step inside, explore and find out more. Text panels 11.4 and a large LCD screen with a looping high-quality video, originally produced by Milde Marketing [21] for the

International Year of Astronomy [13] cornerstone project "100 Hours of Astronomy", deliver key informational points (Figure 11.5, left.)

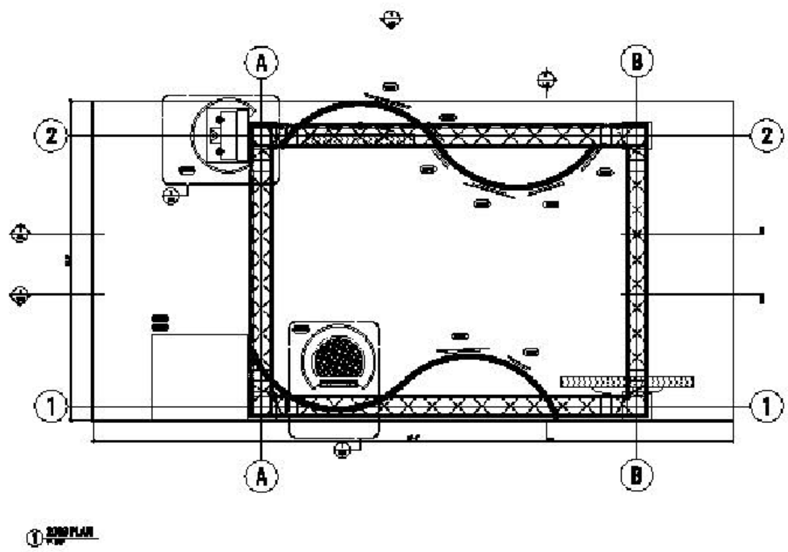


Figure 11.2: Floorplan of the portable exhibit. Design by Lee H. Skolnick Architecture + Design Partnership [26].

The main area of the exhibit explains how gravitational waves are generated by cataclysmic events in the distant universe, how LIGO "listens" for these events, and demonstrates how scientists decode their signals. Three interactive components engage visitors in discovering how LIGO operates and understanding some of the foundations of gravitational wave astronomy: a working and interactive laser interferometer, a grid-patterned rubber sheet to illustrate the curvature of space-time, and the black hole hunter game [14] kiosk. A second LCD screen with looping video compiled of clips from the NSF movie *Einstein's Messengers* [4] and several panels with photographs and diagrams further encourage visitors' interest in LIGO and the deep universe.

The interferometer model, constructed by the Ann Arbor Hands-On Museum [12] in collaboration with the Michigan LIGO group, intuitively shows visitors how an interferometer operates. A fringe pattern is projected on a screen, illustrating the concept of light interference and the effect of environmental noise. By tapping the interferometer case, visitors can disturb the fringe pattern. A photodiode at the output port of the interferometer measures the fringe variation and speakers produce a sound for an ultimate multi-sensory experience. Each key element of the interferometer is called-out and explained on a LCD screen. The concepts of space-time and of gravity as space-time curvature are illustrated with the rubber sheet interactive. Visitors can set a heavy steel ball on the sheet, which stretches the grid-patterned sheet around it. Rolling a second, smaller ball into the depression formed around the larger one, visitors can visually understand how space-time warps around massive objects and affects the motion of bodies in space. (Figure 11.5, right.) The purpose of the Black Hole Hunter game, developed by Cardiff University, is to give visitors an opportunity to do (in a figurative sense) what LIGO scientists do, i.e. look for gravitational signals in noisy streams of data. Simulated gravitational-waves are translated into sound clips. Through a graphical user interface on a computer screen, visitors try to detect simulated sounds of black hole events buried in different static noise clips. (Figure 11.6.)

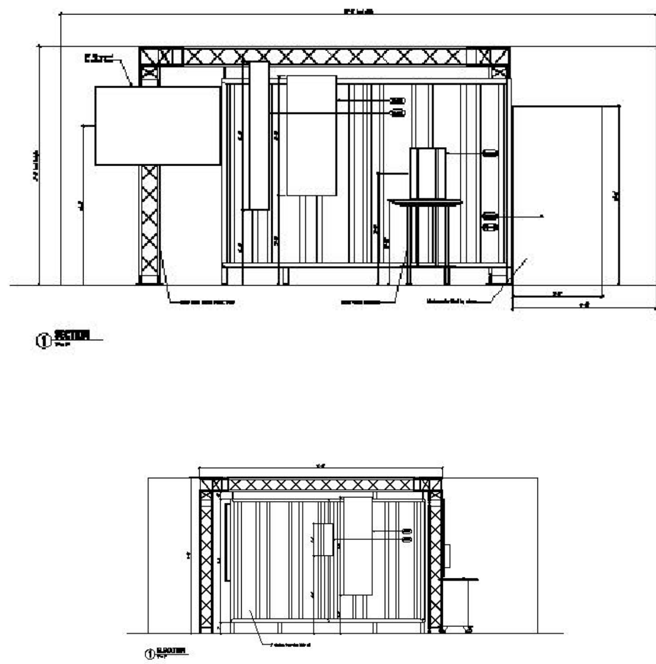


Figure 11.3: Elevation drawings of the 2009 LIGO Touring Exhibit. Design by Lee H. Skolnick Architecture + Design Partnership [26].

Crucial to the design, integration and implementation of these elements was the collaboration between the LIGO Education and Public Outreach group and professional exhibit designers.

U.S. tour of the portable exhibit

The portable version of *Astronomy's New Messengers* debuted at the World Science Festival's Street Fair in June 2009. The one-day event included over one hundred science and educational exhibitors such as the New York Hall of Science, Liberty Science Museum, PBS Kids, and New Scientist Magazine, and was attended by over 150,000 visitors (WSF estimate). A partial list of exhibitors and their programs can be found at `http://www.worldsciencefestival.com/2009/street-fair`. The LIGO exhibit was given a prominent location in front of NYU Skirball Center by the organizers of the World Science Festival. This location allowed the LIGO exhibit to draw an unexpected number of visitors. Pictures of *Astronomy's New Messengers* at the Street Fair can be found at `http://ligo.phy.olemiss.edu/LIGOexhibit/photogallery/WSF.html`. The LIGO exhibit was staffed full time by Marco Cavaglià, Martin Hendry and Szabolcs Marka, Michigan graduate student Evan Goetz, Rochester Institute of Technology graduate student Marcelo Ponce, University of Mississippi graduate student Brooke Rankins, and several students from Columbia University.

After the WSF, the exhibit moved to the Adler Planetarium in Chicago, where it was on display from July 10 to August 10, 2009. During its display at Adler Planetarium, the exhibit was staffed by a host of graduate students and post-docs from the LIGO group at Northwestern University under the direction of Dr. Vicky Kalogera. Adler Planetarium draws an average of 400,000 visitors each

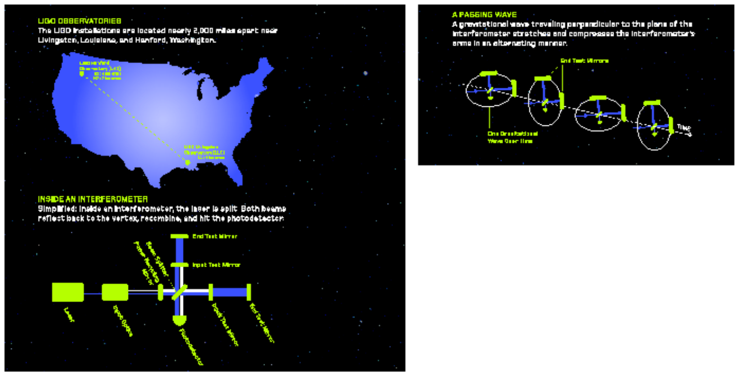


Figure 11.4: Example of graphic panels of the main area of the exhibit. Design by Lee H. Skolnick Architecture + Design Partnership [26].

Figure 11.5: Visitors at the 2009 World Science Festival [27] browsing the exhibit graphic panels (left). K-12 after-school students at the University Museum, Oxford, Mississippi, simulating curved space-time with the rubber sheet interactive (right. Photo credit: Elizabeth Herren.)

year (Adler Planetarium estimate). Although the actual number of visitors to Astronomy's New Messengers was not recorded, the LIGO exhibit was featured prominently in the Adler Planetarium and it is reasonable to assume that was seen by most of the Planetarium visitors in that period.

From September 2009 to February 2010, the LIGO exhibit was on display at several educational institutions in the southern states: The University of Mississippi Museum, Arkansas State University, Rhodes College, Agnes Scott College, the University of Florida, the University of South Alabama, the LIGO Livingston Science and Education Center, Louisiana Tech University, and Southeastern Louisiana University. These institutions were selected to maximize the impact of the exhibit in reaching to diverse groups (Agnes Scott College is a small liberal arts women's college, the Arkansas State University and Southeastern Louisiana University are medium-size institutions in industrial and rural areas, respectively) as well as for their recruiting potential (Rhodes College and the University of Florida).

The nationwide tour of the exhibit restarted in October 2010 at the First Science and Engineering

Figure 11.6: Playing with the Black Hole Hunter game. The interferometer kiosk is in the background. Photo credits: Elizabeth Herren.

Expo in downtown Washington, D.C. During its two-day display on Freedom Plaza, the exhibit was staffed by Martin Hendry (Glasgow U.), Kathy Holt (LIGO SEC), Dennis Ugolini (Trinity U.) and a host of graduate students from the LIGO group at the University of Maryland. The participation of the LIGO exhibit at the Washington Expo was sponsored by NSF as one of the agency's signature displays. According to the organizers' estimate, the event was attended by over 500,000 visitors. After the Expo, *Astronomy's New Messengers* was on display at Catawba Science Center (Hickory, NC) for about four months, before moving to Trinity University (March 2011) and to the atrium of the Planetarium at the University of Texas-Arlington, near Dallas TX, where it is scheduled to be on display through July 2011. Planned future stops of the exhibit will include the Stafford Air and Space Museum in Weatherford OK, Louisiana State University, Embry-Riddle University, and several other science centers and colleges throughout the U.S.

Host institutions are generally required to pay for inbound transportation, be responsible for any damages, theft, or vandalism incurred while the exhibit is on their premises, and provide labor for set-up and tear-down under the supervision of the project PI. These conditions are enforced through the signing of a MOU between the LSC, the University of Mississippi and the host institution. Examples of previously signed MOUs are available in the LIGO DCC repository.

Most of the exhibit displays at Universities and science centers were inaugurated by well-attended public lectures and other outreach companion activities such as after-school activities with K-12 kids, and tours of teachers and students from local middle and high schools. Two 'Einstein's Cosmic Messengers' performances by internationally acclaimed composer and percussionist Andrea Centazzo were sponsored by the University of Mississippi and the University of Florida.

Educational material was also developed. Specifically, in addition to the PowerPoint presentations for the public lectures, an exhibit web page and two companion tri-fold brochures were produced, which explain the LIGO experiment and the various interactive components of the exhibit. These brochures were distributed to visitors during the exhibit displays. A signature cotton 'Black Hole Hunter' T-shirt was also designed and produced. Several hundreds of them were given away to visitors during the exhibit displays at various locations. They were also given to student helpers and used as a prize for kids playing the Black Hole Hunter game. The T-shirt design consist of a graphical simulation of two colliding black holes and gravitational-wave emission on the front, and the URL of the new LIGO web site, www.ligo.org, on the back.

Design of the extended exhibit

The 1000 sq. ft. version of *Astronomy's New Messengers* premiered at the Broad Street Ballroom, a few blocks from New York City's stock exchange building, on June 5, 2010 on the occasion of the 2010 World Science Festival. The design of the large-scale exhibit draws upon elements of the touring exhibit (and upon lessons learned from the former's evaluation). In addition to the interactive components that are present in the portable version of the exhibit (Black Hole Hunter game, rubber sheet and interferometer kiosk) the extended exhibit blends LIGO science with high-concept artwork through incorporation of an interpretive 3-D lighting display and a large table-top interactive model interferometer.

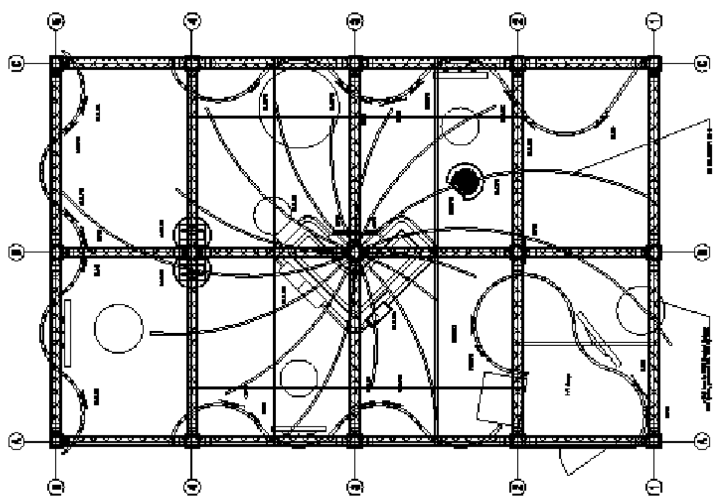


Figure 11.7: Floorplan of the extended exhibit. The table top interferometer is at the center. The spiral patterns are the strands of diodes suspended from the ceiling. Design by Lee H. Skolnick Architecture + Design Partnership [26] and Leni Schwendinger Light Projects [19].

The floorplan of the larger *Astronomy's New Messengers* exhibit is illustrated in Fig. 11.7. The exhibit is modular and self-contained. It requires an unimpeded area of 25' $\times$ 40' ($\sim$ 7.6 m $\times$ $\sim$ 12.2 m) with a ceiling clearance of 17' ($\sim$ 5.2 m). Total weight is approximately 3500-4000 lbs. ($\sim$ 1600-1800 kg) and requires 11 20-amp circuits for power. LIGO scientific ideas (the search for gravitational waves and the quest for the unknown) are embedded in the exhibit design from "the undulating waveform shape of the space to the programming of the light sculpture and the graphic design." The large-scale exhibit incorporates the elements of the portable exhibit on a grander scale – e.g., using larger flatscreen displays and poster boards, and two interactive Black Hole Hunter stations rather than a single one. The astounding green-laser table-top interactive interferometer was designed and realized by Grant Meadors (graduate student) and Keith Riles (PI) of the Michigan Gravitational Wave Group. The interferometer, with arms of about 1 and 1.5 meters, respectively, is hosted in a custom-built plexiglass case and bulls-eye fringes are projected on a wide screen. An original LIGO input optics is on display close to one of the arms. Above the table-top interferometer, a major, high-concept work of art in the form of an interactive three-dimensional lighting display is suspended from the ceiling, symbolizing the Universe above the Earth. This unique artwork is easily visible from afar and its distinctive appearance is instrumental in drawing visitors towards the exhibit and allowing them to be exposed to the science at the basis of LIGO research in an exciting and visually stunning manner. Sounds from visitors and audio templates of binary inspirals, pulsars, bursts and stochastic background are translated and displayed on a spatial field of strands of diodes, creating a dazzling show of light and sound in real time, representing the everlasting link between Earth and the Universe. Interactivity between visitors and the light sculpture is achieved through a touchscreen display at the center of the exhibit, underneath the suspended display.

Figure 11.8: The extended exhibit at the Broad Street Ballroom in NYC. The Black Hole Hunter stations are on the left. Table-top interferometer and touchscreen are at the center. Above, the light sculpture shines with blue strands of diodes. Design by Lee H. Skolnick Architecture + Design Partnership [26] and Leni Schwendinger Light Projects [19].

The LIGO exhibit was featured as an offical event of the 2010 World Science Festival. During its five-day display in downtown New York City, *Astronomy's New Messengers* was staffed full time by Marco Cavaglià and Brooke Rankins (U. Mississippi), Szabolcs and Zsusza Marka (Columbia U.), Grant Meadors (Michigan) and a host of enthusiastic graduate and undergraduate students from Columbia University. Two public panel discussions were held during the festival: A LIGO-sponsored signature event on the theme of gravitational-wave astronomy and featuring high-profile scientists (Laura Danly, Andrea Lommen, Kip Thorne and Rai Weiss) with moderator Marcia Bartusiak, and an interdisciplinary art & science panel discussion featuring exhibit designer Lee Skolnick, light artists Leni Schwendinger and Marco Cavaglià at the CUNY Graduate Center with introduction by Brian Schwarz and Adrienne Klein. Both events were part of the official program of the World Science Festival. The web site `http://ligo.phy.olemiss.edu/LIGOexhibit` contains an extensive collection of pictures and videos of the exhibit displays and ancillary events.

The large-scale LIGO exhibit was stored in NYC for a few months after the World Science Festival. After being crated and refurbished, it has recently being put again on display in the lobby of the University Center at Shawnee State University (Portsmouth OH), where it is scheduled to remain through August 2011. Negotiations to display the exhibit at Science Central (Fort Wayne, IN) from September 2011 to January 2012 are in an advanced stage.

A signed MOU similar to the agreement for the portable exhibit is requested to loan the exhibit. Host institutions are generally required to pay for inbound transportation, be responsible for any damages, theft, or vandalism incurred while the exhibit is on their premises, and provide labor for set-up and tear-down. Examples of previous MOUs are available in the LIGO DCC repository.

Evaluation

The LIGO exhibits were well received and had a very positive impact on their audiences. The Black Hole Hunter game and the light sculpture are certainly a hit, in particular with kids and young adults. The interactive interferometers are also very popular with visitors, as well as the rubber sheet interactive which illustrates the curvature of space-time.

The effectiveness of *Astronomy's New Messengers* was evaluated through a survey which was administered to visitors. The evaluation was performed by the Center of Educational Research and Evaluation of the University of Mississippi. The results of the study confirm that both the portable exhibit and the large-scale exhibit were well received at the majority of sites where they were displayed. Approximately 80% of the respondents to the survey stated that the exhibit helped them 'very much' or 'some' to understand what is LIGO and how it works, and what are gravitational waves. Over 70% of the respondents stated that the exhibit increased their interest in science and 'agree' or 'strongly agree' that the government should spend money on projects like LIGO. Although comments were not solicited in the survey, several written comments by respondents will help in further improving the exhibit and its impact on the public.

Cavaglià also worked in close contact with Bernard Whiting and Guido Mueller to advertise the University of Florida International REU program (see below). Brochures of this REU program were put on display at the exhibit venues and distributed at the public lectures.

11.4 Local exhibitions

11.4.1 ImagineRIT

Every year the Center for Computational Relativity and Gravitation (CCRG) RIT showcases their work at the ImagineRIT festival [25]. In May 2010 CCRG presented the exhibit *Can't you see it? It's a Black Hole!*. In May 2011 CCRG presented the exhibit *Space Monster in 3D*. These exhibits consisted of multiple interactive components and presentations explaining the research being done at CCRG.

The first component of the *Space Monster in 3D* exhibit is a computer game which allows visitors to shoot down alien spaceships with a laser gravitationally lensed by a black hole. This game is suitable for children 6 to 12 and teaches younger children how strong gravity can deflect light. The game was shown on a 50-inch screen, and was visible from a great distance. In the second component of the exhibit, the visitors could see real 3D visualizations of simulations performed at CCRG. The visitors used shutter glasses in order experience the 3D effect. The 3D movies are suitable for all age groups. The movies were chosen for its visual appeal. The movies were shown in a repeat mode on a 20 inch screen. A new multimedia presentation that describes the physics behind the above exhibits and explains why CCRG research is important in understanding the universe was also part of the exhibit. This presentation used both still slides and movies to explain how gravity affects the universe. The presentation was suitable for visitors 12 and up and was shown on a 20-inch screen. The game and the 3D movies were the biggest attractors for different reasons, and led very often to deeper discussions of our research. The presentation was a helpful tool for explaining our research but did not attract many visitors. The 3D movies were the 'coolest' thing according to the comments of our visitors. Besides showing stunning videos, the also showed that science can be cool.

11.4.2 UK exhibitions

In the UK since 2008 there has been a number of opportunities to present a multimedia exhibit on gravitational waves to a wide range of audiences, age groups and demographics. In July 2008 the groups from Glasgow, Cardiff, Birmingham and Southampton, together with our German Colleagues from the AEI Golm and Hannover and Milde Marketing, were selected to present the exhibit "Can you hear black holes collide?" at the Royal Society Summer Science Exhibition in London. This exhibit contained a number of components, including a table-top interferometer, a large (approx. 4m $\times$ 2m) backdrop on gravitational wave astronomy, multimedia displays showing looping movies on gravitational wave astronomy, an innovative "sound shower" that simulates as audio signals the 'chirps' associated with binary black hole mergers, and several computer consoles running the Black Hole Hunter interactive game. The exhibition was very successful and was attended by several thousand visitors – mainly of high school age.

The expertise gained through our involvement in the 2008 Royal Society exhibition also contributed significantly to the conception and design of the "Astronomy's New Messengers' exhibit described in detail elsewhere in this report. Elements of this Royal Society exhibit have subsequently been displayed at a large number of science festivals, exhibitions and other events around the UK. Significant highlights include:

- The University of Glasgow group presented their Black Holes exhibit at the Scottish Festival of Science, held at Glasgow Science Centre in September 2009 and September 2010, and again at a Science Careers Fair, held at Glasgow Science Centre in February 2011. Both events were attended by several hundred visitors, in the latter case mainly high school students who were about to make their subject choices for more advanced study. Glasgow Science Centre has agreed to host a table top interferometer (to be constructed by Glasgow University) as a permanent exhibit, with installation expected late in 2011. The Glasgow group have also presented their exhibit at the Scottish Parliament and the Royal Society of Edinburgh, as part of high-profile Science Showcase events supported by the Scottish Government.

- The University of Glasgow group also presented their Black Holes exhibit at the Kelvingrove Museum in Glasgow, to accompany the 'Doctor Who' exhibition which ran there from January to December 2009. This provided an excellent opportunity to reach out to a slightly different demographic from that encountered at science centers and science festivals.

- The UK gravitational wave community contributed several artefacts to the 'Galileo: Cosmos and Culture Exhibition' which was launched at the Science Museum in London, in July 2009 and will run until early 2012. The exhibition seeks to explore the impact of astronomy on science and wider society, as part of the UK celebrations to mark International Year of Astronomy 2009. The exhibition includes an Advanced LIGO prototype beam splitter, a GEO600 Sapphire test mass and a full-size model of one of the proposed LISA spacecraft (provided by AEI Hannover and Milde Marketing). These gravitational wave contributions were coordinated by Martin Hendry (Glasgow). The exhibition has been highlly acclaimed and at the end of its run it is hoped that some or all of the gravitational wave exhibits will be transferred to the space gallery at the Science Museum for permanent display.

- The University of Birmingham group presented a gravitational waves exhibit, featuring their own Michelson interferometer and elements of the original Royal Society 2008 display, at the British Festival of Science, which took place in Brimingham in September 2010. The exhibit was attended by several thousand visitors and was very popular. A similar presentation, led by the University of Glasgow, is planned for the 2012 British Festival of Science which will be hosted by the University of Aberdeen.

- In October 2010 the Unversity of Glasgow group participated in a multimedia event at Glasgow Royal Concert Hall, in collaboration with Glasgow Science Centre. The event featured a live concert presentation of 'Icarus at the Edge of Time' – a classical music piece written by Philip Glass based on the eponymous children's story by Brian Greene, which updates the Icarus myth to a journey around a black hole. Before and after the concert guests were invited to visit a science exhibition in the foyer of the Concert Hall, which featured the Glasgow group's black hole exhibition. The event was a major success and Glasgow Royal Concert Hall has expressed the wish to collaborate with the Glasgow group on similar events in the future.

11.5 Multimedia and web-based outreach

The ligo.org website

Most of the web-based outreach of the LSC relies on the ligo.org web site (`http://www.ligo.org`) and the LIGO Lab web site (`http://www.ligo.caltech.edu`). On June 12, 2009, the ligo.org website was redesigned and streamlined through the efforts of the LSC Web Committee (`lsc-webcomm@ligo.org`) chaired by Ben Owen. The web site is targeted mainly to a general audience but it contains a LSC/Internal link to the LSC TWiki with useful information for LSC members. A ligo.org sandbox `http://www.lsc-group.phys.uwm.edu/webcommphp/index.php` is used by the LSC Web Committee to update content before roll out. The ligo.org sandbox is only viewable by the LSC but not by the general public.

The ligo.org portal contains links to subpages with topics of interest for the general public: "news", "science" (a layman introduction to LIGO & gravitational waves), "students/teachers/public (information and resources regarding LIGO and gravitational waves of special interest to students and teachers), "multimedia" (a collection of videos, images and sounds), "partners" (links to other gravitational-wave experiments and collaborations), and "about" (a short introduction of the LSC). The site map is listed below:

- LSC home page
- LIGO Lab
- Community/environment

- LSC/internal
  - News: Latest news
    - Latest news
    - Upcoming events
    - Press releases
    - Blog
  - Science: Introduction to LIGO and gravitational waves
    - Introduction
      - Introduction to LIGO and gravitational waves: Introduction
      - Introduction to LIGO and gravitational waves: Newton, Einstein and gravitational waves
      - Introduction to LIGO and gravitational waves: "Ripples on Space-Time"
      - Introduction to LIGO and gravitational waves: Sources of gravitational waves
      - Introduction to LIGO and gravitational waves: Continuous gravitational waves
      - Introduction to LIGO and gravitational waves: Inspiral gravitational waves
      - Introduction to LIGO and gravitational waves: Burst gravitational waves
      - Introduction to LIGO and gravitational waves: Stochastic gravitational waves
      - Introduction to LIGO and gravitational waves: Detecting gravitational waves
      - Introduction to LIGO and gravitational waves: Using multiple detectors
      - Introduction to LIGO and gravitational waves: An interferometer
      - Introduction to LIGO and gravitational waves: LIGO's interferometer
      - Introduction to LIGO and gravitational waves: The potential of gravitational waves
    - Popular articles
    - LSC scientific publications
  - Students/Teachers/Public: LIGO information and resources
    - Students
    - Teachers
    - Public
  - Multimedia
    - Images
      - Image gallery: LIGO Hanford Observatory
      - Image gallery: LIGO Livingston Observatory
      - Image gallery: Astrophysical sources
      - Image gallery: Lasers
      - Image gallery: Optics
      - Image gallery: People at work
      - Image gallery: Seismic isolation
      - Image gallery: Vacuum envelope
    - Videos
    - Sounds
  - Partners: Partner experiments and collaborations
    - GEO
    - Virgo
    - LCGT

    - ∗ LISA
  - About
    - ∗ Charter
    - ∗ Bylaws
    - ∗ Member institutions
    - ∗ Membership directory
    - ∗ Research white papers
    - ∗ LSC/internal

- Funding acknowledgments
- Contact information
- Legal
- Credits

An effort is currently underway to create a Spanish version mirror of the ligo.org web site.

Space Place

The Space Place effort is a set of intertwined products and partnerships with a nationwide reach. NASA's Space Place has a website (`http://spaceplace.nasa.gov`) in both English and Spanish for elementary school kids, their parents, and their teachers, with interactive games, projects, and amazing facts. Informal surveys at teacher conferences have found that about half the teachers have heard of or have used the website. Over 50 different NASA missions are represented on the website.

Figure 11.9: Screenshot of The Space Place home page. In upper right corner is the Fact of the Day, which links to one of the activities or fun facts on the site.

Space Place makes a real effort to tailor its content to this young audience, and to reach out to diverse communities (such as native Spanish speakers). Examples of Space Place products are the

Figure 11.10: Screenshot of the "Black Hole Rescue Game," Spanish version.

Black Hole Rescue Game at `http://spaceplace.nasa.gov/en/kids/blackhole`, and the Cosmic Viewer at `http://spaceplace.nasa.gov`.

As part of the website, Space Place also produces "Space Place Live!" a cartoon talk show, featuring interviews of renowned scientists, such as Michelle Thaller of the Spitzer mission and Kip Thorne of LISA. (Go to `http://spaceplace.nasa.gov/en/kids/live` and click on "Meet Michelle Thaller" or "Meet Kip Thorne.") These "episodes" are also carried on NASA TV.

Figure 11.11: Meet Kip Thorne!

Space Place has partnerships with over 30 newspapers, each of which runs a monthly Space Place column on its kids page. Space Place also works with over 250 amateur astronomy clubs across the country, each of which receives an original monthly column for their newsletter and/or website. Space Place collaborates with over 350 museums and planetariums in the U.S., each of which has a Space Place bulletin board type display where they feature NASA's latest paper products, sent to them monthly.

In 2010, Space Place team leader Nancy J. Leon worked with Marco Cavaglia (UMiss) and LSC-EPO group members to create more visibility for the LIGO experiment on Space Place, and to reach this young audience, as well as the large audience represented by their partnerships. Funding for this project were secured by the UMISS group through a supplemental award to the group research award. This led to the design and production of the "LIGO Amazing Fact" [9], a kids' newspaper article and an astronomy club column. These articles were distributed to more than one hundred newspapers across the U.S. and abroad. A Spanish language version of the LIGO material on the

Space Place website was also produced to reach diverse and underserved communities.

Outreach activities with EVO

EVO (Enabling Virtual Organizations) [15] is a videoconferencing and desktop sharing system developed at the California Institute and now in use by some of the major scientific experiments worldwide, such as the Large Hadron Collider experiments at CERN and many others. LIGO and the LSC recognized that there was a need for a higher bandwidth environment for communicating information interactively within such a large collaboration geographically distributed around the world. To facilitate the exchange of information, the LIGO Laboratory, the LSC and the EVO technologist jointly developed and submitted a proposal to NSF to develop and enhance feature sets in support of the scientific and collaborative activities surrounding LIGO. The NSF issued a three-year award on the basis of the collaborative merits of the proposed activities for enhancing the virtual collaborative network for LIGO science.

Recently, the use of EVO by the LSC has been extended to include educational and outreach venues as with the LaserFest [18] broadcast through the sinergy of the LSC remote participation committee, the EPO group and the EVO technologist.

Laserfest

In Fall 2010, over 700 students from schools across the U.S. participated in the LIGO LaserFest event. In a 50-minute EVOcast, LIGO scientists informed students from participating schools of the broad range of uses of lasers from every day devices they use, to LIGO's attempts to detect gravitational waves from astrophysical sources. Directly from the labs where frontier research is being conducted, students received a rare glimpse of remarkably sophisticated laser systems that are leveraging state-of-the-art quantum physics to probe the fundamental nature of space-time. The LIGO LaserFest event was centered around three live sessions on November 15, 2010 with interactive Q&A panel discussions with the audience, and a recorded webcast that was made available on stream for a few days after the live EVOcast. During the event, classrooms were "virtually transported" to the LIGO sites in Washington and Louisiana and to LIGO's MIT and Caltech labs. Here LIGO senior researchers and students explained to the audience how one of the most sophisticated laser systems in the world works. Six undergraduate LIGO students from the LIGO labs and Caltech participated to Q&A panels after the live sessions. LIGO LaserFest was received enthusiastically by teachers and students. Results of a follow-up survey to evaluate the effectiveness of the event show that over 90% of participating teachers would like to take part in future EVO-based educational programs which would expose students to multiple ways of gaining information and allow them to interact personally with scientists. "I hadn't experienced the EVO environment before," one teacher comment reads. "I think it is amazing to let kids see this window into collaborative science to help them realize just how much collaboration goes on in research." The partnership between LaserFest, LIGO and EVO has undoubtedly shown that science outreach in the classroom via EVO has the potential to dramatically increase student interest in physics and promote science among the youth.

Other EVO initiatives

In early 2011, a proposal was submitted to the American Physical Society to seek funding for outreach activities in schools with EVO. The proposal focused on the use of EVO to connect LSC scientists in the lab and students in participating high schools across the nation. The quality of EVO broadcasts, together with the system's adaptability to a wide range of working environments, reliability and low cost, allows direct interaction between scientists and learning environments that typically lack resources for ambitious e-learning activities. Proposed broader impacts were educating students to become successful scientists, promoting the growth of science in geographically and economic disadvantaged educational institutions, and help to enhance diversity within the tomorrow's scientific community. Unfortunately, the proposal was not funded. The LSC is currently seeking alternative sources of funding to support the proposal.

11.6 Einstein@Home

Einstein@Home (`http://www.einsteinathome.org`) is a volunteer distributed computing project: it uses computer time donated by computer owners all over the world to search for gravitational waves using data from LIGO and GEO600. It also searches for radio pulsars in binary systems, using data from the Arecibo Observatory in Puerto Rico.

The project was developed by Bruce Allen, the current director, and collaborators, and it was officially launched on 2005 as part of the American Physical Society's contribution to the World Year of Physics. Einstein@Home was based on SETI@Home, a similar program looking for signs of extraterrestrial life in radio data from the Arecibo Observatory. The pioneering developer of SETI@Home, David Anderson, is helping with Einstein@Home.

As of April 2011, over 293,000 volunteers in 219 countries have participated in Einstein@Home. The project is hosted by the University of Wisconsin-Milwaukee and the Max Planck Institute for Gravitational Physics (Albert Einstein Institute, Hannover, Germany) and runs on the Berkeley Open Infrastructure for Network Computing (BOINC) software platform. It is currently carrying out a search of data from the entire LIGO S5 run (S5GC1), using over 8000 hours of data and a search of archival radio data from the Parkes Multi-Beam Pulsar Survey (PMPS).

On August 2010, the Einstein@Home project announced their discovery of a new disrupted binary pulsar, PSR J2007+2722, in radio data from Arecibo; it appears to be the fastest-spinning such pulsar discovered to date. The computers of Einstein@Home volunteers from USA and Germany observed it with the highest statistical significance. On March 2011, the project announced their second discovery: binary pulsar PSR J1952+2630, observed with volunteers' computers from Russia and UK.

Participants in Einstein@Home can download software to their computers that receives data from a central server. The software processes gravitational wave data when not being used for other computer applications, like word processors or games. Then, the computers send the processed data back to the server and can get more to analyze. Einstein@Home does not affect the performance of computers and greatly speeds up this exciting research. Einstein@Home is available for Windows, GNU/Linux and Macintosh OS X platforms.

The project's website `http://einstein.phys.uwm.edu/` offers outreach opportunities through its message boards, especially "Cafe Einstein" and "Science" for discussing the project itself and physics in general.

11.7 Schools and Conferences

Since 2004 the Center for Gravitational Wave Astronomy (CGWA) located at the University of Texas at Brownsville (UTB) has hosted the Gravitational Wave Summer School at the university's facility

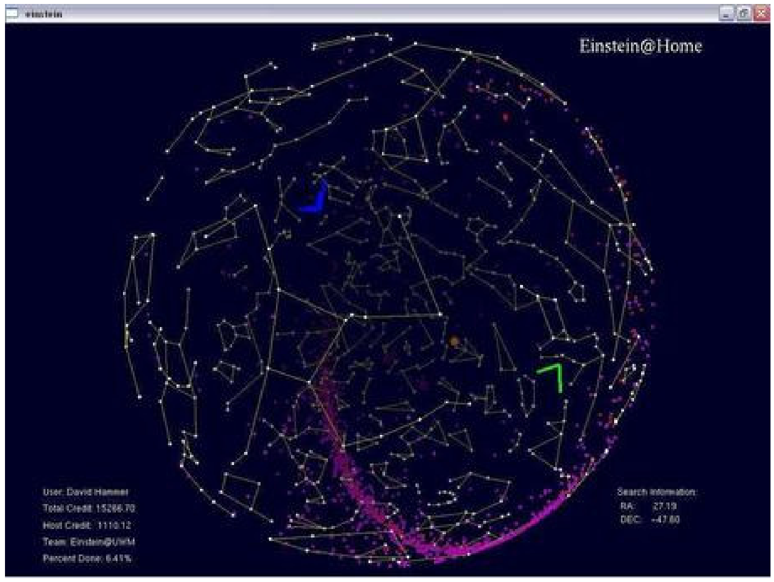


Figure 11.12: The Einstein@Home screensaver.

on South Padre Island, Texas. The two-week introduction to gravitational wave astronomy is designed for graduate students and upper level undergrads, and topics covered typically include an introduction to general relativity, astrophysics of gravitational wave sources, detector instrumentation, and data analysis. Over the past six years approximately 200 students from 22 different countries have participated in the Summer School. Instructors have included Curt Cutler (Max-Planck-Institut für Gravitationsphysik), Peter Saulson (Syracuse University), Bernd Bruegmann (Penn State), Scott Hughes (Massachusetts Institute of Technology), Cole Miller (University of Maryland), Miguel Alcubierre (Universidad Nacional Autónoma de México), Teviet Creighton (University of Texas at Brownsville), José Antonio González (Universidad Michoacana de San Nicolás de Hidalgo, Instituto de Física y Matemáticas), Peter Shawhan (University of Maryland), and Joe Romano (Cardiff and University of Texas at Brownsville). (The instructors' institutions are given for the time that they participated in the Summer School.) Scholarships are available for travel, accommodations and per diem expenses. The 7th Gravitational Wave Summer School will take place May 30-June 10, 2011.

In addition to the Gravitational Wave Astronomy Summer School CGWA faculty organized and taught three-week introductions to gravitational wave astronomy in China to graduate students during the summers of 2005-9. The co-directors of the summer programs were Rick Jenet of UTB and Qiu-He Peng of Nanjing University. For the summers 2005-9 the programs took place in the cities of Nanjing, Nanchong, Chengdu, Beijing, and Kunming respectively. Approximately 60 graduate students from throughout China attended each program. Instructors covered topics such as an introduction to general relativity, an introduction to gravitational wave signal detection methods, digital signal processing and signal detection theory, and gravitational wave detection using pulsar timing methods.

The LSC also participates in educational programs for high school students and teachers. The University of Texas at Brownsville hosts another annual summer school called Astronomy Ambassadors, so named because the students are expected to serve as ambassadors for science at their high schools. Though the school's topic can be somewhat broad (the 2009 school focused on "pulsar astron-

Figure 11.13: At the CGWA school.

omy"), the content includes lectures and research projects on gravitational astronomy and the LIGO experiment. LSC members at the University of Oregon have introduced gravitational-wave content into the QuarkNet workshop for high school teachers, including lectures, interferometer building, and LIGO seismic data analysis.

In the UK many postgraduate and undergraduate students working the various gravitational wave groups participate in the STEMNET Ambassadors scheme (see `http://www.stemnet.org.uk`). STEMNET creates opportunities to inspire young people in Science, Technology, Engineering and Mathematics (STEM) subjects; specifically the STEMNET Ambassadors scheme provides coordination and training to support outreach undertaken by students to schools in their local area. This can take the form of a single visit, to give a talk or lead a workshop discussion, or can be a series of visits in which the students develop a particular area of the school curriculum. In several UK universities Physics departments offer a credit bearing course for advanced undergraduates who will undertake an educational project via an extended series of visits to a local school, pairing each student with a local physics teacher.

In Scotland there have been significant recent developments in the design of the school syllabus across all subjects, with the introduction of the 'Curriculum for Excellence' (see `http://www.ltscotland.org.uk/`). This initiative aims to provide a coherent, more flexible and enriched curriculum for students aged 3 to 18, and in the sciences it aims to place much greater emphasis on methodology rather than specific knowledge. The new physics syllabus undertaken by high school students prior to graduation has been revamped with the goal of promoting: a deeper understanding of the physics; the development of problem solving and other generic skills; a greater emphasis on open-ended enquiry and an appreciation of topical research. The last category has created an excellent opportunity to showcase gravitational wave research. In 2010 Hendry (Glasgow) was invited to join the design team for the new high school physics curriculum and is developing in collaboration with Learning and Teaching Scotland formal educational materials on gravity, gravitational waves and cosmology. As part of these activities the Glasgow University group has hosted several teachers' workshops, in collaboration with the Institute of Physics in Scotland. The Cardiff University group has also carried out similar activities in promoting its STFC-funded multimedia schools lecture

"Gravity Beyond the Apple".

Recently gravitational-wave conferences have been devoting more attention to education and public outreach. The 8th Eduardo Amaldi Conference on Gravitational Waves, held in New York City, June 21-26, 2009, featured a parallel session devoted to the subject, along with an invited plenary talk by Fred Raab of LHO. The LSC-Virgo March 2011 meeting included a two-day EPO retreat with 35 attendees from more than twenty institutions.

Other notable conference contributions included:

- Marco Cavaglia of the University of Mississippi represented LSC outreach efforts at the 2008 Annual Meeting of the Astronomical Society of the Pacific in St. Louis, MO. He submitted a poster and proceedings note entitled "Gravitational-wave Astronomy: Opening a New Window on the Universe for Students, Educators and the Public," detailing the educational efforts at the LIGO observatories, collaborations with artists and musicians, and the Einstein@Home project.
- GEO collaborators contributed a LISA booth to the 213th American Astronomical Meeting in Long Beach, California, January 4-8, 2009, including a LISA satellite model and supporting material about gravitational-wave astronomy in general.

11.8 Student recruitment

A primary avenue for recruitment into the gravitational-wave community is the opportunity for undergraduate research. Many LSC members involve students in their research programs, particularly at undergraduate-only universities such as Carleton College or Trinity University. Some institutions, including Caltech, LSU, RIT, and the University of Florida, host Research Experiences for Undergraduates (REU) programs with support from the National Science Foundation. These programs will be described in detail in the next section. High school students can also be recruited through summer research experiences; at least four physics majors at the University of Texas at Brownsville credit their degree program choice to participation in UTB's Astronomy Ambassadors summer program.

Students can also be targeted at conferences that emphasize student participation. For example, the LSC was represented by an exhibitor's booth at the Sigma Pi Sigma Quadrennial Congress at the Fermi National Accelerator Laboratory in Batavia, IL, in November 2008. Over 600 students, alumni, and faculty attended this conference of the national physics honor society. Booth staffers included Tiffany Summerscales of Andrews University, Ilya Mandel of Northwestern University, and master's student Brooke Rankins from the University of Mississippi. And Marco Cavaglia contributed an exhibitor's booth at the Fall Joint Meeting of the National Society of Black Physicists and Hispanic Physicists and Physics Diversity Summit in Nashville, TN, November 11-13, 2008.

LSC members also attract student attention by including gravitational-wave astronomy and interferometry examples in their coursework, or introducing entirely new courses about the field. Yanbei Chen and Rana Adhikari at Caltech have developed "Ph 237: Gravitational Waves" as a two-semester web-based course, with the first semester focusing on sources and phenomenology, and the second semester covering gravitational-wave detectors. Course materials can be found at `http://www.pma.caltech.edu/~ph237/yr2008/`. Peter Saulson of Syracuse University includes LIGO technological examples in his sophomore-level "Vibrations, Waves, and Optics" course, while Zsolt Frei of Eotvos University includes four weeks of gravitational-wave lectures in his "Extragalactic Astrophysics" course. And Manuela Campanelli and Carlos Lousto have produced a publicly-available waveform catalog to make it easier for instructors everywhere to discuss gravitational-wave sources in the classroom; the catalog can be found at `http://ccrg.rit.edu/downloads/waveforms`.

11.9 REU Programs

The Research Experience for Undergraduates (REU) program of the National Science Foundation (NSF) was established to provide undergraduate students the opportunity to participate in summer research programs and to establish scientific contacts outside of their own department. It targets especially students from smaller colleges and minority students which often do not have the research possibilities that large research universities can provide to their students. Most REU awards are given to renowned national Universities to host between 10 and 20 students each summer. A few international REU (IREU) awards are given to Universities to send a similar number of students to large scale international research facilities such as CERN.

11.9.1 UF IREU on gravitational physics

Bernard Whiting and Guido Mueller (both from the University of Florida) operate the International REU in the field of Gravitational Physics as part of their commitment to the LIGO Science Collaboration and the international field of gravitational research in general. The goal of the IREUs adds an international component which allows the students to learn also about the growing internationalization of research and to establish scientific contacts beyond the borders of the United States.

Initial motivation and early history of the UF IREU

The UF IREU program was initially suggested by Beverly Berger (NSF) at the LSC meeting in Hannover in 2003 as a way to offer students and their advisors from smaller LSC institutions opportunities to collaborate with partners in Europe, Australia, and Japan. Guido Mueller then explored the possibility to send one student to work with Jim Hough and Sheila Rowan at the University of Glasgow and one student to work with Benno Willke and Maik Frede at the Albert Einstein Institute and the Laser Zentrum in Hannover. Both groups graciously accepted to host two students in the summer of 2004 and NSF funded this as part of a supplement to our main research grant. Both students were UF students and both research projects fitted nicely into our general research endeavor somewhat contrary to the motivation behind NSF's REU program as the UF group is hardly one of the smaller LSC institutions. However, it allowed us to gain experience with the organization such as required health insurance, housing, and potential visa issues without having to select students based on paper applications. For the following year, we worked together with David Blair (UWA/Gingin) and David McClelland (ANU) and sent again two UF-students and one student from Trinity University (Dennis Ugolini's group) to ANU and Gingin. This was again supported by a supplement to our research grant. After these two 'test-runs' Guido Mueller asked Bernard Whiting to join him in the organization and to finally submit a proposal for an official International REU site. This proposal was turned down and NSF supported again one UF student to work for Andreas Freise in Birmingham and one student from Embry-Riddle University (Andri Gretarsson's group) to go to Glasgow using supplemental funding to our research grants. Our second proposal was then approved.

The International REU

The International REU for Gravitation sent initially 3 students to Gingin, one student to Canberra and one student to Hannover. These students were all from smaller colleges such as Simmons College or California State University in Dominguez Hills or minority serving institutions such as the University of Puerto Rico. It was a particularly successful year in the sense that two of the students are now graduate students in Australia(!) and one student entered the graduate program at UF.

Starting in 2008, we also included the US-students which participate in the LIGO-VIRGO undergraduate student exchange program. This program was independently started by Riccardo DeSalvo (California Institute of Technology). However, as most of the organizational tasks and problems for sending US-students to VIRGO are identical to the problems we face sending students to our initial LSC partners abroad, it was reasonable to combine these parts of both programs; Riccardo is still managing the Italian students visiting the US. This, the fact that the costs per student are actually lower than initially expected, and that we were always able to find hosts allowed us to accept 12(!) students in 2008 and 15(!) in 2009.

Although every application will be looked at individually, we have a strong preference for applications from within the LSC and so far we have never turned down any application from within the LSC if it was submitted in time (best before the holidays start in December) and supported by an LSC member. However, the number of applications from within the LSC is always around 3-5 and most students are not connected to the LSC or any other gravitational research program such as LISA. As with all REUs, NSF urges us to select minority and female students as well as students from smaller colleges first before accepting applications from majority students from major research universities. The fact that many of our students are still majority students from places such as Princeton or the University of Southern California shows that we still need more help to recruit students which fit our preferred profile. It might be argued that this gives us a chance to attract highly talented students to our specific field of research; however, the yield among these students is very very low. It is simply not working as well as hoped.

At this point we would like to thank all our hosts for their willingness to provide research opportunities, organize housing, and their patience working with us and the students to make all this work. I also want to point out that we have many more hosts now than we have funding for students or timely applications. We occasionally hear complaints that our deadline is too early and we should move it back into February, the typical deadline for other national REUs. However, the organization of hosts, projects, housing, visas, the briefing meeting at UF, and many other little things for an international REU with many different hosts spread across the entire globe requires much more time initially (and much less later over the summer).

Tables 11.1 and 11.2 show the various hosts and home institutions of the students in the years 2007-10. The entire program including application procedures and schedules can be found at `http://www.phys.ufl.edu/ireu`. The website also contains links to past projects and many pictures taken by the students during their IREU experience.

11.9.2 RIT REU program

The Computer Science (CS) Department at RIT has an active REU grant. Summer 2010 was the second year of the three year REU at Rochester Institute of Technology (NSF Grant No. 085174). Over the summer, computer science faculty at RIT conducted research with 12 undergraduate students. In scientific computing, the ability to create effective visualizations is vital as it leads to a

	International Host	Home Institution
2007	Gingin/UWA	Simmons College San Jose State University Cal. St. Uni., Dominguez Hills
	ANU Canberra	Andrews University
	AEI Hannover	University of Puerto Rico

	International Host	Home Institution
2008	University of Sannio	Rice University
	VIRGO, Cascina	University of Southern Cal. University of Rochester University of Virginia
	Cardiff University	Duke University Rochester Inst. Of Tech.
	AEI Hannover	University of Florida Trinity University
	NAOJ, Tokyo	Penn State University Southeastern Louisiana U.
	University of Glasgow	Embry Riddle University Southeastern Louisiana U.

	International Host	Home Institution
2009	University of Paris	Princeton University
	Naples	New College of Florida Bucknell University
	Cardiff	Reed College Univ. of Cal. Berkeley
	AEI Hannover	University of Florida University of Illinois University of Notre Dame
	Glasgow	University of Wisconsin Indiana University
	Birmingham	University of Rochester
	VIRGO, Cascina	University of Illinois Wesleyan University Eastern Kentucky University
	ANU	University of Massachusetts
	Benevento	University of Evansville

Table 11.1: 2007-09 hosts and home institutions of the UF IREU

	International Host	Home Institution
	University of Perugia	Rhodes University
		U of Florida
	University of Trento	Texas A&M
		Valdosta State U., GA
	Cardiff	Rutgers
		U of Oregon
2010	Glasgow	Bryn Mawr
	Hanover	UMass
		Dickinson College
	Adelaide	Haverford College
	Amsterdam	U of Arizona
	Tokyo	Berkeley
		Tufts University
	VIRGO	Carleton College

	International Host	Home Institution
	La Sapienza, Rome	LSU (x 2)
	Glasgow	Embry-Riddle, Prescott, AZ
		Saint Vincent College, Latrobe, PA
	Seoul National University	CalState Fullerton
		U of Florida
	Hannover	MIT
2011	Birmingham	DePauw University
		U of Louisville, KY
	VIRGO	Carleton College
	Trento/Padua	Embry-Riddle, Prescott, AZ
	Amsterdam	Indiana University
	APC, Paris	Kenyon College
		UMass Amherst
	Adelaide	U of Florida

Table 11.2: 2010-11 hosts and home institutions of the UF IREU

greater understanding of the data under scrutiny. Spiegel is a distributed visualization framework designed to handle extremely large multi-dimensional data sets. Spiegel was developed using the Java programming language, and follows the Unix pipeline model which allows the system to be easily extended. A visualization program in Spiegel comprises a set of simple components that are connected together through communication endpoints. Each component performs some specific task such as reading data, data, filtering data to extract or compute certain attributes, or creating a visual representation of the data. Figure 11.14 depicts the basic Spiegel program structure. The extractor accepts a file or data handle and sends requests to one or more distributed file servers. The extractor then accepts and pre-processes the data stream (if necessary) and sends the result to the visualization component(s) where further computation is performed to create some visual and/or audio representation of the data which can then be sent to video/audio output devices. The Spiegel framework provides two primary avenues for student research:

- Security and efficiency of communication and data transfer between distributed file systems and components.
- Creating effective visualizations of large multi-dimensional data sets.

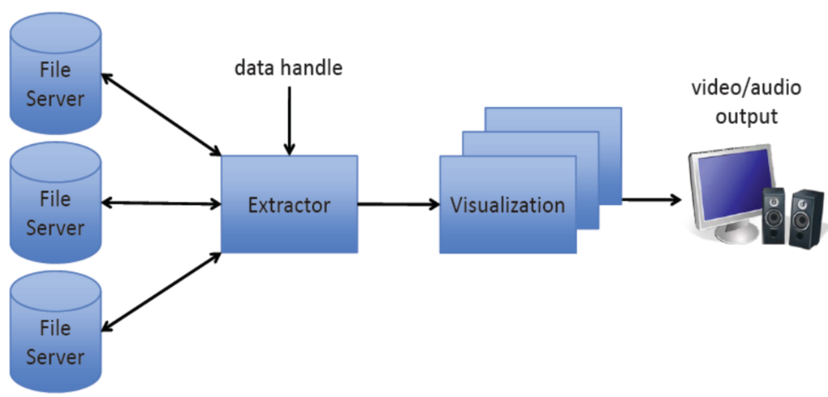


Figure 11.14: Overview of the Spiegel framework.

Student projects

High Performance File Systems

Simulations of galactic phenomena such as colliding black holes that produce gravitational waves can result in terabytes of data. To access, retrieve, and process such large amounts of data rapidly and securely requires efficient high performance file systems such as Hadoop, Google File System, and PVFS. Four students (three supported by this REU project, assisted by another student who was supported by a different grant) worked on this project to develop a software system that conducts rapid image identification and categorization for galaxy data. The project approach can be viewed as an automated GalaxyZoo, which is an online project that relies on input from the general public to classify images of over 60 million galaxies. The students implemented the system using the Hadoop distributed file system on commodity hardware. The system supports rapid image categorization using computer vision techniques and MapReduce on a cluster of computers.

Visualization Using RenderMen

Traditionally, the Spiegel framework used Java3D or JOGL to create the final rendered images. These libraries rely on a fixed pipeline approach and are unable to create the eye-catching visuals that are commonplace in movies. One of the best-known systems to create images is Pixar's RenderMan. During the 2009 summer REU program, students extended the Spiegel system to support RenderMan. In 2010, three students worked to emulate existing astronomical imagery such as images captured by the Hubble Space Telescope. In order to accomplish this they developed techniques for rendering individual stars and also took into account factors such as galaxy density. The students submitted the results of their research to an international conference. It was accepted as a poster: Paul Cassidy, Tyler Kilburn, Vincent Salemink, Hans-Peter Bischof, and Reynold Bailey, *Improving the Visualization of Galactic Events using Pixar's RenderMan,* 19th International Conference on Computer Graphics, Visualization and Computer Vision 2011, to appear. Paul Cassidy presented the poster at the conference in February 2011.

User Perception

From a visualization perspective, it is crucial to understand whether the simulations created are scientifically meaningful and relevant to the professionals in the field. Three students conducted research to investigate the differences in the way that experts and novices look at galactic simulations. By extracting fixations from an eye-tracking device they determined what aspects of the data the astrophysicists consider more important. Using this information they were able to create customized visualizations which were more relevant to professionals. Their research resulted in the following conference paper: Janelle Arita, Jenniffer Feliz, Dennis Rodriguez, Hans-Peter Bischof, Manjeet Rege, and Reynold Bailey, *Creating Audience Specific Galactic Simulations Using Eye-Tracking Technology.* International Conference on Information Visualization Theory and Applications, 2011. Dennis Rodriguez presented the paper at the conference in March 2011.

Gesture-based Interfaces

The traditional keyboard and mouse computer interface is well suited for 2D applications such as document editing, but as 3D environments become more prevalent there arises a need for new methods of user input. An immersive 3D interface is preferable, but is often cost prohibitive. Four students conducted research to develop a Natural User Interface (NUI), named NuWii for the Spiegel system. The interface makes use of Nintendo Wii Remotes as infrared tracking cameras to detect 3D gestures made by the user. These gestures are interpreted and used to control the viewing camera's parameters throughout the course of a visualization. Their research resulted in the following conference paper: Amy Ciavolino, Camille Marvin, Jason Creighton, James Coddington, Hans-Peter Bischof, and Reynold Bailey, *Toward Affordable Gesture Based Interfaces: An Exploration with Wii Remotes*. International Conference on Information Visualization Theory and Applications, 2011, under review. Jason Creighton presented the paper at the conference in March 2011.

Products

The following papers and posters (refereed publications) are either accepted or currently under review as the products of this year's REU program:

- Paul Cassidy, Tyler Kilburn, Vincent Salemink, Hans-Peter Bischof, and Reynold Bailey, *Improving the Visualization of Galactic Events using Pixar's RenderMan,* 19th International Conference on Computer Graphics, Visualization and Computer Vision 2011, to appear. [Poster]
- Janelle Arita, Jenniffer Feliz, Dennis Rodriguez, Hans-Peter Bischof, Manjeet Rege, and Reynold Bailey, *Creating Audience Specific Galactic Simulations Using Eye-Tracking Technology.* International Conference on Information Visualization Theory and Applications, 2011.
- Amy Ciavolino, Camille Marvin, Jason Creighton, James Coddington, Hans-Peter Bischof, and Reynold Bailey, *Toward Affordable Gesture Based Interfaces: An Exploration with Wii Remotes.* International Conference on Information Visualization Theory and Applications, 2011.

Some of the REU program products last year were available this year:

- Reynold Bailey (Moderator), Guy-Alain Amoussou, Tiffany Barnes, Hans-Peter Bischof, and Tom Naps, *Relevant Real-World Undergraduate Research Problems: Lessons from the NSF-REU Trenches,* 41st ACM Technical Symposium on Computer Science Education. [Panel at SIGCSE 2010]

11.9.3 Caltech REU Program

Since 1997, Caltech has hosted the Undergraduate Research at LIGO REU program. Each year around 30 undergraduates (including several international students) participate in 10-week research projects at either Caltech or one of the LIGO observatories. Topics for 2011 research projects include:

- Vibration isolation test of a mirror suspension for the prototype interferometer gravitational wave detector
- Optical gyroscopes for the LIGO gravitational wave detectors
- Prototyping adaptive feed-forward seismic noise cancellation at the 40-meter interferometer
- Crackling upconversion in leaf springs
- Ultra-stable Fabry-Perot cavities for laser frequency stabilization
- Implementing digital control for quad-maglev suspension
- Studying quantum noise in advanced gravitational-wave detectors
- Gravitational-wave memory for spinning, inspiralling compact binaries
- Gravitational radiation in scalar-tensor theory
- Diagnosis of the 40m prototype interferometer with auxiliary laser-beam injection
- Modeling the Advanced LIGO response to gravitational waves and calibration

- Exploration of the latest numerical-relativity-inspired waveforms from compact binary system inspiral, merger, and ringdown
- Optimal strategies for electromagnetic follow-up of gravitational wave candidates
- Real-time decisions for gravitational wave detection
- Identifying correlated detector noise contaminating search for stochastic gravitational-wave backgrounds
- High performance computing and the search for periodic gravitational waves
- A new magnetar gravitational-wave search: GW stacking using timing information from electromagnetic light curves
- Site selection for third generation detectors
- Tests of Einstein gravity: counting polarizations
- Properties of neutron stars, their pulsational modes, and gravitational wave emission
- Vetoes for gravitational-wave transients using instrumental coupling models
- Constraining parity violation in the propagation of gravitational waves from spinning neutron stars
- Extracting information about the central engine of core collapse supernovae using gravitational wave signals
- Characterization of a squeezed-light source
- Characterization and commissioning of Advanced LIGO systems
- Investigating gravitational waves from the ringdown of accreting black holes
- Optical follower feedback control loop for the photon calibrator
- Development of interferometric techniques for advanced gravitational wave detectors

Further information about the Caltech REU can be found at: `http://www.ligo.caltech.edu/LIGO_web/students/undergrads.html`

11.9.4 LSU REU Program

Louisiana State University has an REU program funded through 2012. The program spans all of the research fields in physics and astronomy pursued at LSU, and includes a project in LIGO and gravitation, sponsored by Gabriela Gonzalez, Jorge Pullin, Parampreet Singh, and Peter Diener:

> "An REU student will participate in activities involving the calibration and characterization of the LIGO data stream, as well as contributing to the search for gravitational waves hiding in the noise. The student will be able to visit and do some of their work at the LIGO Livingston Observatory, 30 miles from the LSU campus. Another possible

project is simulating black holes and supernova explosions on Louisiana's and the nation's fastest supercomputers, helping to analyze and visualize simulation results to determine their visibility in gravitational, electromagnetic, and neutrino detectors."

Further information about the LSU REU can be found at http://www.phys.lsu.edu/newwebsite/undergraduate/reu_program/.

11.10 Diversity programs

A philosophical tenet of both the LIGO Laboratories and the LSC is that increasing the diversity of the constituency "will promote a diversity of new ideas and approaches to the scientific, technical, management and administrative challenges we face." [29] The LIGO community is actively seeking to broaden its membership not only in the terms of ethnicity, race and gender, but to include "people with disabilities, different sexual orientations, different languages, different academic training, different economic circumstances and different backgrounds." The LIGO community's diversity initiative incorporates the policies of CalTech [2], MIT [3], and the NSF [24]. The LIGO Laboratory Diversity Plan notes that increasing the diversity of scientific professionals can most likely be addressed by increasing science, technology, engineering, and mathematics (STEM) career awareness in K-12 students. The LIGO directorate and individual LSC members have taken steps to broaden the participation of students at all levels of educational attainment. These efforts will be discussed in this section of this white paper.

11.10.1 The LIGO Laboratory diversity plan

Fred Raab is the LIGO Laboratory Diversity Officer and chair of the 12-member LIGO Laboratory Diversity Committee [7], and reports directly to the LIGO Directorate. The LIGO Laboratory Diversity Plan [29] is available to LSC members. Key points of the plan are noted here:

- All members of the LIGO community have a responsibility to encourage diversity.
- Instruments have been developed to track or estimate LIGO community demographics and LIGO outreach audience demographics (LSC demographic information is available to LSC members at https://my.ligo.org/myinfo.php?do=demo_report)
- A concerted effort will be made to recruit at conferences and meetings that traditionally have a higher concentration of underrepresented groups. Additionally, the establishment of networking channels to reach underrepresented groups is encouraged.
- An atmosphere that promotes inclusion will be established at the LIGO labs.
- The LIGO labs are active in reaching out to their respective local communities, each of which is comprised of populations that have been historically underrepresented in the STEM's fields.

LSC EPO Diversity Committee

The LSC EPO Diversity Committee was formed in 2009 with the purpose of increasing the demographics of under-represented groups in the LSC, assess current status of diversity initiatives, and help in the expansion of current programs and the creation of new ones. The LSC EPO Diversity

Committee interacts closely with the LIGO Lab Diversity Committee, chaired by Fred Raab, for the development of diversity initiatives within the collaboration. A survey is currently being developed to establish member perceptions of the climate within the LSC due to other people's demographics (ethnicity, gender, sexual identity, disability, . . .) and acquire and record information about diversity programs among the LSC member institutions.

11.10.2 Diversity initiatives from LSC member institutions

University of Western Australia and Gravity Discovery Centre

The University of Western Australia and the Gravity Discovery Centre (GDC) are collaborating with the Graham (Polly) Farmer Foundation to develop programs designed to be particularly relevant to multicultural audiences with special reference to Australian indigenous students. The G(P)FF is a foundation that specializes in providing opportunities and support for Australian indigenous students. The project is part of the Science Education Enrichment Project which is described at the website `http://www.seeproject.org.au/` The diversity component is one of three main foci as quoted below from the web site: *"Many science centres in Australia provide science enrichment that supports and complements formal science education in schools. This project will examine impacts of science enrichment programs associated with the Gravity Discovery Centre. There are three main foci of research:*

A) *Does involving students in original research have a positive influence on their attitudes towards science and choice of studies?*

B) *Can science center activities correct common physics misconceptions?*

C) *Can use of narrative and digital storytelling build bridges that assist multicultural students to navigate between their culture and western science?*

Academics interested in promoting and enhancing science education (David Blair, Grady Venville, David Coward, Nancy Longnecker from the University of Western Australia, Marjan Zadnik from Curtin University and Martin Hendry at the University of Glasgow) have joined forces with G(P)FF and the GDC Foundation to undertake an in-depth study of the effectiveness of schools' science enrichment programs. The GDC and the Gingin Gravitational Wave Research facility makes it possible to offer three types of science enrichment, one especially designed for indigenous students and those without positive attitudes toward science. The second provides challenging modules, some of which focus specifically on modern concepts of space, time and gravity, including Einstein's theories and the search for gravitational waves. The third enrichment program allows students to take part in real research and offers the possibility of real discoveries, using UWA's large new robotic telescope – the Zadko Telescope.

The motivation of the project is the current science teacher shortage in secondary schools. Many specialist facilities and programs have been set up to provide science enrichment programs. All aim to help reverse the decline of students taking science and at reversing the declining attitudes towards science in schools. Our proposition is that:

a) Specialized enrichment programs stimulate teachers as well as students and can lead to a positive change in student attitudes toward science;

b) Creating positive attitudes toward science in schools is a critical factor in students' career aspirations;

c) Students can be engaged and motivated through exposure to real science and scientific endeavor;

d) For some students, particularly from disadvantaged and indigenous backgrounds, a narrative approach to science can motive and engage them in science.

The SEE project research program aims to test these propositions, through 4 Ph. D. projects, each working with different selected student groups of different ages and different cultural backgrounds.

The University of Mississippi

The University of Mississippi group is attempting to start a program to encourage more women and minorities to enter physics careers by using role models. UMiss' program will focus on visits of LSC women and minority scientists to Mississippi's schools and colleges which generally have limited or no resources to sustain such activities, but where there could be many young students interested in science. In addition to delivering a lecture, the speaker will spend significant time interacting with a reasonably large audience of students. Interested students will then be invited for "hands-on" summer science internships at the University of Mississippi. Preference will be given to students from diverse groups or from a disadvantaged educational background.

The University of Texas at Brownsville

The city of Brownsville is located in South Texas along the border with Mexico. The population of the region is more than 90% Hispanic, so most of the outreach efforts are aimed at Hispanic students. Specific outreach activities supporting the goals of the LIGO Diversity Plan are noted here:

- *Bilingual Presentations.* A significant portion of the population has limited proficiency in English, so it is often necessary to address groups in Spanish, or to give presentations in English and Spanish. Specifically, the Physics Circus, a presentation of physics demonstrations and media clips has been presented in Spanish as required.

- *Girl Scout Activities.* Department personnel helped groups of Girl Scouts earn their science badges, and arranged interactive sessions with the girls and women scientists.

- *Scholarships and retention efforts.* Local students who will major in physics have the opportunity to earn competitive scholarships which will provide support for tuition and books, as well as stipends. The students immediately begin to work with faculty on research projects, and a support network is established to foster the students' progress.

Astrophysics and Dance - Engaging Deaf, Hard-of-Hearing, and Hearing Individuals in Science Education

Bischof and Campanelli (PI) of the Center for Computational Relativity and Gravitation (CCRG), in collaboration with faculty of the RIT's National Institute for the Deaf at RIT, have submitted an NSF Communicating Research to Public Audiences (CRPA) in April 2011. The project, entitled "Astrophysics and Dance - Engaging Deaf, Hard-of-Hearing, and Hearing Individuals in Science Education" will leverage the experience and talents of researchers, scientists, artists and educators to bring the excitement of cutting-edge scientific research on gravitational wave astrophysics to an audience consisting of deaf and hard-of-hearing children and adults and members of the general public. Our goal is to create an original dance and theatrical performance, free and open to a highly diverse audience, which will stimulate learning among all audience members, including deaf and hard-of-hearing individuals. The performance will provide all audience members with access to the most modern concepts from physics and astrophysics and generally enhance their interest in STEM (Science, Technology, Engineering and Mathematics) fields.

11.11 Deliverables

Keith Riles and Ramon Armen of the University of Michigan developed a permanent interferometry exhibit for the Ann Arbor Hands-On Museum in Ann Arbor, MI. The supporting educational materials include a flash player demonstration covering gravitational waves, interferometry, and LIGO. The completed interferometer was prominently mentioned by Exhibit Director John Bowditch in the museum's 2008 annual report. Keith Riles now serves on the museum's Board of Trustees, and has received positive feedback on developing more LIGO-related materials. The exhibit served as a model in developing the traveling interferometer kiosk for the 2009 and 2010 World Science Festivals. Members of the GEO 600 collaboration contributed another interferometry exhibit to the Royal Society 2008 Summer Science Exhibition. Entitled "Can you hear black holes collide?," the exhibit included a hands-on interferometer, the "Black Hole Hunter" computer game, mobile phone ringtones of gravitational waveforms, and a movie on gravitational-wave astronomy.

LSC members also contribute software deliverables, in the forms of games, digital videos and animations.

The *Black Hole Hunter* game mentioned above [14] allows people to search for gravitational wave signals of two black holes colliding in static noise streams. The Black Hole Hunter game was developed as a part of the Royal Society 2008 Summer Exhibition by Cardiff University, the Universities of Birmingham, Glasgow and Southampton in collaboration with the Albert Einstein Institute and Milde Marketing in Germany. Players of *Space Time Quest* are principal investigators of an interferometric gravitational wave observatory [17]. They can select the location for their detector and design it to fit within the budget of their project. At the end of the game, players can turn on their detector and look for gravitational waves. The deeper into space they can detect gravitational waves, the higher their score. *Black Hole Pong* [16] is a new take on the classic game "Pong" where players use black holes instead of paddles to move and sling a mass into their opponent's half of the screen. Every time the mass enters the opponent's space, one point is scored. Space Time Quest and Black Hole Pong were developed by the gwoptics group at the University of Birmingham in UK. The goal of the *Slingshot* strategy game, [8], is to shoot the opponent's spacecraft on the opposite side of the screen. Planets in between players warp space-time and gravitationally attract projectiles, deflecting them from a straight path. (The game name "Slingshot" refers to the fact that stars, planets and moons can be used as a gravitational slingshot to speed up spacecrafts or other masses.) Slingshot was developed by RIT.

The GEO 600 collaboration worked with Milde Marketing to produce a series of video interviews on black holes, which are currently hosted at `http://www.scienceface.org`. David Blair (UWA/Gingin) and SiVIDEO Television Production Services produced the six-minute video "LIGO-Australia: Discovering the Dark Side of the Universe" which is freely available on the AIGO Project webpage `http://www.aigo.org.au` and YouTube [28]. Cinema definition copies are available in DVD format. The Video was sponsored by STM Duraduct, a stainless stell vacuum pipe manufacturer interested in the AIGO project. The full video of the LIGO-sponsored signature event at the 2010 World Science Festival featuring Marcia Bartusiak, Laura Danly, Andrea Lommen, Kip Thorne and

Rai Weiss is freely available at the World Science Festival website [27]. Per signed MOU with the World Science Festival, a reasonable number of video clips can be used by the LSC for outreach purposes.

The collaboration also produced high-quality animations of a black hole merger for their Royal Society Summer Science Exhibition entry; these animations are now hosted in the Albert Einstein Institute multimedia archive at `http://numrel.aei.mpg.de/Visualisations/`. Another visualization outreach effort comes from the Center for Computational Relativity and Gravitation at the Rochester Institute of Technology. Their download archive at `http://ccrg.rit.edu/downloads` includes black hole merger waveforms generated by Manuela Campanelli, Carlos Lousto, and Yosef Zlochower, with accompanying animated movies created by Hans-Peter Bischof.

Shaun Hooper from UWA created a musical composition: *The Black Hole Orchestra* which combines many sounds from pulsars, CBC sources, bar mode spindowns and black hole normal modes in a short appealing composition suitable for public lectures and freely available from `http://www.aigo.org.au`.

11.12 Relationship to other existing outreach programs

AIGO's Gravity Discovery Centre

The Gravity Discovery Centre (GDC), operated by the GDC Foundation is an independent non-profit facility set up at the instigation of the WA Government to provide education resources to complement the Australian International Gravitational Observatory (AIGO) Research Centre at a location 80km north of Perth CBD. It was set up through a major fundraising process that led to a total investment of more than $10M.

The GDC was designed to be a learning center that focussed on modern physics, astronomy and biodiversity. It was funded mainly through private sector donations. In parallel with the development of the buildings and exhibitions the GDC Foundation worked with a group of talented and dedicated school teachers to develop education programs linked to exhibits. Stage 1 of the GDC was opened in 2003 and Stage II in 2008. It is now a large scale facility containing more than 2000 square meters of exhibits, displays and educational resources. It is located beside the AIGO Research Facility where up to 20 research personnel conduct large scale experiments with high power lasers, all related to the discovery of gravitational waves, a new spectrum of radiation expected to allow humanity to listen to the gravitational "sounds" of black holes and the big bang.

The facilities of the GDC include a large public astronomy center (Gingin Observatory), the new state of the art robotic Zadko telescope owned by UWA, a 20m pendulum tower, a 1km scale model of the solar system, the Leaning Tower of Gingin, (a 45m steel tower for students to do free fall experiments), and research laboratories available for student visits. The main GDC buildings include four large scale galleries

1. The Discovery Gallery: discovering gravity, and the other fundamental forces of the universe, the links between space and time, and the links between time and gravity.

2. The Innovation Gallery: examples of local innovations and inventions: displays organised in cooperation with local high technology businesses.

3. The Cosmology Gallery: exhibitions on the origin of the universe including a 60m timeline of the universe from the big bang to life on earth, including exhibits of meteorites, minerals and

fossils and also including cultural cosmology with large scale artworks depicting creation stories from indigenous culture and world religions.

4. The Biodiversity Gallery which focuses on the unique and extraordinary diversity and specialisations of plants and invertebrates on the 50km^2 pristine bushland of the GDC.

The GDC currently has 20,000 visitors per annum, half of which are school groups from WA and SE Asia, who undertake curriculum related enrichment programs. The GDC is unique and innovative. It combines art with science, real research with learning modules linked to large scale facilities such as the Leaning Tower and the Pendulum Tower, and cosmology linked to astronomy, geology, paleontology and traditional cultural beliefs. The founders of the GDC won the Prime Minister's Eureka Prize for Promoting Science. It was written up in Nature July 10, 2008.

Recent initiatives from UWA and the Gravity Discovery Centre

John and Robin DeLaeter Scholarship Program

In 2010 the GDC raised funds by public subscription, in honour of John and Robin DeLaeter, to set up a new scholarship program with view to motivating young people by involving young people in the creation of promotional and educational products at the GDC. The first two scholarships were awarded in November 2010, leading to very exciting video products, one a youtube type movie about curved space created by a 16 year old high school student and a professional level movie about impacts by a postgraduate student. Two scholarships will be awarded annually.

Movie about LIGO-Australia

In 2010 the UWA group organised the creation of the move "Discovering the Dark Side of the Universe with LIGO-Australia". (See section on deliverables for more details.)

Internship Program

The UWA group has continued its very successful internship program, with groups of international students undertaking 3-6 month projects at Gingin. All students are also expected to participate in EPO activities at the GDC, acting as tour guides and offering lab tours to small groups of public visitors and school groups. Four students from India, two from China and one from France participated in the program in 2010. Two students from India and two from France participated in 2011.

Gravity Discovery Centre Funding

In 2011 the West Australian Government announced four year funding for the GDC. to supplement the 50% of budget coming from entry fees and shop sales.

Friends of the Gravity Discovery Centre

In 2010 a voluntary support organisation for the GDC was formed called the "Friends of the Gravity Discovery Centre Inc." The organisation works actively with the GDC Foundation to promote the case for a long baseline detector at Gingin. In 2010-11 the FGDC organised two well attended public lectures by Stan Whitcomb and David Blair about LIGO-Australia.

Other Outreach Activities

The GDC is actively involved in developing educational material on the general theme of Einsteinian Physics suited for the new National Secondary School Curriculum, and offers teacher professional development in this area.

Relation to Existing NASA Astrophysics E/PO programs

NASA has many astrophysics missions that have extensive Education and Public outreach programs that create materials and resources explaining many of the processes that emit electromagnetic radiation from objects that are natural scientific targets for LIGO. These targets include supernovae, gamma-ray bursts, neutron star pulsars and black holes. Several of these NASA missions have E/PO programs led by Lynn Cominsky at Sonoma State University (SSU), who has joined the LSC EPO effort in 2011. The SSU-led missions include: XMM-Newton (a focusing soft X-ray telescope, launched by ESA in 1999), the Swift gamma-ray burst explorer (launched by NASA in 2004), the Fermi Gamma-ray Space Telescope (launched by NASA in 2008), and the upcoming Nuclear Spectroscopic Telescope Array (NuSTAR) mission, to be launched by NASA in 2012.

The SSU E/PO group has developed educational materials for these missions which can be used by LSC members for teacher professional development, student activities, and informal audiences. All formal educational materials have been approved by NASA Education Product Review, and are available in 508-compliant downloads, as well as in hard copy (by email request to lynnc@universe.sonoma.edu).

Formal educational materials include;

- *Active Galaxies* (grades 9-12, 2002, revised and reprinted in 2011) This guide accompanies an educational wallsheet that uses Active Galaxies as an engagement to each selected topics in physical science and mathematics. It was developed as part of the Fermi E/PO program. The AGN Educator Guide features three curriculum enhancement activities, background information, assessment information, student worksheets, extension and transfer activities, and detailed information about the physical science and mathematics content standards. Download from `http://fermi.sonoma.edu/teachers/agn.php`
- *Gamma-ray Bursts* (grades 9-12, 2004) This guide accompanies an educational wallsheet that uses Gamma-ray Bursts as an engagement to teach selected topics in physical science and mathematics. It was developed as part of the Swift E/PO program. The GRB Educator Guide features four curriculum enhancement activities, background information, assessment information, student worksheets, extension and transfer activities, and detailed information about the physical science and mathematics content standards. Download from `http://swift.sonoma.edu/education/index.html`
- *Dying Stars and the Birth of the Elements* (grades 9-14, 2005) - developed with Project CLEA, Gettysburg College. This interactive computer-based laboratory simulates the observation of a supernova remnant using an imaging X-ray telescope. It was developed as part of the XMM-Newton E/PO program. Students explore the effects of changing the abundances of elements on the emergent x-ray spectrum, to try to match the observed data. Teacher and student manuals are provided, including background information, assessment information and detailed standards information. Download from: `http://xmm.sonoma.edu/edu/clea/index.html`
- *Newton's Laws of Motion and Gravitation Educational Wallsheet Set* (grades 6-8, 2007) This is a set of 4 posters depicting and explaining Newton's laws of motion and gravitation that were developed as part of the Swift E/PO program. A set of classroom activities accompanies each poster. The activities were created to complement each other as an overall unit, whether in science or math. Download from `http://swift.sonoma.edu/education/index.html`

- *Supernovae* (grades 9-12, 2008). This guide is distributed on a CD, and uses Supernovae as an engagement to teach selected topics in physical science and mathematics. It was developed as part of the XMM-Newton and Fermi E/PO programs. The Supernova Educator Guide features four curriculum enhancement activities, background information, assessment information, extension and transfer activities, and detailed information about the physical science and mathematics content standards. The CD also contains a computerized version of one of the activities "Crawl of the Crab" and open source software to analyze historical images of the expanding nebula. Download from `http://xmm.sonoma.edu/edu/supernova/index.html`

Informal educational materials include:

- *Black Holes Fact Sheet* (2006, reprinted in 2009) This illustrated fact sheet answers eight of the most commonly asked questions about black holes, and was created to distribute with the Black Hole planetarium show. It also highlights observations by the Fermi Gamma-ray Space Telescope. The original version (featuring a future satellite concept called EXIST) is also available in Spanish.

- *Active Galaxies Pop-up Book* (grades 3-8, 2006) The Active Galaxies pop-up book is a very large rectangular pop-up book with foldouts that was developed for use in classrooms for grades 3 and up and for special needs audiences. Active galaxies, a major scientific target for the Fermi mission, contain super-massive black holes at their cores, and sometimes emit jets of particles and light. When opened, a model of an active galaxy with jets pops up out of the center. One foldout contains explanatory information for the parts of the galaxy depicted in the central pop-up as well as a glossary, while the other contains a well-tested classroom activity "Tasty Active Galaxy." The back of the book features a whimsical cartoon story "How the Galaxy Got Its Jets." It is accompanied by an educator's guide for use in the classroom which can be downloaded from: `http://fermi.sonoma.edu/teachers/popup.php`

- *Space Mysteries* (2001 - 2010) `http://mystery.sonoma.edu` Space Mysteries are a series of inquiry-driven interactive Web explorations, which take advantage of the student's natural curiosity to build critical thinking and analytical skills. The mysteries include Alien Bandstand, Live From 2-Alpha, Star Market, Solar Supernova? and Galactic Doom?. Each Mystery has been constructed to teach at least one of the important physical science standards (e.g., conservation of energy, motion, or forces), and is accompanied by materials to be used by the classroom teachers. The original three mysteries feature videos with character actors. The more recent two mysteries use Flash. Solar Supernova? was released in 2007 and Galactic Doom? was released in 2010. Of particular interest to LIGO audiences are: Alien Bandstand, Live from 2-Alpha, and Solar Supernova?

- *Gamma-ray Burst Skymap website* (2004 - present) `http://grb.sonoma.edu` The Gamma-ray Burst Skymap website automatically updates for each gamma-ray burst as it occurs, whether detected by Swift, Fermi or other orbiting satellites. For each burst, the location on the sky, starmap, constellation and detecting mission are generated automatically. It is then quickly updated by hand to include a written description of the burst properties and scientific significance, as observations continue. An iPhone application using the GRB skymap database is under construction in 2011.

- *Epo's Chronicles* (2008 - present) http://eposchronicles.org Join Epo, a sentient spaceship and its humanoid companion, Alkina, in this weekly webcomic as they explore the galaxy and try to discover their origins. Each weekly "eposode" is accompanied by links to resources, multi-media and scientific background information, and is translated into Spanish, Italian and French. Recently Epo's Chronicles featured two weekly "eposodes" about LIGO.

Major outreach products developed by the SSU E/PO group include:

- *Black Holes: The Other Side of Infinity* (2006). This full-dome digital planetarium show was directed by Tom Lucas, with seed funding from Fermi E/PO, primary funding from the National Science Foundation, and in association with the PBS science series NOVA. Prof. Cominsky was one of two science directors for the show which premiered 1/31/06 at the Denver Museum of Nature and Science. Narrated by actor Liam Neeson, this show provides a groundbreaking scientifically accurate perspective on black holes. It is available through Spitz, Inc. and is accompanied by an Educator's Guide developed by SSU E/PO. See http://www.spitzinc.com/fulldome_shows/show_blackholes/index.html
- *Monster of the Milky Way* (2006). The companion PBS NOVA show to the Black Holes planetarium show described above, this television program uses many of the same supercomputer simulations. It premiered 10/31/06. Prof. Cominsky also served as science director for this show, which was also directed by Tom Lucas. It can be watched in streaming download from: http://www.pbs.org/wgbh/nova/blackhole
- *Black Hole Rescue Game*. This interactive game improves the science literacy of students in grades 4-12. After reading an article about black holes, the students "rescue" letters to form a vocabulary word that appears in a list, before the letters fall into a black hole. It was developed by NASA's JPL Space Place team, in partnership with the SSU E/PO group, as part of the XMM-Newton E/PO program. It is available in both English (http://spaceplace.nasa.gov/en/kids/blackhole/) and Spanish (http://spaceplace.nasa.gov/sp/kids/blackhole/index.shtml#).

The main websites for the SSU-led E/PO programs are:

Fermi Gamma-ray Space Telescope http://fermi.sonoma.edu

Swift Gamma-ray Burst Explorer http://swift.sonoma.edu

XMM-Newton mission http://xmm.sonoma.edu

Space Mysteries http://mystery.sonoma.edu

Gamma-ray Burst Skymap http://grb.sonoma.edu

SSU also maintains a "Black Hole Resource Area" at http://fermi.sonoma.edu/teachers/blackholes/index.php which has many external links to other resources and good websites with general information.

Other NASA missions that study black holes, pulsars, and cosmic cataclysmic events include the Chandra X-ray Observatory (http://chandra.harvard.edu), and missions supported by NASA's Goddard Space Flight Center. Goddard runs a very informative website about high-energy astrophysical phenomena for middle and high-school students, *Imagine the Universe!* at http://imagine.gsfc.nasa.gov.

I2U2

Interactions in Understanding The Universe, I2U2, is a set of interactive activities which have been designed to strengthen the education and outreach activities of scientific experiments at U.S. universities and laboratories. The I2U2 program is funded by NSF and the US Department of Energy's Office of High Energy Physics in the Office of Science. I2U2 creates and maintains an infrastructure and common fabric to develop hands-on laboratory course content and provide an interactive learning experience that brings tangible aspects of each experiment into an accessible "virtual laboratory" setting for education at different levels and in various venues. The I2U2 collaboration of scientists, computer scientists and educators directly addresses the urgent national priority to grow and sustain the scientific workforce, and to promote the public's appreciation of and support for the complex collaborations of our national scientific programs. The LIGO Hanford Observatory is an active participant in the I2U2 organization, and has developed a LIGO-oriented e-Lab which is available through `http://www18.i2u2.org/elab/ligo/home/project.jsp`.

QuarkNet

QuarkNet is a teacher professional development program funded by the National Science Foundation and the US Department of Energy. Teachers work on particle physics experiments during a summer and join a cadre of scientists and teachers working to introduce some aspects of their research into their classrooms. The program includes a commitment to ongoing professional development for a minimum of three years, including on-site workshops, mentoring and continued contact with laboratory scientists. Goals for teachers include a deeper understanding of physics content, an appreciation for the machinery of modern science, an introduction to inquiry-based teaching as well as evolution in individual teaching to a more student-centered mode of instruction. Now in its twelfth year, QuarkNet involves about 100,000 students from 500+ US high schools who do web-based analysis of real data, collaborate with other students worldwide, remotely control television cameras in experimental areas, and visit the experiments. Through inquiry-oriented investigations students learn kinematics, particles, waves, electricity and magnetism, energy and momentum, radioactive decay, optics, relativity, forces, and the structure of matter. For more information about QuarkNet, see `http://quarknet.fnal.gov/index.html`.

The UK STFC Science in Society Program

As already noted in the section on Funding Sources, in the UK the Science and Technology Facilities Council operates an extensive Science in Society program. This extends over a very wide range of topics and issues, reflecting the fact the STFC supports research and innovation and operates facilities relevant to many fields of physics – including astronomy, particle physics and nuclear physics – as well as in chemistry, materials science and life sciences. The aims of the STFC Science in Society program are to stimulate and respond to the latest research developments, to link STFC science and technology with schools and young people for the nation's STEM and skills agendas, to support researchers' public engagement work, and to develop the STFC Labs and Campuses as excellent technical sites for outreach and training programs. The main target audiences of the STFC program are the science-inclined public, young people aged 11-16, their teachers, new audiences not traditionally engaged with STFC science, and opinion formers such as Government, industry and Parliament. In Astronomy the Science in Society program is closely aligned with the high-level research goals of the STFC Astronomy program:

1. Do we understand the extremes of the Universe?
2. How do galaxies form and evolve?
3. What is the origin and evolution of stars and planets?
4. How do we fit in?

It seems clear that gravitational wave astronomy is relevant to several of these 'big questions', and the goal of the outreach undertaken by the UK gravitational wave groups has been to link the gravitational wave field into the broader context of astronomy outreach priorities. In this regard, in July 2010 Hendry (Glasgow) was awarded a Science in Society Fellowship on the theme of 'Exploring the Dark Side of the Universe', which aims to coordinate a UK-wide program of outreach to schools and the wider public on the themes of gravitational wave astronomy, cosmology and relativity. Further details of this project can be found at http://www.stfc.ac.uk/Funding+and+Grants/SandS/12242.aspx.

Another important dimension to the outreach program in the UK, and one with which STFC is becoming increasingly engaged, is awareness of Dark Skies. (See, e.g., http://www.darkskydiscovery.org.uk). Various initiatives are underway to establish a nationwide network of community-based groups and local organisations working together to make it easier for everyone to enjoy and be inspired by the night sky. These are well-linked to international programs (see, e.g., http://www.darksky.org/) but with a strong national and regional flavor. A crucial part of the UK network is the large number of amateur astronomical societies that exist across the UK. These groups are often highly knowledgeable, innovative and endlessly enthusiastic; during International Year of Astronomy they led a large number of high-impact public outreach events across the country and they represent a very valuable resource, going forward into the era of gravitational wave astronomy, for both assisting with delivery of future outreach projects 'on the ground' and also advocacy to funding bodies and politicians in support of our field. A specific, and very successful, example of where the amateur and professional astronomy communities worked well in the past was the 'Scottish Solar System' project (see http://www.scottishsolarsystem.org.uk) coordinated by Martin Hendry (Glasgow) during International Year of Astronomy 2009.

12 Needs and future plans

The LSC EPO working group is an international network of scientists interested in public outreach. By combining different ideas and approaches across many institutions, LSC EPO group members are able to create outreach programs and materials which are far more powerful and effective than they would be if LSC member institutions worked independently. In the near future, the LSC EPO working group will remain active by continuing current programs and developing new initiatives.

On March 17-18, 2011, the LSC EPO group had its first retreat and face-to-face meeting in conjunction with the annual spring LVC meeting in Arcadia, CA. Over 30 people attended the event. The first day of the retreat was devoted to short presentations on current and planned EPO programs. A core of LSC EPO members met the second day to discuss needs and future directions of LSC EPO. Areas of LSC EPO in need of improvement were singled out and desirable new outreach programs were identified. Also stressed was the need to strengthen the relationships between the members of the EPO working group and increase coordination of outreach activities among LVC member institutions. The results of the F2F discussion are reported below. The remaining of this section is intended to help LSC member institutions and international partners prioritize their EPO initiatives and develop new effective programs that are in line with the needs of the collaboration.

Educational material

While much educational material has been developed by the LSC and international partners on gravitational-wave astronomy and LIGO science, the EPO working group identified four main areas where additional resources are needed:

1. **Printed material.** Additional printed material such as fliers, posters, brochures, pamphlets for science fairs, etc. *that can be used by all LSC groups for outreach* is needed. It is important that this material is sufficiently generic to be used by the collaboration at large with minimal adaptations. (For example, a flier that focuses exclusively on a specific initiative which is developed by a single member institution, while important per sé, it is not of much use to other collaboration members.) Source files for the printed material should be available to all collaboration members and be posted in the EPO repository at `https://wiki.ligo.org/EPO/`.

2. **Multimedia.** Many multimedia resources for outreach activities were developed by LSC groups in the past. Notable examples include the Einstein@home, the Black Hole Hunter and Space Time Quest games, educational videos such as "LIGO-Australia: Discovering the Dark Side of the Universe," and the LIGO Space Place web page. With the widespread use of the Internet and the emergence in the mass market of new computer and mobile devices, more media-oriented resources are needed. In particular, development of animations, mobile phone apps, online games and videos for use in LSC outreach is encouraged. Updating and monitoring

Wikipedia, Wikimedia and/or similar web-based resources is also of primary importance to effectively reaching out the public.

3. **Write-ups of LSC science results.** The LSC has produced in the last few years noteworthy scientific results. These results are generally summarized in the press and in blogs and are often riddled with with inaccuracies and misinterpretations, which require corrective intervention. Even when a press release is available, it may be necessary to have some additional, ready to use and approved text for EPO purposes. One possibility for improving the correct interpretation of LIGO science by the public, would be to create short write-ups of LSC observational papers, or *EPO abstracts*, that could be used in blogs and as complement to press releases. A proposal to add EPO abstracts to LSC publications is being submitted to DAC for consideration.

4. **Formal Education.** In the past, formal education initiatives have been mainly pursued by the LIGO Observatories. The Observatories are training hundreds of teachers each year in their local service areas, and often have requests from local teachers for standards-aligned material specific to LIGO that they can use in their classrooms. In addition, there will be great interest from teachers world-wide in available formal education resources when Advanced LIGO detects its first gravitational waves. Development of new formal education resources, which are standards-aligned, classroom tested and reviewed by educators and pedagogical experts, is a time consuming and lengthy process, which must be started soon if these materials are going to be ready by 2015. A subgroup on formal education has recently been created as part of the EPO working group to coordinate the definition and implementation of formal curriculum development activities. Due to the long-lead time and the potential for national and international impact, this is a top priority for future EPO group efforts.

Interdisciplinary activities

Interdisciplinary activities across scientific disciplines or art, science and humanities are extremely successful in reaching out to a wide segment of the population. Production of interdisciplinary initiatives and deliverables by LSC groups is strongly encouraged.

Political outreach

"Political outreach" refers to educational and outreach initiatives aimed at informing the political class and the segment of the citizenry which is active in politics, and from which the national leadership is largely drawn. Political outreach is different than lobbying; the former is done for sake of informing while the latter aims at requesting support or assistance. Political outreach is also different for each country. While LSC-wide political outreach should be responsibility mainly of the LSC Spokesperson, the LSC Council, the Executive Committee, and group PIs, the EPO group could assist these parties by developing suitable educational and outreach material. For example, the EPO group could provide a PI who needs to talk to his/her own Congress representative with printed material and other deliverables. Outreach at professional and businness organizations (e.g., Rotary Clubs, Kiwanis) is also important. The focus of material for political outreach is in general different than the focus of material for the general public outreach.

Professional outreach, conferences, and tours

"Professional outreach" refers to educational and outreach initiatives aimed at informing the physics community, astronomers, scientists and professional organizations in general about LIGO science. The LSC needs to have a presence at all major national meetings (AAS, NSTA, APS...) as an exhibitor. This white paper contains a list of conferences where LSC participation would be desirable. The LIGO lab and some LSC members already participate in a few nationwide events as exhibitors. LSC groups are encouraged to send representatives to these events and help organize or staff a LIGO booth.

The LIGO observatories have often organized tours for professional people such as scientists from other disciplines and engineers. LSC groups are encouraged to follow the Lab example. If a major professional organization has a meeting near a University where a LSC group is active, their Lab could be opened for tours. (This is also important for political outreach.)

Outreach to young adults

There is the need for LSC-wide outreach programs targeting kids and young adults. The `http://www.ligo.org` portal contains a lot of information, but it is not kid-friendly. The development of a "LIGO-kids" web-portal with material understandable by K-12 students on the model of NASA's Space Place is encouraged.

Development of outreach initiatives aimed at teaching astronomy and LIGO science to afterschool clubs, Girl and Boy Scouts, astronomy amateur clubs, and science cafés would also fill an important gap in current LSC outreach efforts. While many LSC groups are pursuing similar initiatives in their local communities, it is important that their programs and experiences are shared with other LSC groups and applied on a national scale.

International outreach

Working with members of the worldwide network of gravitational wave observatories to promote outreach in gravitational wave astronomy and science in general is of primary importance, as well as expanding current outreach and educational initiatives to non-LSC countries. Collaborations with groups such as the National Society of Black Physicists or the National Society of Hispanic Physicists to reach out to Africa or South America is encouraged. Translation in foreign languages of LIGO outreach material and videos (e.g., *Einstein's Messengers*) would be important in communicating LIGO science to non-US audiences.

Recruitment

Initiatives aimed at increasing recruitment of new scientists in the LSC should be expanded. LSC institutions should actively promote student recruitment and develop resources for this purpose. Helping with the organization of workshops, conferences and outreach events at local, national and international levels should be part of this effort. There is also a pressing need to increase the number of REU opportunities in the LSC. LSC institutions are encouraged to develop outreach initiatives in these areas.

Increasing diversity

Women and minorities are still underrepresented in the LSC. A priority of the LSC is to promote diversity in science and engage students from traditionally underrepresented populations. The LSC and LIGO Lab share a commitment to recruit students, postdoctoral fellows and permanent hires from diverse and underrepresented groups. Initiatives to encourage more women and minorities to enter physics careers are encouraged, especially if they can be applied at a national level. LIGO regularly exhibits at the annual conferences of NABP/NAHP (National Association of Black and Hispanic Physicists), AISES (American Indian Science and Engineering Society) and SACNAS (Society for the Advancement of Chicano and Native American Science).

LSC participation in these meetings is of extreme importance for increasing diversity in the LSC and helping recruitment efforts. LSC and Lab outreach leaders continue to look for opportunities that will expand this list. To upgrade the quality of LIGO's message at conferences and to improve the efficiency of exhibition setup, take-down and transport, LIGO Lab in 2011 will purchase a 10' × 10' backdrop/conference display that will be available for use in exhibition halls and similar venues. Production of additional materials aimed at outreach to underrepresented populations that could be used at these events are encouraged.

Strategic planning and coordination among LSC groups

In the development and production of an outreach initiative, LSC groups should try and conform as much as possible to these standards:

- The initiative should be a priority for the LSC-wide outreach effort;
- It should be coordinated with the EPO working group;
- It should lead to the production of deliverables that can be used also by other LSC groups;
- It should be sustainable;
- It should reach the widest-possible audience;
- It should be possible to assess its efficacy and success.

At the recent EPO meeting in Arcadia, the importance of coordinating EPO initiatives among groups, and avoiding unnecessary duplication of efforts were both stressed. Coordination among member institutions in the field of outreach is still far from being optimal. It was suggested that better coordination between groups could be achieved by requiring EPO initiatives to be made within the context of the EPO working group and by conforming to the priorities listed in this white paper. EPO activities should be discussed and vetted with the EPO group before the preparation of the annual MOU. The PI of LSC groups filing an OUT attachment should ensure that reported contributions and proposed activities are relevant to the LSC EPO program, are shared with other groups and are well documented in the EPO wiki repository.

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